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SESI PENGAJIAN: 2007/2008

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"I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of the Bachelor of Mechanical Engineering "

Signature : ....
Name of Supervisor : Mr. Mohd Rashidi bin Maarof
Date : ......23/11/07......

CUTTING FORCE OF END CUTTING TOOL MILLING MACHINING

SHARIFAH NOOR SHAHIRAH BT SYED MOHD NORDIN

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

Faculty of Mechanical Engineering
Universiti Malaysia Pahang

NOVEMBER 2007

DECLARATION

I Sharifah Noor Shahirah declare that this thesis entitled "Cutting Force of End Cutting Tool Milling Machining" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:...
Name	:Sharifah Noor Shahirah bt Syed Mohd Nordin
Date	:...

DEDICATION

Special to my beloved Ma and Abah..

Syed Mohd Nordin bin Syed Hussin
Siti Meriam bt Mat Rashid

Not forget to my lovely sister and brothers..

Syed Mohd Nor Izzat bin Syed Mohd Nordin
Sharifah Nor Syazwani bt Syed Mohd Nordin
Syed Mohd Nor Irshad bin Syed Mohd Nordin
Syed Mohd Nor Ijlal bin Syed Mohd Nordin

ACKNOWLEDGEMENT

Alhamdulillah, thank you Allah for giving me the world worth life. Without His mighty I won't be able to finish this project on time.

Secondly, thanks to my supervisor, Mr. Mohd Rashidi b Maarof and not forget Mr. Zamzuri b Hamedon for his superb guidance and advice. I sincerely appreciate the labs technicians, for their guidance through this project in the End Milling process.

Special thanks to my beloved parents and all my family for their constant support and encouragement.

I am also indebted to my dear friends especially and my classmates for their ideas, comments and supports in bringing this project fruition. Indeed, I could never adequately express my indebtedness to all of them. Thank you.

ABSTRACT

In end milling, depth of cut is one of the cutting parameter that affects the cutting forces. In this study, three components of the cutting forces developed during end milling AISI 1020 Mild Steel. However, this project are focusing more on cutting force at vertical direction(z-direction) seems that the main reasons of this project is to study the effects of depth of cut on the cutting force besides to analyze the cutting force between 2-flute and 4-flute helical end mill. For the cutting force measurement, a Kistler Quartz 3-Component Dynamometer was used. Depending on the different depth of cut where value for spindle speed and feed rate are constant, the cutting forces were evaluated for the AISI 1020 Mild Steel. Within certain cutting parameters range, the increasing depth of cut increased the cutting forces. Beside that, cutting force requirement for 2-flute High Speed Steel helical end mill are higher compare to 4-flute High Speed Steel helical end mill.

ABSTRAK

Di dalam proses end milling, kedalaman pemotongan adalah salah satu parameter yang mempengaruhi daya pemotongan. Di dalam kajian ini, tiga komponen daya pemotongan dibangunkan untuk proses end mill AISI 1020 Mild Steel. Walaubagaimanapun, didalam projek ini daya pemotongan pada arah menegak(arah z) lebih difokuskan memandangkan objektif utama projek ini adalah untuk mengkaji kesan kedalaman pemotongan terhadap daya pemotongan disamping untuk menganalisis daya pemotongan diantara 2-flute High Speed Steel helical end mill dan 4-flute High Speed Steel helical end mill. Untuk pengukuran daya pemotongan pula, 3-komponen kuarza dynamometer Kistler digunakan. Daya pemotongan AISI 1020 Mild Steel pula bergantung kepada kadar kedalaman pemotongan dimana nilai halaju pemotongan dan kadar kedalaman pemotongan per halaju pemotongan adalah tetap. Berdasarkan kajian projek ini, di bawah lingkungan parameter pemotongan yang tertentu, jika kedalaman pemotongan bertambah, daya untuk pemotongan juga bertambah. Selain itu, daya pemotongan yang diperlukan untuk 2-flute High Speed Steel helical end mill adalah lebih tinggi berbanding 4-flute High Speed Steel helical end mill.

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LIST OF SYMBOLS

b = Cutting width

D = Cutter diameter

d = Depth of cut

dt t= Maximum thickness of the zone

F = Friction force

F_c = Cutting force

f = Feed / tooth

h = The plastic contact length.

l = Length of cut

l_c = The extent of the cutter's first contact with the workpiece

N = Rotational speed of the milling cutter, rpm

n = Linear speed of the workpiece or feed rate

t = Cutting time

Vc = Chip velocity

Vx = Sliding velocity of the chip

v = Surface speed of cutter

w = Width of cut

$t1$ = Uncut depth

LIST OF FORMULA

(1) Cutting Speed, ***V***

$$V = \prod DN$$

(2) Feed per Tooth, ***f***

$$f = \frac{v}{Nn}$$

(3) Intensity of shear plane heat source, ***Ip***

$$lp = \left(\frac{FsVs}{bt1}\right)$$

(4) Intensity, of the frictional heat source, ***Ic*****,**

$$Ic = \frac{FVx}{hb}$$

(5) Material Removal Rate, ***MRR***

$$MRR = \frac{lwd}{t} = wdv$$

(6) Power, P

$$P = T\omega \qquad \omega = 2\prod N$$

(7) Strain Rate, *E*

$$E = \frac{Vc}{dt}$$

(8) The Cutting Time, *t*

$$t = \frac{(l + I_c)}{v}$$

- Based on assumption that $l_c < l$.

(9) Torque,T

$$T = \frac{F_c D}{2}$$

(10) Undeformed Chip Thickness, t_c

$$t_c = \frac{2fd}{D}$$

APPENDICES

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CHAPTER 1

INTRODUCTION

1.1 Project Background

The development of miniaturized technologies has become a global phenomenon that continues to make an impact across a broad range of applications that encompasses many diverse fields and industries including automotive, portable consumer electronics, precise part production, and biomedical. Subsequently this trend has caused more and more interest in the issues involved in the design, development, operation and analysis of equipment and processes for manufacturing components. One technology used to create these miniaturized components is milling. The cutting forces of the milling process provide vital information for the design, modeling, and control of the machining process. A typical part that can be produced on a milling machine equipped with computer controls. Such part can be made efficiently and repetitively on computer numerical control (CNC) machine without the need for refixuring or reclamping the part.

According to the *Altintas, Y (2000)* milling is the process in which a cutter is held in rotating spindle, while the workpiece clamped in the table is linearly moved toward the cutter. The factors influence cutting process such as cutting parameters, materials properties, tools geometry and machine tool workpiece system. It will generate wear, torque, chips removal and thermal stress during machining workpiece whereas the finishing should considered dimension accuracy and quality.

Based on the *Kalpakjian and Schmid (2001)* the aspects need to be considered is cutting force on the workpiece that are subjected by the cutter tools. Data on cutting force is required so that:

1. Machine tools can be properly designed to avoid excessive distortion of the machine
2. Elements and maintain the desired dimensional tolerances for the finished part, tooling and tool holders and working devices.
3. It can be determined, in advanced of actual production, whether the workpiece is capable of withstanding the cutting forces without excessive distortion [2]

In this project high speed steel of helical end mills cutting tools will be developed for material machining. Cutting tools geometry parameter for instance cutter angle, number of teeth and diameter will be used on producing cutting force and torque for CNC milling machine. Based on mechanics modeling of milling force and torque proposed by *Altintas*, *Y (2000)*; cutting conditions, tool geometry, cutting constant, integration angle and height are applied as input parameters model the machining of end mill. Cutting force can be measured by using suitable dynamometers with resistance-wire strain gages or force transducers such as piezoelectric crystal.

1.2 Problem Statement

The milling process compare to the other metal machining process is quite slow thus having a low production rate. Manufacturing managers, schedulers, and engineers constantly try to overcome with the effects of cutting tool selection. *Inaccuracy of cutting tool will contribute to poor surface finish, tool damage, chatter, dimensional accuracy and many other problems that contribute to low productivity and much time will be wasted (Kalpakjian and Schmid, 2001).* Milling process can cut the non-ferrous and ferrous material. To machine the ferrous material, harder cutting tool is needed. One of popular cutting tools that are used is

High Speed Steel (*HSS*). This study helps to improve the performance of a milling process by using High Speed Steel cutting tool as a cutter. It is worth to understand the capability of carbide cutting tool during machining of ferrous metal for a better understanding of milling machining characteristic. This knowledge will help mass production machining in our industry.

1.3 Project Objectives

1. To analyze the cutting force of 2-flute and 4-flute of helical end mill tool on AISI 1020 Mild Steel.
2. To study the effect of depth of cut on cutting force in end milling process.

1.4 Project Scopes

1. Using 2-flute and 4f-lute High Speed Steel as a cutting tool
2. Using AISI 1020 Mild steel as a workpiece
3. Applied an end milling cutting process type slot milling
4. Experimental of cutting force using Quartz 3-Component Dynamometer.

1.5 Project Flow Chart

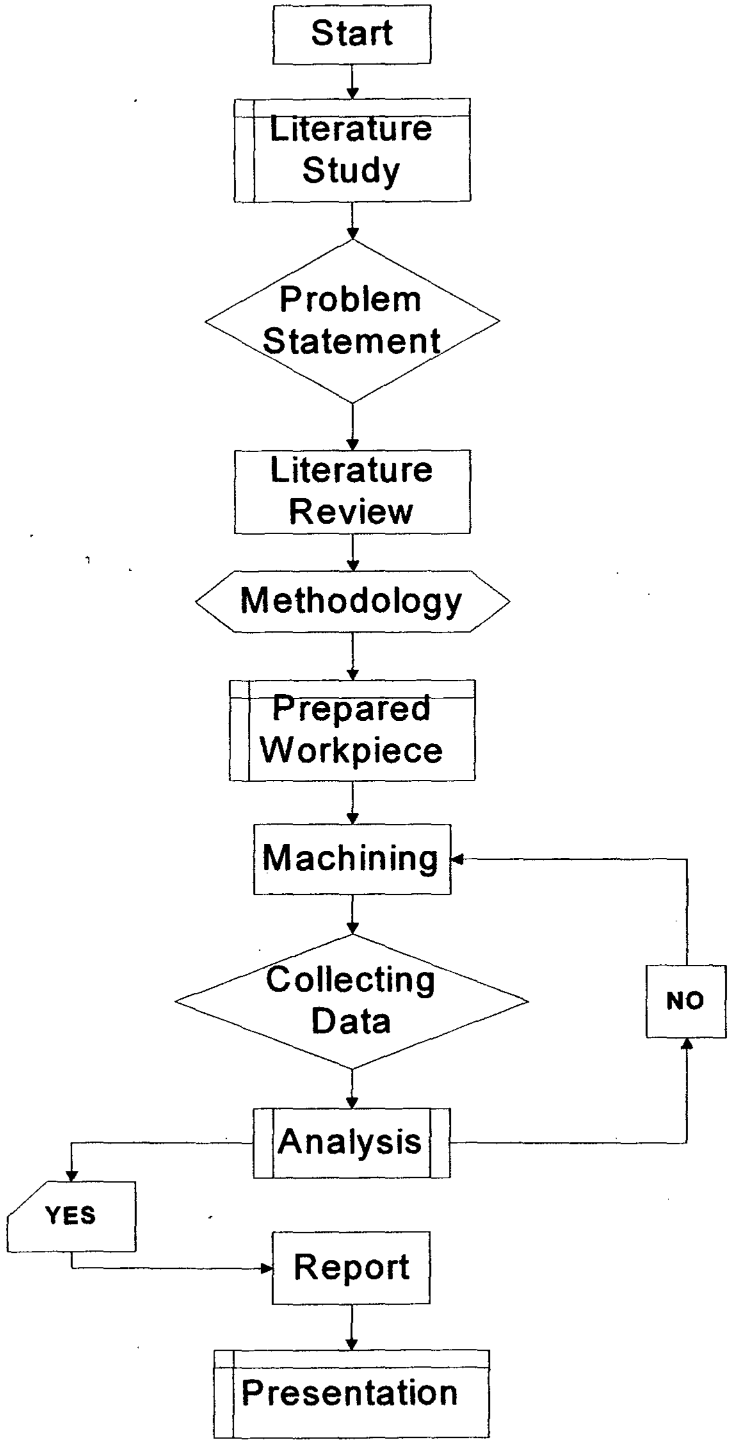


Figure 1.1: Project flowchart

GHANT CHART OF FINAL YEAR PROJECT	SEMESTER 2 2006/2007 SESSION														
DURATION	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15
TASK															
Briefing about PSM															
1. Briefing PSM project from Mr.Gan Leong Meng															
-What is PSM															
-How to do a PSM Report															
2. Received log book from faculty															
3. First meeting with supervisor															
-confirmation the project title,objective and project scope															
Literature Riview															
1.Gather informations for the project															
2.Literature study based on the information															
-Mechanics of metal cutting															
-Types of milling															
-Milling Operation															
-Applications															
-Milling Parameter															
-Material used															

Figure 1.2: Gantt chart of final year 1

Briefing on CNC Milling Operation by FKM Assistant Engineering							■								
Mid Term Holiday								■							
Meeting with supervisor			■	■	■	■	■	■	■	■					
1. Showed literature riview draft															
2. Choosed which material and type machine that are going to used															
based on the infrastructure at FKM Lab															
Methodology															
1. Get the information about System Operation Prosess from FKM Lab											■				
2. Draft the Methodology with Supervisor												■			
3. Finalize the methodoly draft with supervisor												■			
Submit PSM 1 Draft Report,Log book the supervisor												■			
Final Year Project 1 Presentation														■	
Briefing on Dynamometer device Operation															■

Figure 1.3: Gantt chart of final year 1

GHANT CHART OF FINAL YEAR PROJEC				SEMESTER 1 2007/2008 SESSION											
DURATION	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11	V12	V13	V14	V15
TASK															
Prepared vorpiece															
Machining															
Get force and graph															
Result & Analysis															
Report FYP 2															
Submit FYP 2 Report															
Final Presentation															

Figure 1.4: Gantt chart of final year 2

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

For a long time, manufacturing engineers and researchers have been realizing that in order to optimize the economic performance of metal cutting operations, efficient quantitative and predictive models that establish the relationship between a big group of input independent parameters and output variables are required for the wide spectrum of manufacturing processes, cutting tools and engineering materials currently used in the industry. Furthermore, it has been observed that the improvement in the output variables, such as tool life, cutting forces, surface roughness, etc., through the optimization of input parameters, such as feed rate, cutting speed and depth of cut, may result in a significant economical performance of machining operations. In the case of the milling process, the rotating speed, the cutting depth and sending speed are very important. These important elements are affected by the materials, the shapes and the roughness of the surface and etc. Generally, in order to get the high roughness, the cutting depth must be set to small, and the sending speed must be set to low.

2.2 Classifications of Milling

2.2.1 Slab Milling

In slab milling, also called peripheral milling, the axis of cutter rotation is parallel on the workpiece surface to be machined *(Kalpakjian and Schmid, 2001)*. Cutter for slab milling may have straight or helical teeth resulting in, respectively, orthogonal or oblique cutting action. As indicating by *Krar, Amand & Ostwald, (1994)* the helical tooth on the cutter is preferred over straight teeth because the load on the tooth is lower, thus smoother operation and reducing tool forces and chatter.

2.2.2 Face Milling

In face milling, the cutter is mounted on a spindle having an axis of rotation perpendicular to the workpiece surface *(Kalpakjian and Schmid, 2001)*. The milled surface results from the action of cutting edges located on the periphery and face of the cutter. *(See figure 2.1)*

2.2.3 End Milling

Flat surface as well as various profiles can be produced by end milling. The cutter in end milling has either straight or tapered shanks for smaller and larger cutter sizes respectively. The cutter usually rotates on an axis perpendicular to the workpiece, although it can be tilted to machine-tapered surfaces *(See figure 2.1)*.

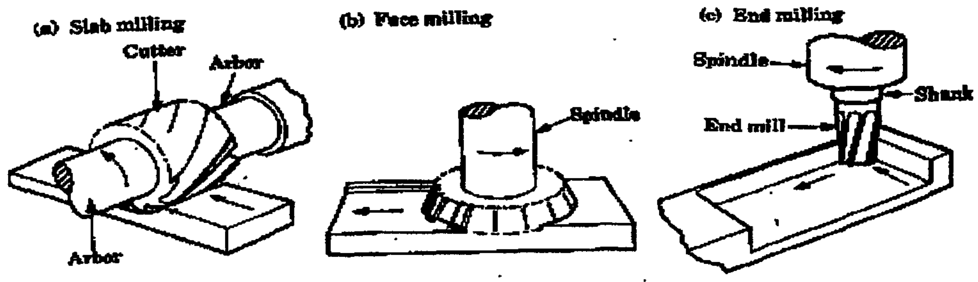


Figure 2.1: Basic types of milling cutters and milling operation

2.3 Mechanism of Milling

Methods of milling operation can be divided into two ways that is Up milling and Down milling.

2.3.1 Up Milling (Conventional Milling)

The safest way to machine a piece of metal using a horizontal miller is to feed the metal into the cutter, against its rotation. This is called up-milling and it is the technique used in school workshops. The metal must be held very firmly in a large machine vice, usually a nylon or leather mallet is used to hammer round the handle of the vice to ensure it is extremely tight. In up milling the maximum chip thickness is at the end of the cut. The advantages of using Up Milling are the cutting process is smooth, provided that the cutter teeth are sharp. However they may be a tendency for the tool to chatter and the workpiece has a to be pulled upward *(Kalpakjian and Schmid, 2001).*

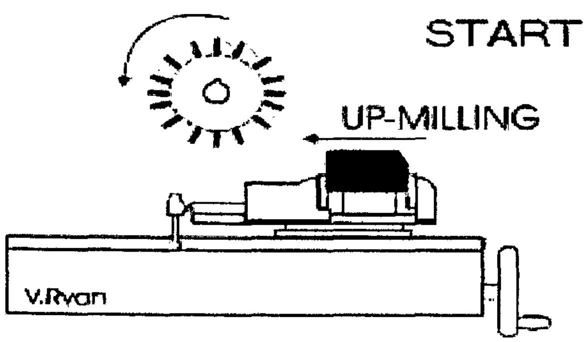


Figure 2.2: Example of up milling *(HAAS CNC MILLING MACHINE)*

2.3.2 Down Milling(Climb Milling)

Down milling is also referred to as climb milling. The direction of cutter rotation is same as the feed motion *(See figure 2.3)*. For example, if the cutter rotates counterclockwise, the workpiece is fed to the right in down milling. The advantage is that the downward components of the cutting force hold the workpiece in place. However it is not suitable for the machining of a workpiece having a surface scale such as hot worked metals, forgings and casting. The scale is hard and abrasive and can causes excessive wear and damage to the cutter teeth, shortening tool *(Kalpakjian and Schmid, 2001)*. If the machine is equipped with a backlash eliminator certain types of work can best be milled by Climb Milling

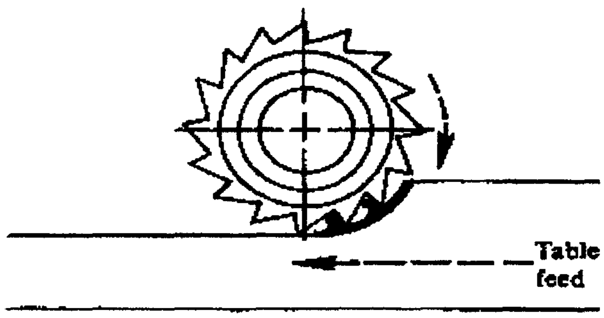
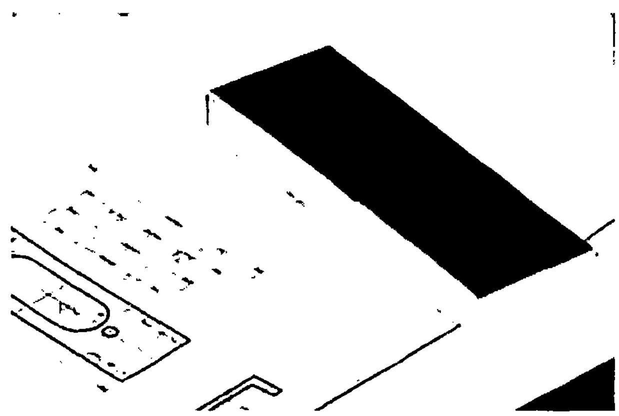


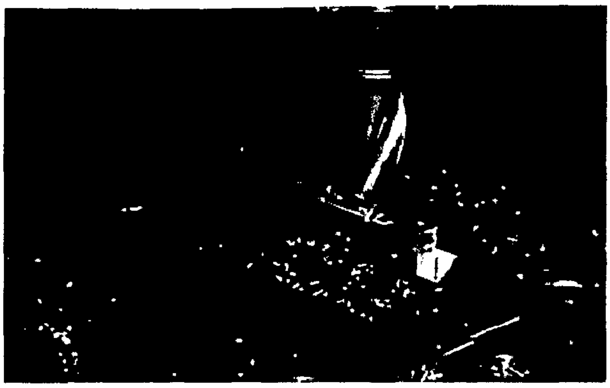
Figure 2.3: Example of down milling

2.4. Procedures of Milling Processing



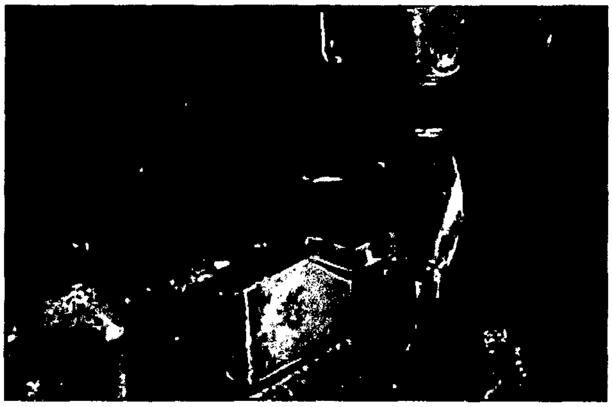
(1) Cut Board Material

A material was cut by a band saw. The size is bigger about 3 mm than the final size.



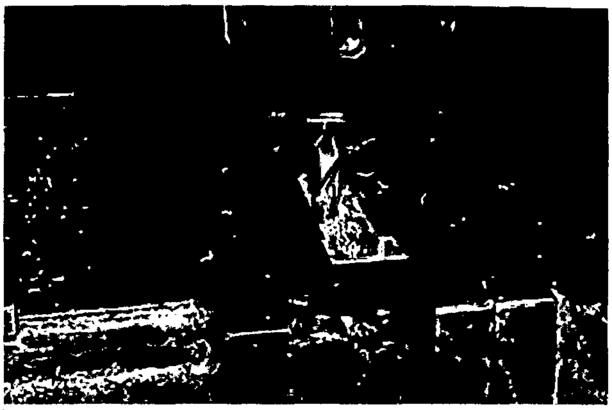
(2) Cutting of Bottom Surface

The material is cut with the bottom edge of the end mill. In such ways, two face of the material can be cut.



(3) Cutting of Side Surface

The material is cut with the side edge of the end mill. When the vise is set in the vertical position accurately, the material can be get the accurate rectangle easily.



(4) Shaped Part

The material is shaped with the end mill. Since it has a complex shape, we are careful in the processing.

(5) Drilling

The tool is changed from the end mill to a drill.

(6) Completed Part

This is a completed part. It is not so simple shape, but the milling process is not so difficult.

2.5 Milling Machining Setup

A milling machine is a power-driven machine used for the complex shaping of metal (or possibly other materials) parts. Its basic form is that of a rotating cutter or end mill which rotates about the spindle axis (similar to a drill), and a movable table to which the workpiece is affixed. That is to say the cutting tool generally remains stationary (except for its rotation) while the workpiece moves to accomplish the cutting action. Milling machines may be operated manually or under computer numerical control.

Milling machines can perform a vast number of complex operations, such as slot cutting, planing, drilling, rebating, routing, etc.

Cutting fluid is often pumped to the cutting site to cool and lubricate the cut, and to sluice away the resulting swarf. There are two main types of mill, the vertical mill and the horizontal mill.

2.6 Types of Milling Machines

2.6.1 Vertical Milling Machine

A vertical miller is used to shape metals such as mild steel and aluminium. It can also be used to shape plastics such as Perspex and Nylon. Full size milling machines such as the one shown below are powerful but also very accurate/precise. The cutting tools are very expensive and are broken easily if the machine operator tries to take too deep a cut, in one go. When using a vertical miller, the machine should be set up to cut away only a small amount of metal each time the cutter passes over the surface of the metal.

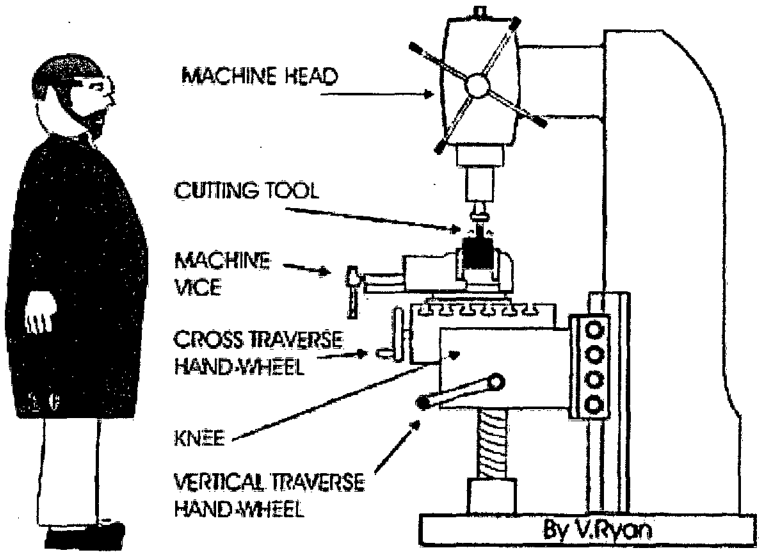


Figure 2.4: Illustration of vertical milling machine (*HAAS CNC MILLING MACHINE)*

Wide selections of cutting tools are available. They are made from high speed steel and are strong enough to cut through mild steel, cast steel and aluminum. Three examples are shown below with an example of the profile they cut into the metal. *(See figure 2.5).*

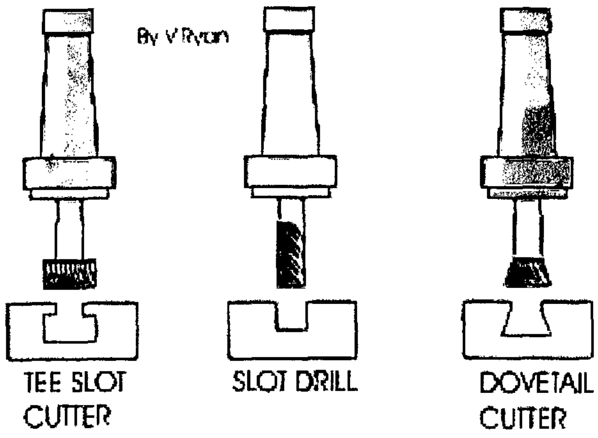


Figure 2.5: Types of high speed steel cutters *(V.Ryan, 2001)*

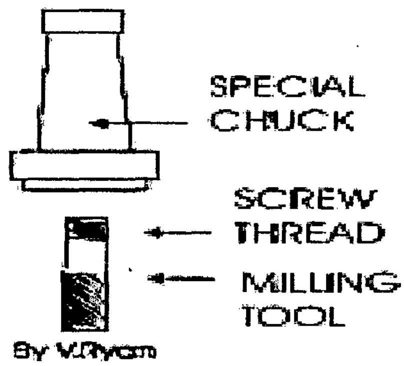
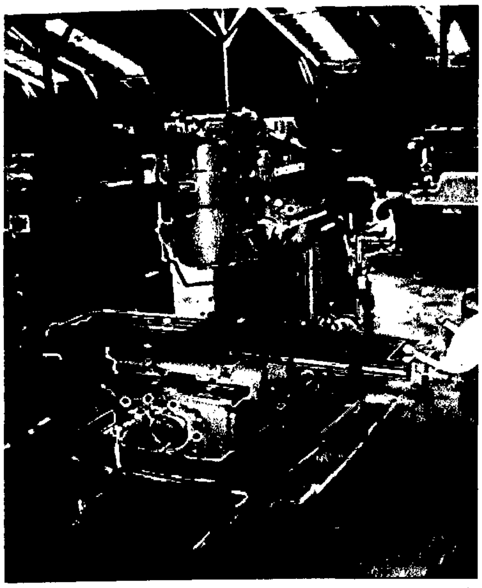


Figure 2.6: Example of chuck *(V.Ryan, 2001)*

The milling tool has a screw thread at one end. This is turned into the chuck. A cloth is wrapped around the tool before this is done as it can easily cut through flesh. Care must be taken when setting up a cutting tool *(See figure 2.6)*.



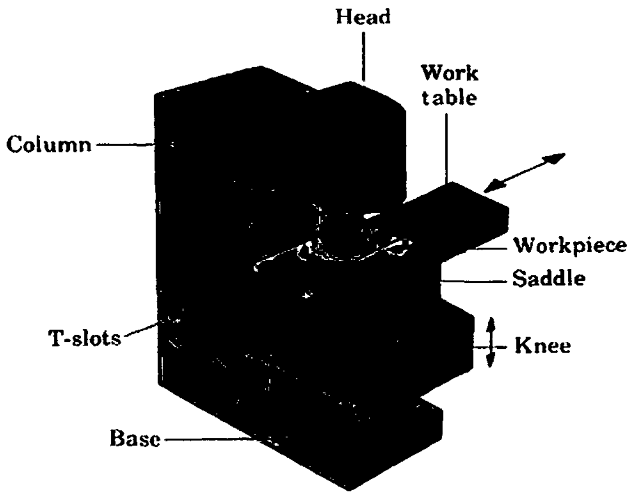


Figure 2.7: Example of vertical milling machine

2.6.2 Horizontal Milling Machine

The Horizontal Milling Machine is a very robust and sturdy machine. A variety of cutters are available to removed/shape material that is normally held in a strong machine vice. This horizontal miller is used when a vertical miller is less suitable. For instance, if a lot of material has to be removed by the cutters or there is less of a need for accuracy - a horizontal milling machine is chosen.

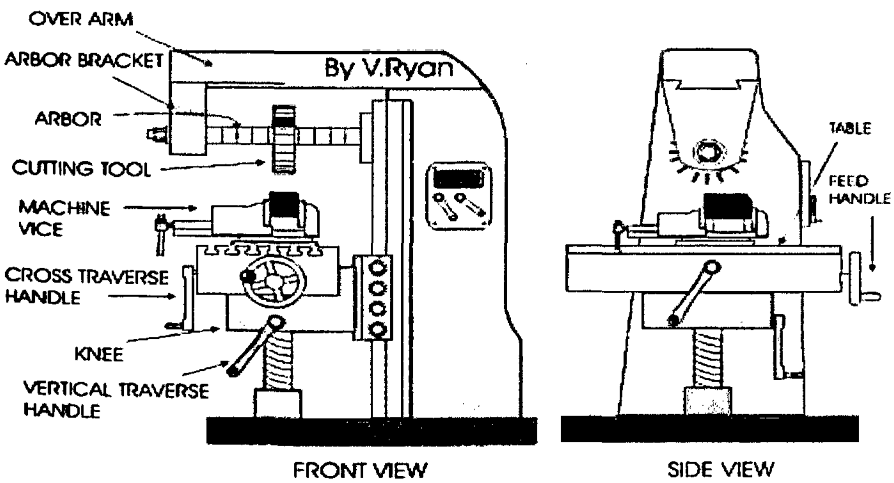


Figure 2.8: Illustration of horizontal milling machine *(V.Ryan, 2001)*

The cutter can be changed very easily. The arbor bracket is removed by loosening nuts and bolts that hold the arbor firmly in position. The arbor can be slid off the over arm. The spacers are then removed as well as the original cutter. The new cutter is placed in position, spacers slid back onto the arbor and the arbor bracket tightened back in position *(See figure 2.9)*.

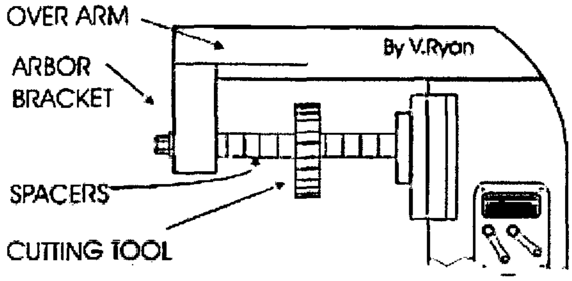


Figure 2.9: Example of change the cutter from the arbor *(V.Ryan, 2001)*

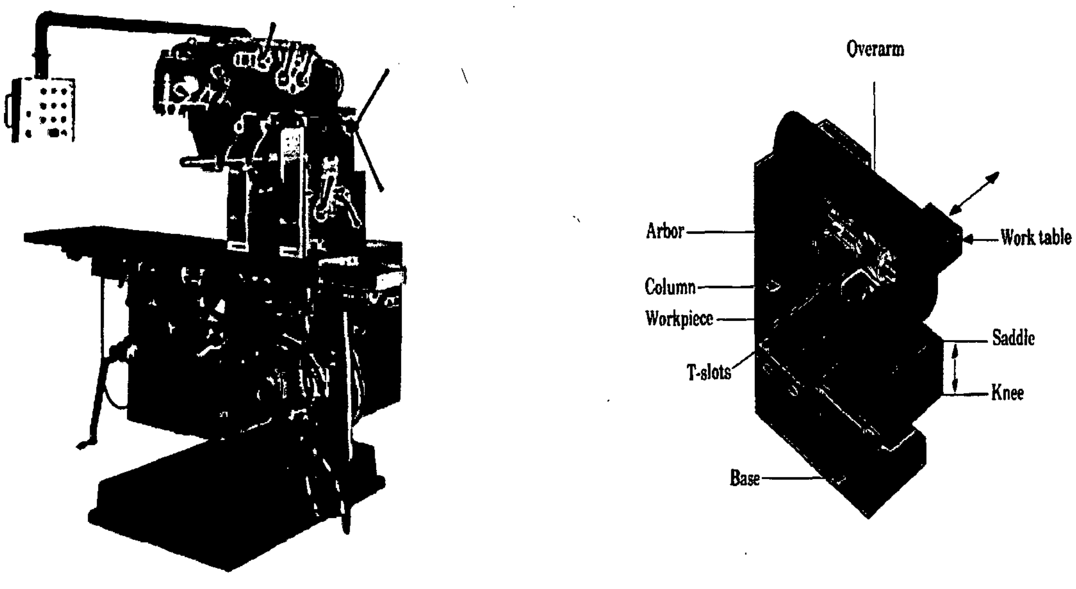


Figure 2.10: Example of horizontal milling

2.6.3 Computerized Numerical Control machine *(CNC machine*

CNC machine is a ***Computerized Numerical Control*** machine, the tool is controlled by a computer and is programmed with a machine code system that enables it to be operated with minimal supervision and with a great deal of repeatability. CNC mills can perform the functions of drilling and often turning. CNC Mills are classified according to the number of *axes* that they possess. Axes are labeled as x and y for horizontal movement, and z for vertical movement. The same principles used in operating a manual machine are used in programming a CNC machine. The main difference is that instead of cranking handles to position a slide to a certain point, the dimension is stored in the memory of the machine control once. The control will then move the machine to these positions each time the program is run *(HAAS CNC MILLING MACHINE)*. CNC machine also economic to use for big size capacity for production and for special case CNC can be use.

The benefit why we choose to use CNC machine is:

a) To increase volume production
b) To maintained the item is consistence
c) To decrease reject item
d) To reduce tooling cost
e) To reduce human handling
f) Can be used for difficult or special design / item.

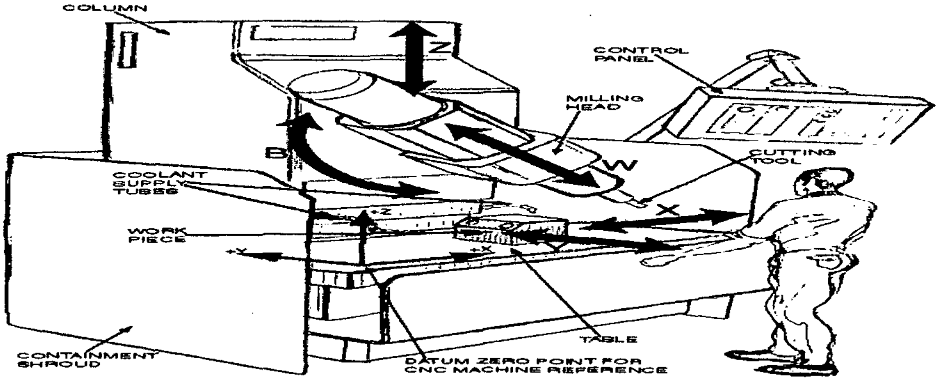


Figure 2.11: CNC milling machine 5axes *(Eing-Jer Wei & Ming-Chang Lin, 2004)*

2.7 CUTTERS

A large range of cutters are available. They are generally made from high speed steel which means they will cut through metals such as mild steel and aluminum. Some of the profiles (shapes) of the cutters are shown below. Cylindrical cutters are used to remove a lot of waste material from a surface. More detailed cutters, such as concave cutters, are used to machine a shape onto a surface.

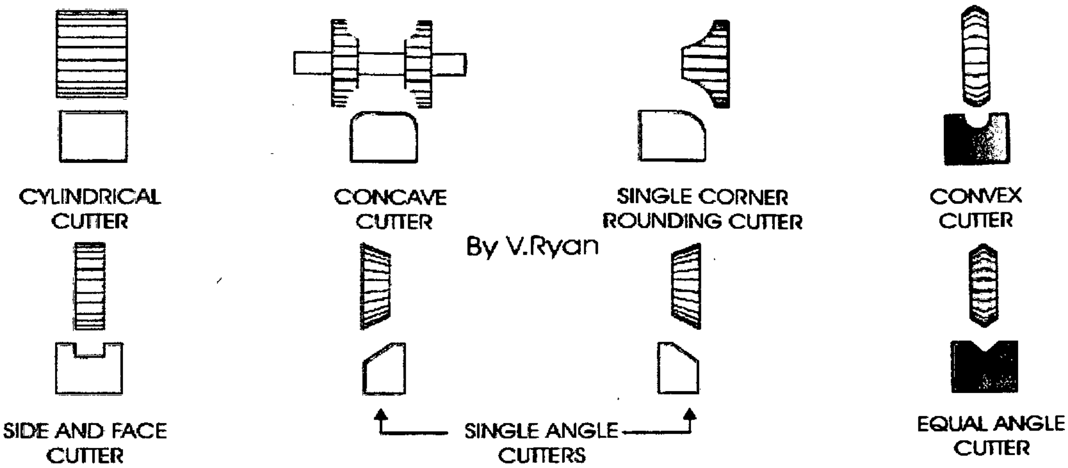


Figure 2.12: Types of cutter in milling operations *(V.Ryan, 2001)*

When machining with any of these cutters it is important to use coolant (soluble oil) as the cutter will heat up as well as the material being machined. The coolant cools the cutters and the material which means that the expensive cutters last longer. It is also necessary to remove material a little at a time. Several slow passes over the material may be needed to manufacture the desired shape.

2.7.1 End Mill Selection

Utilize the shortest possible tool available for the application with the largest diameter permissible and the shortest flute length as depth of cut allows. (See chart on pp.158-161) Extra length end mills have excessive overhang, thus a reduction in feed up to 25% may be required. Stub length end mills, due to their short overall and flute length, have more rigidity, thus an increase in feed rates of up to 25% may be requires.

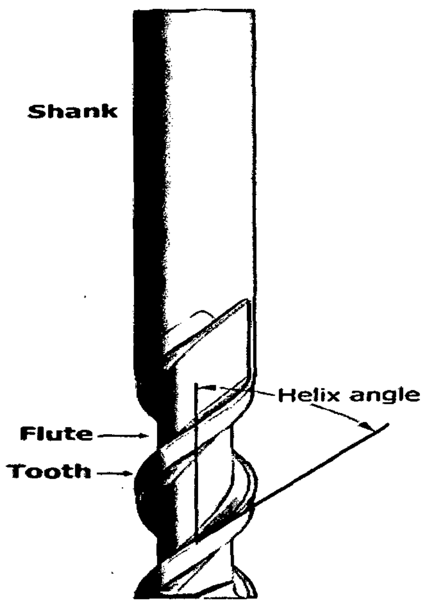


Figure 2.13: An end mill cutter with 2-flute

2.7.1.1 Flutes / teeth:

The flutes of the milling bit are the deep helical grooves running up the cutter, while the sharp blade along the edge of the flute is known as the tooth. The tooth cuts the material, and chips of this material are pulled up the flute by the rotation of the cutter. There is almost always one tooth per flute, but some cutters have two teeth per flute. Often, the words flute and tooth are used interchangeably. Milling cutters may have from one to many teeth, with 2, 3 and 4 being most common. Typically, the more teeth a cutter has, the more rapidly it can remove material. Therefore, a 4-tooth cutter can remove material at twice the rate of a 2-tooth cutter *(Wikipedia)*.

2.7.1.2 Helix angle

The flutes of a milling cutter are usually helical. If the flutes were straight, the whole tooth would impact the material at once, causing vibration and reducing accuracy and surface quality. Setting the flutes at an angle allows the tooth to enter the material gradually, reducing vibration. Typically, finishing cutters have a higher rake angle (tighter helix) to give a better finish.

2.7.1.3 2-flute

2-flute end mills allow for maximum chip volume and are used for plunge milling, roughing of slots, or peripheral milling. These multipurpose tools allow for high feed rates where part finish and dimensional accuracy are not critical. When plunge cutting, it is recommended to use approximately 25 – 50% of the feed per tooth *(Precision Dormer).*

2.7.1.4 3-flute

3-flute end mills are more rigid; with less cut interruption the 2-flutes *(Precision Dormer).* They have more chip volume area then a 4-flute, allowing higher metal removal rates. The 3-flute end mill has all the machining capabilities of a 2-flute end mill, and is ideal for slotting applications. Improved part finish and dimensional accuracy can be achieved in a wider range of materials over a 2-flute end mill.

2.7.1.5 4-flute

4-flute end mills are stronger then either the 2 or 3-flute designs. The added rigidity allows higher metal removal rates with minimum deflection. Improved workpiece finishes and dimensional accuracy can be achieved. Limited chip volume area restricts stock removal rates and deep plunge cutting is not recommended. The 4-flute design is commonly used for finishing operations.

2.8 Cutting Tool Geometry

Cutting tools have many shapes, which are described by various angles or geometries. Each tool shape has a specific purpose in machining, but the overall goal is to achieve the most productive separation of chips from the workpiece. Selection of the right cutting tool geometry is critical to machining productivity.

Geometries for metalcutting tools vary with the type of operation being performed, the workpiece material, the power and speed of the machine being used, and the tolerances required for surface finish and other part characteristics. For example, indexable inserts to disposable tools that are rotated, or indexed, to access their multiple cutting edges which are designed with complex combinations of grooves, flats, angles, and curves that define their cutting capability.

Inserts for turning are a single-point cutting tool that is, they do their work with only a single edge in contact with the workpiece. Although most turning operations are performed using coated, indexable carbide inserts, tool materials for turning range from high-speed steel to ceramics and superhard materials such as cubic boron nitride (CBN) and polycrystalline diamond (PCD).

The majority of turning operations use just a handful of basic tool geometries. The geometry of the toolholder itself largely determines how the insert is presented to the work.

However, the elements of geometry for turning inserts include:

- Basic insert shape and size
- Relief angle, angle of inclination, rake angle, and lead angle
- Nose radius
- Chipbreaker design.

The most important determinant of general insert shape is workpiece geometry. An 80° diamond insert, for example, is very versatile; it allows users to cut a 90° shoulder and perform facing operations on a variety of part configurations. But parts with many contours may require a different shape.

Insert shape is a trade-off between strength and versatility. Larger point angles are stronger and often used for roughing operations. Smaller angles (35 - 55°) are more versatile for intricate work. Generally, the largest point angle suitable for the job should be applied. This approach assures use of the strongest possible insert and thus minimizes the possibility of a sudden tool failure.

Relief angle allows the cutting edge to work freely without unnecessary rubbing on the workpiece. Several angles are important when introducing the tool edge into the rotating workpiece. Angle of inclination is the angle of the insert seat or pocket in the toolholder, from front to back. This inclination can be positive, negative, or neutral.

Rake angle is the angle at which the trailing face of the insert falls away from the workpiece. It may also be positive, negative, or neutral. Effective rake angle is determined by the combination of the toolholder's angle of inclination and the rake built into the insert.

Lead angle--the angle between the direction of the cutting tool feed and the cutting edge--is important for chip formation, as well as for determining the direction of cutting forces, the length of cutting edge that contacts the workpiece, and the way the edge contacts the work

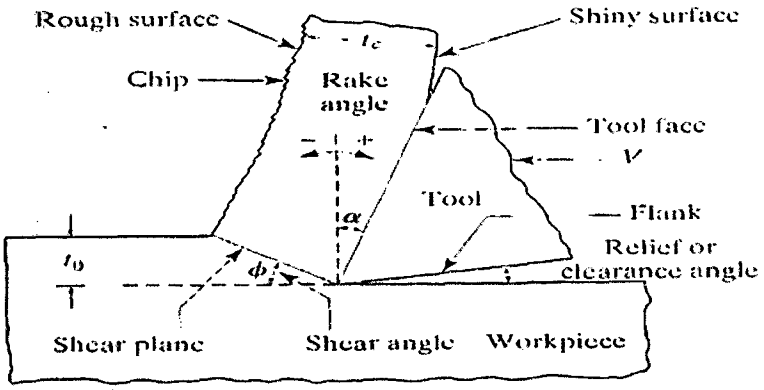


Figure 2.14: Schematic illustrations of orthogonal cutting *(Kalpakjian & Schmid, 2001)*

Tool nose radius is a factor that affects both insert strength and workpiece surface finish. The radius may be large for strength, or sharp for fine-radius turning. A large nose radius providing better heat dissipation and improved tool life besides it is also influences chip formation.

Edge preparation is another important aspect of insert geometry. Sharp edges tend to be weak and tend to fracture, so insert cutting edges are generally prepared with particular forms that strengthen them. These include a honed radius, a chamfer, a land, or a combination of the three.

A radius is applied to most corners to round the sharp edge. Radii for carbide turning inserts generally range between 0.0002 and 0.0030" (5 - 75 μm). A chamfer breaks the corner, while a land is a relief that stretches back some distance on the insert face. Placing a land on the edge before the actual rake angle takes effect strengthens the cutting edge by redirecting cutting forces into the body of the insert.

A special type of edge preparation that has come into wide use for both turning and milling operations is the wiper geometry. Like conventional turning inserts, wiper tools use their leading edge to remove metal and leave a surface of peaks and grooves. But wiper inserts feature additional radii behind the tool nose that are kept in contact with the workpiece after the initial cut. This burnishes peaks, leaving a smoother surface finish.

The real benefit, of wiper geometries according to tool suppliers, is reduced cycle times resulting from increased feed rates. Users may even be able to double feed rates and maintain the same surface finish by applied a standard insert.

Wiper geometries, however, are not for every application. They are not suited to light finishing operations, because they require heavier depths of cut to work correctly. Also, they must be run at higher feeds to take full advantage of the wiper geometry.

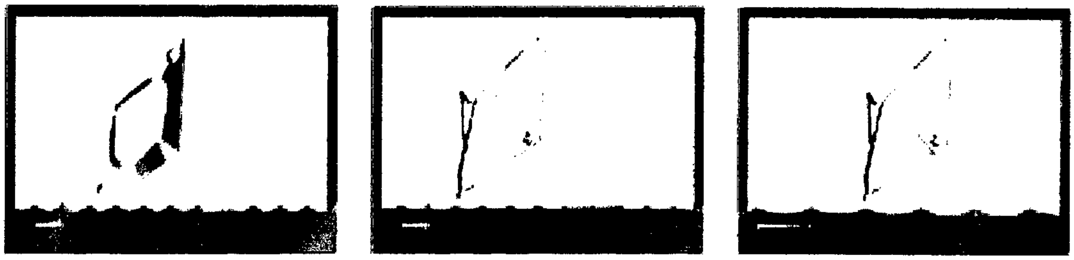


Figure 2.15: Wiper inserts allow users to either improve workpiece surface finish (center) or increase feed rate while maintaining the same surface finish (right)*(B.C. Su, H.C. Hua and Y.L. Hsin, 1998)*

2.9. Chipforming

Chipforming is important for efficient turning operations and good workpiece surface finish. Next to speed, the chipformer geometry of a turning insert has the most influence on the amount of heat generated in the cutting zone.

Chipformers are often referred to as chip breakers. This component of insert geometry forms the chip and causes it break either by itself, by deflecting against the tool, or by deflecting against the workpiece.

The more the chipformer bends the chips, the more heat it generates. So chipformer selection is a trade-off, and the geometry chosen must be matched with the work material feed rate, and depth of cut. The efficiency of some chipformers depends on the depth of cut. Others are more sensitive to feed rate.

The basic types of chips produced by turning include small, curled chips; helical or spiral chips; long, stringy chips; and corrugated chips.Depending on the application, however, making very small chips may not be necessary. An obsession with making very short chips may actually lead to chipforming overkill that can overpower the chipformer and reduce tool life

Chipformer geometries vary widely depending on the workpiece material and other application specifics. A common type of chipformer is essentially a valley between the cutting edge and the land behind the edge. The width of this valley determines the depth of cut or feed rate required for chipforming. Inserts for roughing operations, for example, require a wide valley. Inserts for finishing can be designed with a narrower valley.

For milling tools, chipforming is not as big an issue as in turning; chips essentially break by themselves as a result of the discontinuous nature of the cut. But chipformers on milling inserts perform two essential functions: they reduce the amount of heat in the cutting zone and minimize double-cutting by deflecting chips up and out of the cutting zone.

Tool geometry for milling operations is determined in large measure by the way inserts are held in the cutter body. The axial and radial rakes of the cutter needed for a specific job are determined by the work material, the specific milling operation being performed, the type of machine being used, required feeds and speeds, and other factors.

For example, cutters with both axial and radial rakes negative that are measured in planes parallel and perpendicular to the tool's axis of rotation respectively are well suited for the high impact loads that can occur in milling hard steels and cast irons. Positive cutters are useful for materials that tend to work harden and for any situation where lower cutting forces and horsepower requirements are desirable. Cutters can also have any other combination of positive and negative rakes.

Chip formation especially thickness is critical in milling. Chip thickness varies according to lead angle. Large lead angles produce thinner chips, spreading machining loads over a greater length of the insert edge. While this approach allows higher feeds per tooth, it reduces depth of cut capability. Lead angles in face milling generally vary between 0 and 45°.

Insert geometry also influences overall tool geometry. The overall shape of the insert determines the strength of the cutting edge, the number of indexes available per insert, and workpiece surface finish.

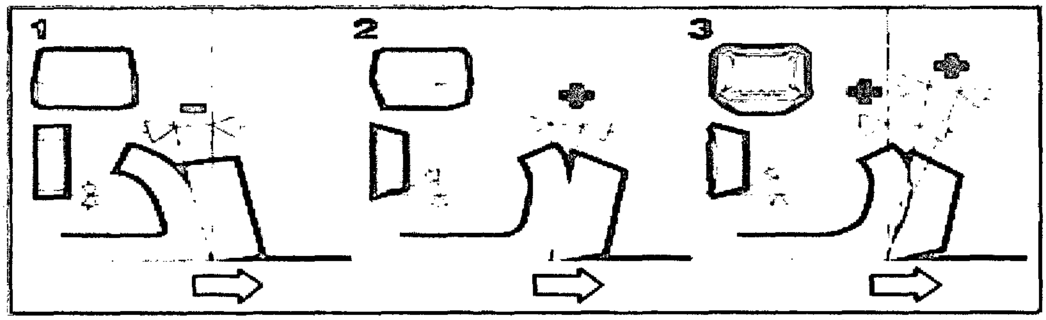


Figure 2.16: Both cutter body geometry and insert geometry can influence the way tools are presented during milling. From left: negatively held insert, positively held insert, and positively shaped insert.

Insert shapes for milling range from round to octagonal, square, triangular, and unique shapes made possible by advances in tool production techniques. Each of these shapes is suited for a range of applications. Round inserts, for example, allow multiple indexes depending on the depth of cut being used, and are most often applied for milling of high-strength steels, heat-resistant alloys, titanium alloys, and other difficult-to-machine materials. Maximum depth of cut when using round inserts is half the insert diameter.

Edge preparations for milling inserts range from up-sharp to chamfers, radii, and negative lands. A radius produces a strong corner and spreads wear and heat. Chamfers and negative lands increase edge strength. As in turning, the trade-off is one of insert edge strength versus higher cutting forces and heat generation.

On inserts with radius edges, workpiece surface finish can be maintained by using a parallel land, a straight edge on the insert parallel to the plane of cutter rotation. When surface finish requirements are very high, use of wiper inserts is common. On larger diameter cutters for face milling, wiping is achieved by positioning one insert below the others to smooth out surface. In milling, wiper inserts are for finishing operations in short-chipping or soft materials.

For mold making and other applications that require milling of complex contours, solid and insert ballnose end mills are available. Insert end mills are used mainly for roughing and semi-finishing operations.

Large diameter ballnose tools may feature a cutting edge that uses several inserts staggered along some length of the cutter body. Inserts with a helical cutting edge provide smooth cutting action with reduced chatter and improved workpiece surface finishes while allowing users to take heavier cuts. The tools shear the work material, increasing metal removal rates while reducing machining stresses and longer tool life.

A current trend in milling insert design is toward positive geometries that provide free cutting with reduced machining forces and lower horsepower requirements. According to one tool supplier, a 1° increase in positive rake cuts power requirement by 1.5% and also reduces vibration.

These types of inserts have a high helix on the edge and large relief angle to facilitate uninterrupted chip flow. Geometries feature combinations of helical edges, chamfers, lands, and edge radii.

Strength is maintained in the sharp cutting edges of positive inserts by using tougher tool materials and by redirecting cutting forces to a better-supported area of the tool. Careful design of the transition from the cutting edge to other parts of the tool geometry also helps add strength. Positive-geometry inserts designed for milling aluminum, for example, feature very wide chip gullets that make chips more manageable and remove heat from the cutting zone.

2.10 Effect of Tool Angles

In general it can be said that poor cutting conditions giving increased specific cutting energies and increased tool temperature result in higher tool wear rates. Because an increased in rake angle usually leads to an improvement in cutting conditions, a longer tool life would be expected. However, when the tool rake angle is large, the cutting edge is mechanically weak, resulting in higher wear rates and shorter tool life. Therefore, for an otherwise constant set of cutting conditions, an optimum rake exists giving a maximum tool life.

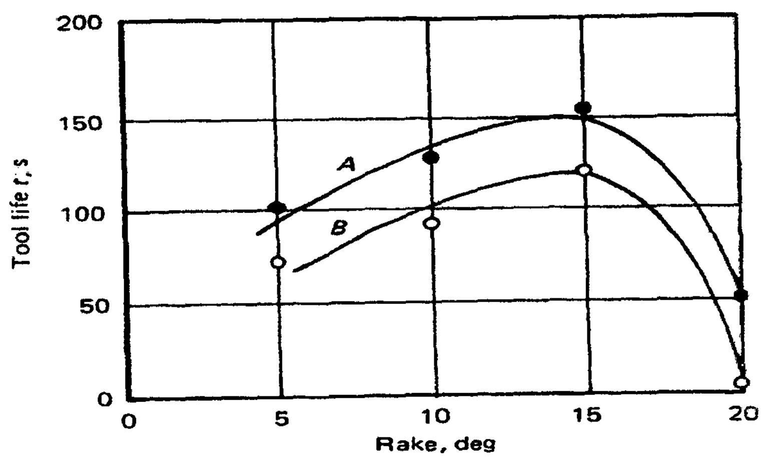


Figure 2.17: Effect of tool rake on tool life *(Geoffrey B & Winston A. Knight, 1900)*

A typical relationship between rake angle and tool life is shown, where the optimum rake is approximately 14 deg when cutting high-strength steel with a high-speed steel tool.

2.11 Temperature in Cutting

Heat has critical influences on machining. To some extent, it can increase tool wear and then reduce tool life, increase the thermal deformation and cause to environmental problems *(Arthur R. Meyers & Thomas J. Slattery, 2001)*. However, due to the complexity of machining mechanics, it's hard to predict the intensity and distribution of the heat sources in an individual machining operation. Especially, because the properties of materials used in machining vary with temperature, the mechanical process and the thermal dynamic process are tightly coupled together. Since early this century, many efforts in theoretical analyses and experiments have been made to understand these phenomena, but many problems are still remaining unsolved.

When a material is deformed elastically, the energy required for the operation is stored in the material as strain, and no heat is generated. However, when a material is deformed plastically, most of the energy used is converted into heat.

Conversion of energy into heat occurs in the two principal plastic deformation *(See figure 2.11),* the shear zone or primary deformation zone, *AB* and the secondary deformation zone *BC.* If, as in most practical circumstances, the cutting tool is not perfectly sharp, a third heat source *BD* would be present owing to friction between the tool and the new workpiece surface. However, unless the tool is severely worn, this heat source would be small and is neglected in the present analysis.

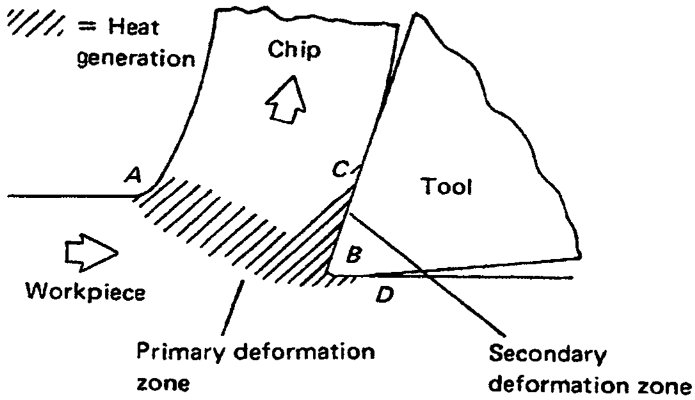


Figure 2.18: Generation of heat in orthogonal cutting *(Arthur R. Meyers & Thomas J. Slattery, 2001)*

2.11.1 Heat Generated in Primary Zone

Referering to *Boothroyd (2001)* Heat generated in this zone is mainly due to plastic deformation and viscous dissipation But in classical machining theory, the rate of heat generated is the product of the shear plane component, *Fs*, of the resultant force and the shear velocity, *Vs*, i.e., the shear energy is completely converted into heat.

If heat source is uniformly distributed along the shear plane, the intensity of shear plane heat source, *Ip*, satisfies the following relation:

$$Ip = \left(\frac{FsVs}{bt1} \right)$$

Where *b* is the cutting width and *t1* the uncut depth.

2.11.2 Heat Generated in Secondary Zone

In this region, because of the complexity of plastic deformation, this part of heat was ignored in many previous theoretical researches.

Boothroyd (2001) has shown that the secondary plastic zone is roughly triangular in shape and that strain rate, E., in this region varies linearly from an approximately constant value along the tool/chip interface given by

$$E = \frac{Vc}{dt}$$

Where *Vc* is the chip velocity, *dt* the maximum thickness of the zone.

Hence the maximum intensity of heat source in this zone is proportional to the strain rate.

2.11.3 Heat Generated at Interface between Tool & Chip

Heat is generated at the tool/chip interface by friction. The intensity, *Ic*, of the frictional heat source is approximately by

$$Ic = \frac{FVx}{hb}$$

Where *F* is the friction force, *Vx* the sliding velocity of the chip along the interface, and h is the plastic contact length.

2.11.4 Temperature Distribution near Cutting Zone

The typical temperature distributions are shown as follows: Here are the isothermal lines for dry orthogonal cutting of free machining steel with a carbide tool.

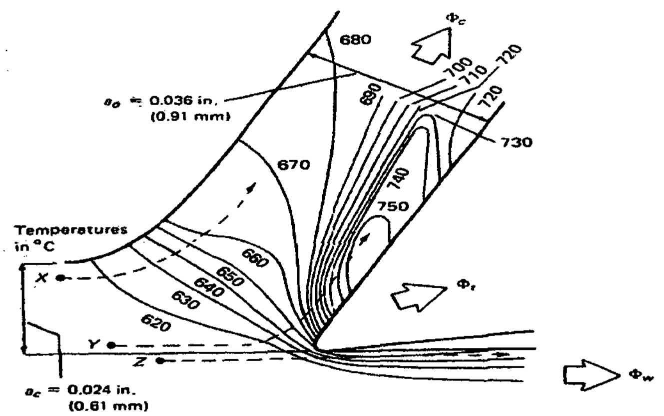


Figure 2.19: Temperature distribution in workpiece where the cutting speed is 75 ft/min and the workpiece temperature is 611° C (G. Boothroyd and Winston A.K, 2001)

2.12 Milling Parameter

The most important factors affecting the efficiency of a milling operation are cutter speed , feed and depth of cut. If the cutter is run too slowly, valuable time will be wasted, while excessive speed results in loss of time replacing and regrinding cutters. Somewhere between these two extremes is the efficient cutting speed for the material being machined.

The rate at which the work is fed into the revolving cutter is important. If the work is fed too slowly, time will be wasted and cutter chatter may occur which shortens the tool life of the cutter. If the work fed too fast, the cutter teeth can be broken. Much time will be wasted if several shallow cuts are taken instead of one deep or roughing cut.

2.12.1 Cutting Speeds

Cutting speed may be defined as the rate (or speed) that the material moves past the cutting edge of the tool, irrespective of the machining operation used the surface speed. A cutting speed is the same whether it is the speed of the (stationary) cutter passing over the (moving) workpiece, such as in a turning operation, or the speed of the (stationary) workpiece moving past a (rotating) cutter, such as in a milling operation. What will affect the value of this surface speed for mild steel are the cutting conditions.

For a given material, there will be an optimum cutting speed for a certain set of machining conditions, and from this speed the spindle speed (RPM) can be calculated. Factors affecting the calculation of cutting speed are:

- The material being machined (steel, brass, tool steel, plastic, wood)
- The material the cutter is made from (Carbon steel, High speed steel (HSS), carbide, ceramics)
- Depth of cut being taken

Cutting speeds are calculated on the assumption that optimum cutting conditions exist, these include:

- Metal removal rate (finishing cuts that remove a small amount of material may be run at increased speeds)
- Full and constant flow of cutting fluid (adequate cooling and chip flushing)
- Rigidity of the machine and tooling setup (reduction in vibration or chatter)
- Diameter of the cutter
- Surface finish required [8]

Since different type metals vary in hardness, structure, and machinability, different cutting speed must be used for each type of metal and for various cutter materials.

2.12.2 Feed

The feed per tooth (Ft) value is one of the most important factors selected in the milling operation because it will determine the amount of material removed by each tooth, the tooth load on the milling cutter, the finish on the workpiece, and the cutter life.

Feed in milling machine is defined as the distance in millimeters per minute that the work moves into the cutter. Feedrate is dependent on the:

- Surface finish desired.
- Power available at the spindle (to prevent stalling of the cutter or workpiece)
- Rigidity of the machine and tooling setup (ability to withstand vibration or chatter).
- Strength of the workpiece (high feed rates will collapse thin wall tubing)

- Characteristics of the material being cut, chip flow depends on material type and feed rate. The ideal chip shape is small and breaks free early, carrying heat away from the tool and work.

A single point cutting tool is the simplest tool type to calculate feed rate for, however with a milling machine or jointer where multi tipped/fluted cutting tools are involved then feed rate becomes dependent on the number of teeth on the cutter. The greater the number of cutting edges, the higher the feed rate permissible *(Krar, Amand &Ostwald, 1994).*

The milling feed is determined by multiplying the number of teeth in the cutter, and the revolutions per minutes of the cutter. When peripheral milling, the highest feed rate can be achieved when the width of cut is less then the radius of the end mill. When machining softer materials, the feed per tooth can be increases by as much as 25%. When using extra length end mills, the feed should be reduced by 25%. When using stub end mills, the feed may be increases by up to 25 *%(Precision Dormer).*

Chip per tooth is the amount of material that should be removed by each tooth of the cutter as it revolves and advances into the work.

2.12.3 Depth of Cut

Where a smooth accurate finish is desired, it is considered good milling practice to take a roughing and finishing cut. Roughing cuts should be deep, with a feed as heavy as the work and the machine will permit. Heavier cuts may be taken with helical cutters having fewer teeth than those having many teeth. Cutter with fewer teeth is stronger and has a greater chip clearance than cutters with more teeth *(Krar, Amand &Ostwald, 1994).*

Finishing cuts should be light, with a finer feed than is used for roughing cuts. Lighter cuts and extremely fine feed are not advisable, since the chip taken by each tooth will be thin and the cutter will often rub the surface of the work rather than bite into it, thus dulling the cutter. When a fine finish is required, the feed should be reduced rather than the cutter speeded up, more cutters are dulled by high speeds than by high feeds.

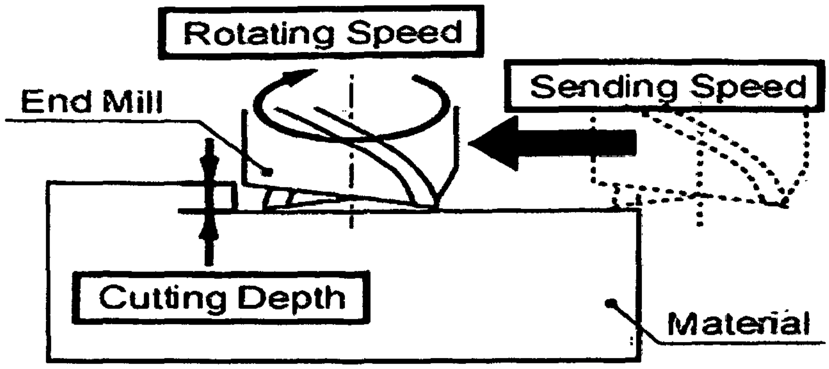


Figure 12.20: Two out of three important elements in milling

CHAPTER 3

METHODOLOGY

3.1 Introduction

In order to accomplish the objectives of this project, a methodology flowchart has been created (See Figure 3.0). It is used as guidelines to make sure the project run successfully. Below is the summary of the methodology flowchart:

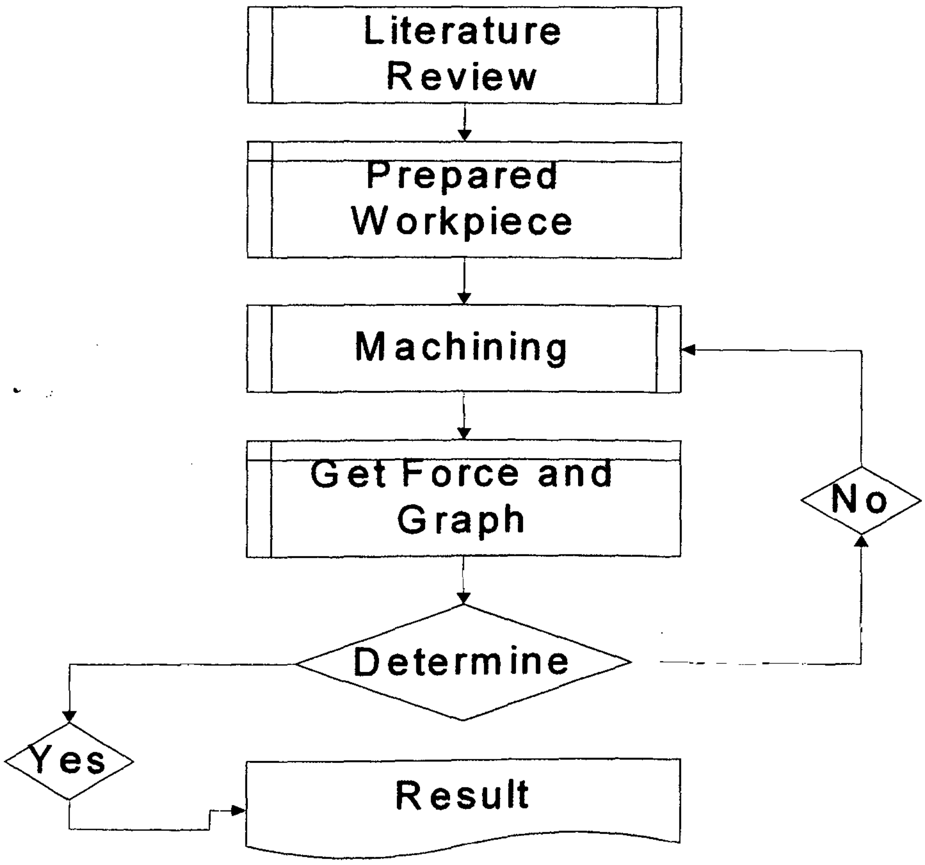


Figure 3.1: Solving Method Flowchart

3.2 Problem Statement

In the industry nowadays, milling machining process are one of the most method used to produce many other part with more complex shapes either the material is ferrous or non ferrous. So the objective of this project is to investigate or analyze the mechanistic of end cutting tool milling in term of improving the performance of the end milling operation. The performance of the end milling operation can be achieved by consider some factors that are contribute more on the efficiency of the operations. After all, it is more valuable if the operation milling achieved an optimum performance without put too much costs on it.

3.3 Literature Review

To achieve the main goal of this project some literature study and researches need to be done to enhance the information and knowledge related to this project. All the information is gathered, so that it will give a clear view in order to understand the basic concept regarding this title. All the related and useful information gained trough supervisor, reading journals, books and so on will be used in the future for the analysis of this project

There are various ways to collect data from the existing milling operation in the industry:

1. Define the purpose of the milling process.
2. Identify the problems occurs.
3. Understand the milling mechanism and mechanics of metal cutting.
4. Gather the information on milling parameter based on the material, types of cutter and type of machine that are going to be used.

This is the most effective and most important of all the steps involved. Relevant information is gathered regarding the operation that is studied. The data may be in the form of table, procedures, drawing, through out product characteristics, cutter been used types of machine and many more

3.4 Workpiece Preparation

The workpiece for this project is cut based on desires dimension and size which is block 100x100x50 mm by using band saw that are available in the Faculty of Mechanical lab. After cut the material into desired dimension and size, the workpiece then machining by using CNC milling machine and grinding to get smooth flat surface finish. Lastly, the workpiece need to be clean to remove all contaminants that alter on the workpiece surface.

3.5 Machining

The milling machining by process need to be execute again in order to get all the data that are going to be used for the analysis. The machining is running under certain fixed milling parameter which is cutting speed and feed rate but different depth of cut. These value need to be change time by time in order to get an optimum cutting force.

3.6 Get Force and Graph

During the machining, the Quartz 3-Component Dynamometer device is using to get the graph. The workpiece is mounting on the Dynamometer to get the value of cutting force in 3 axes from the machining process. If the graph is not relevant, the machining need to be repeated by set up again an appropriate milling parameter until the relevant graph is achieve.

3.7 Specific of the Experiment

3.7.1 Workpiece Preparation

The workpiece that is AISI 1020 Mild Steel is cut by using Band Saw Machine with the dimension 100x100x50 mm. after cut the workpiece into the desired dimension, the workpiece then machining by using HAAS CNC Milling to get the smooth flat surface. By using HAAS CNC Milling Machine the workpiece is drill through for the screw hole for workpiece to mounting tightly on the Dynamometer. The workpiece need to be mounting very well to avoiding the vibration during the end milling process to get the accurate cutting force.

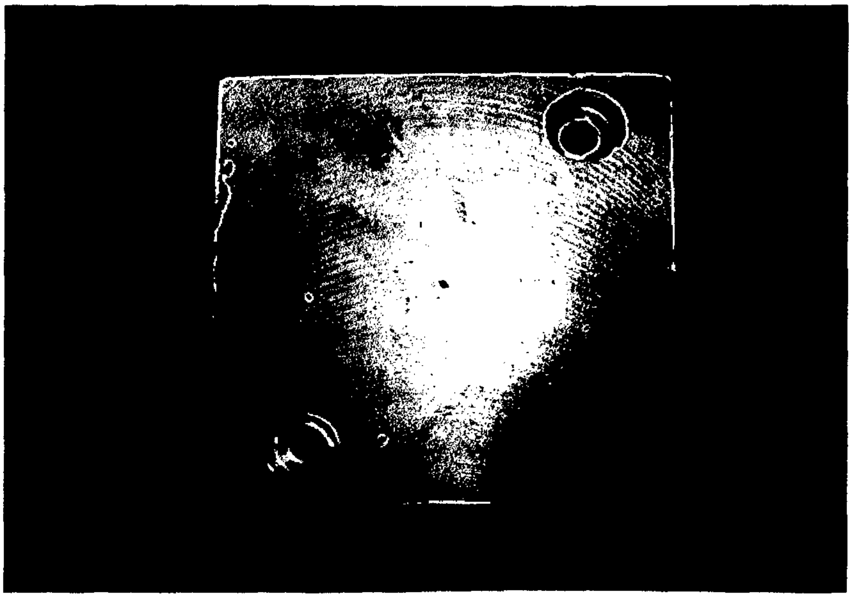


Figure 3.2: AISI 1020 Mild Steel, dimension 100x100x50 mm

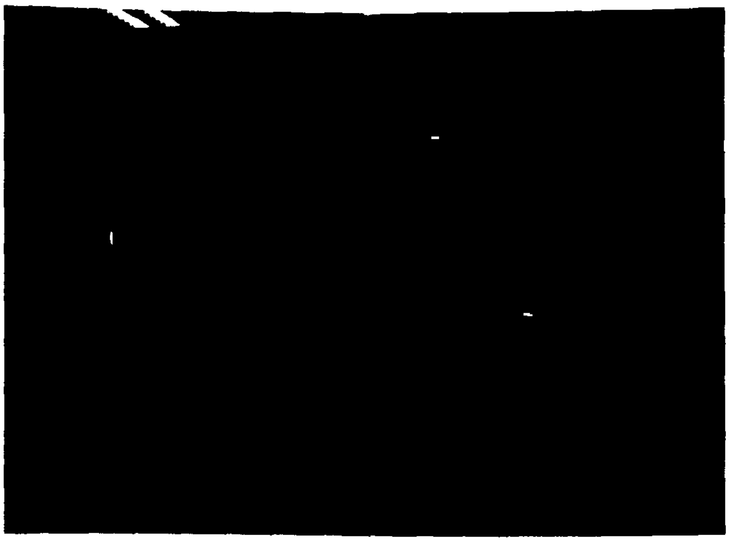


Figure 3.3: The HAAS CNC milling machine that had been used to flat the surface workpiece

3.7.2 Machining

To get the data for the cutting force of the 2-flute and 4-flute helical end mill, the Milling Conventional Machine 3-axis is used to mill the workpiece. The milling process is running under certain milling parameter which is depth of cut, spindle speed and feed rate. The value of the spindle speed and feed rate is referring to the book Table for the Metal Trade. This value is determined based on the type of the workpiece, the diameter of the tool and type of tool. However, the value is not available in the Conventional Milling Machine that has been used. Therefore, the closed value from Conventional Milling Machine is applied.

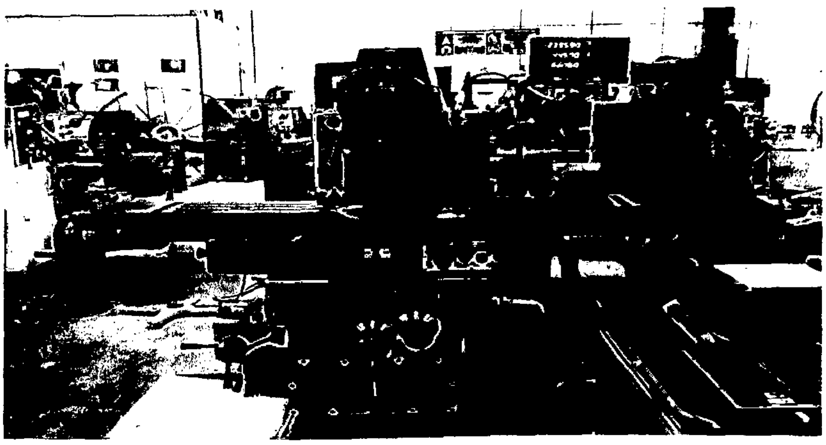


Figure 3.4: Milling Conventional Machine used to end mill the workpiece

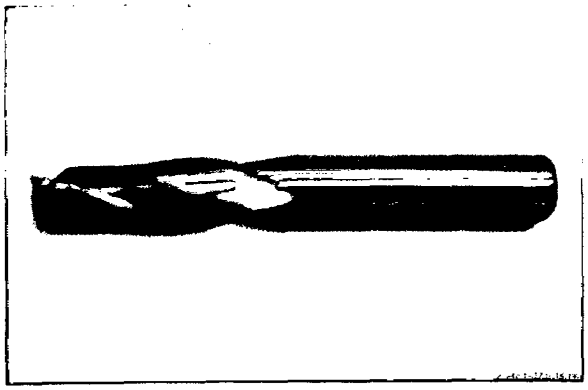


Figure 3.5: 2-flute High Speed Steel end mill

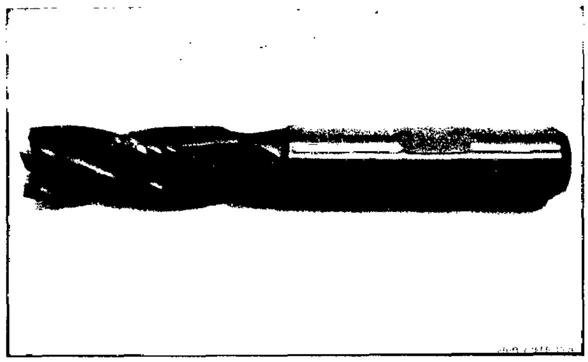


Figure 3.6: 4-flute High Speed Steel end mill

3.7.3 Get Force and Graph

The workpiece is mounting tightly on the Quartz 3-Component Dynamometer device. The contact zone between cutter and the workpiece during the end mill process are evaluated by Dynamometer. The workpiece is slot mill using 2-flute helical end mill by applied the different value for depth of cut and constant value of the spindle speed and feed rate while the Quartz 3-Component Dynamometer collect the data. To get the accurate value of the cutting force, the data is taken 3 times for every depth of cut. For the better result, make sure the wokpiece is mounting tightly to avoid the vibration and use the coolant for the longer tool life. It is also necessary to remove material a little at a time. To get an accurate result it is important to face mill the workpiece every time before the end mill process. It is because after the end mill process, the waved surface left causing a structural vibration. This structural vibration will affect the accuracy of the cutting force. After the experimental on the 2-flute High Speed Steel is done the same process is repeated by using 4-flute High Speed Steel end mill.

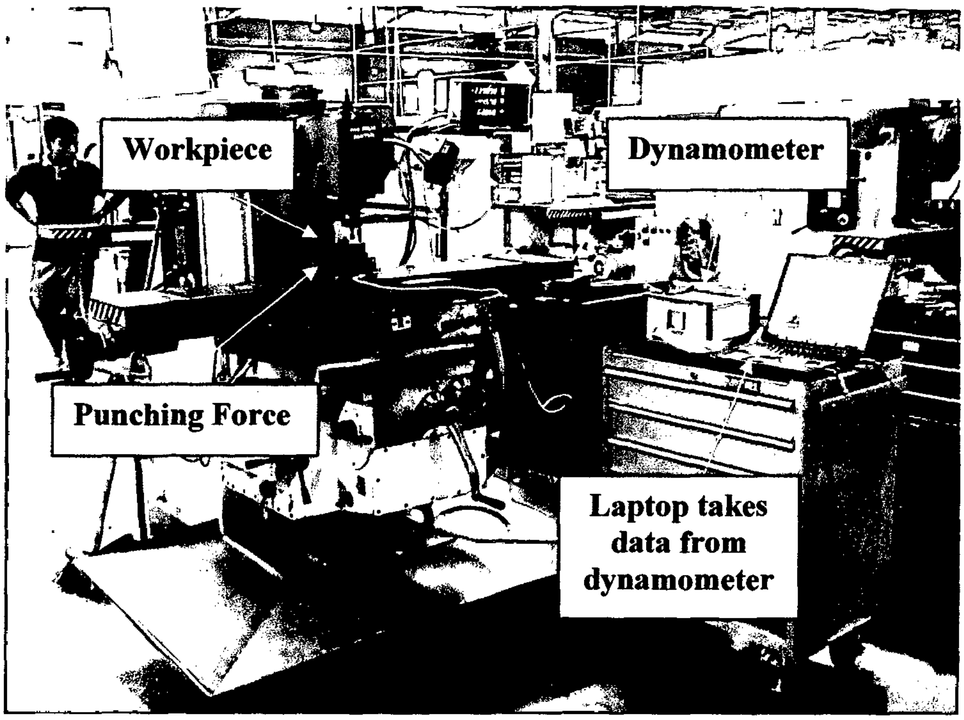


Figure 3.7: Kistler Quartz 3-Component Dynamometer is used together with Milling Conventional Machine to get the data of cutting force

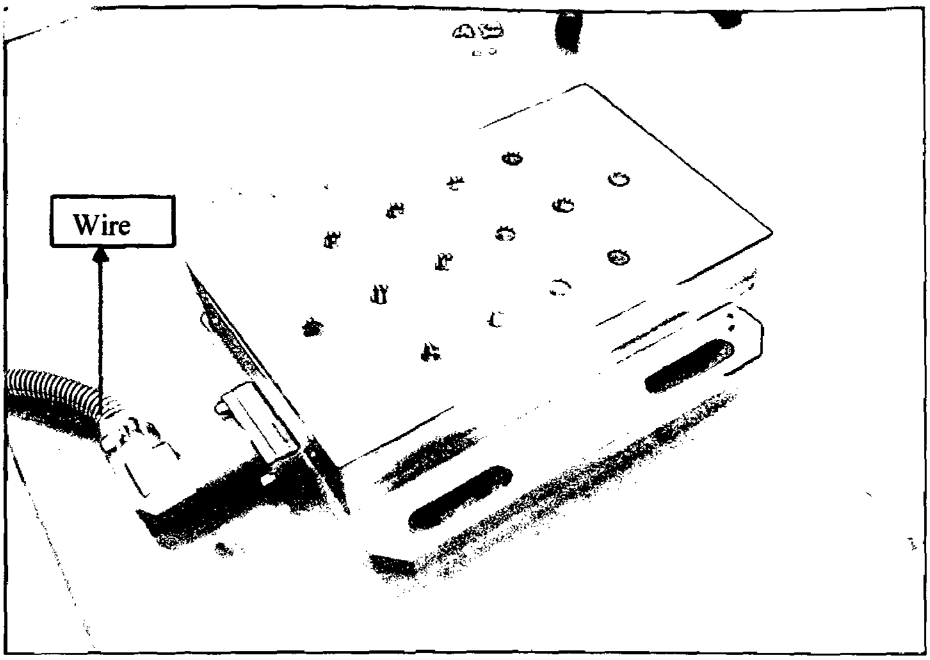


Figure 3.8: Punching Force to detect force on the workpiece. Wire to connect Punching Force and Dynamometer

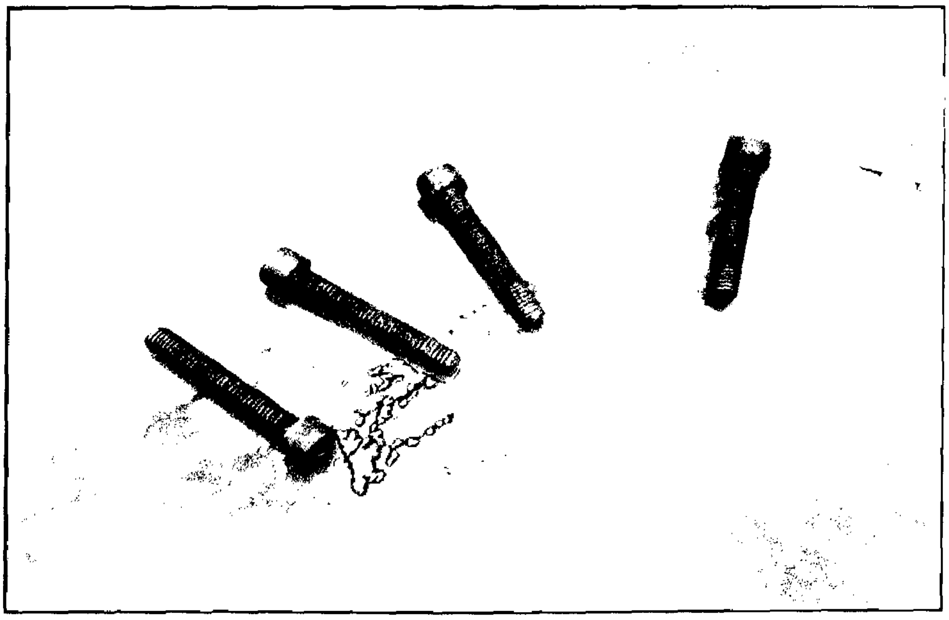


Figure 3.9: L-key screw use to fastening

3.8 Result Comparison

Graphs and data from the experiments is gather to analyze and make a comparison to determine at what value the milling parameter should be apply in order to achieve an optimum cutting force.

3.9 Expected Result

After experiment analysis been performed, it is time to compare between the existing milling parameter and also the milling parameter through the results that is gained. These desired results must prove that the performance of milling operation is improved in term of effectiveness of cutting force after being tested and analyzed, compared to the previous performance of milling operation.

3.10 Conclusion

To conclude, cutting tool milling are one of the metal cutting process that are widely used in industry nowadays. Cutting tool milling machining have various type of milling processes that every types are vary on their specification in the functions. In this project end milling machining were choose because end milling is using to produce a complex part. The main objective of this project is to improve the performance of the cutting operation on end mill. To achieved the primary objective of this project, there are certain factors needs to be consider because the fluctuating of these factors resulting on the cutting force of the end milling process. Thus, effects on the tools life, wear, surface finish, volume of the productions, chatter and so on. To avoid or reduces all these negative effect, research on need to be done. Beside enhance the understands on the mechanics of the cutting tools, literature study on the milling parameter, types of cutter, material to be used and other elements that related to this project need to be done.

CHAPTER 4

RESULT AND DISCUSSION

4.0 Introduction

Milling operations are one of the most common machining operations in industry. It can be used for finishing, edge finishing, material removal and etc. There are several parameters that are influence the forces acting on the cutter. Because of these parameters, the forces may become unpredictable and result in larger dimensional variations when products are produced.

The cutting force analysis is applied in order to determine the optimum cutting force in vertical direction which is z direction in Conventional Milling Machine for the end mill process by using the material Mild Steel AISI 1020 and to make a comparison for the cutting process between 2 flute HSS and 4 flute HSS helical end mill. Beside that, this analysis also helps to improve the performance of the end mill process.

In this project, two types of cutting tool are using which is 2-flute and 4-flute High Speed Steel to cut the mild steel in slot mill situation. The experiment will be operating in three different value of the depth of cut (0.2, 0.4, 0.8 mm) and the value for the feed rate and spindle speed was constant. Table 4.1 and 4.2 shown the parameters that have been used for this experiment.

Table 4.1: The parameter use for the end mill process of the 2-flute HSS end mill based on the type of material and cutting tool used.

Material	Tool	Depth of Cut(mm)	Spindle Speed(rpm)	Feed Rate(mm/rpm)
Mild Steel AISI 1020 100x100x50 mm	2-flute High Speed Steel Diameter 16 mm	0.2 0.4 0.8	400	50

Table 4.2: The parameter use for the end mill process of the 4-flute HSS end mill based on the type of material and cutting tool used.

Material	Tool	Depth of Cut(mm)	Spindle Speed(rpm)	Feed Rate(mm/rpm)
Mild Steel AISI 1020 100x100x50 mm	4-flute High Speed Steel Diameter 16 mm	0.2 0.4 0.8	400	50

Based on the type of wokpiece and cutting tool, the feed rate and spindle speed for this experiment is 50 mm/rpm and 500 rpm. However, the value for the spindle speed is not available in the Conventional Milling Machine that has been used. So the value of 400 rpm is choose because it is the nearest value available.

4.1 Cutting Force Data Analysis

4.1.1 2-flute High Speed Steel Helical End Mill

4.1.1.1 Details:

1. Depth of Cut = 0.2 mm
2. Feed Rate = 50 mm/rpm
3. Spindle Speed = 400 rpm

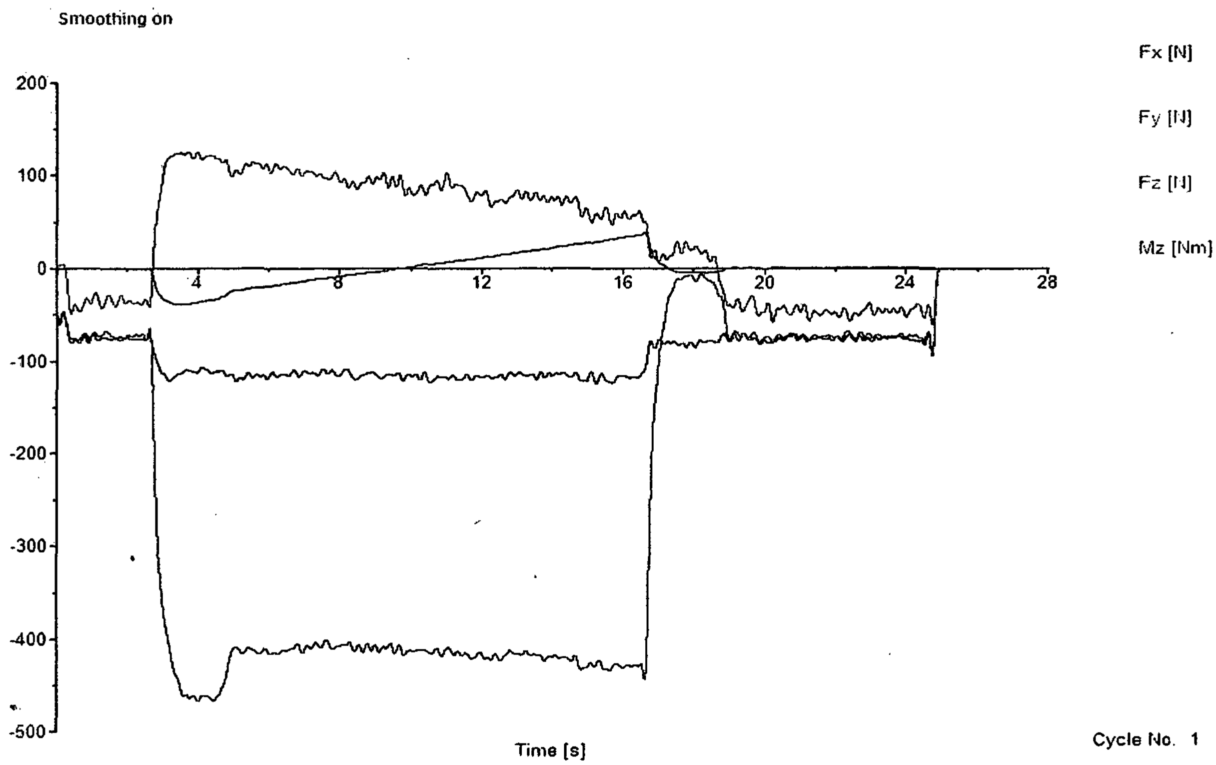


Figure 4.0 : Cutting force of 0.2 mm depth of cut (x,y and z direction)

Graph 4.2 shows the simulation of the cutting force at the depth of cut 0.2 mm using 2-flute HSS helical end mill. When the cutting process, started it can be observed that the value for the cutting force is higher and after 6 seconds became decrease.

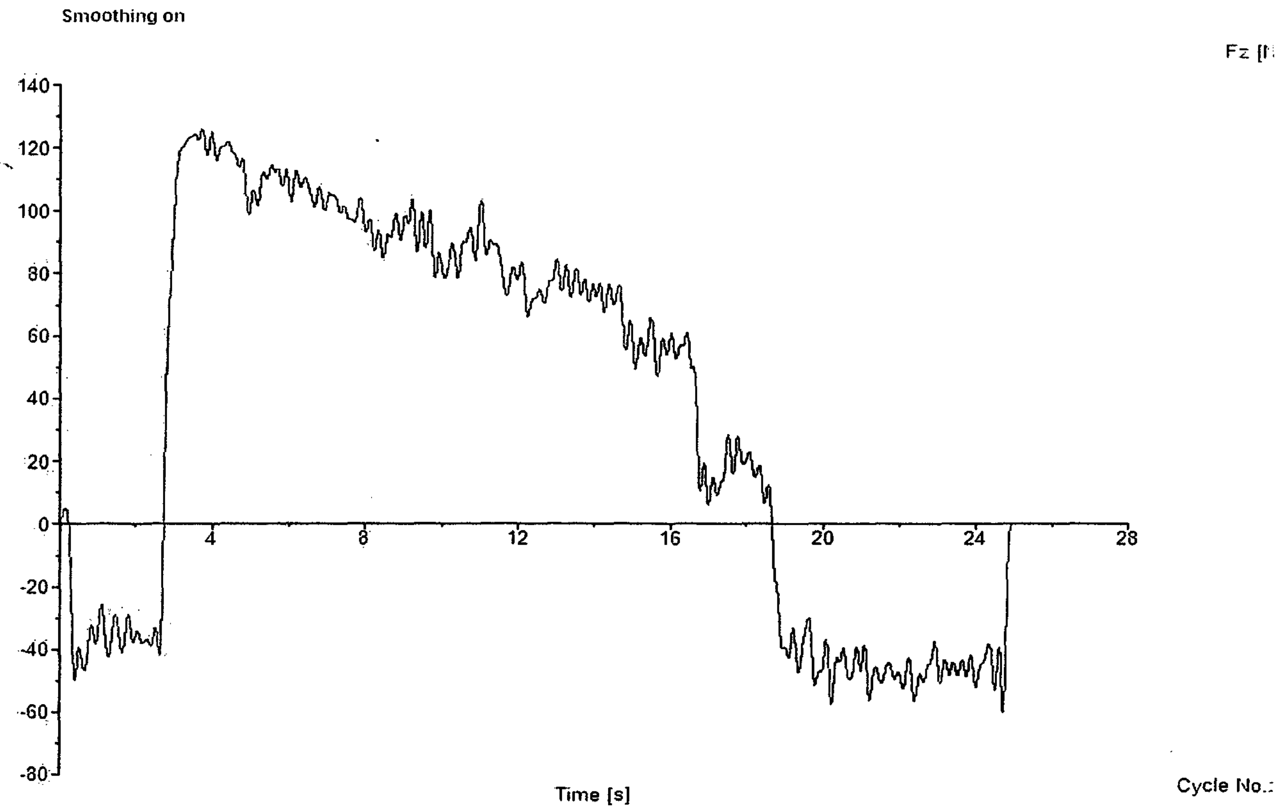


Figure 4.1: Cutting force of 0.2 mm depth of cut for z direction

4.1.1.2 Details:

1. Depth of Cut = 0.4 mm
2. Feed Rate = 50 mm/rpm
3. Spindle Speed = 400 rpm

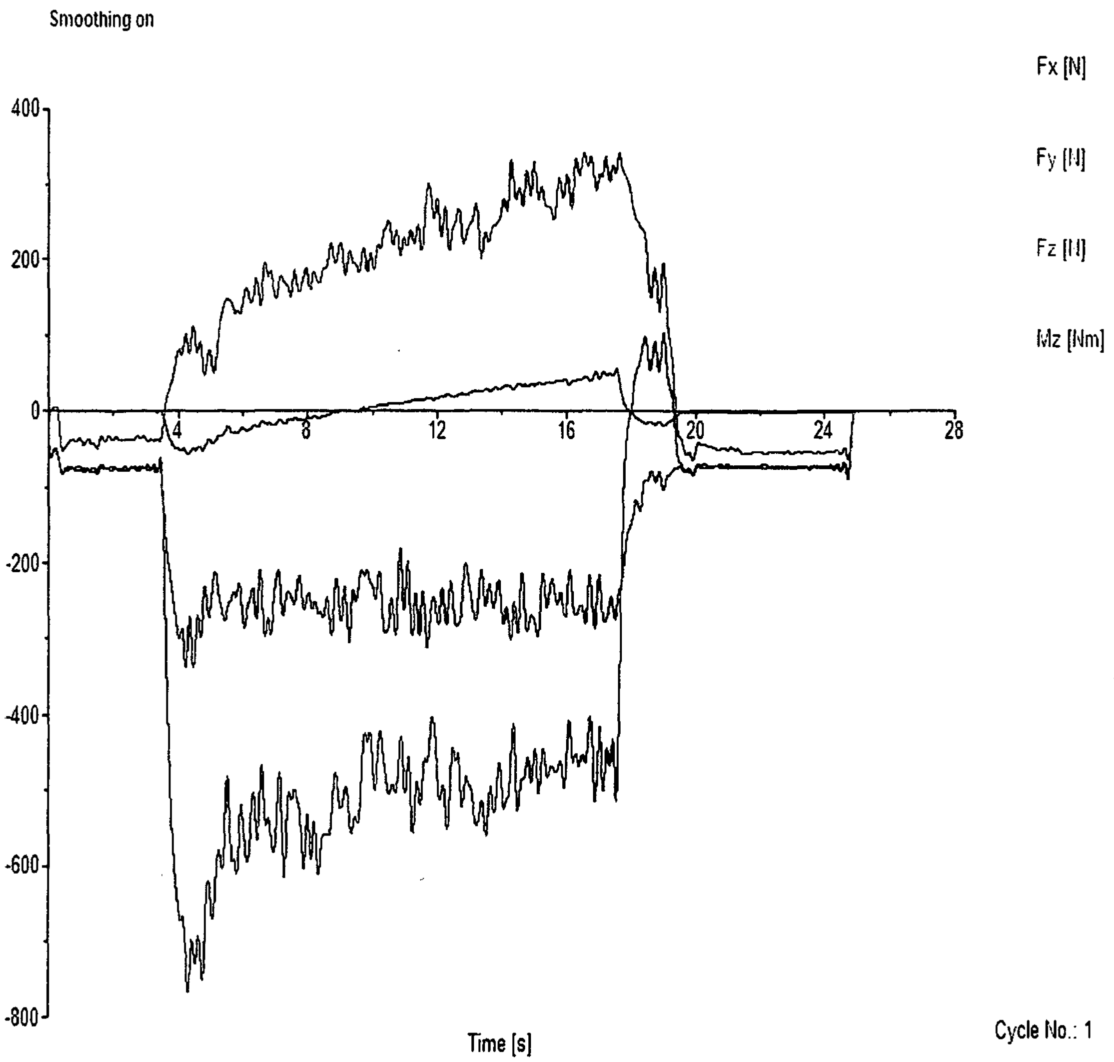


Figure 4.2: Cutting force of 0.4 mm depth of cut (x,y and z direction)

When 0.4 mm depth of cut was applied, the simulation of the cutting force is lower than cutting force for 0.2 mm depth of cut. However, the force is increase constantly compare to simulation for 0.2 mm depth of cut.

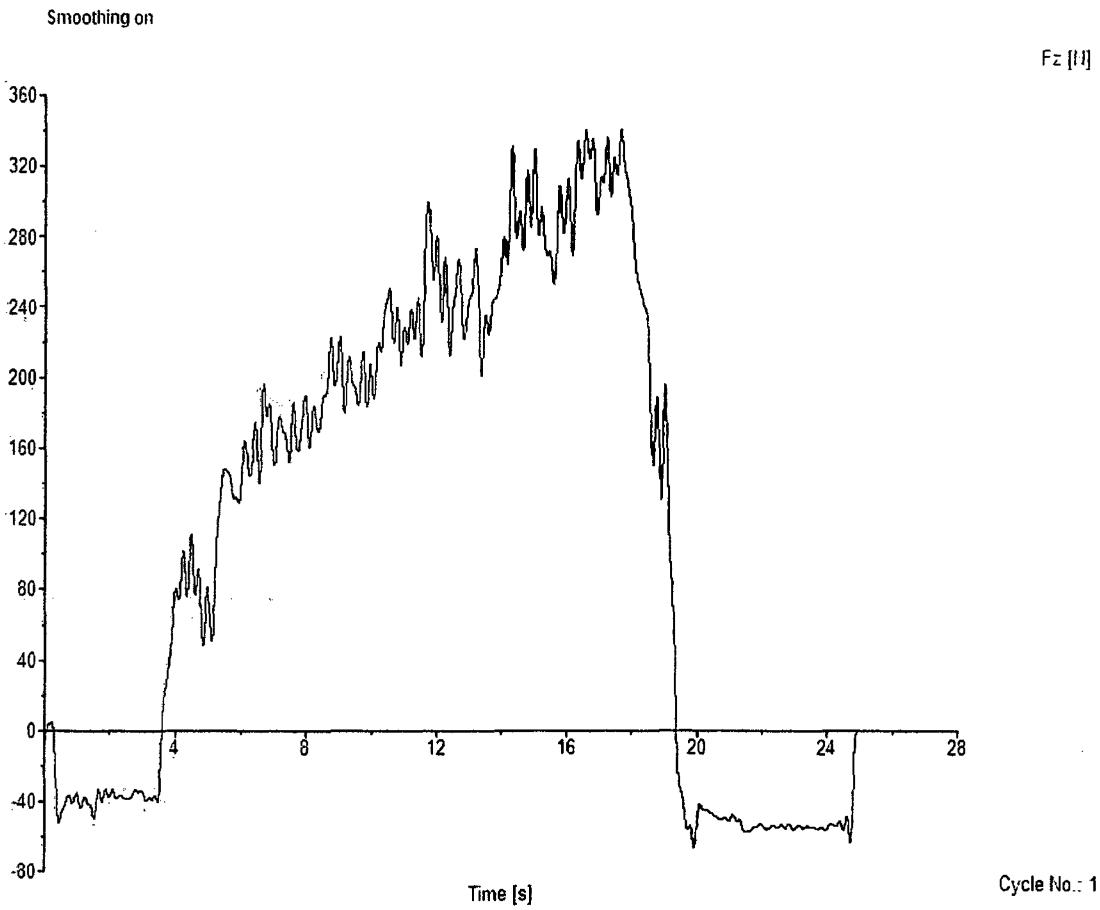


Figure 4.3: Cutting force of 0.4 mm depth of cut for z direction

4.1.1.3 Details:

1. Depth of Cut = 0.8 mm
2. Feed Rate = 50 mm/rpm
3. Spindle Speed = 400 rpm

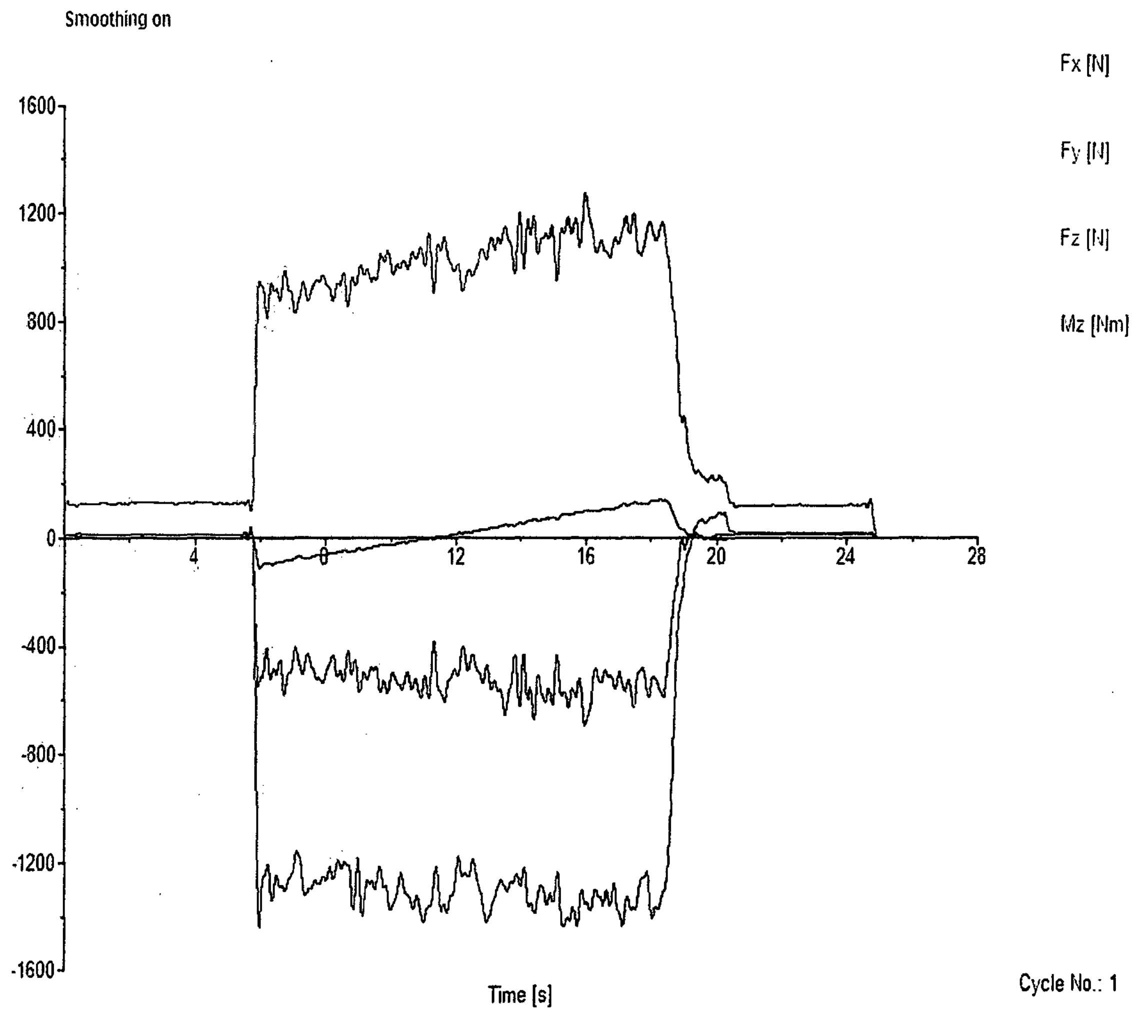


Figure 4.4: Cutting force of 0.8 mm depth of cut (x,y and z direction)

0.8 mm depth of cut showed higher cutting force compare to 0.2 mm and 0.4 mm. Moreover, the cutting force is constant and not increase slightly compare to 0.4 mm depth of cut.

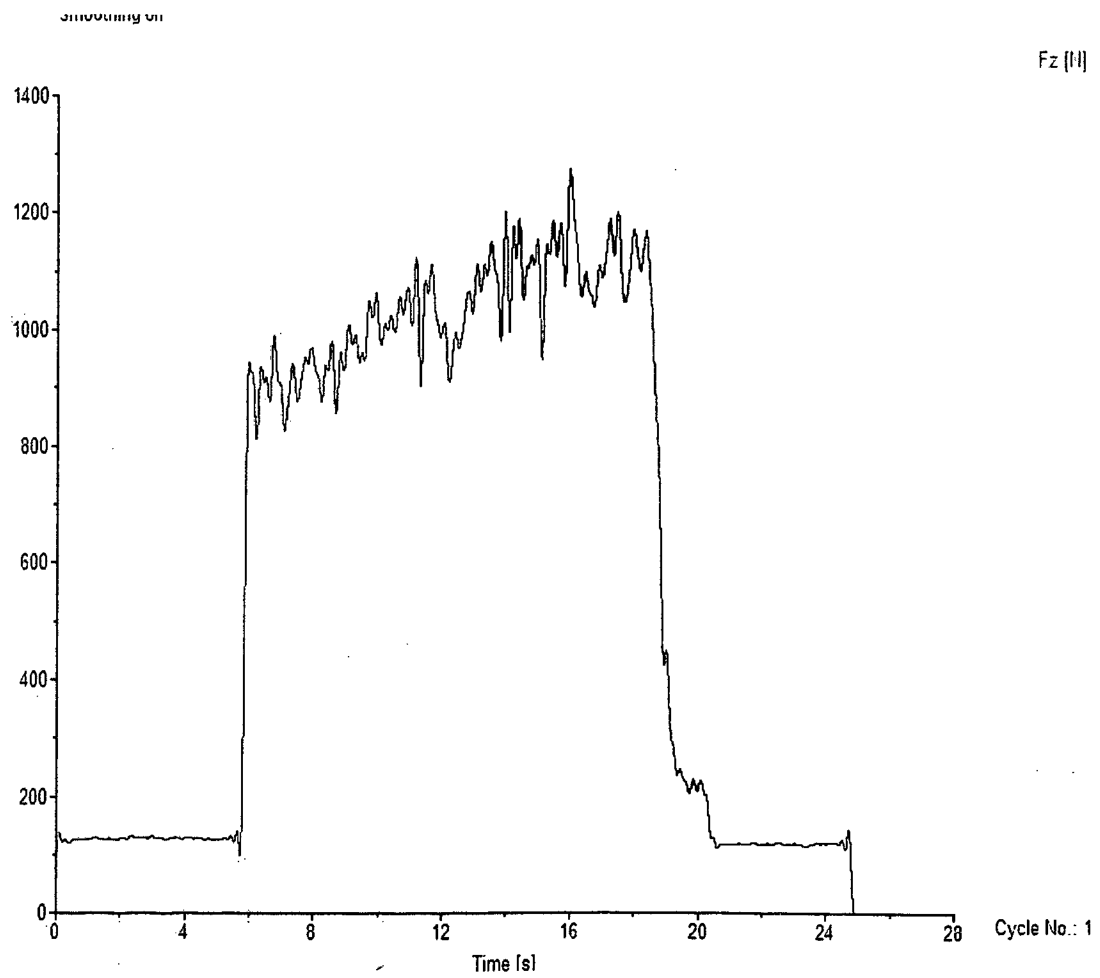


Figure 4.5: Cutting force of 0.8 mm depth of cut for z direction

4.1.2 4-flute High Speed Steel Helical End Mill

4.1.2.1 Details:

1. Depth of Cut = 0.2 mm
2. Feed Rate = 50 mm/rpm
3. Spindle Speed = 400 rpm

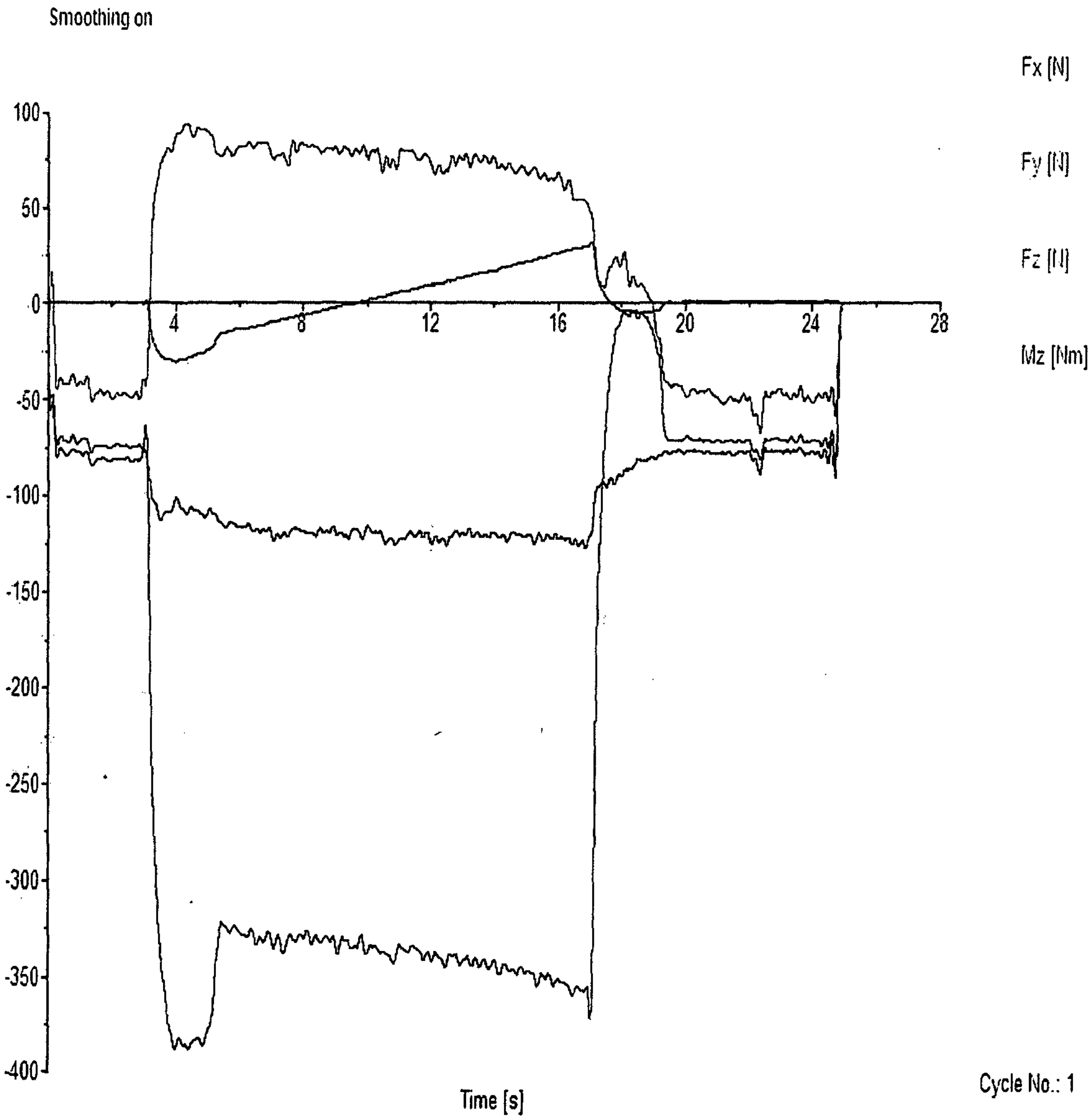


Figure 4.6: Cutting force of 0.2 mm depth of cut (x,y and z direction)

Graph 4.8 shows that even though the simulation cutting force is decrease constantly, cutting force for 0.2 mm for 4-flute HSS end mill is lower than cutting force 0.2 mm depth of cut for 2-flute HSS end mill.

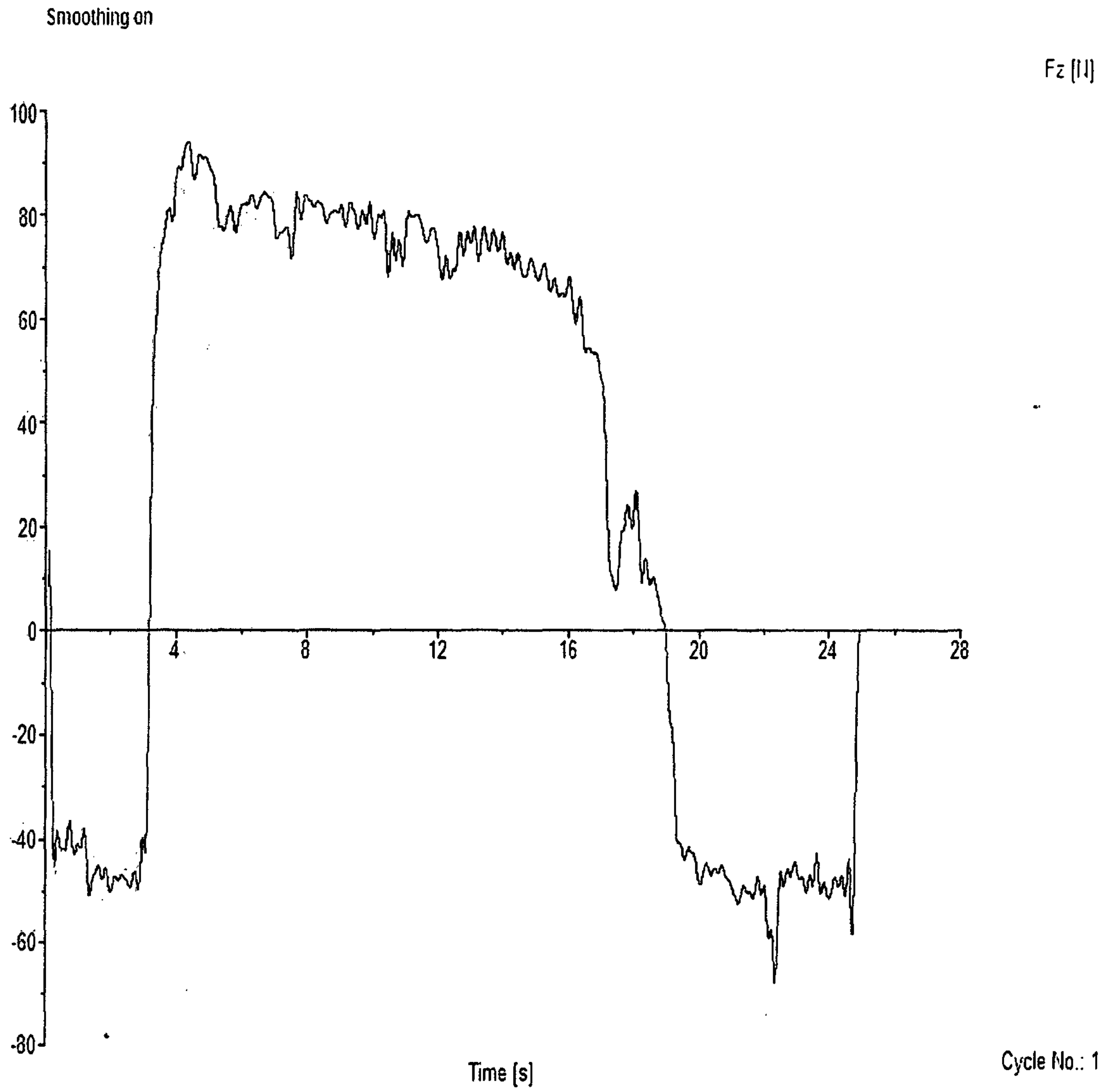


Figure 4.7: Cutting force of 0.2 mm depth of cut for z direction

4.1.2.2 Details:

1. Depth of Cut = 0.4 mm
2. Feed Rate = 50 mm/rpm
3. Spindle Speed = 400 rpm

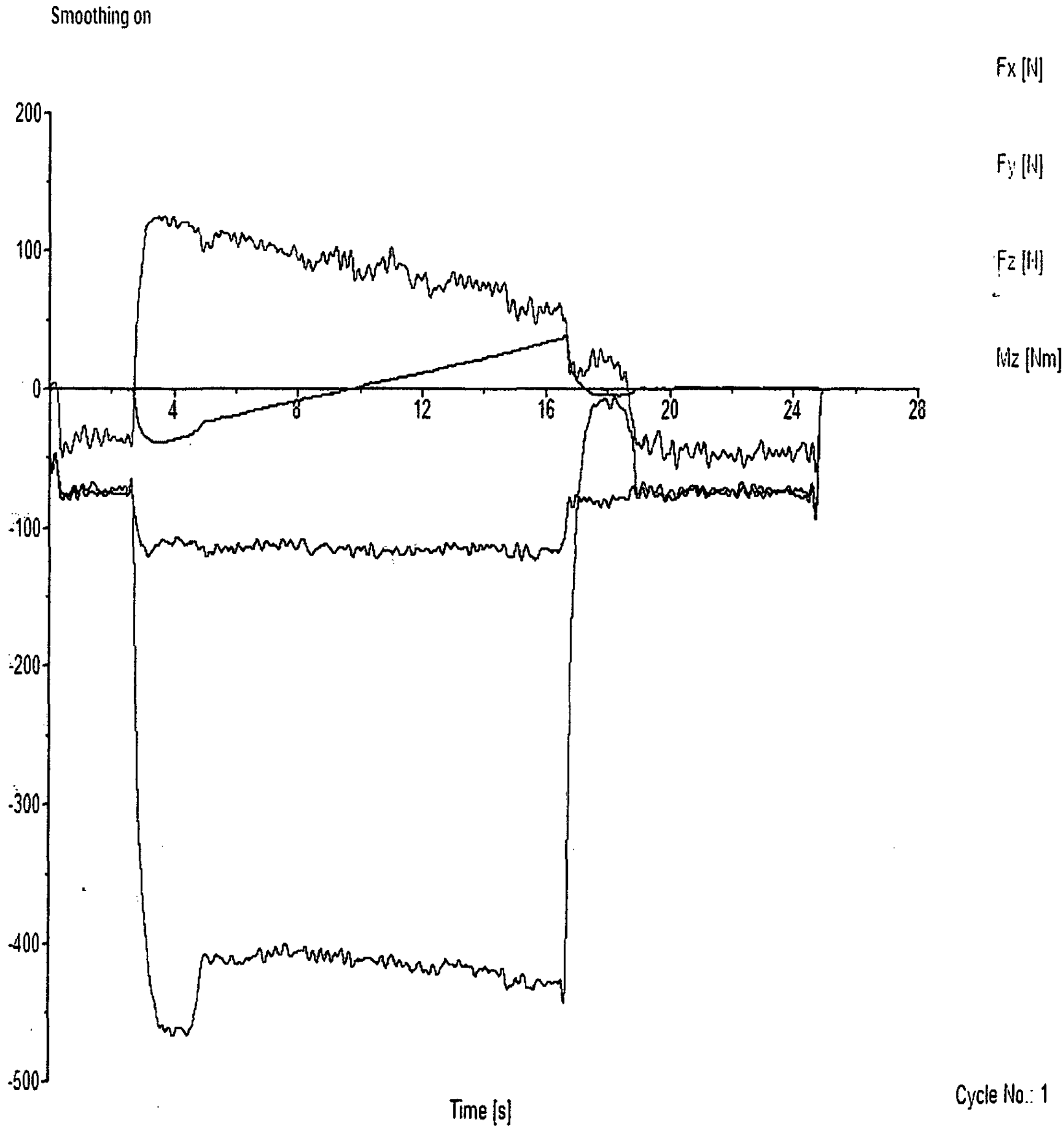


Figure 4.8: Cutting force of 0.4 mm depth of cut (x,y and z direction)

Graph 4.10 shows that the simulation cutting force for 0.4 mm depth of cut is decrease constantly. However, the simulation of the cutting force is higher than cutting force of 0.2 mm depth of cut.

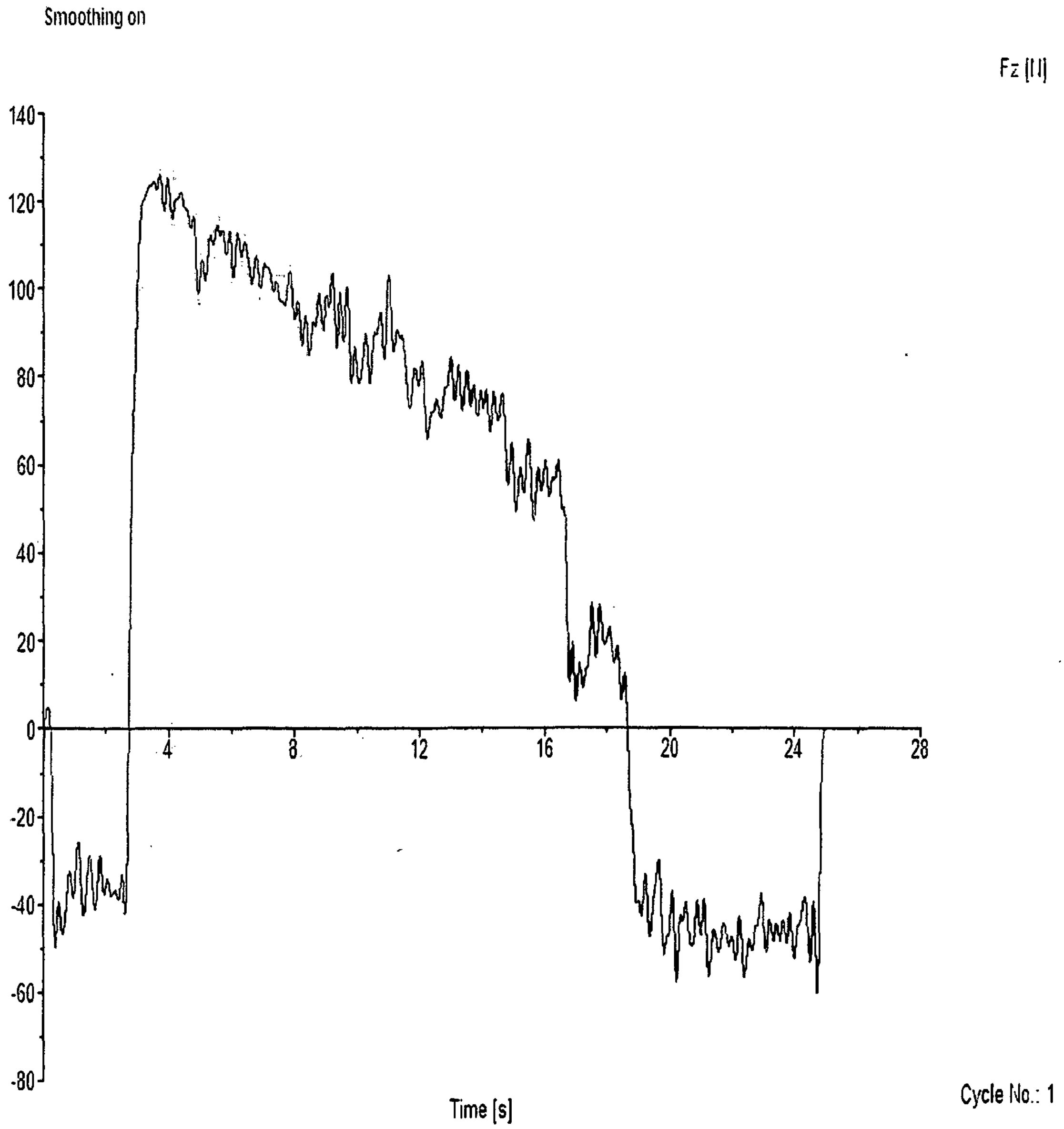


Figure 4.9: Cutting force of 0.4 mm depth of cut for z direction

4.1.2.3 Details:

1. Depth of Cut = 0.8 mm
2. Feed Rate = 50 mm/rpm
3. Spindle Speed = 400 rpm

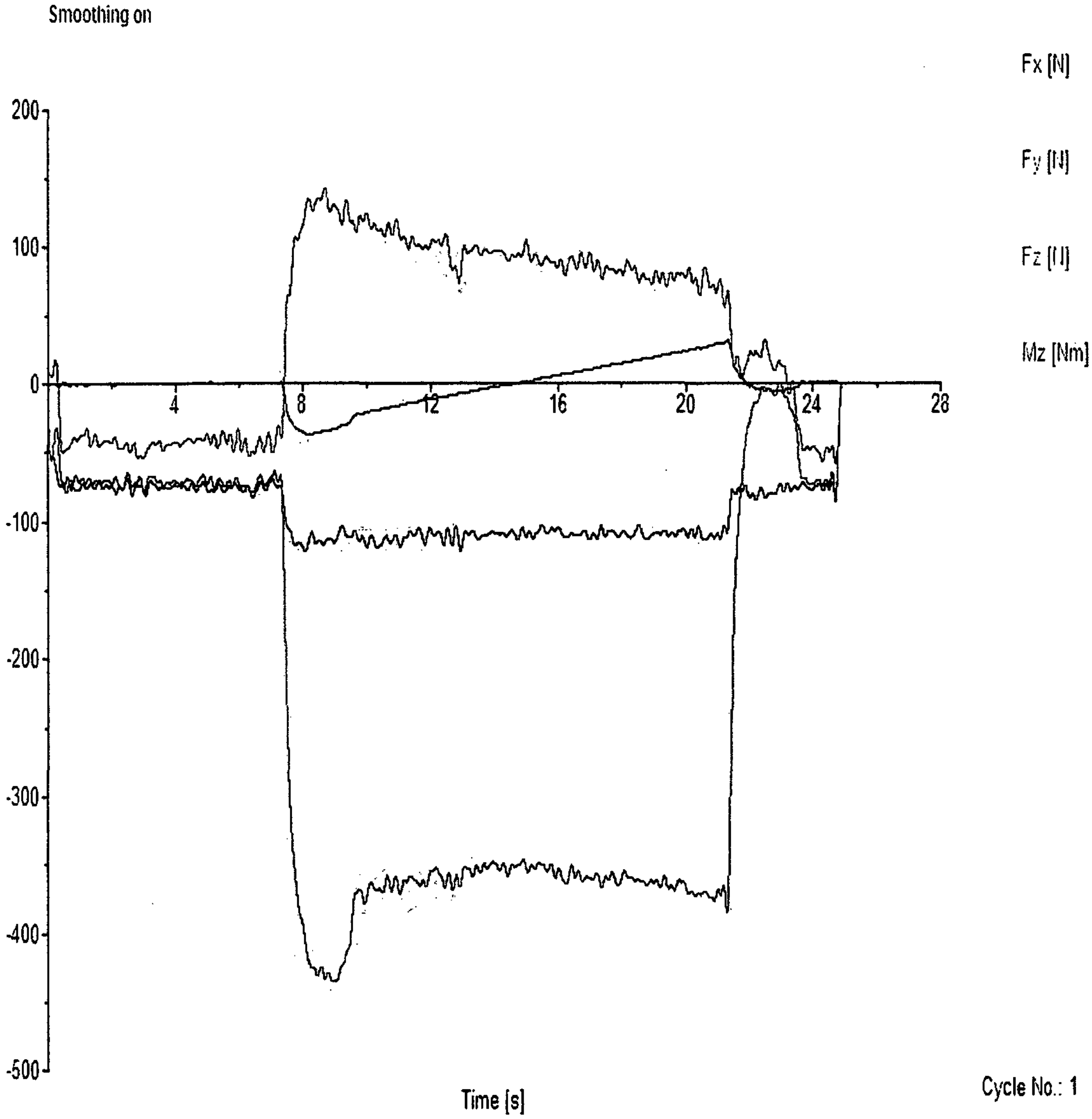


Figure 4.10: Cutting force of 0.8 mm depth of cut (x,y and z direction)

For the 0.8 mm depth of cut its can be observed that the cutting force simulation is decrease constantly. The increasing of the cutting force is not much different compare to cutting force of the 0.4 mm depth of cut.

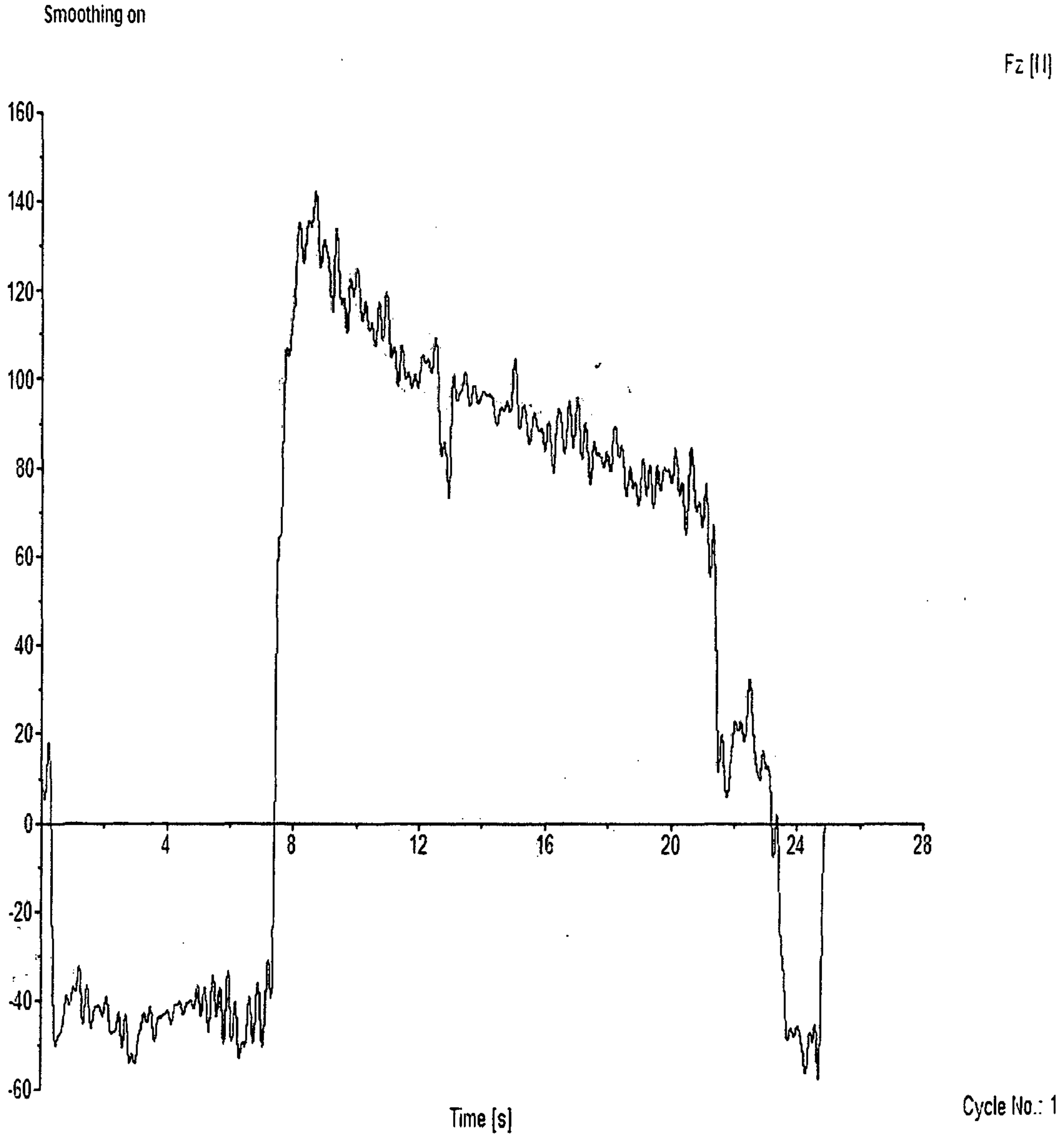


Figure 4.11: Cutting force of 0.8 mm depth of cut for z direction

The average value of cutting force for every millisecond (data from Quartz 3-Component Dynamometer) is calculated and the results are shown in the table below.

Table 4.3: The average value of the cutting force (z direction) for 2-flute HSS helical end mill

2-flute High Speed Steel Helical End Mill			
Spindle Speed(rpm)	**Feed Rate(mm/rpm)**	**Depth of Cut(mm)**	**Fz(N)**
400	50	0.2	36.05323
		0.4	117.9358
		0.8	604.9774

Table 4.4: The average value of the cutting force (z direction) for 4-flute HSS helical end mill

4-flute High Speed Steel Helical End Mill			
Spindle Speed(rpm)	**Feed Rate(mm/rpm)**	**Depth of Cut(mm)**	**Fz(N)**
400	50	0.2	26.53522
		0.4	36.05323
		0.8	39.30172

From the graph 4.13, it is shown that the differences between cutting force for 2-flute HSS and 4-flute HSS end mill. Cutting force for 2-flute resulting a higher increasing for every depth of cut. However, for the 4-flute HSS end mill a portion of increasing rate happened for the cutting force. The comparison between the cutting force for 2-flute and 4-flute HSS end mill, 2-flute HSS end mill cause a higher force requirement in end mill process for the mild steel.

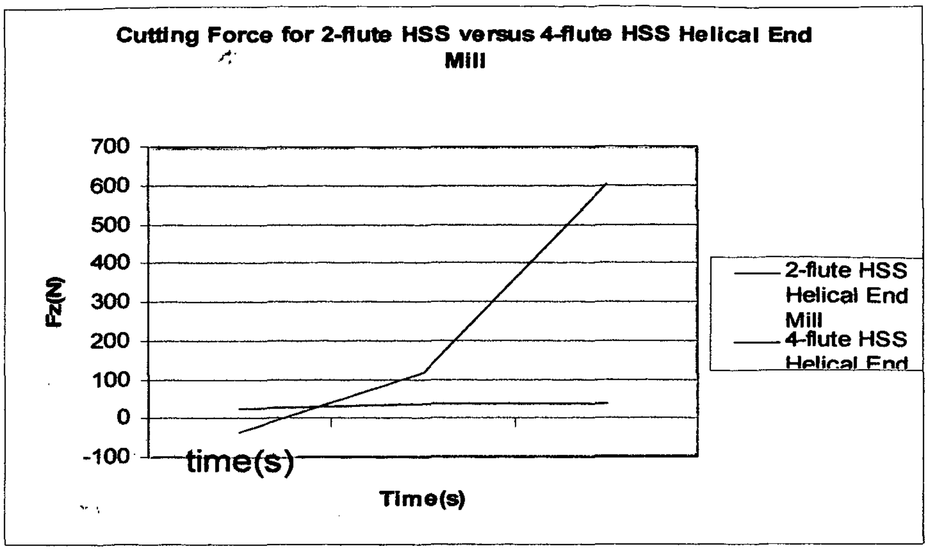


Figure 4.12: Cutting Force for 2-flute HSS end mill versus 4-flute HSS end mill

4.2 Discussions

Referring to the table 4.3 and 4.4 can be see that the cutting force is increasing with the increase of the depth of cut either end mill process that using 2-flute HSS end mill or using 4-flute HSS end mill. This can be explained that, the depth of cut affected the length of the contact area in the axial feed and rotational direction respectively. Therefore, when the depth of cut is increases, the length of the contact area also increased and thus increases the cutting force (*Weng Hsiang Lai)*.

Based on the result from the table 4.3 and 4.4 of the cutting force at z direction (seems the cutting process is running in the vertical direction), the 2-flute HSS end mill causes a higher force requirement compare to the cutting force of the 4-flute HSS end mill. This is because 4-flute HSS end mill are stronger then 2-flute HSS end mill designs. 4-flute HSS end mill have a greater helix angle compare to 2-flute HSS end mill. With the greater helix angle, effective shearing action is increasing. Thus, reducing the cutting force. It also reducing the amount of heat generated during the milling process *(Dayton)*. This explained why the force requirement for the 4-flute HSS end mill is lower than 2-flute HSS end mill.

From the overall result, it is shown that the cutting force is not constant starting the initial cutting process until the end of the cutting process. The graph of the cutting force in z direction is fluctuating. This is affected by the chatter vibration during the cutting process. Chatter in the form of vibration and noise is a frequent challenge when end milling. When chatter arises it tends to be self-sustaining until the problem is corrected. This condition causes poor finish on the part and will damage and significantly reduce the life of tools.

Compare the graph of cutting force 4-flute and 2-flute HSS end mill, it resulting that the graph of 4-flute HSS end mill is constant compare to 2-flute HSS end mill. With helix angles, chip load is applied to the entire flute length in a progressive siding action similar to that of a snowplow with its blade angled off to one side. This makes the cutting forces much more constant with less chance for chatter *(Dayton)*.

Obviously, 4-flute HSS end mill have a greater helix angles, so that the greater the helix angles the cutting force is more constant and this statement is answered why the graph of cutting force for 4-flute HSS end mill is more constant than 2-flute HSS end mill. Besides that, end mills with a higher helix angles also tend to produce much better workpiece finish.

Beside the helix angles that causes the chatter vibration, other factors might contributes on the accuracy of the chatter vibration during handling the experiment. The workpiece might not rigid as possible while mounting on the dynamometer. When the workpiece is not rigid, during the cutting process it will cause some chatter vibration thus affects the cutting force. The combinations of the spindle speed and feed rate that has been used might not suitable to cut the mild steel. This is because, if the feed rate is too high it will influence the rigidity and stability of the workpiece and cutting tool.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATION FOR FUTURE WORK

5.1 Conclusions

The end milling process was chosen to investigate the effect of the depth of cut on cutting force. Besides it is used to analyze the cutting force for the 2-flute end mill and 4-flute HSS end mill.

2-flute and 4-flute High Speed Steel helical end mill is used in this project as a cutting tool and the Conventional Milling Machine to run the cutting process. The mild steel AISI 1020 is mounted on the Kistler Quartz 3-Component Dynamometer and when the cutting process is running, the dynamometer is gather the data of the cutting force in every millisecond. From these data, the average values of the cutting force is calculated and get the single data for the cutting force at z direction seems the material is cutting in vertical direction (end mill).

Generally it could be concluded that this project achieved its objective which to study the effects of depth of cut on the cutting force end milling machining and to analyze the comparison of the cutting force of 2-flute HSS and mill and 4-flute HSS end mill.

Refer to the table 4.3 and table 4.4, cutting force is increase with the increasing of depth of cut. Moreover, between the cutting force for the 2-flute and 4-flute HSS end mill, 2-flute required higher cutting force compare to the force requirement for the 4-

flute HSS end mill. Based on the experimental results, the main conclusions of this project can be drawn as follows:

1. The depth of cut is proportional to the cutting force
2. 2-flute High Speed Steel end mill cutting force requirement is higher than the 4-flute High Speed Steel end mill cutting force requirement.

5.2 Recommendations for Future Work

Study various parameters that affected the value of cutting force and the process of the end mill. From the information gather, do some analysis about this project. Which one is the better process to choose and which parameter is influence the cutting force the most. Identify cutting conditions to prevent inaccuracy on the result and the experiment.

Based on the result and from my observation while running this project, I recommended that 2-flute end mill is better in slot milling machining and 4-flute end mill is good for finishing the material. In addition, it is better to use the coolant while doing machining to avoiding tool damage, well in heat transfer for tool and resulting a smooth finishing.

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APPENDIX

Appendix A 1 :Dynamometer Device

KISTLER Quartz 3-Component Dynamometer Type 9257B

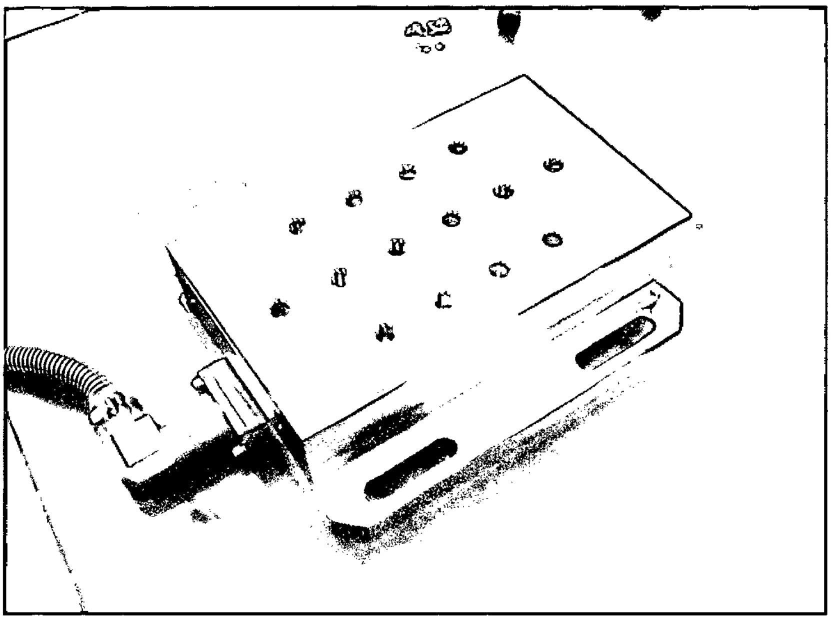

Figure .4.1 :. KISTLER Quartz 3-Component Dynamometer Type 9257B
(Dynamometer at Faculty of Mechanical Engineering lab)

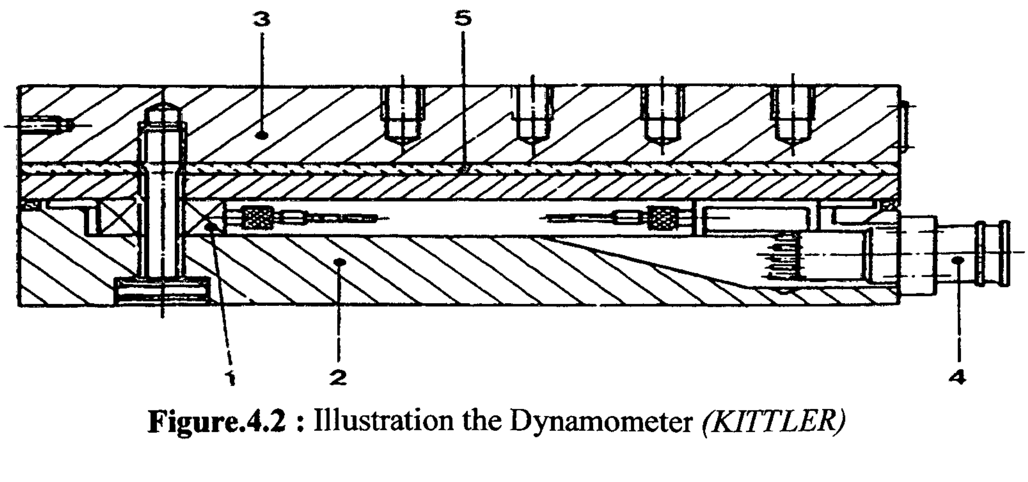

Figure.4.2 : Illustration the Dynamometer *(KITTLER)*

(1) Force sensor

(2) Baseplate

(3) Top plate

(4) Connector

(5) Thermal insulation coating

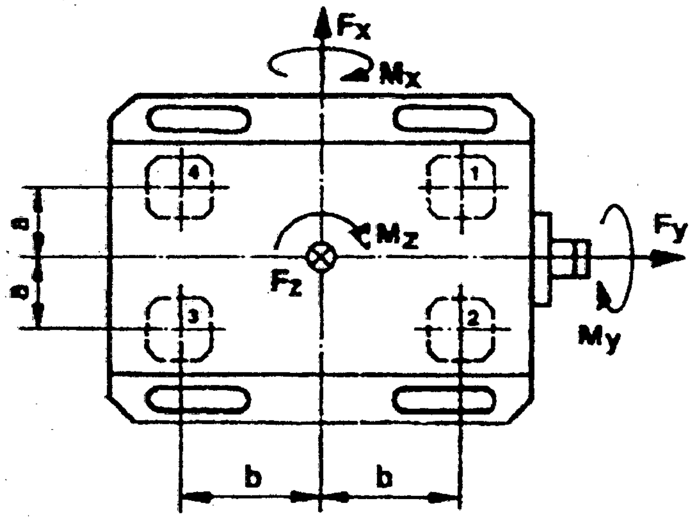

Figure.4.3: Force and moment measuring with 6 components (Fx,Fy,Fz,Mx,My,Mz)

The individual forces and moments can be calculated as follows:

$$F_X = F_{X1+2} + F_{X3+4}$$

$$F_Y = F_{Y1+4} + F_{Y2+3}$$

$$F_Z = F_{Z1} + F_{Z2} + F_{Z3} + F_{Z4}$$

$$M_X = b.(F_{Z1} + F_{Z2} - F_{Z3} - F_{Z4})$$

$$M_Y = a.(-F_{Z1} + F_{Z2} + F_{Z3} - F_{Z4})$$

$$M_Z = b.(-F_{X1+2} + F_{X3+4}) + a.(F_{Y1+4} - F_{Y2+3})$$

- 'a' and 'b' are the dynamometer constant

- The theoretical values for Type 9257B are:
  a = 30 mm
  b = 57.5 mm

- For accurate moment calculations the value a, b are to be determined with a special calibration.

Appendix A 2 Cutting Conditions Table ***(HAAS CNC Milling Machine)***

TOOL NAME		**WORK MATERIAL**					
		CAST ZIRON		**STEEL**		**ALUMINIUM**	
		V	**Fr**	**V**	**Fr**	**V**	**Fr**
Boring Carbide	20R	60 ~ 70	0.15	60 ~ 75	0.12	90 ~ 115	0.1 ~ 0.15
	50R	70 ~ 85	0.1	75 ~ 90	0.08	115 ~ 140	0.08
	60R	70 ~ 80	0.15 ~ 0.25	80 ~ 90	0.15	130 ~ 150	0.12 ~ 0.1
	100F	90 ~110	0.1 ~ 0.12	10 ~105	0.1	160 ~ 190	0.1
	100R	70 ~ 80	0.25	75 ~ 80	0.2 ~ 0.25	160 ~ 195	0.1
	200F	100 ~110	0.1~ 0.12	105 ~110	0.1	200 ~ 240	0.12
Drill (mm)	5 to 10	20	0.2	25	0.1 ~ 0.2	30 ~ 40	0.1 ~ 0.2
	10	25	0.3	25	0.2 ~ 0.25	50 ~ 55	0.2 ~ 0.25
	20	40 ~ 50	0.3	~	~	~	~

R = Rough Cut
C = Carbide

F=Finish Cut
H=High Speed Steel

Face Mill Carbide		End Mill		Reamer		Tap		
C	H	C	H	C	H	~	50	20
100 ~ 120	80 ~ 100	35 ~ 50	25 ~ 29	11 ~ 16	10 ~ 12	10 to 14	50	25
~	Fz 0.2 ~ 0.25	**Fz 0.1 ~ 0.25**	**Fz 0.1 ~ 0.25**	0.3	0.3	~	0.3	0.35
100 ~ 130	80 ~ 100	30 ~ 50	25 ~ 29	11 ~ 16	10 ~ 12	10 to 12	~	20 ~ 23
~	Fz 0.2~0.25	**Fz 0.1~0.25**	**Fz 0.1~0.25**	0.25 ~ 0.3	0.25 ~ 0.3	~	~	0.25
250 ~ 230	200 ~ 250	50 ~ 80	30 ~ 60	15 ~ 20	15 ~ 20	12 to 17	~	50 ~ 60
~	Fz 0.3 ~ 0.5	**Fz 0.1 ~ 0.3**	**Fz 0.1 ~ 0.3**	**Fz 0.25 ~ 0.3**	0.25 ~ 0.3	~	~	0.25