PROCESS DAMPING TECHNIQUE FOR ALUMINIUM ALLOY AT LOW SPEED MACHINING

MOHD AZFADIR BIN MAT DAUD

UNIVERSITI MALAYSIA PAHANG

UNIVERSITI MALAYSIA PAHANG

BORANG PENGESAHAN STATUS TESIS◆

JUDUL: **PROCESS DAMPING TECHNIQUE FOR ALUMINIUM ALLOY AT LOW SPEED MACHINING**

SESI PENGAJIAN: 2011/2012

Saya, **MOHD AZFADIR BIN MAT DAUD (890120-06-5173)**
(HURUF BESAR)

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

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

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

Disahkan oleh:

_________________________ _________________________

(TANDATANGAN PENULIS) (TANDATANGAN PENYELIA)

Alamat Tetap:

KAMPUNG TANJUNG BETONG
27000 JERANTUT
PAHANG

DR.AHMAD RAZLAN BIN YUSOFF
(Nama Penyelia)

Tarikh: **22 JUN 2012** Tarikh: **22 JUN 2012**

CATATAN:

* Potong yang tidak berkenaan.

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

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

PROCESS DAMPING TECHNIQUE FOR ALUMINIUM ALLOY AT LOW SPEED MACHINING

MOHD AZFADIR BIN MAT DAUD

Thesis submitted in partial fulfilment of the requirements
for the award of Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

JUNE 2012

UNIVERSITI MALAYSIA PAHANG

FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled "*Process Damping Technique for Aluminium Alloy at Low Speed Machining* "is written by *Mohd Azfadir Bin Mat Daud.* I have examined the final copy of this project and in my opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering.

Dr. Siti Rabiatull Aisha Idris

Examiner Signature

SUPERVISOR'S DECLARATION

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

Signature	:
Name of Supervisor	: Dr.Ahmad Razlan Bin Yusoff
Position	: Deputy Dean (Academic & Postgraduate) Faculty of Manufacturing Engineering Universiti Malaysia Pahang
Date	: 22 June 2012

STUDENT'S DECLARATION

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

Signature	:
Name	: Mohd Azfadir Bin Mat Daud
ID Number	: MA08055
Date	: 22 June 2012

Special thanks to my parents for their support and cares, my siblings and special dedications for my supervisor on his guiding towards my project.

ACKNOWLEDGEMENTS

I am grateful and would like to express my sincere gratitude to my supervisor Dr. Ahmad Razlan Bin Yusoff for his germinal ideas, invaluable guidance, continuous encouragement and constant support in making this research possible. He has always impressed me with his outstanding professional conduct, his strong conviction for science, and his belief that a PhD program is only a start of a life-long learning experience. I appreciate his consistent support from the first day I applied to finished the program to these concluding moments. I am truly grateful for his progressive vision about my training in science, his tolerance of my naïve mistakes, and his commitment to my future career.

My sincere thanks go to all my lab mates and members of the staff of the Mechanical Engineering Department, UMP, who helped me in many ways and made my stay at UMP pleasant and unforgettable. Many special thanks go to member engine research group for their excellent co-operation, inspirations and supports during this study.

I acknowledge my sincere indebtedness and gratitude to my parents for their love, dream and sacrifice throughout my life. I am also grateful to my brother and sister for their sacrifice, patience, and understanding that were inevitable to make this work possible. I cannot find the appropriate words that could properly describe my appreciation for their devotion, support and faith in my ability to attain my goals. Special thanks should be given to my committee members. I would like to acknowledge their comments and suggestions, which was crucial for the successful completion of this study.

ABSTRACT

This thesis investigated the process damping performance of tools when machining aluminium alloy at low speed. The objective of this thesis is to prepare the aluminum alloy workpiece for cutting experiment. Second objective of this project is machining the aluminium alloy workpiece with process damping technique which is using high axial depth of cut and low radial depth of cut. The third objective is to compare process damping performance between three different helix tools. The thesis implants process damping techniques to investigate the fatigue process damping performance between tool types. All tools used in this project are uniform helix tools which represent by solid carbide tool, high speed steel coated tool and solid carbide coated tool. By performing machining which is milling process on CNC Haas VF6 vertical milling machine, data for process damping performance is recorded. From the data, process damping wavelength will be calculated for the comparison of performance. The result obtained indicated that the solid carbide tool have the lowest process damping wavelength while high speed steel coated tool have higher process damping wavelength than solid carbide coated tool. The highest process damping wavelength goes to solid carbide coated tool. As a conclusion, solid carbide coated gave the best performance of machining aluminium alloy at low speed.

ABSTRAK

Tesis ini berkaitan dengan prestasi proses redaman untuk alat apabila pemesinan aloi aluminium pada kelajuan rendah di lakukan. Objektif tesis ini adalah menyediakan bahan kerja aluminium aloi untuk eksperimen memotong. Objektif kedua ialah memesin bahan kerja aluminium aloi dengan teknis proses redaman yang menggunakan nilai tinggi bagi kedalaman paksi kedalaman dipotong dan nilai rendah dalam jejari kedalaman pemotongan. Objektif ketiga ialah untuk membandingkan prestasi proses redaman antara tiga alat helix yang berbeza.Implan tesis memproses teknik redaman adalah untuk menyiasat prestasi proses redaman lesu antara jenis alat. Semua alat yang digunakan dalam projek ini adalah jenis helix seragam yang diwakili oleh alat karbida pepejal,alat keluli bersalut berkelajuan tinggi dan alat karbida pepejal bersalut. Dengan melakukan pemesinan yang merupakan proses penggilingan menggunakan mesin Komputer Kawalan Berangka Haas VF6, data untuk prestasi proses redaman direkodkan. Daripada data yang didapati, panjang gelombang proses redaman akan dikira untuk membandingkan prestasi proses redaman. Keputusan yang diperolehi menunjukkan bahawa alat karbida pepejal mempunyai panjang gelombang proses redaman yang terendah manakala alat keluli berkelajuan tinggi mempunyai panjang gelombang proses redaman yang lebih tinggi. Panjang gelombang proses redaman yang tertinggi didapati oleh alat karbida pepejal bersalut. Keputusan menyimpulkan bahawa alat karbida pepejal bersalut memberikan prestasi terbaik dalam pemesinan aluminium aloi pada kelajuan rendah.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

λ_c	Process damping wavelength
h_{max}	Maximum chip thickness
fpt	Feed per tooth
μ	Micro
γ	Relief angle

LIST OF ABBREVIATIONS

AA	Aluminum alloy
Al	Aluminium
BHN	Briness Hardness Number
C	Carbon
CBN	Cubic boron nitride
Co	Cobalt
CNC	Computer numerical control
Cr	Chromium
Cu	Copper
CVD	Chemical vapour deposition
Fe	Iron
FRF	Frequency response function
HSS	High speed steel
Li	Lithium
Mn	Manganese
Mo	Molybdenum
MRR	Material removal rate
Ni	Nickel
Sn	Stannum
Ti	Titanium
TaC	Tantalum carbide
TiC	Titanium carbide
UTS	Ultimate tensile strength

V	Vanadium
W	Tungsten
WC	Tungsten carbide
Zn	Zinc
Zr	Zirconium

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Aluminium alloy is a silverish white metal that is very light compared to other metals such as brass, nickel, steel and copper. It has a very strong corrosion resistance and also a good electrical conductivity. Furthermore, aluminium alloy is having good machinability as it can be turned, milled and bored in the machining process. Aluminium alloy have been the prime material of construction for the aircraft industry for making aircraft airframes. Besides that, it's also widely used in sports equipment and also for high pressure gas cylinders. The costs of aluminium alloy are relatively low compared to titanium alloy. So, in this project, technique to machine this aluminium alloy is done to investigate the process damping performance between different tool types.

A good machinability is one of the characteristics or the advantage of aluminium alloy. In milling process chatter can still be occur and gives bad surface finish to the machined surface. Chatter is one problem that needs to be overcome as it can damage the tools and the machines itself. Process damping performance for tools when milling this material will be observed. At low cutting speed process the damping process will occur. The process damping region can be known by observing chatter stability diagram

Therefore, in this project, frequency response of function is initially determined for the flexural system of single degree of freedom. Low radial and high depths of cut are used as cutting process for achieving damping behaviour at low speed. Chatter frequency and surface speed is use to determine process damping performance. A regular milling tool performance which is regular solid carbide is compared with solid carbide coated tool and High Speed Steel (HSS) coated tool.

1.2 PROJECT OBJECTIVES

These are the objective of this research:

i. To prepare Aluminium Alloy workpiece.
ii. To machining Aluminium Alloy using uniform helix milling tools with process damping technique.
iii. To compare process damping performance between three different helix milling tools.

1.3 PROJECT SCOPES

The project needs to prepare workpiece of the material which is Aluminium Alloy. The flexural holds the workpiece also need to be done. Then, the frequency response of the flexural should be determined. When machining Aluminium Alloy using CNC milling machine, it needs to use low radial and high axial depth of cut. Cutting tools for the machining process should be varying in type which are regular solid carbide tool and coated tools. Process damping performance between the tools was then compared. The flow of the project is as in Figure 1.1.The activities done throughout this research are shown in Appendix A.

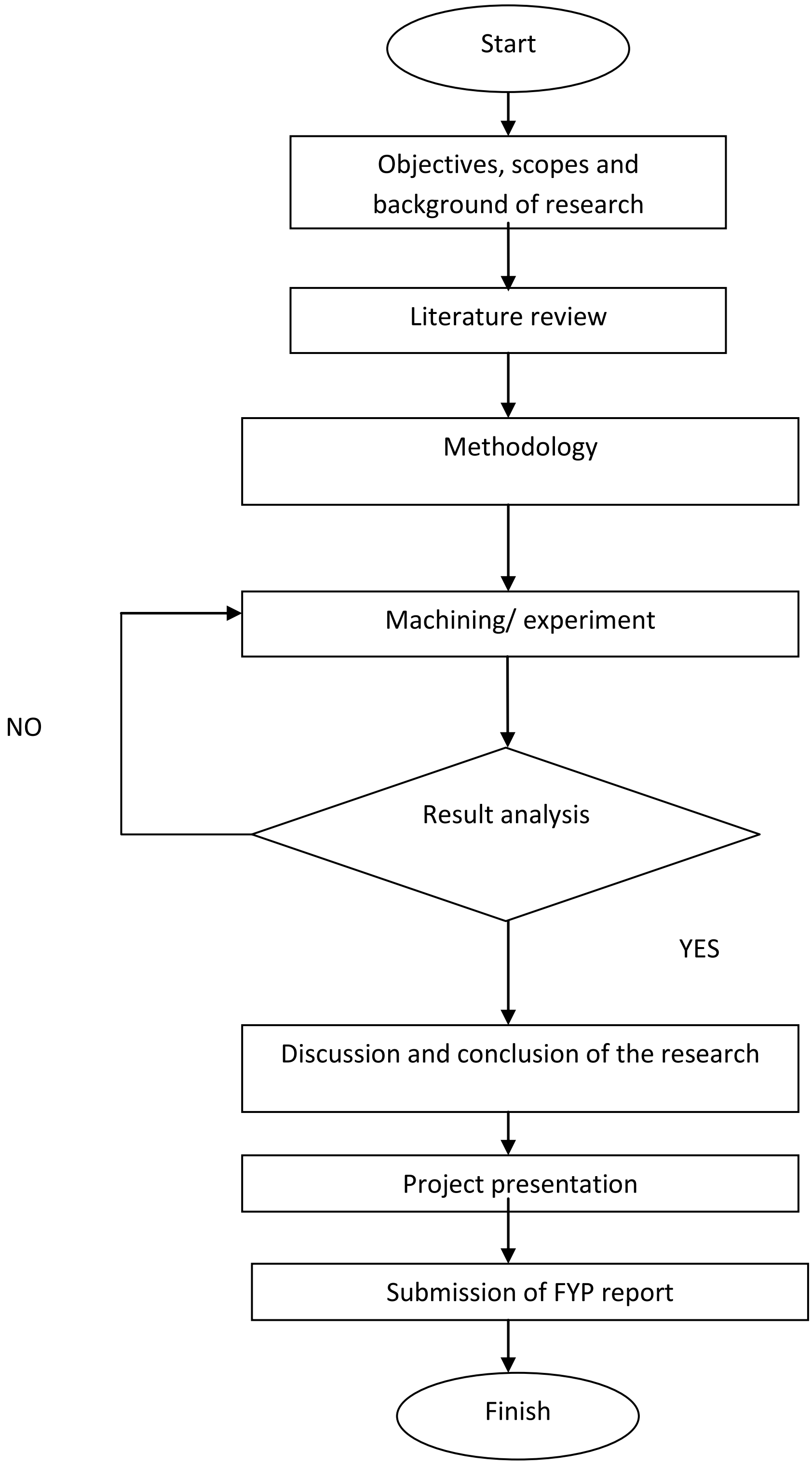


Figure 1.1: Flow chart of the project

CHAPTER 2

LITERATURE REVIEW

2.1 ALUMINIUM ALLOYS

Aluminium alloy are categorized in two types which is cast alloys and wrought alloys. Cast alloys is the alloy that solidified from liquid and used without any mechanical processing while wrought alloy is involving mechanical processing. Their identification and designations are referred to Aluminium Association. This association divide these alloys into different nomenclatures. Two-and three-digit numbers are used for castings whereas four-digit designations are used for wrought alloys.

Aluminium with additives among Cu, Mn, Si, Mg, Mg+Si, Zn and Cu+Li are normally applied. Based on these, the 2xxx (Al-Cu) ,the 6xxx (Al-Mg-Si) and the 7xxx (Al-Zn) alloys are strengthened by aging or precipitation hardening process, to strength levels corresponding to those of low strength alloy steels up to 100ksi UTS and 90-95 ksi yield strength. The highest strengths results in the Al-Zn alloy such as AA 7075 in the age hardened tempers T4 or T6. Therefore, the 7xxx series alloy has been designated as high strength Al-alloys. The compositions and temper designations for aluminium alloy are shown in Table 2.1. The temper designation for aluminium alloys are stated as follows:

i. F-As fabricated, O-Annealed, H-Strain hardened, W-Solution heat-treated.
ii. T- Thremally-treated to produce stable tempers other than F, O and H.
iii. T2-Annealed (for cast product only)

iv. T4-Solution heat-treated and naturally aged at room temperature to substantially stable condition with maximum hardness and strength.
v. T6-Solution heat-treated and then artificially aged at elevated temperature.
vi. T7-Solution heat-treated and then stabilized by overaging treatment.

These high strength Al-alloys in T4 or T6 condition have low ductility and fracture toughness and also prone to stress corrosion cracking. Although the fracture cannot be increased to high levels, equivalent to those found in some quenched and tempered steels, the alloys can be made to resist stress corrosion cracking by treating then to an overage temper T7.As an alternative, high-purity Al-alloys with negligible silicon and iron such as AA 7049 and 7050 can be used. They are immune to stress corrosion cracking in their T6 temper. As the Al-alloys have good thermal conductivity, it helps vastly in engine piston application for example in the selection of using AA 7075-T6 for this application. For high strength Al-alloys, especially the Al-Cu duralumin alloys are commonly used in airframe and airfoil applications. Al-alloys also used in gas turbine engine air compressors and also in transport for wheels and propellers.

Table 2.1: Composition of selected Aluminium Alloys

Alloy No.	Wt.% Alloy Elements	Major Applications
1100	0.12 Cu	
2017	4.0 Cu, 0.5 Mn, 0.5 Mg	
2024	4.5 Cu, 0.6 Mn, 1.5 Mg	
3003	1.2 Mn, 0.12 Cu	
4032	12.2 Si, 0.9 Cu, 1.1 Mg, 0.9 Ni	
4043	5.0 Si	
5056	5.2 Mg, 0.1 Mn, 0.1 Cr	
6061	1.0 Mg, 0.6 Si, 0.25 Cu, 0.2 Cr	
6063	0.7 Mg, 0.4 Si	
7075	5.6 Zn, 1.6 Cu, 2.5 Mg, 0.3 Cr	
7178	6.8 Zn, 2.0 Cu, 2.7 Mg, 0.3 Cr	
7049	7.6 Zn, 1.5 Cu, 2.5 Mg, 0.15 Cr, 0.25 Si, 0.35 Fe	
7050	6.3 Zn, 2.4 Cu, 2.3 Mg, 0.04 Cr, 0.12 Si, 0.15 Fe	
7175	5.6 Zn, 1.6 Cu, 2.5 Mg, 0.24 Cr,	
43	4.5-6.0 Si, 0.8 Fe,0.1Cu, 0.3 Mn, 0.2 Zn, 0.2 Ti	
A132	11.0-13.0 Si, 1.3 Fe, 0.5-1.5 Cu, 0.7-1.3 Mn, 2.0-3.0 Ni, 0.2 Ti	Low expansion piston in IC engines
355	4.5-5.5 Si, 0.6 Fe, 1.0-1.5 Cu, 0.3 Mn, 0.4-0.6 Mg, 0.2 Zn	

Source: Raman (2007)

2.2 CHATTER

Chatter is produced from self-excited vibration during cutting resulting in high amplitude unstable motion. Self-excited vibrations are based on regeneration of the waviness of the surface generated in subsequent cuts. These subsequent cuts are produced by adjacent teeth of the cutter as seen in Figure 2.1. Every cutter removes the material from an undulated surface left by the previous cutter, and leaves behind another undulated surface which becomes the source of self-excitation. It has been shown that at a given speed, increasing the cutter diameter causes the drillstring to transform from a stable system, where vibrations tend to die out, to a system where vibrations build up over time (chatter) until they reach saturation. Saturation can be caused by process nonlinearities such as the cutter jumping out of the cut.

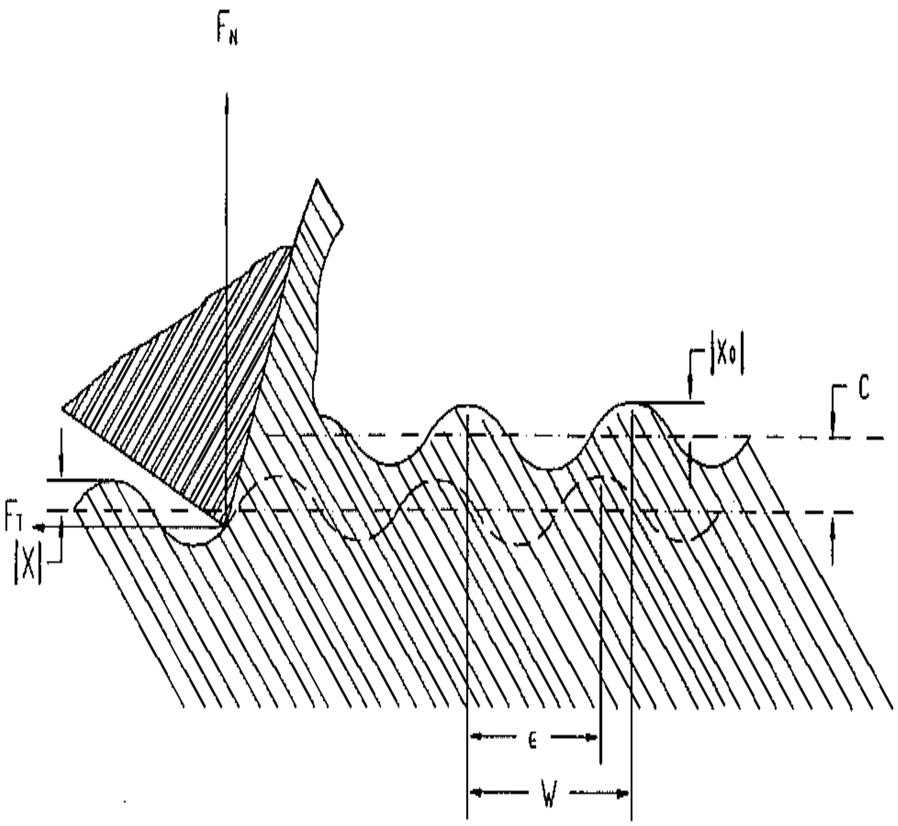


Figure 2.1: Surface generate on typical cutter

Source: Eslayed *et al*. (1994)

Referring to Figure 2.1, the cutting force can be written as (Zamudio, 1988),

$$F = bK_s(C + X_o - X) \tag{2.1}$$

where;

b = width of cut (m)
K_s = cutting stiffness of rock formation (N/m^2)
C = average feed per cutter blade (m)
X = magnitude of current surface undulation (m)
X_o = magnitude of previous surface undulation (m)

Since C is constant, the variable part of the force causing the vibration is;

$$F = bK_s(X_o - X) \tag{2.2}$$

This is a simplified form of the force, where K_s is a real number and the effect of process damping is not included. (X_o-X) is the change in surface position between current and previous cuts. The effect of process damping on the force was considered by many investigators to be included in the imaginary component of one of the parameters affecting the cutting force. These parameters are referred to as dynamic cutting force coefficients (DCFCs) by Tlusty (1978) and Das and Tobias (1967).

Basically in theory, the stability boundary is then independent of the feed rate despite the influence of the feed rate on the mean chip thickness. Apparently, in real process the empirical cutting stiffness K_s, changes with the feed rate so that the feed rate does have some influenced on the overall stability.

The feed rate is better express in term of the maximum chip thickness, h_{max} ;

$$h_{max} = fpt\sqrt{\frac{4r}{D} + \left(\frac{2r}{D}\right)^2} \tag{2.3}$$

From the equation above, r is the radial immersion of the tool, and D is the tool diameter, *fpt* represents feed per tooth which is related to the machining feed rate *f*, number of teeth m, and spindle speed n .This is shown in the equation 2.4:

$$f = m \times fpt \times n \tag{2.4}$$

When a high depth of cut are used at low cutting speed, it will results that the chatter stability will be dominated by process damping effects .Low radial immersion function to reduce the total machining forces and improve the tool life. This approach will be employed in the present study in order to determine the process damping wavelength, λ_c under different tools types.

2.3 REGENERATIVE CHATTER THEORY

Regenerative chatter is a self-excited vibration that can occur during milling and other machining processes. It leads to a poor surface finish, premature tool wear, and potential damage to the machine or tool. Variable pitch and variable helix milling tools have been previously proposed to avoid the onset of regenerative chatter.

As an example, consider a milling tool (such as that shown in Figure 2.2), that shows process in up-milling a workpiece. The forces and displacements on a plane normal to tool axis are shown schematically in Figure 2.3. The forces acting on each tooth can be considered to be a function of the thickness of the chip being removed by that tooth. These forces will cause a relative motion between the tool and the workpiece in the x and y directions. This relative motion imparts a wavy surface finish on the just cut workpiece, and as the tool rotates this wavy surface is cut by the next tooth. The chip thickness is therefore a function of the current relative displacement and that when the previous tool was cutting the workpiece at this location. The result is a natural feedback process, or self-excited vibration, that can be represented by the schematic block diagram in Figure 2.4.

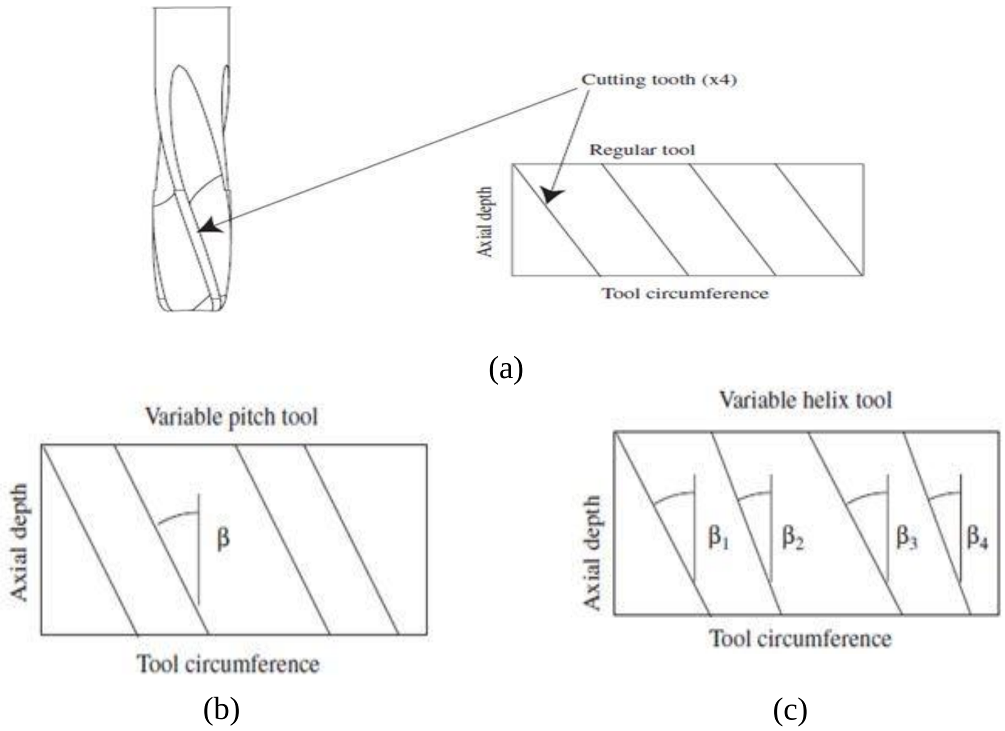


Figure 2.2: Milling tool geometry; (a) Uniform tool, (b) variable pitch tool and (c) variable helix tool

Source: Sims *et al.* (2008)

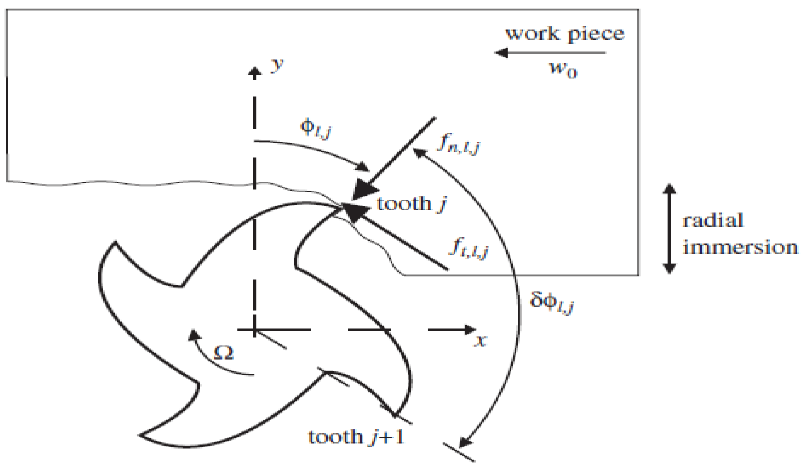


Figure 2.3: Forces on axial slice *l* of a tool (up milling)

Source: Sims *et al*. (2008)

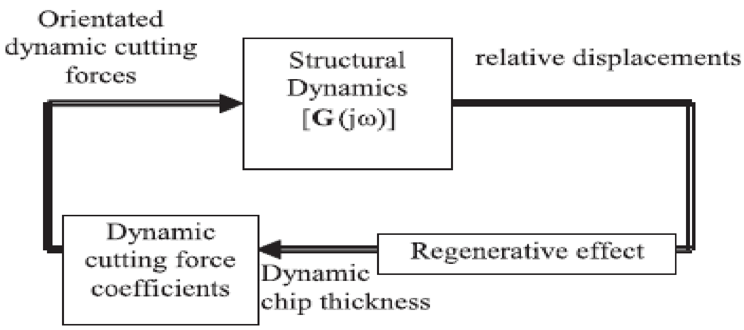


Figure 2.4: Schematic block diagram for regenerative chatter in milling

Source: Sims *et al*. (2008)

2.4 PROCESS DAMPING

One of the most important chatter mechanisms is the process damping force which has a great influence on cutting process stabilization at low cutting speeds. It has been shown in experiment that process damping is generated at the interface between the tool flank and machined surface during dynamic cutting. This process damping is a very significance source of increased stability in machining particularly at low cutting speeds. Tlusty and Ismail (1983) showed that the process damping has significant effect on chatter stability decreasing with cutting speed. Besides, the damping produce from the structure from the machine tools, machining process itself can add damping to the system through a phenomenon known as process damping. The term process damping force or resistance was introduced by Tobias and Fishwicks (1958). They proposed that such force when tool flank or relief face rubs against the wavy workpiece surface at low spindle speed.

Identification and modelling of process damping is addressed as one of the unsolved problems in metal cutting by Altintas and Weck (2004). There have been many attempts to study process damping in turning operation using simulation or experiment method compared to studies in milling operation. One of the main objectives of machining research is to increase productivity which can be achieved by proper selection of cutting conditions. Cutting depth directly affects the material removal rate, and thus productivity, but it is usually limited due to chatter vibrations.

In high speed machining, stability lobes where higher stable depth of cuts are available can be utilized, whereas in low speed cutting the process damping may have significant effect on stability. It is well known that higher stable cutting depths can be achieved under the effect of process damping.

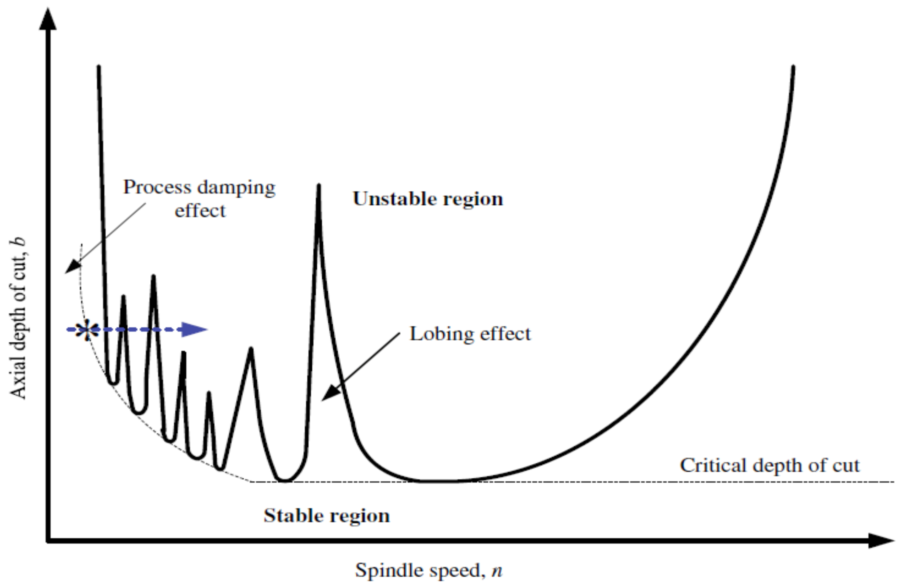


Figure 2.5: Chatter stability lobe

Source: Yusoff *et al*. (2010)

The stability diagram in Figure 2.5 shows the relationship between spindle speeds, depth of cut and chatters stability. The horizontal arrow represents a constant depth of cut with an increasing spindle speed, and the asterisk marker shows the spindle speed at which process damping no longer prevents severe chatter. At high spindle speeds, stability lobes can be observed and this allow high productivity cutting to be performed on easy to machine materials such as Aluminium Alloys. The resulting high surface speed are not compatible with more difficult to machine material such as Titanium Alloys. In this case using low spindle speed is more preferable, where chatter stability is strongly influenced by process damping phenomenon. At low speeds, the wavelength λ of these surface waves is much smaller since the wavelength is proportional to surface velocity v and inversely proportional to regenerative vibration frequency, f_c as in equation 2.5;

$$\lambda = \frac{v}{f_c} \tag{2.5}$$

Forces generated on the cutter are caused not only by the changing thickness of material, but also by interference between the cutter and the previously generated surface. This is the source of process damping. Figure 2.6 shows how process damping develops (Delio, 1989). Damping is produced by the action of the normal force on the tooth. This normal force is dependent on the slope of the surface relative to the relief surface of the cutter edge. The amount of interference between the cutter and the surface depends on the tool relief angle and surface wavelength. The interference produces a varying oscillatory normal force. This force is 90 degree out of phase with the motion of the tool and represents a damping force. As can be seen from Figure 2.6, the minimum relief angle between the tool and the surface occurs at point B producing the maximum upward normal force. This point also corresponds to the point of maximum downward velocity of the tool. As can be seen, this force is opposing the motion. Conversely, at point D, the clearance angle is at maximum and the variational normal force is at minimum. Here the tool is at a maximum velocity in an upward (and minimum in a downward) direction with the minimum variational normal force. It can be seen that tool surface interference inhibits the motion in phase with the tool velocity, and thus the generated force is referred to as a process damping force.

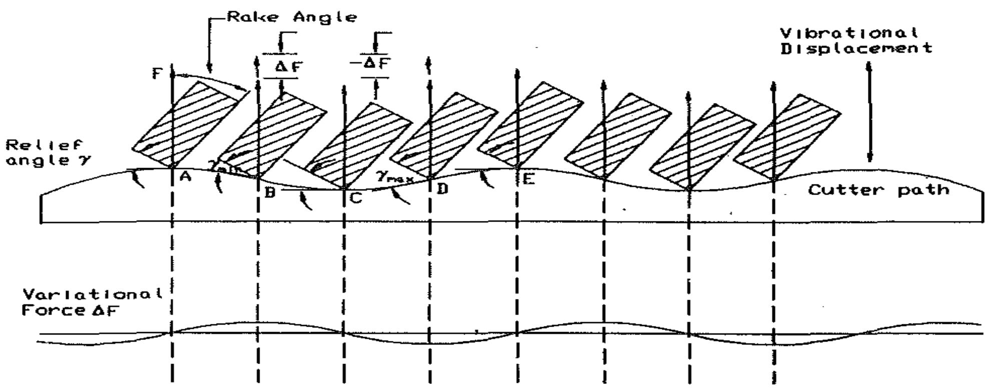


Figure 2.6: Mechanism of process damping

Source: Eslayed *et al*. (1994)

2.5 CUTTING TOOL MATERIAL

Ability to increase metal removal rates depends primarily on the development of cutting tool material. The material removal rate, MRR=*bhv*, can be increased by increasing either width of chip *b*, or the chip thickness, or the cutting speed *v*. The increase of chip thickness leads to tool breakage or faster tool to wear and increase the cutting speed will increase the tool wear rate. Tool wear rate also known as tool life is depends on *h* and *v* in the economy of machining. In Figure 2.7 the improvement of cutting time for different cutting material used was illustrated.

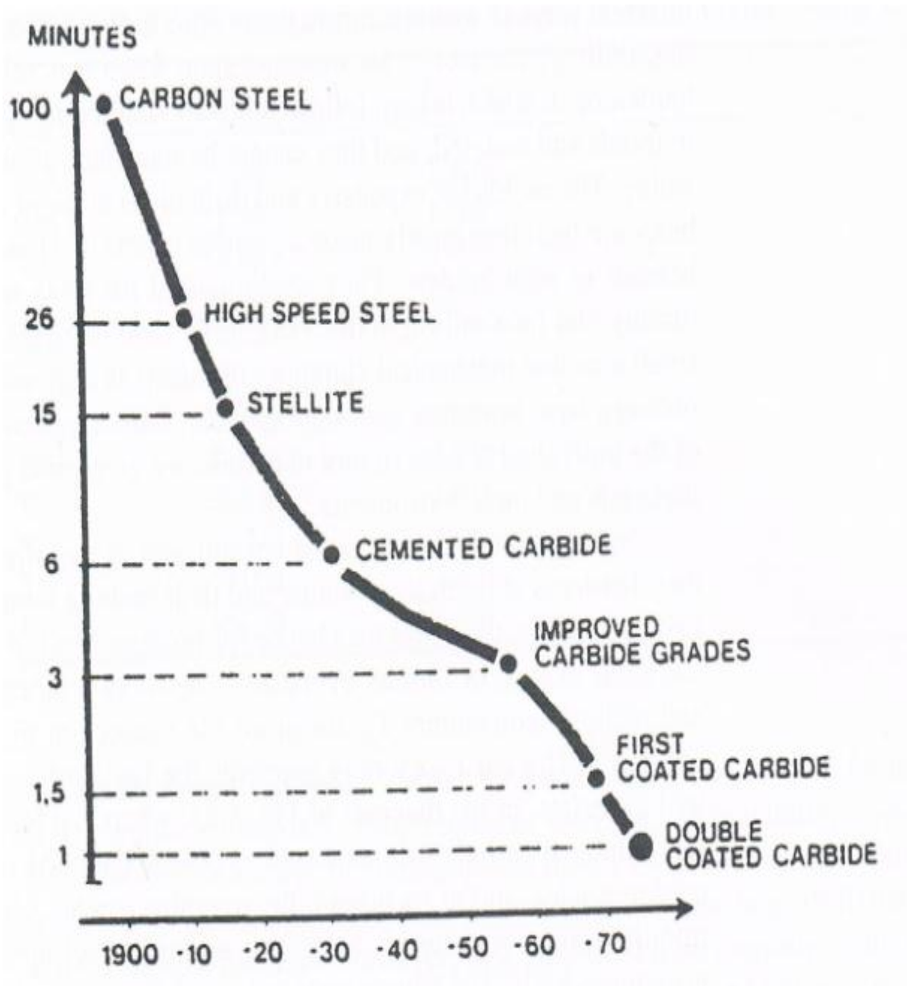


Figure 2.7: Change in cutting time over the past ninety years for machining a 100mm diameter, 500mm long steel shaft with different cutting material.

Source: Tlusty (2000)

2.5.1 Tool material characteristics

Tool material must have this following characteristic. First is having high hot hardness. It is obvious that a tool can penetrate the workpiece and form chip only if it is harder than the workpiece, at the rather high temperature existing in the cut. A tool will allow higher cutting speed if it retains high hardness and at high temperature.

Second, it should have high strength and toughness. The stresses in the tool tip are very high. Both shear and tensile stresses are involves as well as, quite often, impacts. Tools that lack of toughness are very brittle and subjected to various forms of breakage.

And the third is resistance to chemical interaction with workpiece material, to oxidation and to corrosion. At the high temperatures at chip /tool/workpiece contact, chemical reaction in the form of diffusion can lead to rapid erosion and abrasion of tool. Combination of tool and workpiece materials that have high mutual chemical affinity should be avoided. A tools material are preferably inert as possible .A high degree of resistance to oxidation and to corrosion is required due to exposure in some part of the tool tip to air and often to a coolant.

2.5.2 Type of cutting tool material

First type is high speed steel which is divide to two material based which is Tungsten-based and Molybdenum-based. Second type is sintered carbide which also consists of two which are “Straight “grades, WC+Co and Steel-cutting grades, WC, TiC, TaC+Co. Next type is ceramics, Cubic boron nitride (CBN) and synthetic diamond .Lastly is the coated carbides type. Moreover in this research, tool used are solid carbide helix tool which is in the category of high speed steel and also coated carbides helix tool.

2.5.3 High speed steel

All high speed steel (HSS) materials are usually classified into four groups as in Table 2.2, which includes the composition and basic properties of selected grades. The properties wear resistance, toughness; hardness and cost are rated from 1 to 10.

Table 2.2: Composition and properties of selected high speed steels

Steel Class and Grade	C	W	Mo	Cr	V	Co	Wear Resistance	Tough-ness	Hard-ness	Cost
A. Conventional										
T1	0.75	18.0	—	4.0	1.0	—	4	8	5	5
Mi	0.80	1.75	8.5	3.75	1.15	—	4	10	5	3
M2	0.85	6.0	5.0	4.0	2.0	—	5	10	5	3
B. Cobalt added										
M33	0.88	1.75	9.5	3.75	1.15	8.25	5	5	8	5
T5	0.8	18.0	—	4.25	2.0	8.0	5	4	8	6
T6	0.8	20.0	—	4.5	1.75	12.0	5	2	9	8
C. High vanadium										
M3	1.05	6.0	5.0	4.0	2.4	—	6	6	6	4
M4	1.3	5.5	4.5	4.0	4.0	—	9	6	6	4
T15	1.5	12.0	—	4.5	5.0	5.0	10	9	9	6
D. High-hardness Co steels										
M42	1.1	1.5	9.5	3.75	1.15	8.25	6	9	9	5
M44	1.15	5.25	6.5	4.25	2.0	12.0	6	3	10	6

Source: Tlusty (2000)

Group A is conventional high speed steels. It is used for drills, reamers, end mills, broaches, saws, and hobs and for machining carbon and low-alloy steels up to 375 BHN hardness, cast steels and cat irons up to 255 BHN and also for nonferrous metals. Group B is conventional high speed steels with cobalt added. In this group, steels with cobalt added have less toughness but greater hot hardness. They are used for drills and end mills in machining stainless steels, Ti-alloy and Ni-and Co-based alloys.

Third group is group C which is high- vanadium high-speed steels. The characteristic is having high wear resistance due to the very hard carbide of vanadium. They are used for machining steels where long tool life is required, as on single-spindle or multiple-spindle automatics lathes, especially for form tools or for machining of refractory metals. Lastly is group D which is high-hardness cobalt steels (M-40) types. Steels in this group have the highest hot hardness. They are used for drills and end mills in machining heat –treated steels, Ti-alloys, Ni and Co-based alloys.

2.5.4 Coated carbide

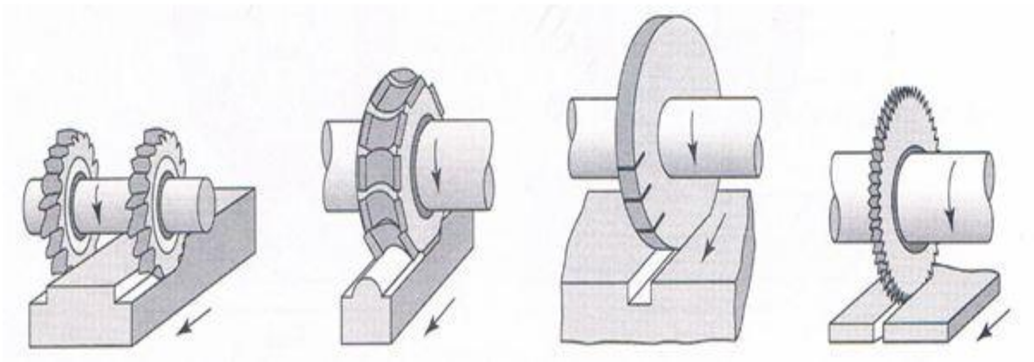
Strong and wear-resistant straight WC-Co grades cannot be used for machining steel because of the chemical affinity between WC and Fe. Solution was found to provide a thin protective coating over the base carbidal material, the “substrate”. Such coatings were first made of solid TiC (not combined with Co).The main problem in coating is to obtain a bond between the coating layer and the substrate that is strong enough to withstand the stresses due to different thermal coefficient of expansion of the two material and to the temperature gradient between them. The coating layer must be rather thin which is 3-5µm; otherwise it will crack and peel off. The coating is generally carried out by chemical vapour deposition (CVD). To coat the inserts with TiC they are heated to a temperature about 1000℃ in an atmosphere of hydrogen containing vapors of titanium tetrachloride ($TiCl_4$). The chloride decomposed at the tool surface to deposit a thin layer of Ti that is carburized by methane included in the atmosphere.

Generally, coated carbides are more universal then the uncoated one and they are used in wider range of applications. This is a great advantage because it reduces the necessary inventory of carbides inserts and also give two times longer tool life .It also permit the use of much higher cutting speed in some application.

2.6 TYPES OF MILLING OPERATIONS

Milling cutters are used are used as individually or combinations to machine various surfaces. These operations are shown in Figure 2.8. Plain milling is the process of milling a surface that is parallel to the axis of the cutter and usually flat. It is done on plain or universal horizontal milling machines with cutter that have teeth only on the periphery.

Form milling is referred to the operation that the number of parallel surfaces and angular relationships that can be machined by peripheral is limited almost only by cutter design. Form milling cutters are usually expensive but it gives good result by producing complex contour as shown in Figure 2.8(b).



(a) (b) (c) (d)

Figure 2.8: Types of milling operations; (a) straddle milling, (b) form milling, (c) slotting and (d) slitting

Source: Nelson and Schneider (2001)

Side milling refer to when a cutter is used has teeth on the periphery and on one or both side. If a single cutter is being used, the teeth on both periphery and sides may be cutting. The machined surfaces in side milling are usually either perpendicular or parallel to the spindle.

In straddle milling the cutter are half-side or plain side milling cutters, and have straight or helical teeth. Stagger-tooth side milling cutter also can be used. The cutters cut on the inner side only, or on the inner sides and the periphery. If straddle milling operation involves side and peripheral cuts, the diameter of the two cutters must be the same. When helical teeth cutters are used; the helix angle must be opposite. An example of straddle milling operation is shown in Figure 2.9.

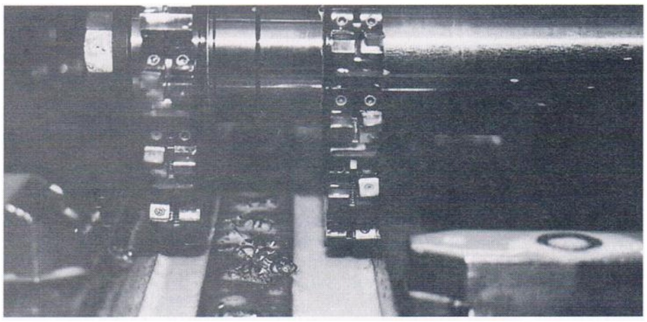


Figure 2.9: Straddle milling operation

Source: Nelson and Schneider (2001)

Another operation in milling is gang milling. In this type of milling, three or more cutters are mounted on the arbor and several horizontal. Vertical or angular surface are machined in one pass as shown in Figure 2.10. In making gang milling setup, several different cutters can be used depends on the job need to be done.

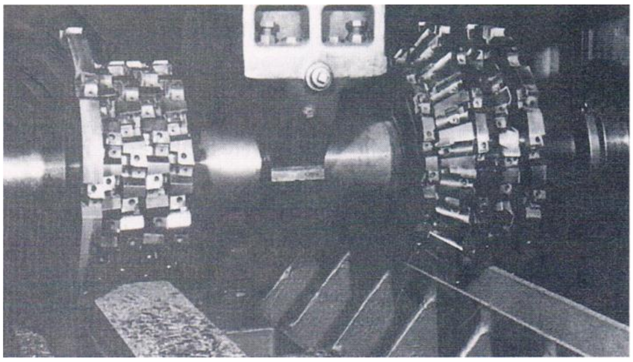


Figure 2.10: Gang milling operation

Source: Nelson and Schneider (2001)

For slotting and slitting operations, milling cutter of either plain or side-cutting type is used. Slotting and slitting are usually done by horizontal milling machine. Metal slitting cutters with different diameters and width are used to cut slot. Figures 2.11 and 2.12 shows the example of slotting and slitting used in manufacturing.

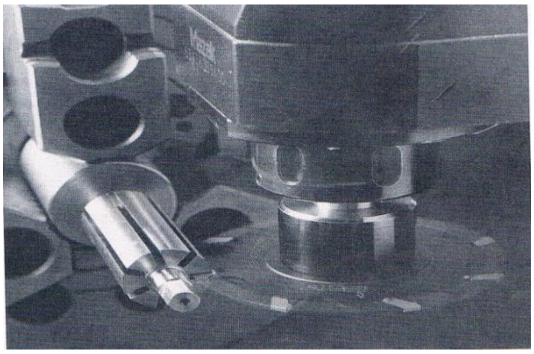


Figure 2.11: Slotting operation used in manufacturing of rotors

Source: Nelson and Schneider (2001)

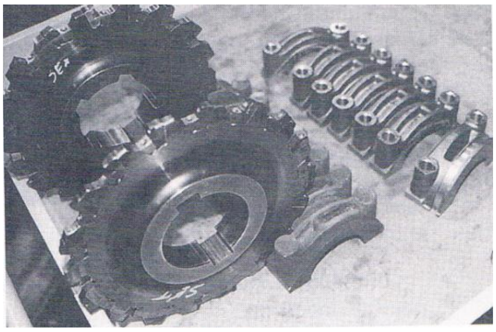


Figure 2.12: Slitting operation to separate cast automotive parts

Source: Nelson and Schneider (2001)

Next type is face milling which can be done on horizontal and vertical milling machines. It produces a flat surface that is perpendicular to the spindle on which the cutter is mounted. The cutter ranges in size and complexity. Large face mills are usually mounted on the nose of spindle. The large face mills are very effective for removing large amount of metals. Face milling operation example is shown in Figure 2.13.

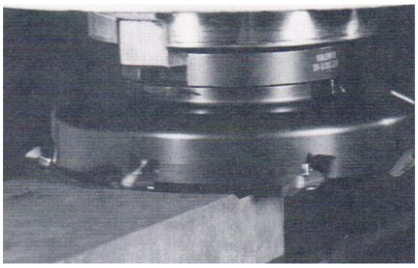


Figure 2.13: Face mill operation

Source: Nelson and Schneider (2001)

The last operation type in milling is end milling. End milling is the most versatile milling operation. Many types of end mill can be used on both vertical and horizontal milling machines. It is available in size ranging from 1/32 to 6 inches (for shell end mills) and in almost any shape needed. Operation of end milling is illustrated in Figure 2.14.

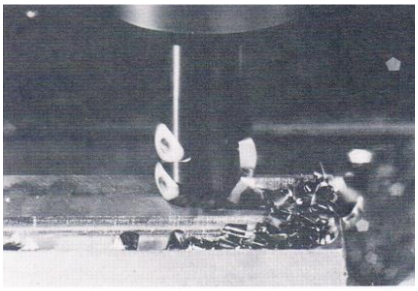


Figure 2.14: End mill operation

Source: Nelson and Schneider (2001)

2.7 SUMMARY

In this project, the material that will be used is Aluminium Alloy 7075 .The operation for machining is end milling. By using the same method as Yusoff *et al.* (2010) but with different parameter, the process damping technique will be applied. Tools that will be used in the experiment are regular solid carbide, High Speed Steel (HSS Co8) coated and lastly solid carbide coated. Further explanation about method and equipment used will be discussed in the next chapter.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter will present the methodology of this research. Several methodology charts were included to explain the flow of research. The important of methodology is to explain design experiment and analyze the data collected. Other than that, this chapter will elaborate more about the process or step that important in order to achieve the objective. Furthermore, it also discusses about the flow of this project what the first thing to do until the end of the project.

3.2 METHODOLOGY FLOW CHART

Process flow chart provided to give an overview the methodology used in the research. Figure 3.1 shows the methodology proposed for investigating this research. From the figure, it shows that the steps to do this research is starting with finding past studies about the project title .This steps is called literature study which act of finding any related journal to the project title .Then it is followed by preparing the workpiece which is Aluminium Alloy 7075.The aluminium alloy is in a form of block Then, aluminium will be cut into desired pieces to be machined. After experiment, the next step is analyze the data. In analyzing the data calculation was done and data that have been recorded will be presented in form of tables and figures. Lastly, documentation and presentation was done before submitting the full report of the project.

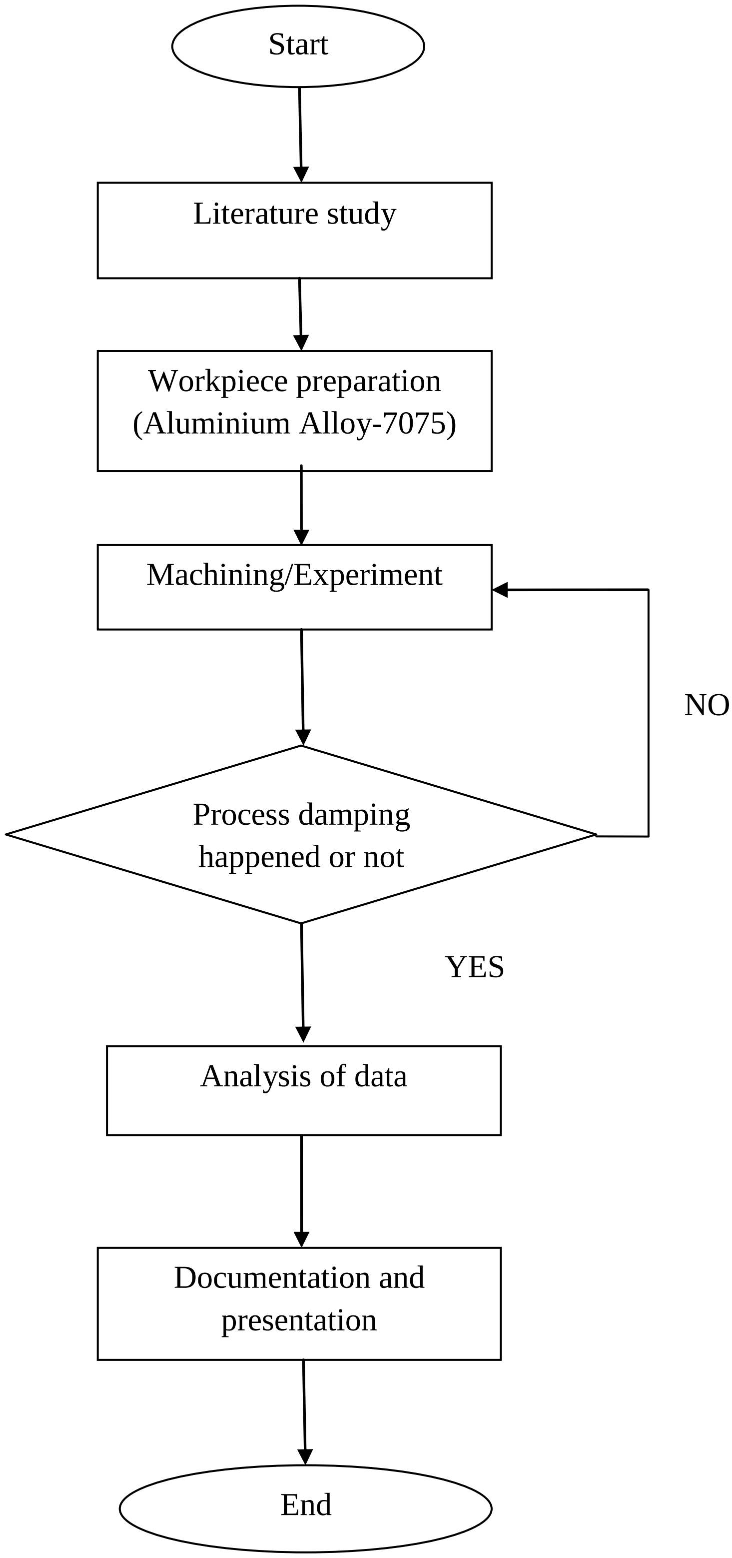


Figure 3.1: Methodology flow chart

3.3 LITERATURE STUDY

To understand the method to run the research, some literatures must be studied to get overview since the student not much knowledgeable about the project. Understanding is important to plan the next step. Even though the student have confused for many fundamentals around, keep going study the literature helping to overcome the problems. Based from previous research, the methodology can be plan properly to achieve the objective of this project. This project is to research about process damping performance when machining aluminium alloy. Also, in literature review gathering data about machining aluminium alloy, tools used ,process damping are useful to guide the research.

3.4 EXPERIMENTAL PROCEDURE

The experiment will be conducted based on the scopes of project, and these will be now introduced. It should be pointed out that the majority of experiments were performance on machining aluminium alloy. Starting with the first requirement, build a single degree of freedom flexural, then machining aluminium alloy using uniform helix and pitch tools with high axial and low radial depth of cut ,and compare process damping performance between different tool types which is regular solid carbide ,high speed steel coated and solid carbide coated.

3.4.1 Cutting tools used in the experiment

All cutting tool that used in the experiment are 4 flutes uniform helix and uniform pitch tool as shown in Figure 3.2. There are three cutting tools that are used in this experiment which was regular solid carbide, HSS coated and solid carbide coated. The information about the cutting tools is shown in Table 3.1. In the table, information about length, diameter, helix angle and pitch angle were shown as a reference for the cutting tool used in the experiment.

Table 3.1: Specification of cutting tools used

Tools	Solid carbide	HSS Co8 coated	Solid carbide coated
Length (mm)	100	110	100
Diameter (mm)	20	20	20
Helix angle (°)	45	45	45
Pitch angle (°)	90	90	90

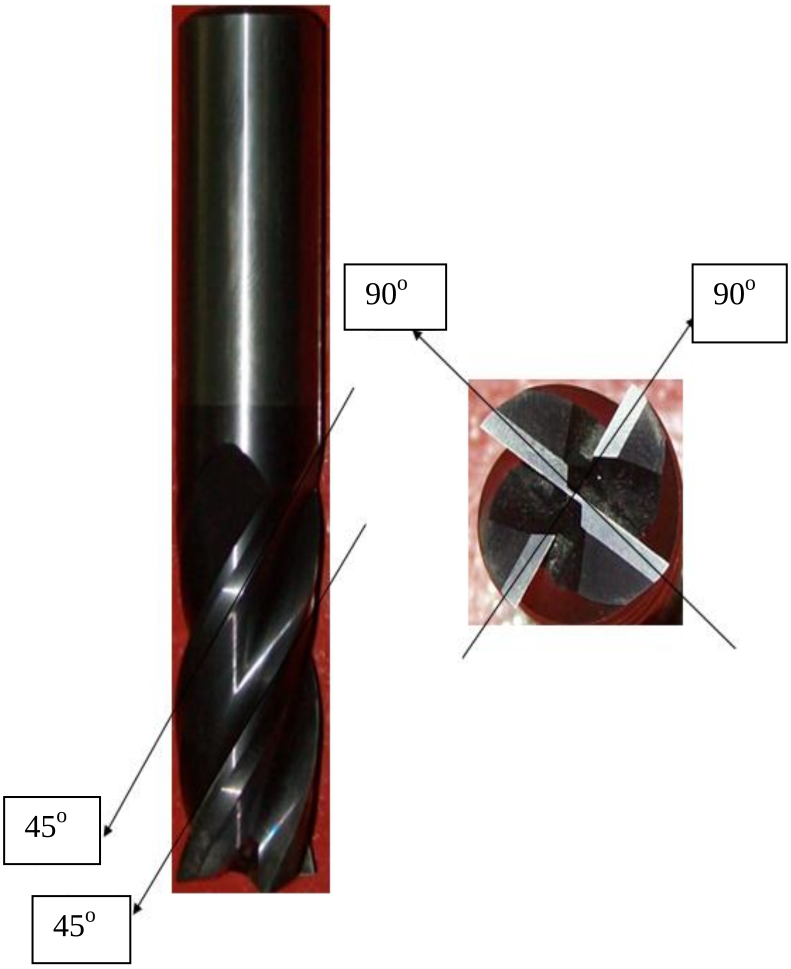


Figure 3.2: Uniform helix and pitch tool

(a) (b) (c)

Figure3.3: Cutting tools used in the experiment; (a) solid carbide, (b) HSS Co8 coated and (c) solid carbide coated

3.4.2 Workpiece preparation

The material used in this experiment was aluminium alloy 7075 block (Figure 3.4). First, the block will be cut into a 150mm long block using benchsaw machine (Figure 3.5). Then it was drill with 8mm diameter drill cutter. On top of the drill hole the, couterbore was done to make the bolt head exactly level as workpiece surface. This is for safety precaution if the cutting tools accidentally cut along the bolt path and to make sure the workpiece that mounted on the flexure is very tight.

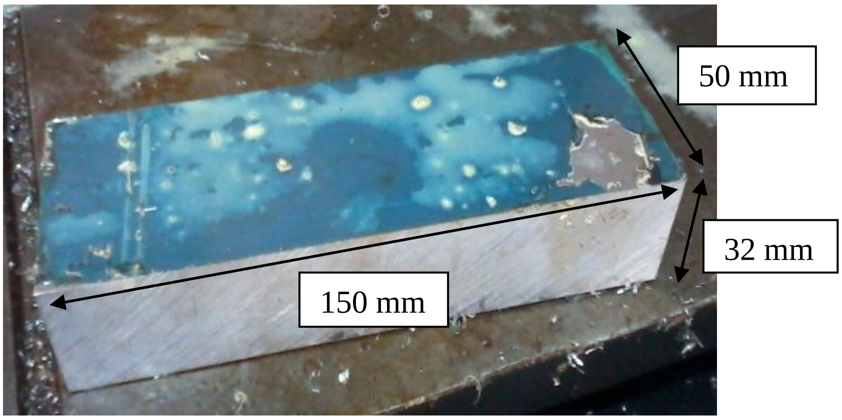


Figure 3.4: Aluminium alloy block

Figure 3.5: Benchsaw machine

3.4.3 Frequency response function measurement

In this project, flexural of single degree of freedom as seen in Figure 3.6 is used to clamp the workpiece on it. In order to make sure the flexural can be used to machining with tools, modal analysis testing is done on the flexural. This modal analysis testing is very important as it give value of frequency response function (FRF).The value of FRF of the flexural is then compared to the value of FRF of tools. If the FRF value of each of them are different, so the flexural can be used in the machining process. If not, the tools with tend to break easily as their frequency response almost the same.

The experimental approach involve the impact hammer model in which testing to measure the flexure frequency response function and cutting tools frequency response function. The data acquisition system apparatus used is a Bruel&Kjaer model type 7539A 5/1 channel (Figure 3.7). For the impact testing, a normal force was created by using a 2302-10 Meggit hammer (Figure 3.8) with vinyl tip was applied at the tool tip. The acceleration response is then captured by a 4507B Bruel&Kjaer accelerometer (Figure 3.9) which is located opposite to the hammer impact point. From the FRF of the analysis, the wavelength of the vibration has been obtained.

Figure 3.6: Flexure

Figure 3.7: Bruel&Kjaer model type 7539A 5/1 channel

Figure 3.8: 2302-10 Meggit hammer

Figure 3.9: Bruel& Kjaer 4507B accelerometer

3.4.4 Process damping experiment

Process damping performance experiment was performed by using CNC Haas VF6 vertical milling machine as shown in Figure 3.10.From the frequency response function, the resonant frequency obtained was used to choose a starting value for the spindle speed, so that the expected wavelength of vibration was $\lambda=0.1mm$.This was achieved by using both equation 2.5 and the relationship between tool diameter, spindle speed and surface speed. Based on previous study by Yusoff *et al*. (2010), the initial wavelength was reported to be below the process damping wavelength, λ_c. Furthermore, the maximum chip thickness the feed per tooth was determined using equation 2.3 and 2.4.

A low radial width of cut (r = 1 mm) and large axial depth of cut (b = 7 mm) were used to minimise forced vibration, reduce tool wear and prevent damage to the tool if severe chatter occurred. The spindle speed, *n* and feed rate, *f* were incremented simultaneously by 10% to maintain constant fpt and h_{max}, until chatter was detected. Process damping performance was then evaluated in terms of λ_c from equation 2.5. Here, the chatter frequency was obtained from Fourier analysis of the vibration signal, and the surface speed v was determined based upon the spindle speed at which chatter occurred. The procedure was repeated for five h_{max} values between 0.04 and 0.12 mm and for each tool. In the machining, a block of aluminium alloy (7075) was mounted on a flexible structure as shown in Figure 3.11 and 3.12.During cutting; vibration signal was recorded using an accelerometer type PCB 352C33 (Figure 3.13).The accelerometer was connected to the Hi-Speed USB Carrier NI USB-9162 (Figure 3.14) and connect to the computer by using National Instrumentation and Measurement software. This software was only used for obtaining the acceleration signal. The acceleration and frequency when machining was recorded using software called Dasylab. From the software, data for the frequency domain graph and time domain graph will be recorded.

Figure 3.10: CNC Haas VF6 vertical milling machine

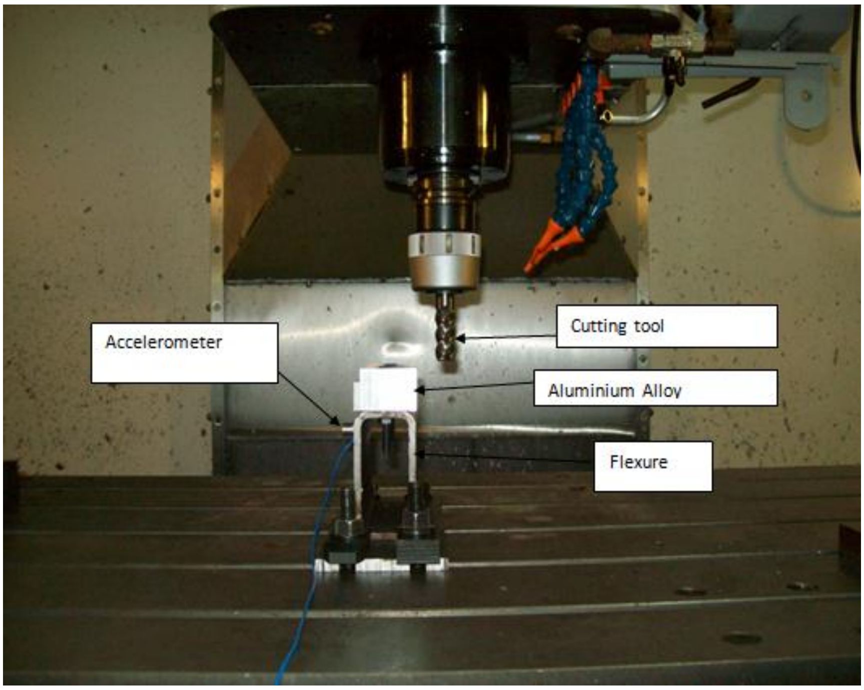


Figure 3.11: Machining apparatus and position of workpiece

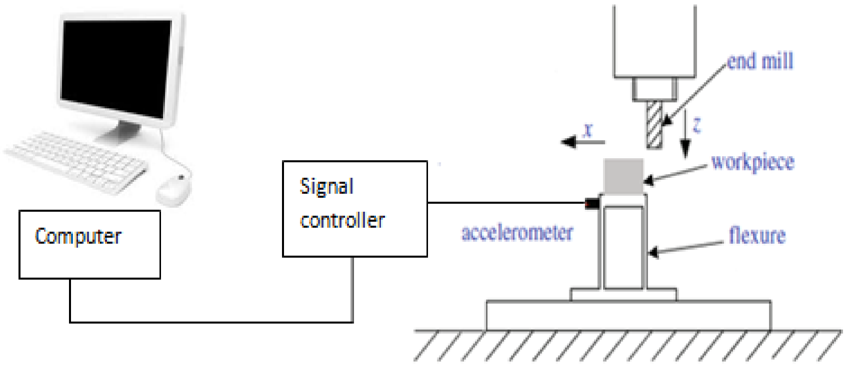


Figure 3.12: Schematic diagram of the cutting procedure

Figure 3.13: PCB 352C33 accelerometer

Figure 3.14: Hi-Speed USB Carrier NI USB-9162

3.5 ANALYSIS OF DATA

The data get from cutting experiment was then analyzed. The spindle speed at which the chatter occurs will be recorded. The aspect considered was the process damping wavelength of each tool used. The process damping performance was illustrated in the process damping wavelength versus maximum chip thickness graph. In this experiment, at every h_{max} the spindle speed starting is the same, while the feed rate is vary when other h_{max} value is used. The limit of spindle speed is 7151 rpm as the limit of CNC Haas VF6 milling machine is 7500 rpm. Sample of coding used in the machining is shown in Appendix B .The spindle speed at which the chatter occurs included with feed rate and the frequency at which the chatter happened was recorded. From the data, spindle speed and frequency value is used to calculate the process damping wavelength using equation 2.5.

3.6 DOCUMENTATION AND PRESENTATION

Lastly, documentation is very important for every project to make sure all the data and result has been document. For this project documentation is the final report and the log book. Final report is including all the information and data about the project. Actually, log book is a record about the work flow while do the project and the analysis. For the presentation, it is more to explain about the result and the analysis of this project. It needs to explain about method that was used to get the result for example from the cutting experiment; the vibration signal was recorded using accelerometer. This is important to make sure the validation of the result is clear.

3.7 SUMMARY

All steps of methodology of this research have been explained to get an overview the flow of research will be done. Next chapter will include the data collected and the analysis done to meet the objectives of the study.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter discusses the experimental result that obtained after done the process in the methodology. The results will be expressed in tables and graphs to provide the reader with a clearer view. The experimental result will then be analysed and compared.

4.2 RESULTS

The result of experimental test will now be presented to investigate the influence of tool types on process damping performance. Initially, the frequency response function (FRF) of flexure was measured and also for all the tools.

4.2.1 Frequency response function of flexure

As previously mentioned the FRF of flexure was measured to get the initial spindle speed to start the experiment. From the conducted experiment it shows that the dominant frequency of the flexure was observed at 376 Hz as shown in Figure 4.1. The FRF of tools have very huge different compared to the frequency of flexure. Thus, the experiment can be done as huge distinction between tools and flexure in the frequency response function experiments is significant in order to get a dominant damping frequency.

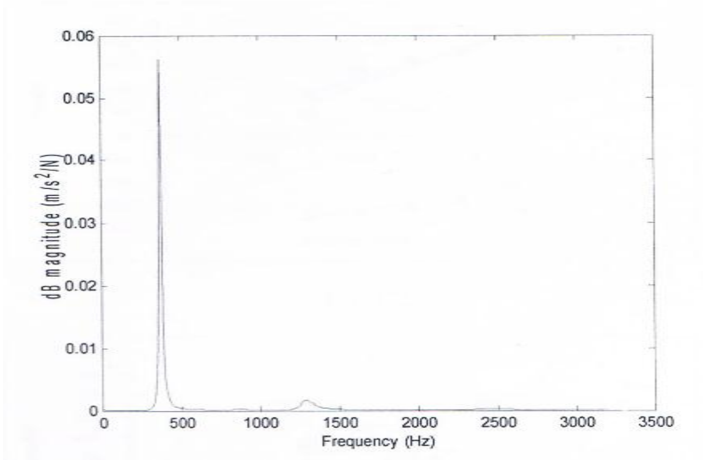
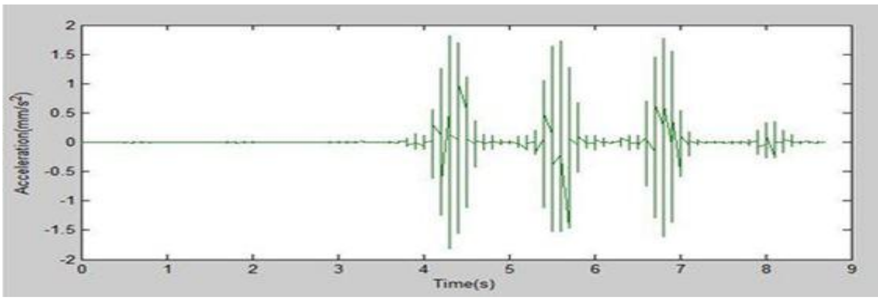


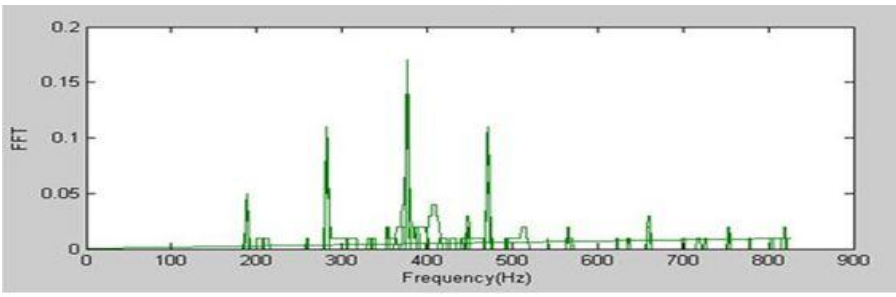
Figure 4.1: Frequency response function of the flexure

4.2.2 Chatter detection result

Figures below was built from h_{max} =0.06 mm data for solid carbide coated tool.It shows the flow from the beginning of cut until chatter occurred.

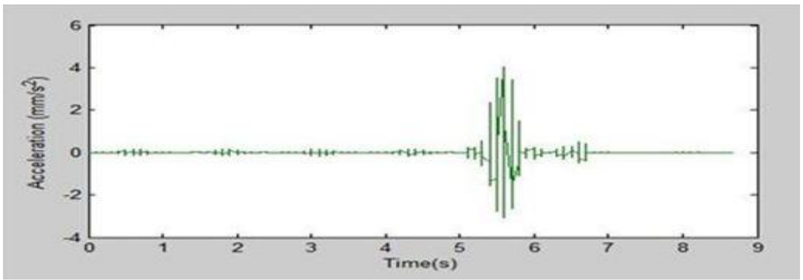


(a)

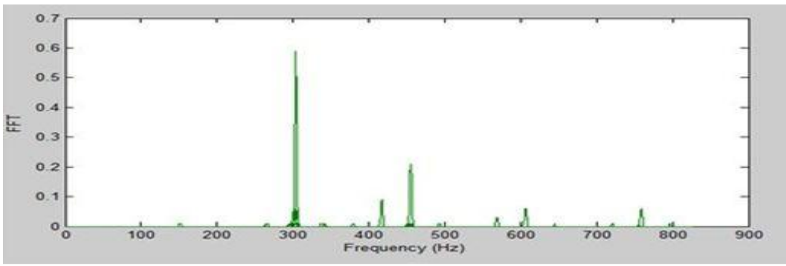


(b)

Figure 4.2: Stable condition with n=1414 rpm and f=566 mm/min; (a) acceleration amplitude and (b) frequency domain graph

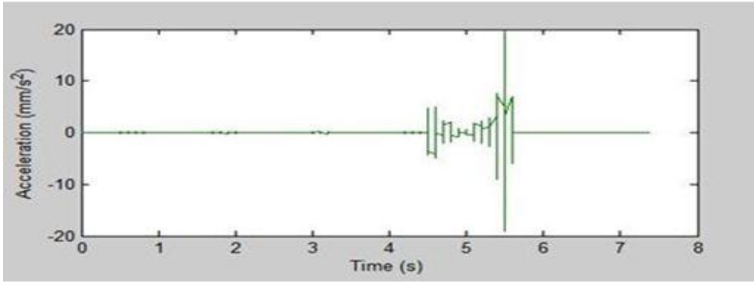


(a)

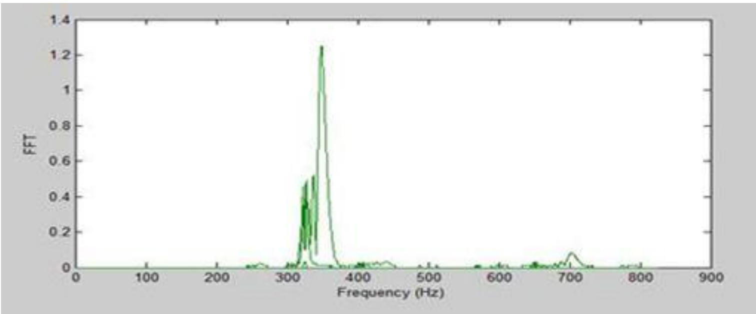


(b)

Figure 4.3: Stable condition with n=2278 rpm and f=911 mm/min; (a) acceleration amplitude and (b) frequency domain graph

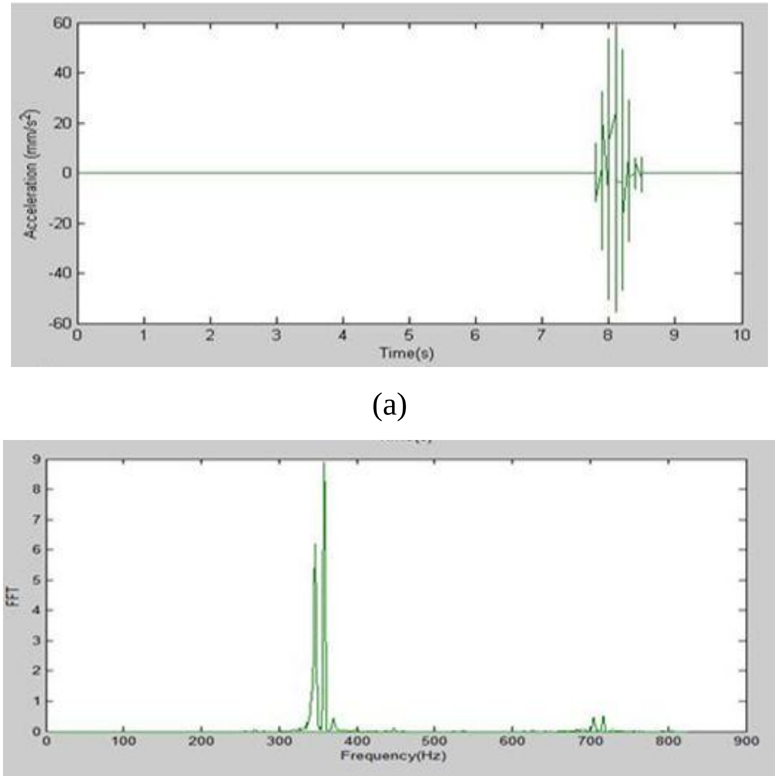


(a)



(b)

Figure 4.4: Stable condition with n=4885 rpm and f=1953 mm/min; (a) acceleration amplitude and (b) frequency domain graph



(a)

(b)

Figure 4.5: Chatter detection at n=5373 rpm and f=2149 mm/min; (a) acceleration amplitude and (b) frequency domain graph

Using the procedure that was previously describe, the value of FRF of flexure was used to get the initial values for the spindle speed and also the feed rate for each maximum chip thickness , h_{max} values. This leads to an initial speed of 600 rpm at h_{max} 0.04mm and the initial feed rate f=160 mm/min. This procedure was then repeated for other h_{max} values .In machining the workpiece, the spindle speed was increased smoothly and continuously under constant feed per tooth, *fpt* by 10%. This process was done until chatter was found. An example of result for h_{max} 0.06 mm for solid carbide coated tool was shown to demonstrate the method as shown in Figures 4.2, 4.3, 4.4 and 4.5.In the beginning of the cut (Figure 4.2), the vibration level was very low .As the spindle speed increased (Figures 4.3 and 4.4) the vibration magnitude start to grow compared to the beginning of the cut. A Fourier analysis indicates the peak frequency was close to the natural frequency of the flexure. Obviously, the vibration at the chatter frequency was the highest as shown in the Figure 4.5. Based on this result, the corresponding process damping wavelength was then determined.

All the tools used were 4 flute uniform helix and pitch. The data at which the chatter occurred was recorded by analyzing the graph from the accelerometer signal as shown in Tables 4.1, 4.2, 4.3 and 4.4. The tools were named as below:

(i) Tool 1- Solid carbide coated
(ii) Tool 2-HSS Co8 (High speed steel) coated
(iii) Tool 3- Solid carbide

Table 4.1: Chatter detection for solid carbide coated tool

Tool 1	Spindle speed,n (rpm)	Feed rate (mm/min)	Frequency (Hz)
h_{max} 0.04 mm	4885	1303	325.8
h_{max} 0.06 mm	5373	2149	358.1
h_{max} 0.08 mm	6501	3467	363.7
h_{max} 0.10 mm	5373	3582	356.4
h_{max} 0.12 mm	5910	4727	361.3

Table 4.2: Chatter detection for HSS Co8 coated tool

Tool 2	Spindle speed,n (rpm)	Feed rate (mm/min)	Frequency (Hz)
h_{max} 0.04 mm	5910	1576	354.84
h_{max} 0.06 mm	4441	1776	295.97
h_{max} 0.08 mm	5373	2865	358.1
h_{max} 0.10 mm	5373	3582	356.45
h_{max} 0.12 mm	5373	4298	358.1

Table4.3: Chatter detection for solid carbide tool

Tool 3	Spindle speed,n (rpm)	Feed rate (mm/min)	Frequency (Hz)
h_{max} 0.04 mm	3336	890	437.9
h_{max} 0.06 mm	3670	1467	451.6
h_{max} 0.08 mm	3670	1597	454.8
h_{max} 0.10 mm	3670	2446	460.5
h_{max} 0.12 mm	5373	4298	358.1

Table 4.4: Repeatability for solid carbide tool

Tool 3	**Spindle speed,n (rpm)**	**Feed rate (mm/min)**	**Frequency (Hz)**
h_{max} 0.04 mm	3033	809	371.78
h_{max} 0.06 mm	2757	1103	355.65
h_{max} 0.08 mm	3033	1617	373.39
h_{max} 0.10 mm	2757	1838	366.94
h_{max} 0.12 mm	5910	4727	358.87

4.2.3 Process damping wavelength calculation

Based from the result that has been tabulated, the process damping wavelength, λ_c for each tool was calculated. First, the surface speed,v need to be calculated by using diameter of cutting tool and spindle speed at which chatter happened .The surface speed was then divide by frequency at which the chatter occurred, f_c to get the process damping wavelength. All calculation was shown in Tables 4.5, 4.6, 4.7 and 4.8.

Table 4.5: Calculation for solid carbide coated tool

$\boldsymbol{h_{max}}$	$\boldsymbol{v = \frac{\pi D n}{1000}}$	$\boldsymbol{v}$**,mm/s**	$\boldsymbol{\lambda_c = \frac{v}{f_c}}$	$\boldsymbol{\lambda_c}$**,mm**
0.04 mm	$v = \frac{\pi(20)4885}{1000}$	306.9336	$\lambda_c = \frac{306.9336}{325.8}$	0.94
0.06 mm	$v = \frac{\pi(20)5373}{1000}$	337.5955	$\lambda_c = \frac{337.5955}{358.1}$	0.94
0.08 mm	$v = \frac{\pi(20)6501}{1000}$	408.4698	$\lambda_c = \frac{408.4698}{363.7}$	1.12
0.10 mm	$v = \frac{\pi(20)5373}{1000}$	337.5955	$\lambda_c = \frac{337.5955}{356.4}$	0.95
0.12 mm	$v = \frac{\pi(20)5910}{1000}$	371.3362	$\lambda_c = \frac{371.3362}{361.3}$	1.03

Table 4.6: Calculation for HSS Co8 coated tool

h_{max}	$v = \frac{\pi Dn}{1000}$	v,mm/s	$\lambda_c = \frac{v}{f_c}$	λ_c,mm
0.04 mm	$v = \frac{\pi(20)5910}{1000}$	371.3362	$\lambda_c = \frac{371.3362}{354.84}$	1.05
0.06 mm	$v = \frac{\pi(20)4441}{1000}$	279.0362	$\lambda_c = \frac{279.0362}{295.97}$	0.94
0.08 mm	$v = \frac{\pi(20)5373}{1000}$	337.5955	$\lambda_c = \frac{337.5955}{358.1}$	0.94
0.10 mm	$v = \frac{\pi(20)5373}{1000}$	337.5955	$\lambda_c = \frac{337.5955}{356.45}$	0.95
0.12 mm	$v = \frac{\pi(20)5373}{1000}$	337.5955	$\lambda_c = \frac{337.5955}{358.1}$	0.94

Table 4.7: Calculation for solid carbide tool

h_{max}	$v = \frac{\pi Dn}{1000}$	v,mm/s	$\lambda_c = \frac{v}{f_c}$	λ_c,mm
0.04 mm	$v = \frac{\pi(20)3336}{1000}$	209.6070	$\lambda_c = \frac{209.6070}{437.9}$	0.49
0.06 mm	$v = \frac{\pi(20)3670}{1000}$	230.5929	$\lambda_c = \frac{230.5929}{451.6}$	0.51
0.08 mm	$v = \frac{\pi(20)3670}{1000}$	230.5929	$\lambda_c = \frac{230.5929}{454.8}$	0.50
0.10 mm	$v = \frac{\pi(20)3670}{1000}$	230.5929	$\lambda_c = \frac{230.5929}{460.5}$	0.50
0.12 mm	$v = \frac{\pi(20)5373}{1000}$	337.5955	$\lambda_c = \frac{337.5955}{358.1}$	0.94

Table 4.8: Calculation for solid carbide tool (repeat)

h_{max}	$v = \frac{\pi Dn}{1000}$	v,mm/s	$\lambda_c = \frac{v}{f_c}$	λ_c,mm
0.04 mm	$v = \frac{\pi(20)3033}{1000}$	190.5690	$\lambda_c = \frac{190.5690}{351.78}$	0.51
0.06 mm	$v = \frac{\pi(20)2757}{1000}$	173.2274	$\lambda_c = \frac{173.2274}{355.65}$	0.49
0.08 mm	$v = \frac{\pi(20)3033}{1000}$	371.3362	$\lambda_c = \frac{190.5690}{373.39}$	0.51

Table 4.8: Continued

h_{max}	$v = \frac{\pi Dn}{1000}$	v,mm/s	$\lambda_c = \frac{v}{f_c}$	λ_c,mm
0.10 mm	$v = \frac{\pi(20)2757}{1000}$	173.2274	$\lambda_c = \frac{173.2274}{366.94}$	0.47
0.12 mm	$v = \frac{\pi(20)5910}{1000}$	371.3362	$\lambda_c = \frac{371.3362}{358.87}$	1.03

4.2.4 Repeatability of selected cutting tool

A selection of test was repeated to observe the influence of process variability and also to confirm that the analysis approach gave consistent results. When performing repeated test after other experiment, it should be considered that there would be slight amount of tool wear, so the influence of this wear could be compared to other process parameters. The repeatability test was conducted for tool 3 which is the regular solid carbide. Graph for process damping wavelength, λ_c versus maximum chip thickness, h_{max} was then plotted.

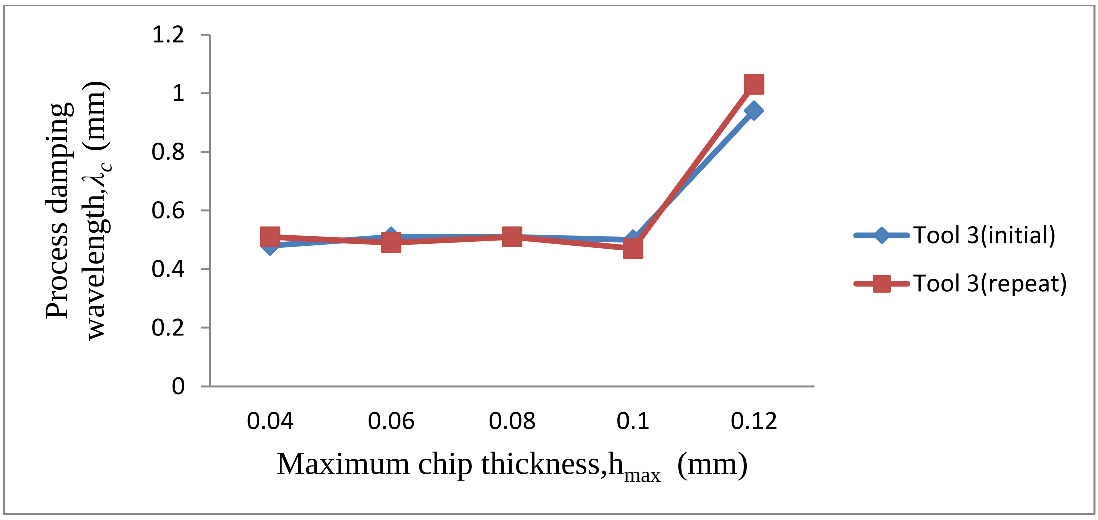


Figure 4.6: Repeatability test on tool 3(regular solid carbide)

Figure 4.6 shows the difference between initial test and repeated test in term of process damping wavelength, λ_c value. Based on the figure, the pattern of the graph is quite similar. For h_{max} 0.04 mm, the process damping wavelength for the tool 3 (repeat) are higher than the initial process damping wavelength .Meanwhile, at h_{max} 0.06 mm the process damping wavelength for repeated tool was lower than the initial value similarly at h_{max} 0.10 mm. At h_{max} 0.08 mm the process damping wavelength does not change and for the last value of h_{max} which is 0.12 mm, the repeated test give higher process damping wavelength compared to its initial value. From the overall analysis, the error percentage between initial test and repeated test were less than 10 %. This amount is still acceptable for confirming the test results.

4.2.5 Process damping wavelength analysis

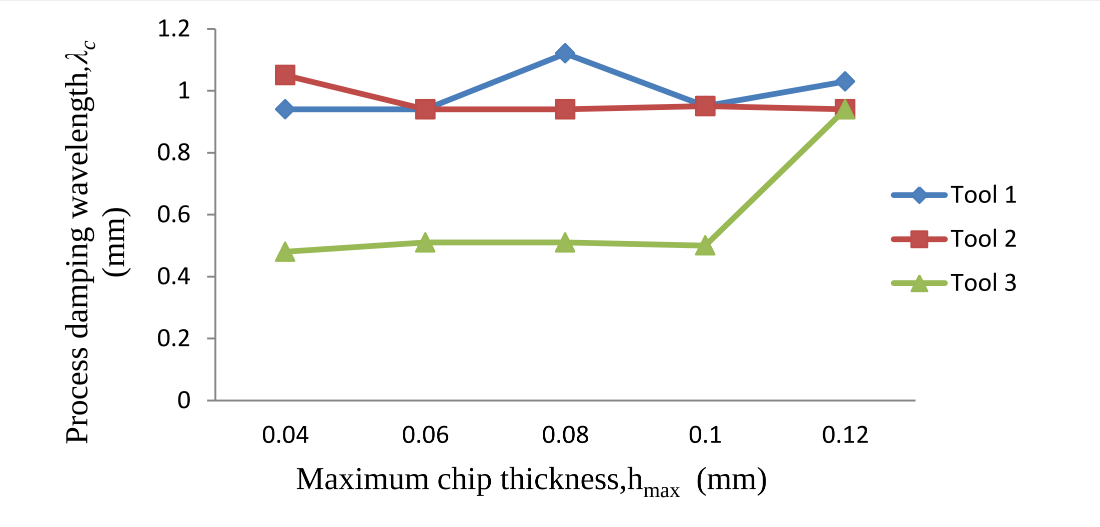


Figure 4.7: Comparison of process damping wavelength for each tool

Figure 4.7 shows the relationship between maximum chip thickness, h_{max} and process damping wavelength, λ_c for each tool that was used in the experiment. It should be restated that this experiment concerned of machining an aluminium alloy block on a very flexible workpiece or flexure. Based on graph, it can be seen that coated tools have different performance compared to uncoated tools. First, comparison for h_{max} 0.04 mm shows that tool 3 have the lowest process damping wavelength which is 0.48 mm, compared to tool 1 which is 0.94 mm and lastly tool 2 with 1.05 mm process damping wavelength.

At h_{max} 0.06 mm, tools 3 still have the lowest process damping wavelength while tool 3 and tool 2 have the same process damping wavelength. When h_{max}0.08 mm is used, it shows that the highest process damping wavelength is tool 1 and followed by tool 2 and lastly tool 1. Next for h_{max} 0.10 mm, the patterns of the graph were similar to the performance of each tool at h_{max} 0.06 mm. When the h_{max}value increased to 0.12 mm, the tool that has the highest process damping wavelength was tool 1 while tool 2 and tool 3 shared the same process damping wavelength. Apparently, the measured process damping wavelengths were different to those previous studies by Yusoff *et al*. (2010). This could be because of the different of the axial and radial depth value that used in the experiments.

4.3 DISCUSSION

The results have demonstrated some interesting and useful relationship between coated or uncoated tool and process damping performance. A several issues are worthy of further discussion. The experimental data shown in Figures 4.2, 4.3, 4.4 and 4.5 indicates that the vibration during machining has grown quite steadily as the spindle speed was increased. This situation makes it difficult to identify a discrete transition from stable to unstable cutting for example in determining the occurrence of chatter. The gradually increased in vibration amplitude observed in present experiment has two implications. First, it shows that process damping phenomenon have very great influence in chatter stability as no clearly definable transition from stable machining which have low vibration amplitude to unstable machining which have high vibration amplitude. Secondly, the steadily growth in vibration makes it more difficult to determine reliably the boundary between acceptable and unacceptable cutting that was indicated by the process damping wavelength. It shows that the quantification and classification of process damped milling performance remains an issue for further research.

Possible mechanism that have given rise to the behaviour observed in this experiment also been a considerable issue. The influence of feed rate in machining parameter could be considered. The increased in maximum chip thickness value cause the feed rate to increase and this result to deeper tool’s penetration into the workpiece. It shows that different maximum chip thickness will result to different performance damping wavelength as illustrated in Figure 4.3. In practice, the chip thickness also a function of tool diameter and machining radial immersion as was shown in equation 2.3. A further work could investigate whether varying the tool radial immersion has an equivalent effect to varying machining feed rate. Meanwhile, in machining practice there was other factor that influences the chosen radial immersion such as tool life. The tool life is a critical factor under process damped conditions and for given material removal rate the tool wear can spread across more of tool's length by using larger axial immersion and low radial immersion.

Finally, in any experimental involving machining chatter and process damping, the issues of experimental accuracy and repeatability should be highly considered before making conclusion for the collected data. In this present study, the experimental error was finding by using repeatability test for chosen tool used in the experiment. The repeatability test showed variations less than 10%, which is still acceptable for defining the performance of process damping wavelength for each tool.

CHAPTER 5

CONCLUSION & RECOMMENDATIONS

5.1 CONCLUSION

In this project there are a few objectives that need to be fulfilled. Based from the results and experiment done, the objectives of this project have been achieved. Workpiece preparation is an important part in this project. It has been done using equipment that was discussed in the methodology of this project. The workpiece was prepared successfully for the milling operation.

In machining process which was milling operation itself, the process damping technique was applied. The used of high axial depth of cut and low radial depth of cut represent the process damping technique. The machining process was done successfully to get the data in the experiment.

This experiment has contributed the results demonstrating influence of coatings on tool for process damping performance at low speed milling .It have been shown that process damping performance of uncoated tool which is regular solid carbide are lower than the coated tools used in this experiment which was HSS Co8 coated and solid carbide coated. Solid carbide coated is the best tool based on the process damping wavelength analysis with 1.12 mm process damping wavelength at maximum chip thickness, h_{max} 0.08 mm.

Through this conclusion, choosing a better cutting tool is easier if low speed milling is to be employed. This conclusion only for material Aluminium Alloy-

7075, but if other materials which was harder to machined material such as titanium alloy will need further investigation on their process damping performance.

5.2 RECOMMENDATIONS

For every studies and researches that has been done, there are always further improvements. So in this research, there are some suggestion and method that can be taken into account when running this research in the future. In investigating process damping performance, cutting tools with different tool geometry such as variable helix and pitch also can be used. Besides that, other difficult to machine materials also can be used in this experiment.

Furthermore, different parameter for the process damping technique also can be done. So, the result can be compared to our previous study. Investigating the surface roughness for the surface that have no chatter and surface that have chatter also can improved this result of this present study. Lastly, different value of maximum chip thickness also can be used to see the effect on process damping wavelength in future studies.

REFERENCES

Ahmadi K. and Ismail F. , 2011, Analytical stability lobes including nonlinear process damping effect on machining chatter, International journal of machine and tool manufacture , Volume 51, pages 296-308

Altintas Y., Eynian M. and Onozuka H., 2008, Identification of dynamic cutting force coefficients and chatter stability with process damping, Cooperative International Research Program Annals Manufacturing technology, Volume 57, pages 371-374

Altintas Y. and Weck M., 2004, Chatter Stability in Metal Cutting and Grinding, Annals of the Cooperative International Research Program, Volume 53, Issue 2, pages 619-642

Arslan M.C., Çatay B.and Budak E., 2004, A decision support system for machine tool selection, Journal of Manufacturing Technology Management, Volume 15, Issues 1, pages 101 – 109

Budak E. and Tunc L.T., 2009, A new method for identification and modelling of process damping in machining, October 2009, Volume 131, Issue 5, pages 051019

Budak E. and Tunc L.T., 2010, Identification and modelling process damping in turning and milling using new approach, Cooperative International Research Program Annals Manufacturing Technology, Volume 59, pages 403-408

Das M. K. and Tobias S. A., 1967, The Relation between the Static and the Dynamic Cutting of Metals, International Journal Machine Tool Design and Research, Volume 7, Issue 2, pages 63-89

Delio T.S., 1989, A Senior-Based Adaptive Control Constraint System for Automatic Spindle Speed Regulation to Obtain Highly Stable Milling, Ph.D. Dissertation, University of Florida, Gainesville, FL, pages 42-44

Eslayed M.A., Wells R.L., Dareing D.W.and Nagirimadugu K., 1994, Effect of process damping on longitudinal vibrations in drillstrings, Volume 116/129

Lee B.Y., Tarng Y.S. and Ma S.C., 1995, Modelling of the process damping force in chatter vibration, Volume 35, Issue 7, pages 951-962

Lin S.C., Devor R.E., Kapoor S.G and Sutherland J.W., 1990, A new approach to estimating the cutting process damping under working conditions

Nelson D.H. and Schneider G.J., 2001, Applied Manufacturing Process Planning With Emphasis on Metal Forming and Machining, Upper Saddle River

Raman A., 2007, Material Selection and Applications in Mechanical Engineering, New York

Rahnama R.,Sajjadi M. and Simon S.P. , 2009, Chatter suppression in micro end milling with process damping, Journal of material processing technology, Volume 209, Issue 17, pages 5766-5776

Stone E., Ahmed S., Askari A. and Tat H., 2005, Investigations of process damping forces in metal cutting, presented at the Computing Research Repository.

Sims N.D., Mann B., Huyanan S., 2008, Analytical prediction of chatter for variable pitch and variable helix milling tools, Journal of Sound and Vibration , Volume 317 , pages 664–686

Tlusty J., 1978, Analysis of the State of Research in Cutting Dynamics, Cooperative International Research Program Annals, Volume 27/2, pages 583-589

Tlusty J. and Ismail F., 1983, Special Aspect of Chatter Milling, American Society of Mechanical Engineers Journal of Industry, Volume 105, pages 24-32

Tlusty J., 2000, Manufacturing Processes and Equipment, Prentice Hall, Upper Saddle River

Tobias S.A. and Fishwick W., 1958, Theory of regenerative machine tool chatter, The Engineer, Volume 205, pages 199-203

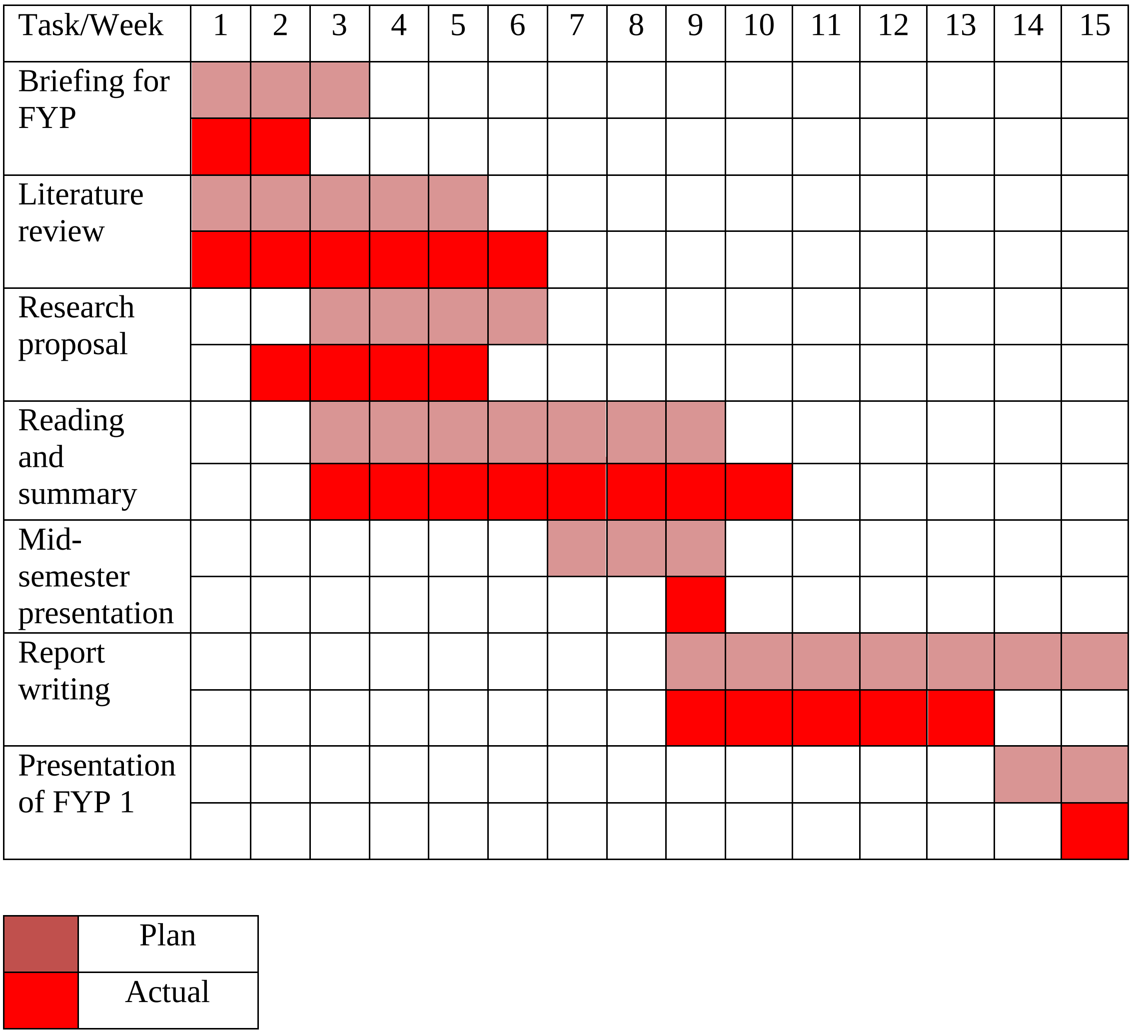
Yusoff A.R., Turner S., Taylor C.M. and Sims N.D., 2010, The role of tool geometry in process damped milling, International Journal Advance Manufacturing Technology, Volume 50, pages 883-895

Zamudio C.A., 1988, Self-Excited Vibrations in Oil Drilling, M.Sc. thesis, University of Florida, Gainesville, FL, pages 53-67.

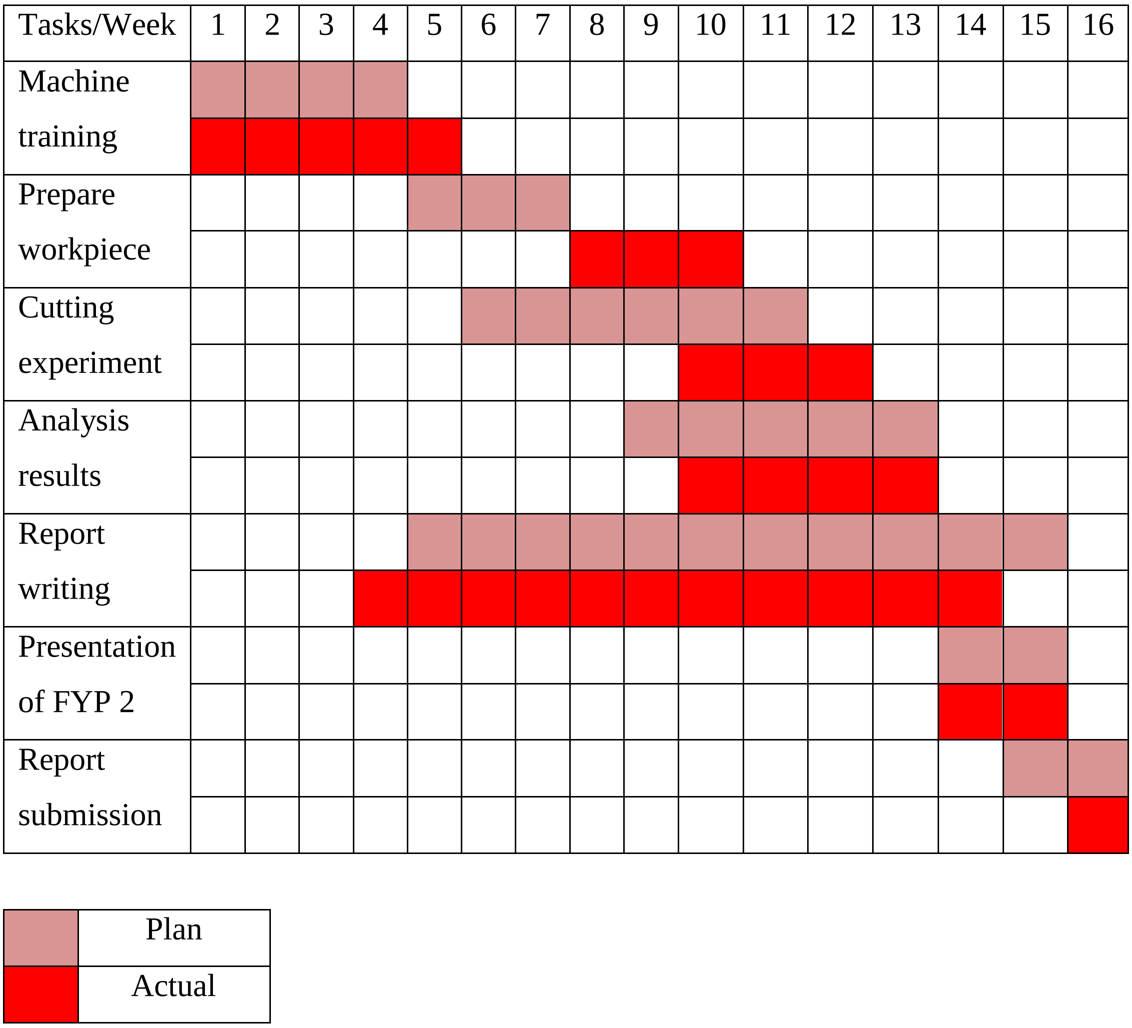
APPENDIX A

GANTT CHART

A1: GANTT CHART FOR FYP 1



A2: GANTT CHART FOR FYP 2



APPENDIX B

CNC CODE FOR MILLING PROCESS

```
O02121 ;
G21 ;
G00 G17 G40 G49 G80 G90 ;
M08 ;
M06 T3 ;
G90 G54 Y20. X8. ;
S600 M03 ;
G43 H03 Z2. ;
M03 Z-7. F343. ;
G01 X8. Y-25. F160. S660 ;
G01 X8. Y-50. F176. S726 ;
G01 X8. Y-75. F194. S798 ;
G01 X8. Y-100. F213. S878 ;
G01 X8. Y-125. F234. S966 ;
G01 X8. Y-180. F258. ;
G80 M09 ;
M05 ;
G90 G00 Z100 ;
M00 ;
```