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JUDUL: DEVELOPMENT OF FLEXURAL STRUCTURE FOR CHATTER MACHINING TESTING

SESI PENGAJIAN: 2011/2012

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DEVELOPMENT OF FLEXURAL STRUCTURE FOR CHATTER MACHINING TESTING

MOHAMAD ALIF BIN MOHD NASIR

Report submitted in fulfillment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering

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JUNE 2012

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I certify that the project entitled "Development of Flexural Structure for Chatter Machining Testing" is written by Mohamad Alif Bin Mohd Nasir. 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 fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering.

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IN THE NAME OF ALLAH, THE MOST GRACIOUS, THE MOST MERCIFUL

A special dedication of This Grateful Feeling to My…

Beloved parents, for giving me full of moral and financial support. It is very meaningful to me in order to finish up my degree's study. Do not forget also to my loving sister and last but not least to all my lovely lecturers and friends.

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ABSTRACT

This thesis deals with development of flexural structure that be used in detecting chatter on milling machine. The main important point in HSM is to increase MRR thus can reduce cost and increasing production. In this problem, chatter will limit the machining process and sometime will result in damage on cutting tool and surface roughness of material. The role of SDOF flexure is used as platform to perform stability test. It will provide a flexible workpiece with natural frequency. This project is carried out to develop a flexure with ability to be adjustable in height with natural frequency 400-600Hz. The process began using analytical method to identify the natural frequency. The simple calculation was carried out by determining the stiffness of the material. From the analytical method, at height of 13 cm the natural frequency was 424.82 Hz and 580.16 Hz at height of 11 cm. In this project, mild steel was used due to strength and toughness. After the calculation was done, the flexure was modeled using solidwork software and exported to Algor software for FEA. The analysis of flexure was done in order to verify the calculation before the flexure can be fabricated. From the result of FEA, at height of 13 cm the natural frequency reading is 415.23 Hz and 495.22 Hz at height of 11 cm. The flexure that fabricated fully then will enter the final stage to test with modal analysis. The frequency response of the flexure is determined by using impact hammer with giving force at load point and been measured by the accelerometer. The result shows at height 13 cm the natural frequency was 412.5 Hz and 562.5 Hz at height of 11 cm.

ABSTRAK

Kajian ini adalah mengenai pembangunan struktur lenturan yang akan digunakan untuk mengesan kehadiran gegaran pada mesin giling. Perkara utama dalam kepantasan permesinan adalah semasa kadar penyingkiran bahan seterusnya dapat mengurangkan kos dan meningkatkan produktiviti. Dalam pada itu, kehadiran gegaran telah membataskan proses permesinan dan kadangkala menghasilkan kerosakan pada mata pemotong dan permukaan bahan yang dipotong. Peranan struktur lenturan dengan darjah kebebasan tunggal digunakan sebagai pengalas sokongan dalam ujian kestabilan. Ia akan menyediakan satu bahan kerja yang fleksibal dengan nilai frekuensi semulajadi. Projek ini dijalankan bertujuan untuk membangunkan sebuah struktur lenturan dimana ketinggiannya boleh diubah dengan frekuensi semulajadi adalah antara 400-600 Hz. Projek ini bermula dengan menggunakan kaedah analisa pengiraan untuk menentukan nilai frekuensi semulajadi yang diinginkan. Satu jalan pengiraan mudah dilakukan untuk menentukan kekuatan bahan. Daripada pengiraan analisa yang dilakukan, didapati pada ketinggian 13cm nilai frekuensi semulajadi adalah 424.82 Hz dan 580.16 Hz pada ketinggian 11cm. Dalam projek ini, keluli lembut dipilih berdasarkan kekuatan dan keliatan yang terdapat padanya. Selepas pengiraan selesai dilakukan, struktur lenturan di reka menggunakan perisian solidwork dan dieksport ke perisian Algor untuk dianalisis unsur terhingga. Analisis kepada struktur lenturan dilakukan bagi menentukan ketepatan pengiraan analisa yang telah dilakukan pada awalnya sebelum struktur lenturan boleh di hasilkan. Daripada hasil keputusan analisis unsur terhingga, pada ketinggian 13cm bacaan frekuensi semulajadi adalah 415.23 Hz dan 495.22 Hz pada ketinggian 11 cm. Struktur lenturan yang telah siap dihasilkan kemudian memasuki fasa terakhir untuk diuji menggunakan modal analisa. Frekuensi balas oleh struktur lenturan dilakukan menggunakan tukul impak dengan diberikan daya padanya dan diukur menggunakan meterpecutan. Keputusan menunjukkan pada ketinggian 13cm nilai frekuensi semulajadi adalah 412.5 Hz dan 562.5 Hz pada ketinggian 11cm.

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LIST OF SYMBOLS

ω_n	Natural frequency
ζ	Damping ratio
k	Stiffness
I	Moment of Inertia
m	Meter
cm	Centimeter
mm	Millimeters
c	Damping constant
h	Height

LIST OF ABBREVIATIONS

MRR	Material removal rate
HSS	High Speed Machining
2DOF	Two degree of freedom
SDOF	Single degree of freedom
FEA	Finite Element Analysis
FEM	Finite Element Method
FRF	Frequency Response Function
FYP	Final Year Project

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

The main important point in high speed machining is to increase material removal rate (MRR). Consequently, it can simply reduce the production cost and increasing the production. The limitation in achieving MRR at high speed machining operations is instability behavior known as self excited vibration or chatter.

Chatter is a self-excited vibration caused by variations in instantaneous chip thickness. The tool begins to vibrate when flexible tool engages a workpiece because the vibrations are cut into the new surface leaving a wavy surface. The effect when the vibration of the cutting tool is out of phase with the previous surface makes the unstable cutting condition or chatter because of the variations in the instantaneous chip thickness. The workpiece or the tool will face with damage when large force vibrations during chatter.

However, the presence of chatter can be predicted by perform analytical stability to define stable and unstable condition for specific spindle speed and depth of cut. Figure 1.1 shows the unstable and stable cutting condition during machining process. Optimum machining aims to minimize the material removal rate while maintaining a sufficient a sufficient stability margin to assure the surface quality while avoiding chatter.

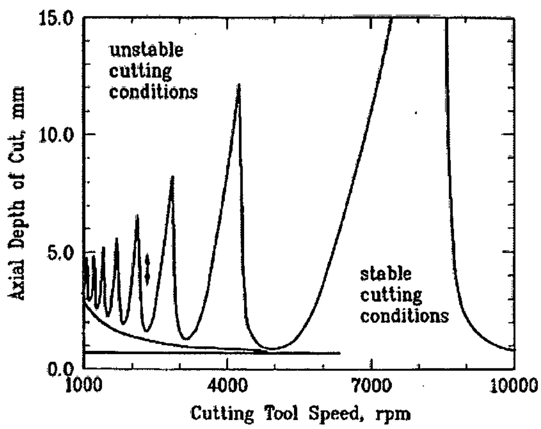

Figure 1.1: The cutting condition during machining process

Source: Daniel, 1997

It is important to minimize the undesirable motion of workpiece during high speed machining. There are several ways can be taken from the steps of mounting the workpiece to an active, supporting workpiece (flexure) and machining the workpiece. The undesirable motion of workpiece will be detected in the supporting structure then a reliable motion is applied to the flexural to minimize undesirable motion of workpiece.

1.2 PROBLEM STATEMENT

Usually designer or engineer will face a problem in increasing material removal rate in high speed machining which chatter will limit the objective. This project was carried out to develop the new flexure design which to investigate the self-excited vibration known as chatter. Stability test was predicted by mounting the workpiece to a single degree of freedom (SDOF) flexure.

1.3 OBJECTIVE

The objective of this project is to develop a single degree of freedom of flexural. The flexure design should can be operates to encourage undesirable motions of the workpiece independently of the machine tool devices. The design also should be adjustable in height in order to achieve the desired frequency in range of 400Hz - 600Hz. Firstly; analytical method was used to predict the natural frequency by determine the parameter of flexural. Then, FEA will simulate the flexural to validate the calculation been made earlier. Lastly, the modal analysis testing will perform to verify the natural frequency by applying force on flexural and measured the FRF of flexural.

1.4 SCOPE

This project required to develop a single degree of freedom of flexure. Below is scope in order to achieve the objective:

i. Search the literature review related to chatter and flexural during machining process.
ii. Make an analysis of advantages and disadvantages due to early invention of flexural.
iii. Develop a new design of flexural based on analytical solution with natural frequency range 400-600 Hz and Finite Element Analysis is used to simulate for verify the natural frequency of 400Hz - 600Hz.
iv. Verify the flexure with modal analysis testing using impact hammer.
v. Make a discussion and conclusion of experiment in a final report.

1.5 FLOW CHART

Figure 1.2 shows the project flow chart for this Final Year Project (FYP) 1. A first meeting has been arranged with the supervisor to discuss about the project title. This project required finding any related article, journal or references related to the project title. Then the proposal can be start to write containing introduction, literature review and methodology. The FYP1 will be ending with the presentation to the panel on week of 14^{th} on this semester seven.

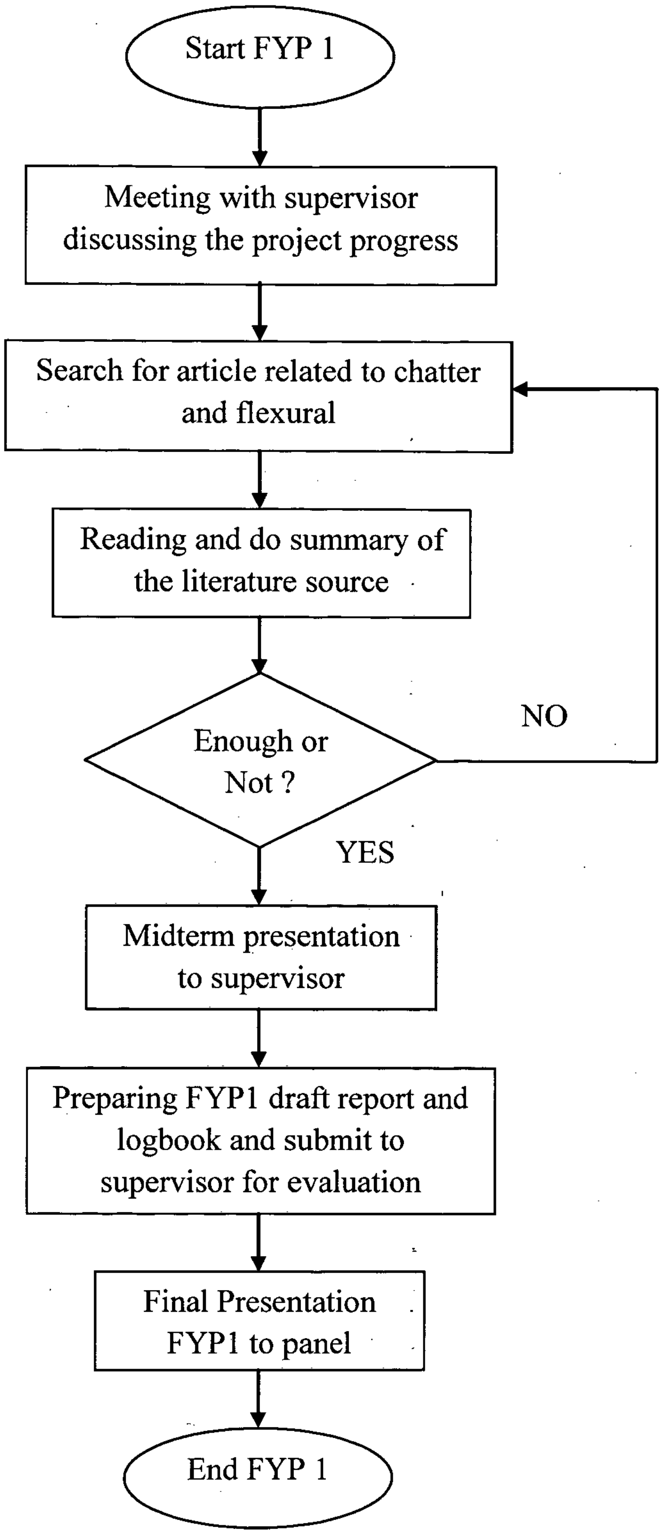

Figure 1.2: Project flow chart

CHAPTER 2

LITERATURE REVIEW

2.1 HISTORY

In 1946, Arnold proposed that chatter as a result of self-induced and forced vibrations, which is governed by the internal damping of the tool (Powell, 2008). Then it found that the fundamental cause of self-excited vibration is because of regeneration of waviness. The interference between the wavy surface because of vibrating tool and workpiece on the previous pass and the vibrating tool and workpiece on the current pass resulted variation in chip thickness then known as regeneration of waviness. The chip thickness remains constant as does the cutting force resulting in stable cut if the vibrations of the current pass are in phase with the vibrations from the previous pass. The chip thickness can vary greatly which means the variation in chip thickness leads to variation in cutting force which can result in self-excited vibrations when the vibrations of the current pass are out of phase with the vibrations from the previous pass. In 1965, Merritt introduced a control system approach to predict stability of a machining operation (Powell, 2008). Then, this method is used to develop analytical stability diagrams.

Cutting vibration adversely influences the tool life and the productivity, and damping is one of the important factors affecting the vibration amplitude and machining stability (Huang and Wang, 2007). There are two types of source of damping in a cutting system which is first structural damping and second one is process damping. The structural damping is related to workpiece, tool, holder and other parts of the machine tool system.

2.2 STABILITY LOBES DIAGRAM

The stability lobes diagram is a well-known method in pre-process of chatter prediction and avoidance. Stability lobe diagram identify stable and unstable cutting zones as a function of the chip width,b and spindle speed as show in Figure 2.1. It is required knowledge of the tool point dynamics whether analytic or time domain to produce these diagram.

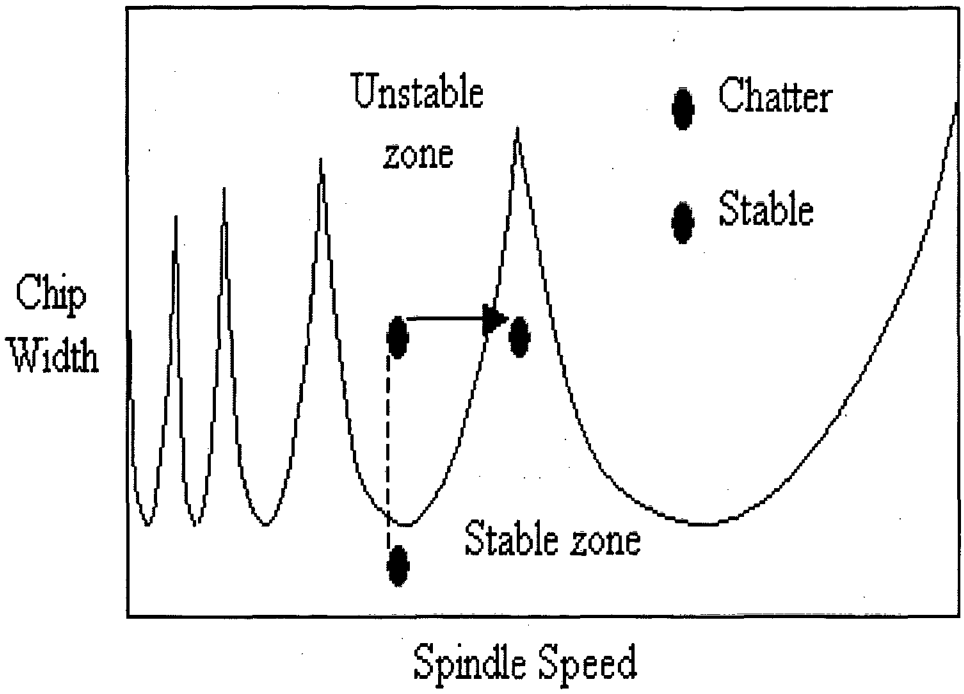

Figure 2.1: The Stability Lobes Diagram

Source: CNC Cookbook Incorporation, 2010

An instrumented hammer is used to excite the tool at its free end in order to obtain the dynamic response. The transducer typically a low mass accelerometer that mounted at the tool point is used to measure the vibration obtained from the impact hammer. To obtain the input for stability analysis it is used the complex ratio of the frequency domain vibration and forced signal. It should be noted that the measured frequency response function (FRF) is specific for the selected substructures (Duncan *et al.*, 2005). Then a new measurement will be obtained if the assembly is altered.

2.3 METHOD AND APPARATUS CONTROLLING CHATTER

The modern development also focuses on apparatus related to the arising chatter in the machine tool assembly during a machining operation. In the apparatus, the machine tool support with its own resonant frequency is function to support a cutting tool and the apparatus is adapted for modulating the resonant frequency of the machine tool support and the cutting tool. Figure 2.2 shows the experiment setup for detecting chatter.

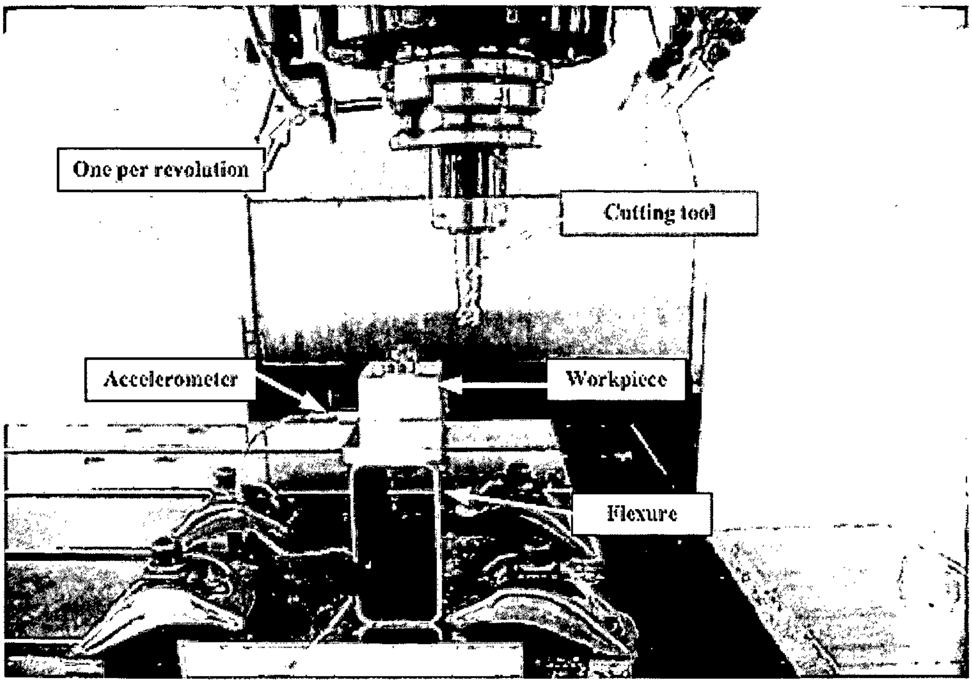

Figure 2.2: Equipment setup for detecting chatter

Source: Yusoff *et al.*, 2010

Chatter is a regenerative instability associated with the playback of irregularities on the workpiece (machined part) from previous cuts to the machine (cutting tool) (Segalman and Redmond, 1999). By modulating the mechanical impedance (time-varying impedance) of a component of the machine tool assembly, it can be used to present invention relates generally to methods and apparatuses for suppressing or preventing chatter in a machine tool assembly. Therefore, with periodically or continuously varying the stiffness of the cutting tool, other component of cutting tool and the resonant frequency of the cutting tool then chatter is being suppressed. Modulating the stiffness of the cutting tool, the cutting tool holder or any other component of the support for the cutting then the varying resonant frequency of the cutting tool can be done. The disturbance to natural frequency of oscillation will occur due to the variable yield stress in the fluid that affecting the coupling of the spindle to the machine tool structure.

Facing with the types of removal process, chatter can turn in a bad condition from the result relation of the cutting dynamics with the modal characteristics of the machine workpiece assembly. Machine tool vibrations are recorded on the surface of the workpiece during metal removal, imposing a waviness that alters the chip thickness. The result of nominal chip thickness will change the cutting force and hence excite vibration in certain conditions. The chatter consequently will cost variability of end product, waste of material, tool damage or wear and decreasing in production rate. There are some methods for maintaining cutting stability like first is small depth of cut. A small of cutting area that the process stays within the stability domain regardless of cutting speed.

Secondly is speed selection. To be in stability situation, depth of cut for a particular cutting speed can be adjusted. Thirdly is decreasing the tool speed. To remain the stability lobes for a given depth of cut can be achieved by adjusting the speed. Fourthly is high stiffness or damping. The stability in the depth of cut and increasing the number of stable process conditions can be raise by maximizing the dynamic stiffness of the cutting machine and the part support through design. Figure 2.3 shows depth of cut between cutting tool and workpiece.

With a lot of searching and development recently is purpose to control chatter in a machine tool assembly during machining process. The machine tool assembly has a plurality of components. The plurality of components has mechanical impedance and the method involving the step of modulating the mechanical impedance of at least one of the plurality of components. The plurality of components includes a cutting tool, a machine tool support, a workpiece or any component of the machine tool assembly (Smith, 2000).

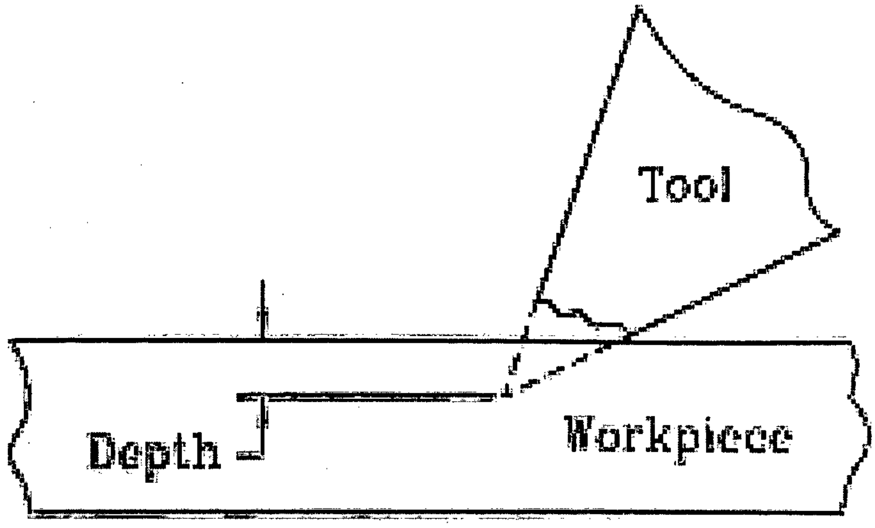

Figure 2.3: Depth of cut during cutting process

Source: Baek *et al.*, 1999

2.4 ROLE OF FLEXURAL FOR DETECTING CHATTER

It is important to minimize the undesirable motion of workpiece during high speed machining. There is several ways can be taken from the steps of mounting the workpiece to an active, supporting structure and lastly machining the workpiece. An undesirable motion of workpiece will be detected in the supporting structure. Then a reliable motion is applied to the flexural to minimize undesirable motion of workpiece. The chatter control fixture can be attached to various types of machine tool devices be retrofitted, and operates to minimize undesirable motions of the workpiece independently of the machine tool devices (Huang *et al.*, 2001).

The variable supporting flexure desire in adaptive for coupling the different type of machining structure. Then the supporting fixture should be mounted to, retrofitted on, a machine bed of any type of machine tool structure. A base and active bad (supporting structure of flexure) is named as active fixture. A bolt is used for securing the active bed to a milling machine and a vise is bolted to a top surface of active bed. The workpiece has been hold by a vise as optional. Figure 2.4 shows one of type flexural coupling.

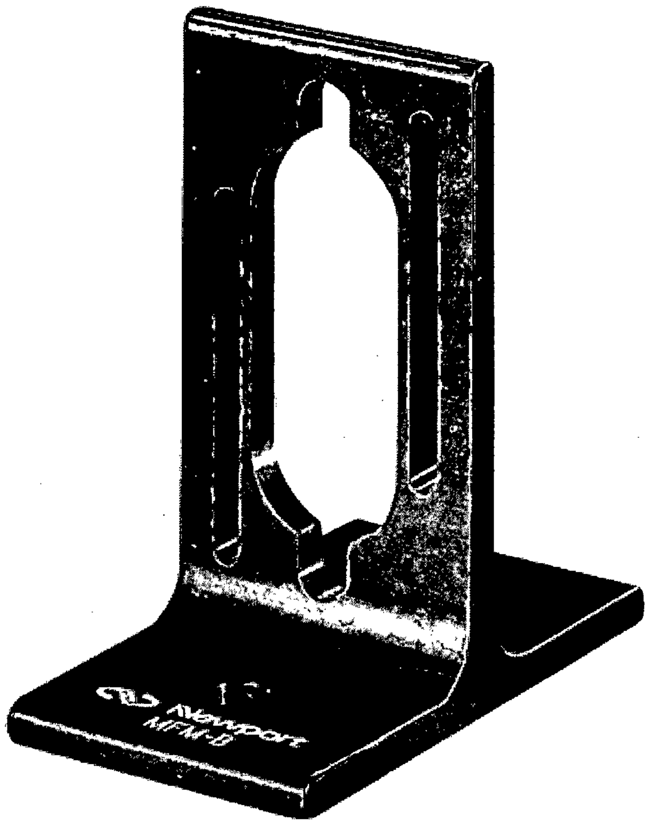

Figure 2.4: Flexural Coupling

Source: Newport Corporation, 1996

The workpiece also can be directly fitted to the active bed directly using another suitable clamping mechanism. The type of active bed can be resized accordingly to various type of machine bed active purposed. Without modifying the existing machine, the active fixture can be installed then enabling easy retrofit and universal adaption to machine bed generally. The active fixture though can be friendly used with the capability to operate efficiently and reliably in fast machining environment, easily and quickly cleanable, no adjustment required and minimum in maintenance. There are six surfaces provided in the invention of active bed.

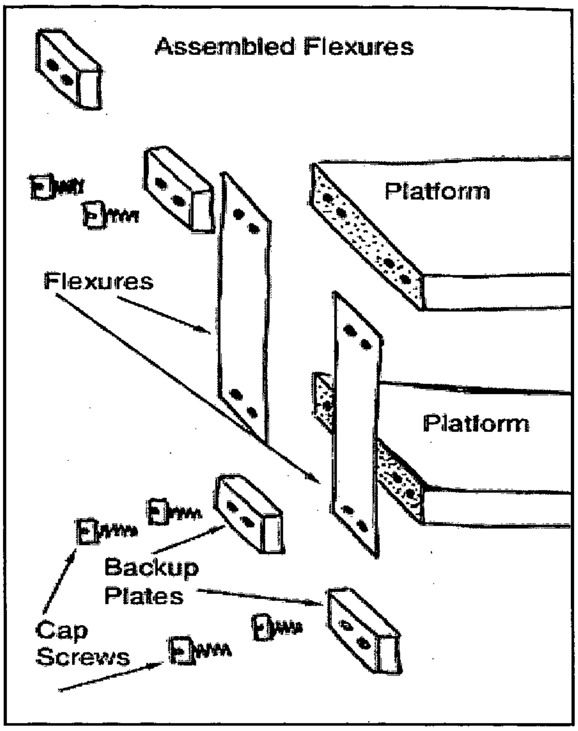

Figure 2.5: A complete flexure

Source: Micro Surface Engineering Incorporation, 1999

A complete flexure as Figure 2.5 consists of the body, leaf flexures and the clamping plate which connected together to perform a complete functional device. The leaf flexure in low efficiency becomes a serious problem which limits the assembling of flexural system. Losses in a big amount of energy may occur because of poor connection the ensuing in accuracy.

A much amount of clamping area can be provided as the contact surface of the clamping plates is to be flat lapped. For designing the clamping plates, in achieving the concentration of the clamping stressed, adjacent to the bending or hinge line of the leaf they more prefer to machine reliefs in the centre of the clamping plate. It actually a bad decision because the centre will bend down even further reducing the clamping area of the design. It is happened when the compressive force of the cap screws is applied to the "U" shaped clamping plate. A fatigue failure accidently occurs due to the excessive high stress concentrations immediately adjacent to the hinge line.

2.5 FLEXURAL CLAMPING PLATE

For completely assembly of flexure, the clamping plate is used to rigidly attach the ends of leaf flexure to the mating parts. The percentage contact between the flexures and flexure body should equally near to 100 percent for the main goal of the assembled flexure. The goal is said to be achieved when the surface of the clamping plate in contact with the flexure should be flat lapped. The type of clamping plate is shown by Figure 2.6 below:

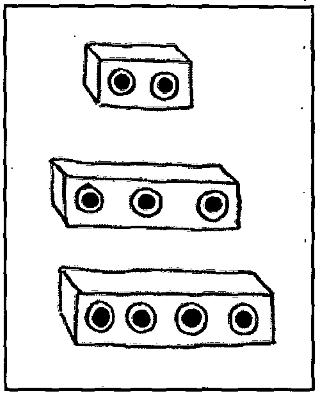

Figure 2.6: The clamping plate

Source: Micro Surface Engineering Incorporation, 1999

2.6 COMPLIANCE STRUCTURE OF FLEXURE

The compliance is to describe the movement of the system during machining process and there a many type of flexure is used to describe the individual sections of the structure that move.

A compound linear flexure needs a second platform with a same length flexure that is suspended under the first platform in order to correct for the drop when the platform is actuated. The distance to the centre between the two platforms must be actuated by a decoupling mechanism as shown in Figure 2.7. The wobble pin, a dual axis notched flexure or a toroidal flexure is provided truly linear motion for the second platform.

The crescent blade flexure is known as a linear translation device. A single crescent device can freely move in z-axis and free to rotate in pitch and roll. To make sure the crescent blade flexure is stabilize in translation motion, it must has at least three blades or leafs.

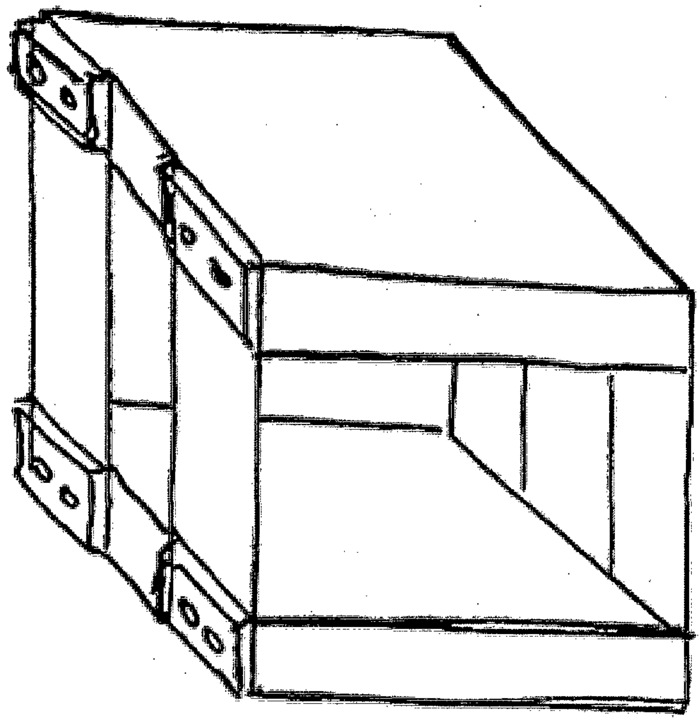

Figure 2.7: A compound linear flexure

Source: Micro Surface Engineering Incorporation, 1999

Two or more cantilever flexures of crossed leaf rotary flexure are mounted at right angles to each other. It offers with better of magnitude order, in off axis stiffness and resistance to parasitic motion although the design is more complex. The leaf flexure is available in variety of different width, length and thickness. Figure 2.8 shows the example of crossed leaf rotary flexure.

The cruciform flexure is a type of rotary flexure. The cross section of the flexure can be design in the type of "X". A very compact structure and high buckling load capacity has been provided by this structure.

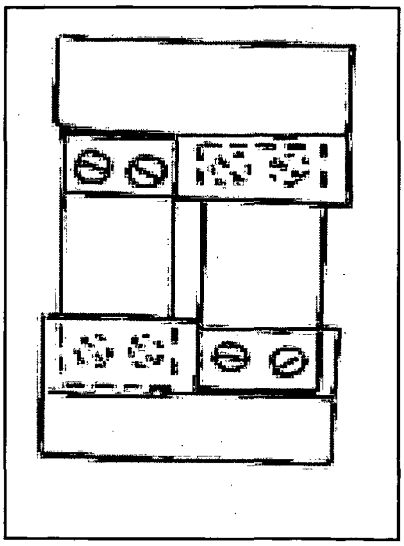

Figure 2.8: Crossed leaf flexure

Source: Micro Surface Engineering Incorporation, 1999

In this design, all of the five degree of freedom is very rigid. In order in increasing more carrying load capacity, more leaf can be added to the cruciform basic design. Figure 2.9 below shows the type of cruciform flexure:

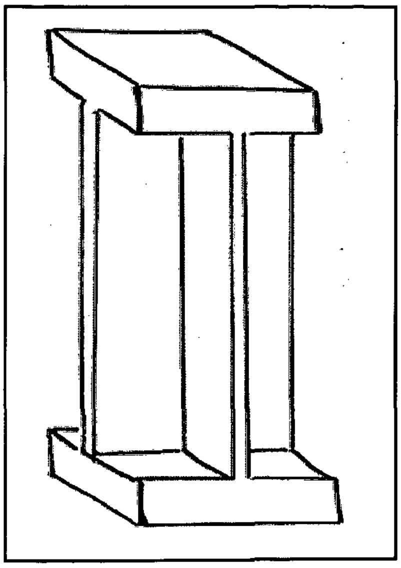

Figure 2.9: Cruciform flexure

Source: Micro Surface Engineering Incorporation, 1999

The diaphragm flexure as Figure 2.10 is widely used a rotary coupling device. The diaphragm flexure consists of a thin, round flexible disk of metal, with a mounting hole in the center, and a series of hole near the periphery to attach it (Gleason, 1952). By using two of the couplings in series with a separation between them, the full benefits of this design can be gained. The usage of disk bellows instead of the simple flat disk can give an improvement in rotary coupling design.

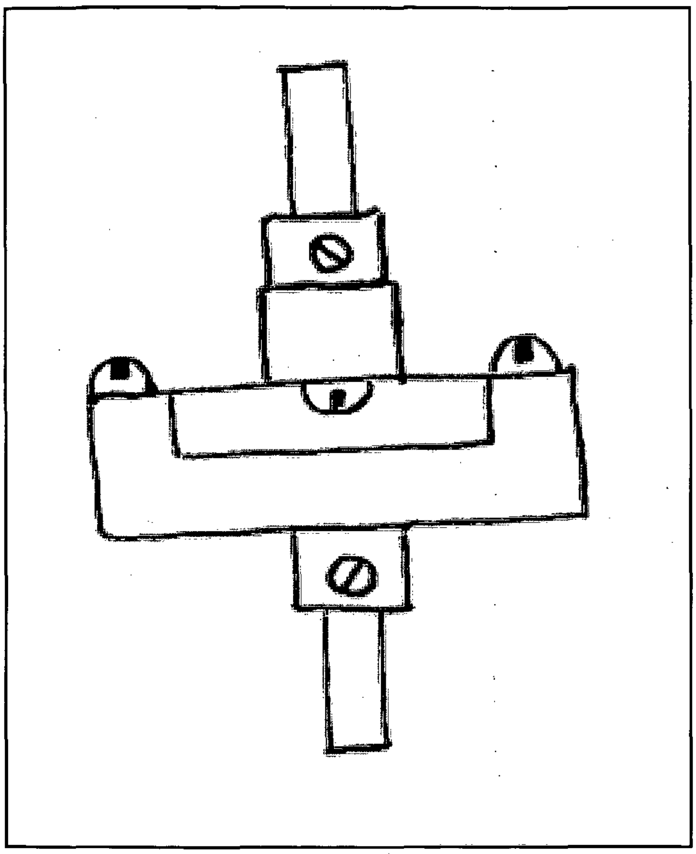

Figure 2.10: Diaphragm flexure

Source: Micro Surface Engineering Incorporation, 1999

For double notched flexure as shown in Figure 2.11, the down area is considerably thin in order to concentrate the flexibility of mechanism in local areas. In a single bar, there are two sets of parallel notches in the double notched flexure. The advantages of this design are it can provides two hinge lines and can be clamped to the mating mechanism with almost 100 percent efficiency because no joint between the flexure and the body. The cross section of the notches also will give an improvement to the linear travel of the system.

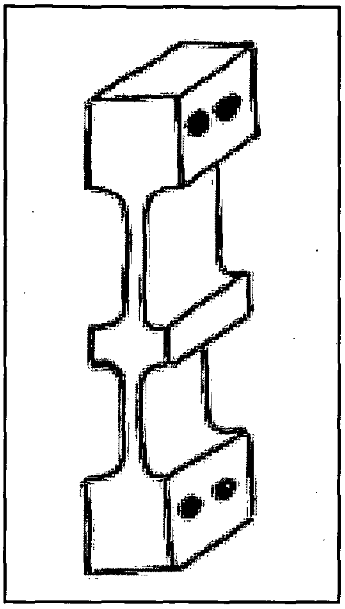

Figure 2.11: Double notched flexure

Source: Micro Surface Engineering Incorporation, 1999

2.7 FLEXURAL DESIGN PROPOSED

The design was proposed by Duncan is type of 2DOF of flexure and is show on Figure 2.12. The design is produced by stacking two SDOF flexures. Thus this flexure can create simple dynamic absorber effect.

When matching the natural frequency between two flexures, the two modes of the combined system split around the original natural frequency and the minimum value of the assembly negative real response is significantly increased (Duncan, 2004). Result is shown in Table 2.1.

The disadvantages of the flexure it is hard to match the top and base flexure frequency and need an additional mass to the large base flexure so the natural frequency can reduced and similarly with the top flexure natural frequency.

Table 2.1: Flexure design parameters and results

	m(kg)	k(N/m)	C(kg/s)	ω_n
Large base flexure				
Modal testing results	1.43	$9.41X10^6$	46.9	408.3
Modal testing results with added mass	2.46	$8.85X10^6$	70.6	301.9
Small base flexure				
Modal testing results	0.108	$6.34X10^5$	4.18	385.0
Modal testing results with added mass	0.155	$5.68X10^5$	2.23	304.7
Top flexure				
Modal testing results	0.145	$5.04X10^5$	1.17	296.3

Source: Duncan *et al.*, 2004

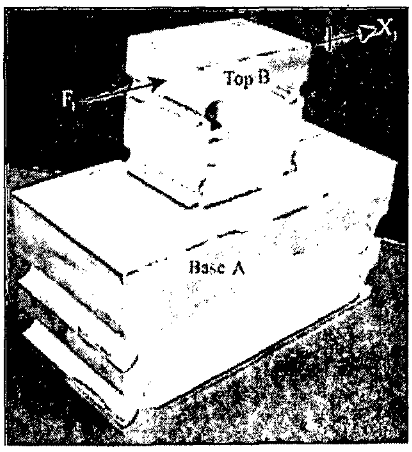

Figure 2.12: 2DOF Flexural by Duncan

Source: Duncan *et al.*, 2004

For the model flexural propose by the Huang and Wang as shown in Figure 2.13, the flexural is flexible in the direction perpendicular to the feed direction. The flexural then is tested by using modal analysis method using impact hammer. The result shows that the modal stiffness is 7.0 x 10^6 N/m, mass is 9.05 kg, damping ratio is 0.0216 and the natural frequency is 140Hz (Huang and Wang, 2007).

The flexure design by Huang and Wang is a type of SDOF flexure. The holder structure can be flexible in the direction perpendicular to the feed direction. The frequency value from modal testing also is 140 Hz give an advantage for detecting chatter when occur. The mass of the flexure is 9.05kg not strength enough for the leaf flexure to support and also hardly user to lift it for an adjustment when required to do so.

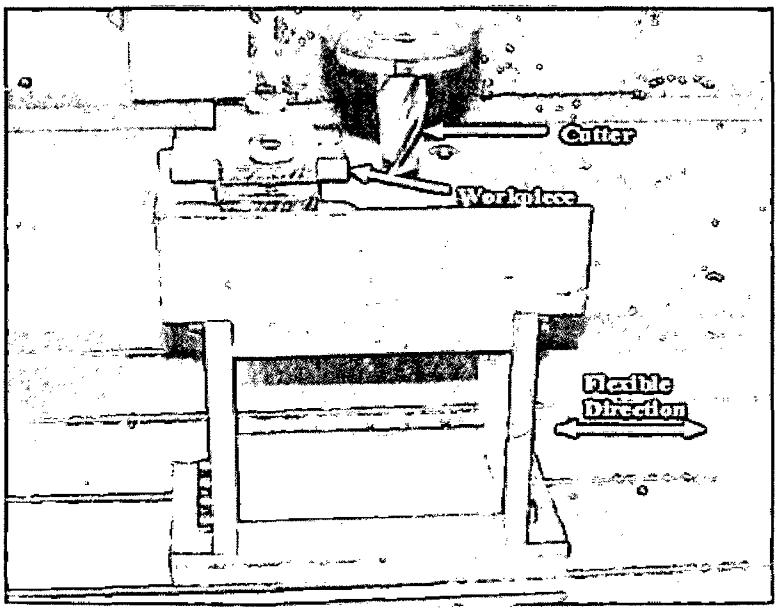

Figure 2.13: Flexural designed by Huang and Wang

Source: Huang and Wang, 2007

The flexural proposed by Yusoff *et al.* involve the experimental testing of impact hammer to measure flexure frequency response function and cutting tool frequency response function. The data acquisition system apparatus used was a Bruel & Kjaer model type 7539A 5/1 channel. From the conducted experiment, it shows that the dominant frequency of flexure was 367 Hz. Figure 2.14 shows the flexural design by Yusoff *et. al.*

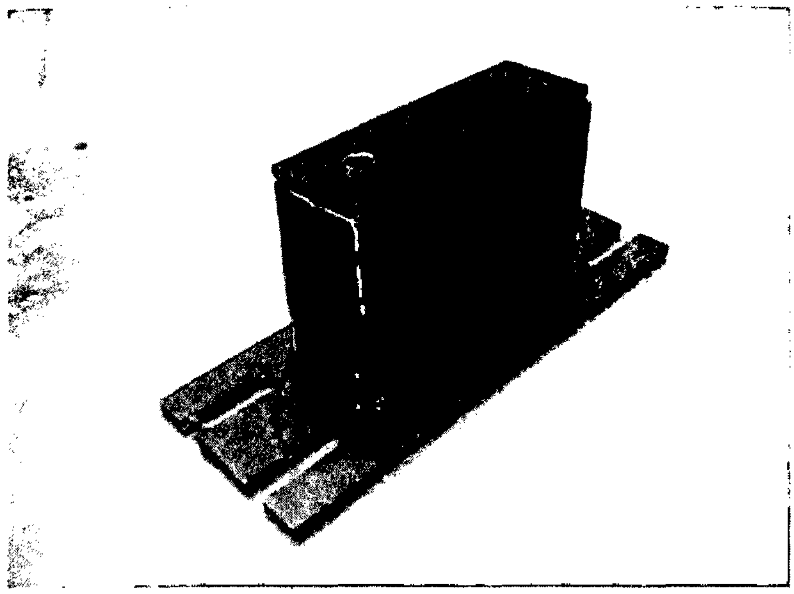

Figure 2.14: Flexural design by Yusoff et al.

Source: Yusoff *et al.*, 2010

Yusoff *et al.* also have introduced SDOF flexure where the flexure with low stiffness ensured process damped cutting conditions despite the low axial depth of cut. The dominant frequency obtained is 367Hz and give a big distinction of frequency between tools and flexure.

The notch hinge flexure as shown in Figure 2.15 is proposed by Mann *et al.* shown a critical geometrical where s is the depth of flexure, a_x is the radius of the circular notch hinge, t is the thickness of the hinge between notches and L is the vertical distance between notch centerlines.

The single degree of freedom of flexural designed by Mann *et al.* was performed with milling test. The flexure was made from the aluminium and instrumented with a single non-contact, eddy current displacement transducer. From analytical solution the value for natural frequency, ω_n determined to be 165Hz. The value of stiffness and damping ratio, ζ give 2.18×10^6 N/m and 0.0032.

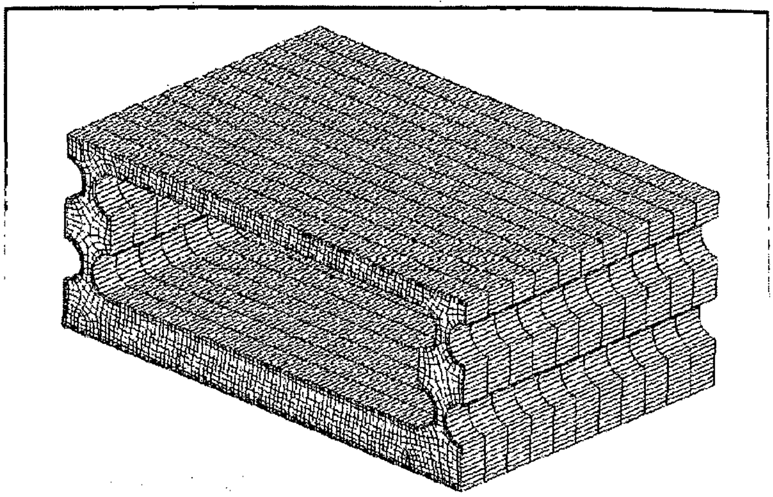

Figure 2.15: Flexural by Mann

Source: Kevin, 2008

Flexure designed by Mann *et al.* to be an order of magnitude compliant than the cutting tool. Although the natural frequency value getting from modal analysis is 146.5Hz, the notch flexure design is hard to fabricate when we are need to determine the radius of circular notch hinge and a quit problem to machine it properly.

2.8 SUMMARY

By recognize the flexural proposed earlier, flexural is known as a good performance structure in proper application. The best performance of this flexural can be determined whether from the design or material used to build it. In this research, in order to obtain the optimum natural frequency about 400-600Hz, flexural proposed by Yusoff *et al.* seems as a good selection based on design and purposes to use it. The type of flexure proposed is SDOF is simple compared to the 2DOF proposed by Duncan. It's because it is not easily to match the natural frequency between top and base flexure. From the material aspect, the flexural was fabricated from a monolithic material and the mild steel selection is a good choice based on strength and toughness and can support high loads thus avoid from buckling and permanent deformation. The design also not consists of multiple parts because it can suffer torsional stiffness, limited load capacity and very sensitive to dimensional tolerance. The less weight possessed by this flexure also give an advantage for easily to adjust it during perform of stability test on milling machine.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter explains clearly the step taken to complete the experiment in obtain the result and discussion. The procedure must be done systematically to make sure there is no mistake and conflict on the result obtain. A good methodology can describe the project flow smoothly and the project framework that contains the process element hence it becomes the guideline to find the objective required.

3.2 FLOW CHART METHODOLOGY

The planning is very important to give an illustration about the project flow process to make sure the progress project is satisfied with the time required. Hence the project will run smoothly as scheduled. The experimental approach involved three steps. First, analytical method was used to determine the parameter of flexure. Then, the FEA was used to analyze the flexure structure before being fabricated. Finally, the modal analysis was applied to measure the flexural FRF. The signal processing was used to observe the FRF response of force applied by impact hammer on point load. This methodology in Figure 3.1 illustrates the sequence of the project along conducting the experiment.

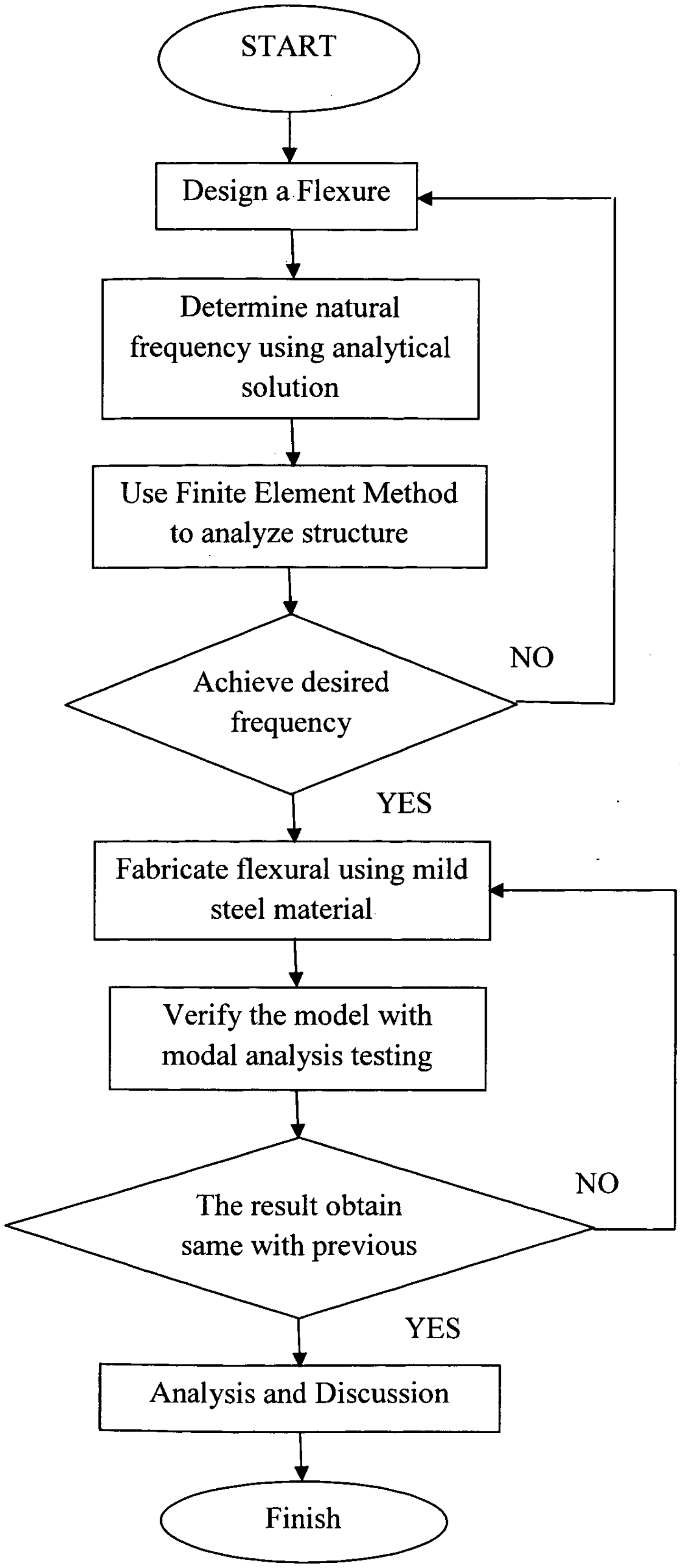

Figure 3.1: Flow Chart of Methodology

3.3 FLEXURE DEVELOPMENT

3.31 Designing Process

Mild steel had been determined as material selection to fabricate the flexural. First, the dimensions of the mild steel need to be calculated. The changing in height of flexural is the main focus in achieving the natural frequency desired. The natural frequency estimation is between 400-600 Hz. The analytical solution is used to determine the stiffness, natural frequency and damping ratio and expressed as in equation 3.1, 3.2 and 3.3.

$$k = \frac{3EI}{L^3} \quad (3.1)$$

Where,

k = stiffness of material

E = modulus of elasticity

I = moment of inertia

L = length of material

$$\omega_{n} = \frac{\sqrt{k}}{m} \quad (3.2)$$

Where,

ω_n = natural frequency

k = stiffness of material

m = mass of material

$$\zeta = \frac{c}{2\sqrt{mk}} \quad (3.3)$$

Where,

ζ = damping ratio

c = damping constant

m = mass of material

k = stiffness of material

3.32 Finite Element Analysis

Finite Element Analysis (FEA) is a type of computer program that use the finite element method to analyze the flexure and find how applied stresses will affect the material. In this case, the flexural designed using solidwork software as shown in Figure 3.2 been analyzed using the FEA software. In this analysis, Algor software is used to determine the natural frequency of flexural. The aim of this analysis is to verify the assignment of material parameters as introduced in the previous method. After the calculation from the analytical method is done, the simple modeling flexural is build using solidwork software as shown in Figure 3.2. The flexural model then been exported to the Algor software to analyze the structure thus verified the calculation before.

3.33 Analysis Setup

This model considers only a 2-D structure without securing bolt connected on the flexure. The assumption was made that there is no movement between top and base flexure during analysis. When performing FEA, the model actually represents a virtual model of a real world situation through the reaction of flexural to the combination of loads and constraints. The area noted as point 3 was constrained in all degree-of-freedom at its base for the flexure to experience the real condition during stability test on CNC milling machine. It also seems reasonable since the base of flexure does not contribute an appreciable amount to the flexure dynamics. A flexure's material properties also assumed as isentropic. A normal force 0f 1000 N was applied at point load noted as point 1. The FRF was measured at the opposite direction of applied force and noted as point 2. Figure 3.3 give the illustration about the flexure analysis condition using Algor software.

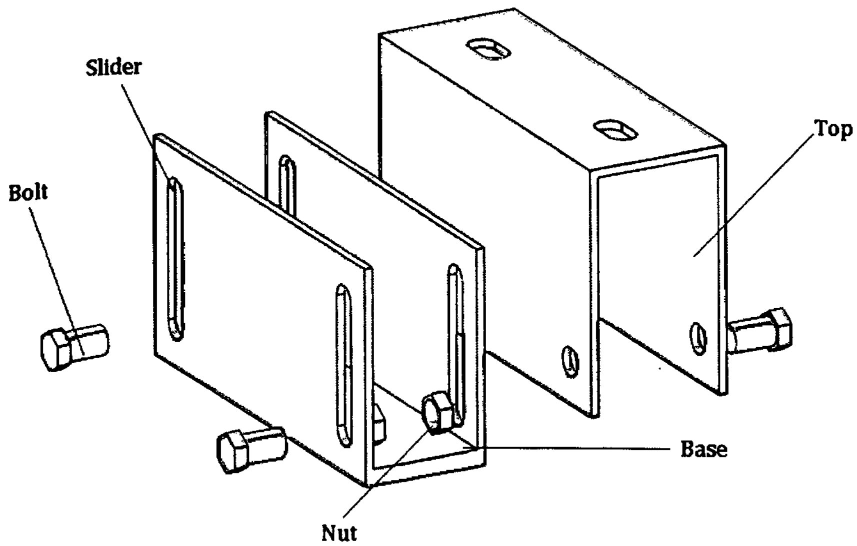

Figure 3.2: Flexure modeling using solidwork software

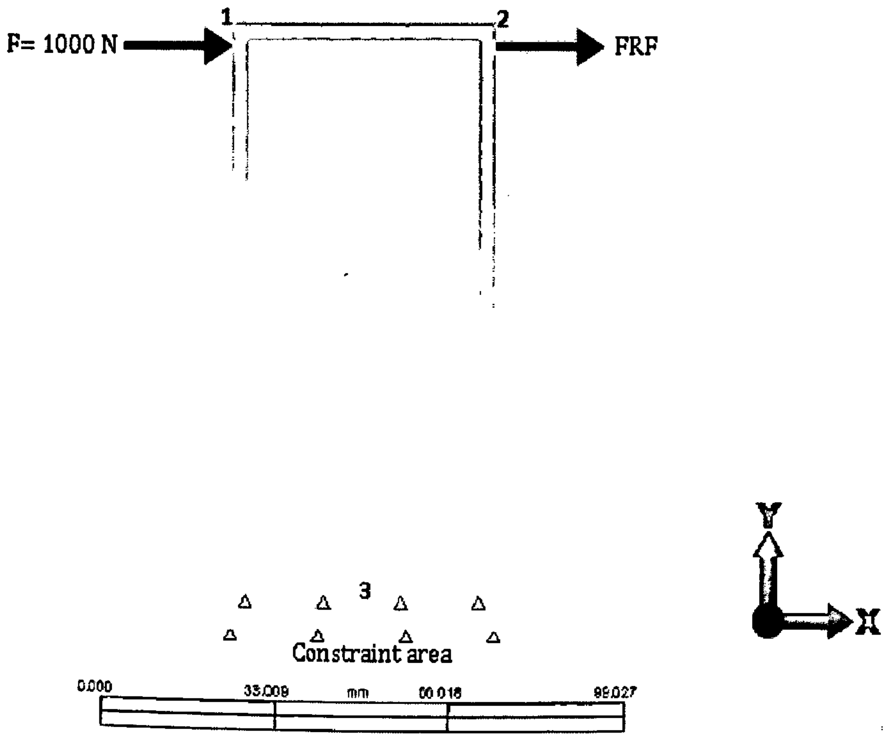

Figure 3.3: FEA analysis using Algor software

3.34 Fabrication of Flexure

Once the analytically and analysis were verified, the flexure has to be fabricate with the specification parameter determined earlier. The flexure is build with the proposed design and the design experimental setup was include from the material selection, machining process and lastly with test to validate the previous data. Figure 3.4 shows the work progress during fabrication of flexural.

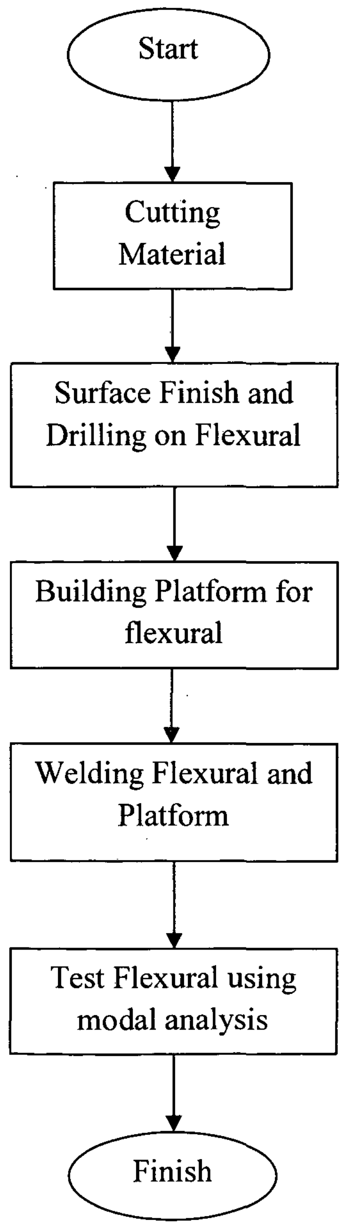

Figure 3.4 : Work Flow of flexure fabrication

The material used to fabricate the flexural is made from the mild steel. Two hollow bar made of mild still was chose and is divided into two parts which will use as top and base flexure. Figure 3.5 shows the hollow bar that used for the fabrication of flexural. The mild steel available at the FKM laboratory is then cut using bend saw machine as show in Figure 3.6 and Figure 3.7. The dimension determined for the flexural was (5 x 15 x 8) cm.

Figure 3.5: Hollow Bar

Figure 3.6: Bend Saw Machine

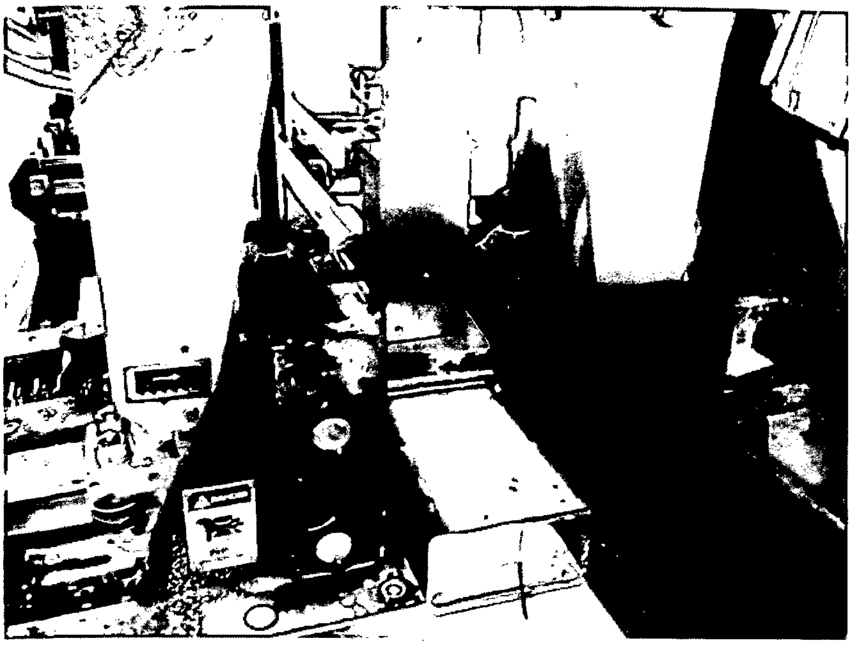

Figure 3.7: Mild Steel Cutting Process using Bend Saw Machine

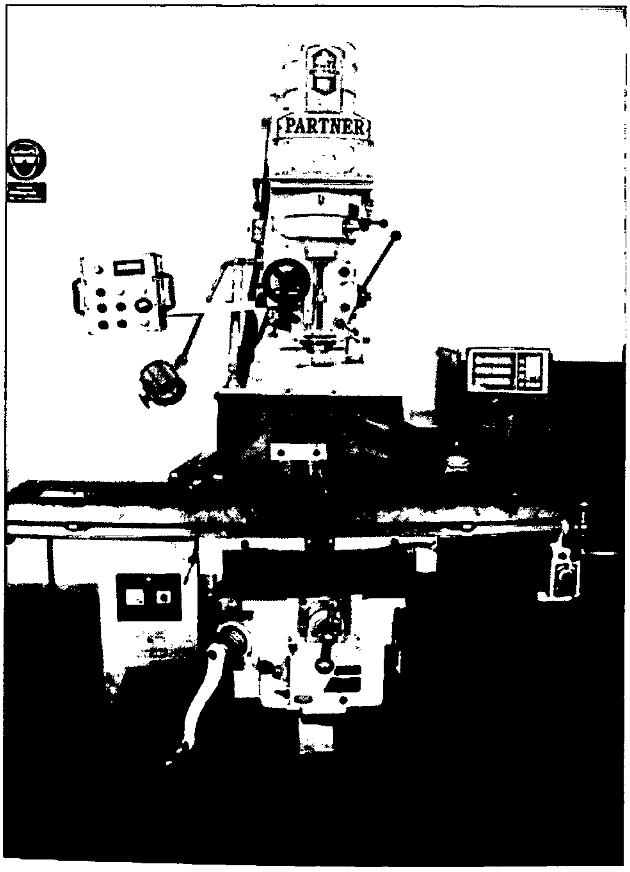

Figure 3.8: Conventional milling machine

Then the facing process was done using conventional milling machine as show in Figure 3.8. It can remove rust on the hollow bar surface to make sure the material is flat and in fine condition. The hole was drilled on the flexural by using three different type cutting tool started with using center drill as the drilling guide, drilling bit and lastly end mill cutting tool with size of 10mm in diameter.

The purpose of the hole on the flexural is to slide up and down suitable with their function in flexible in height adjustment. The secured bolt is used as connection of the top and base flexural. Figure 3.9 and 3.10 show the drilling process using Conventional Milling Machine. The cutting bit used is HSS type and the rpm of the cutting speed has to be calculated first and shown in equation 3.4. The right rpm has been determined first to avoid the cutting tool from damage.

$$\text{RPM} = \frac{cs\ x\ 1000}{\pi x\ d} \tag{3.4}$$

Where,

cs = HSS cutting speed

d = cutting tool diameter

π = 3.142

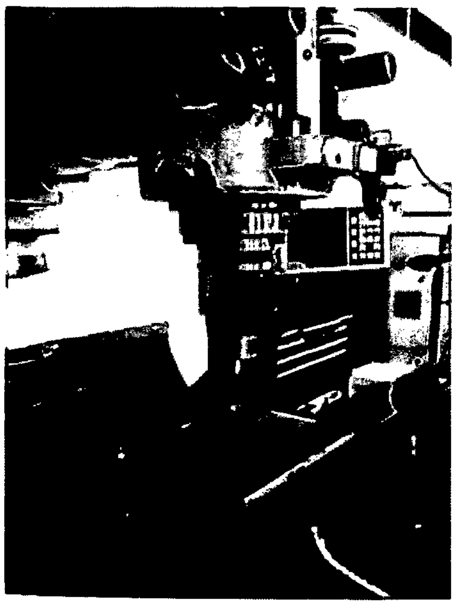

Figure 3.9: Drilling Process using milling machine

Figure 3.10: Preparing for Flexural Platform

The flexural which was drilled then is welded between the flexure and platform before it is installed on CNC Milling Machine. Figure 3.11 shows the welding process of flexure.

Figure 3.11: Welding Process for joining Flexural and Base

3.35 Modal Analysis Testing

The purpose of modal analysis is to construct a mathematical model of the vibration properties and behavior of structure. The FRF expresses the flexure response to an applied force as a function of frequency. The measurement can be done by using impact hammer that excite at the flexural with accelerometer is installed in opposite direction of point load. The impact hammer and accelerometer both is connected to the National Instrument and the computer. The data of the Frequency Response Function (FRF) can be analyzed in order to obtain the natural frequency of flexural. Figure 3.12 shows the experiment setup during modal analysis.

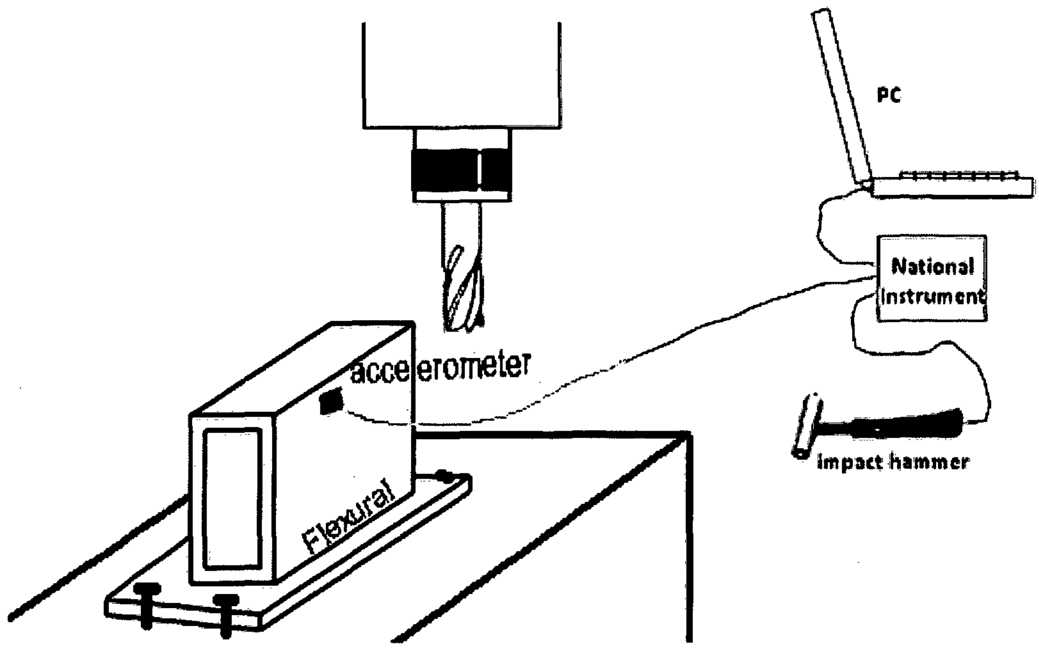

Figure 3.12: Experiment setup during modal analysis

Firstly the flexure platform was clamped on the CNC milling machine for it to experience rigid. The National Instrument will be connecting with the impact hammer, accelerometer and directly to the computer. The Dasy Lab software is used to analyze data from the force of impact hammer when it was applied to the flexure. Figure 3.15 and Figure 3.16 show the National Instrument and PC equipment used during modal analysis.

Figure 3.13 shows the impact hammer that used to apply force on point load and Figure 3.14 shows the accelerometer that attach to the opposite direction of applied force and measure the natural frequency by signal processing data obtain. The position of accelerometer is shown as Figure 3.17.

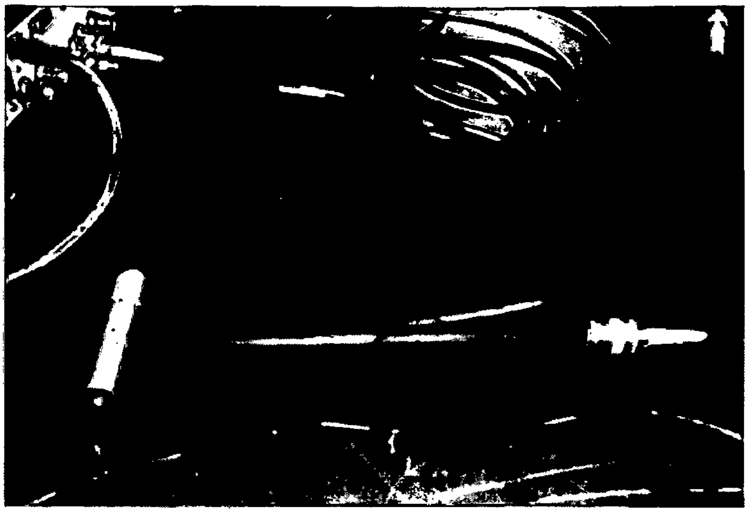

Figure 3.13: Impact Hammer

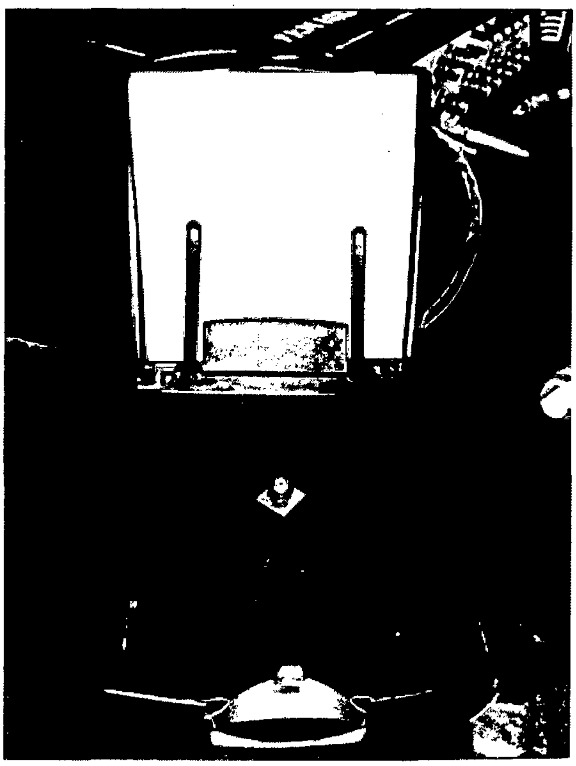

Figure 3.14: Accelerometer

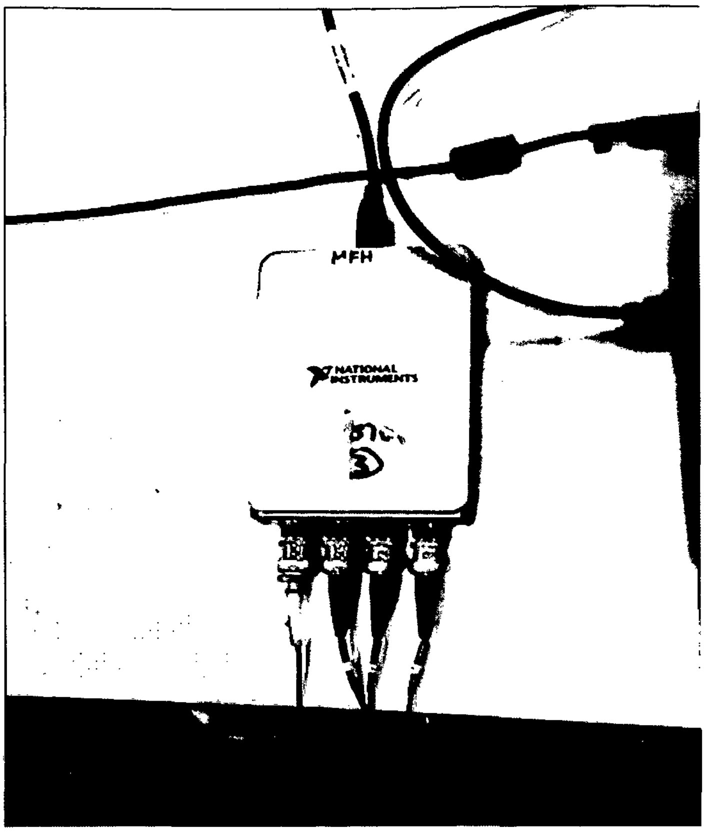

Figure 3.15: National Instrument

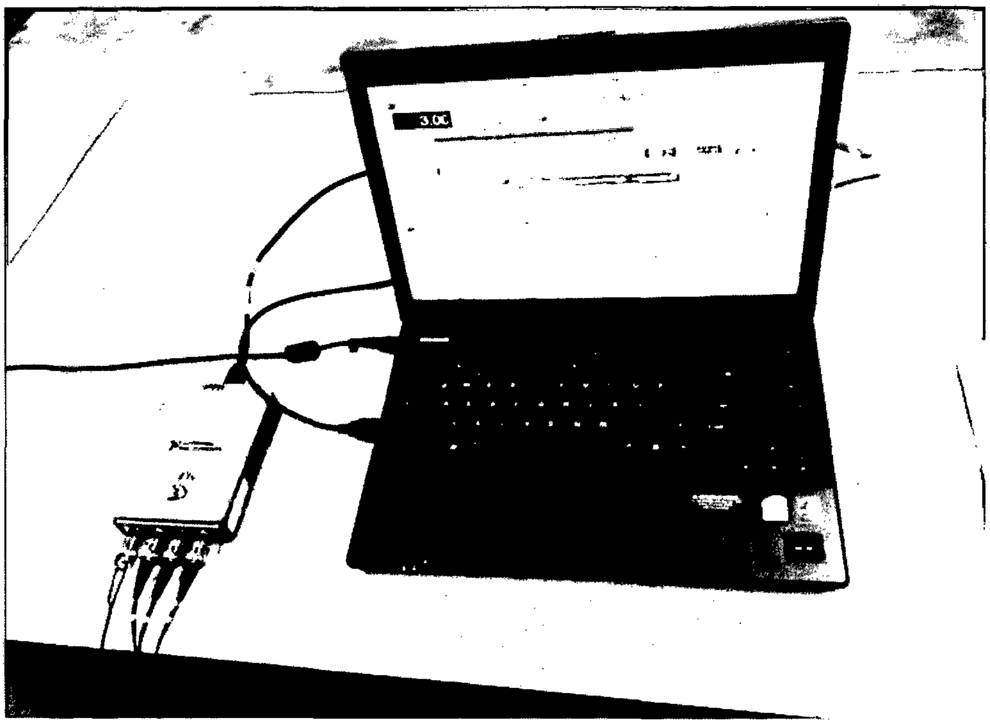

Figure 3.16: PC equipment for data analysis

Figure 3.17: Flexural Tested on CNC Machine

3.4 SUMMARY

There are three methods were performed to determine the natural frequency of flexural. Firstly the analytical method is used to predict the parameter of flexure feature by determine the stiffness and mass of flexural. The FEA then is used to verify the data obtain from the analytical solution. The condition of flexural during analysis will present the actual condition of flexure which measure input-output (Force-FRF) of flexure. Finally the flexural is fabricated and has been tested using modal analysis to validate the natural frequency calculation that made earlier. The different method is used in order to obtain the precise parameter and to avoid the failure on flexure after manufactured. All the data from the three methods used will be discussed on the next chapter for discussion.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

The methodology in the previous chapter has explained the work process during flexure development. This chapter will discuss the result and discussion through the experiment conducted before. The result will be show clearly starting from the first method is used that is analytical method continue with FEA and lastly with modal analysis. The results then will be present in form of table, diagram and graph structure. All the result obtained will be compare in a table for discussion.

4.2 RESULTS FOR ANALYTICAL METHOD

The Analytical Method is done by equating the equation 4.1 and 4.2 to find the desired parameter. This method is important to predict the natural frequency for determine a range of frequencies needed. The Parameter values are gathered in a table and comparison is made before the flexure is developed.

In this project, the height of flexural is calculated using analytical solution in purposed to determine the natural frequency required. The thickness and the width value of the mild steel both are fixed. From the calculation, the estimation natural frequency to be found should be 400Hz-600Hz. Then the damping ratio is calculated after the value of natural frequency is obtained. The data is recorded as Table 4.1.

Table 4.1: Results of analytical method

NO	Thickness,t (mm)	Height,h (cm)	Stiffness,k (N/m)	Damping Ratio,□	Natural Frequency,ω_n (Hz)
1	3	10	487413	1.065×10^{-6}	692.15
2	3	11	366201	1.188×10^{-6}	580.16
3	3	12	282068	1.312×10^{-6}	493.40
4	3	13	221854	1.436×10^{-6}	424.82
5	3	14	177629	1.561×10^{-6}	396.65

From the analytical method, the value of damping ratio is increase with the increasing of flexural height. It means that the oscillation of flexure is increasing at maximum height after a disturbance because of energy is dissipated in dynamic systems. In this situation, the thickness of the flexure is fixed and only the adjustment of flexure height is change. From the calculation, it shows that increasing frequency of flexure is indirectly proportional with height of flexure. The result shows the minimum requirement height of flexure approximately to obtain the natural frequency of 400Hz is 14cm meanwhile 11cm for it to reach 600Hz.

The calculation of the flexural is adapted from the calculation of the beam (free-end structure) since the flexural also was build with constraint base area during stability test. Equation below shows the example of calculation to obtain the parameters as shown in table 4.1:

For:

Thickness, t = 0.3cm

Height, h = 10cm

Width, b = 5cm

$$k = \frac{3EI}{L^3} \tag{4.1}$$

$$I = \frac{1}{12}bh^3 \tag{4.2}$$

$$I = \frac{1}{12}((0.05m)(0.1m)^3$$

$$= 4.167x10^{-6}$$

$$K = \frac{3(38.99X10^6)(4.167X10^{-6})}{0.10^3}$$

$$= 487\ 413\ N/m$$

$$\omega = \sqrt{\frac{k}{m}}$$

$$= \sqrt{\frac{487413}{m}}$$

$$m = pV$$

$$p = 7850\ kg/m^3$$

$$= (7850)(V)$$

$$V = (0.05\ X\ 0.15\ X\ 0.1) - (0.044\ X\ 0.15\ X0.094)$$

$$= 1.296x10^{-4}m^3$$

$$m = (7850)(\ 1.296x10^{-4}m^3)$$

$$= 1.0174\ kg$$

$$\omega = \sqrt{\frac{209440}{1.0174}} = 692.15\ Hz$$

$$\zeta = \frac{c}{2\sqrt{(m)(k)}}\ ,$$

$$c = \frac{t}{2}$$

$$= \frac{0.003}{2}$$

$$= 0.0015$$

$$\zeta = 1.065x10^{-6}$$

4.3 RESULTS FOR FEA

The Algor software is used to analyze the effects of force applied on flexural structure. The FEA results the natural frequency as a response on applied force given. FEA will generate mesh on flexure which including data of structural and properties to define the ability of flexure when react with certain loading conditions. A complex system points called node will determined the location of higher stress and usually occur at higher density node. This FEA is bringing to validate the data prediction from the analytical method. The data obtained is show as Figure 4.1, 4.1, 4.3, 4.4 and 4.5 and Table 4.2 shows the natural frequency obtained with different height during test using Algor software.

Material model : Isotropic

Mesh operation : Solid mesh

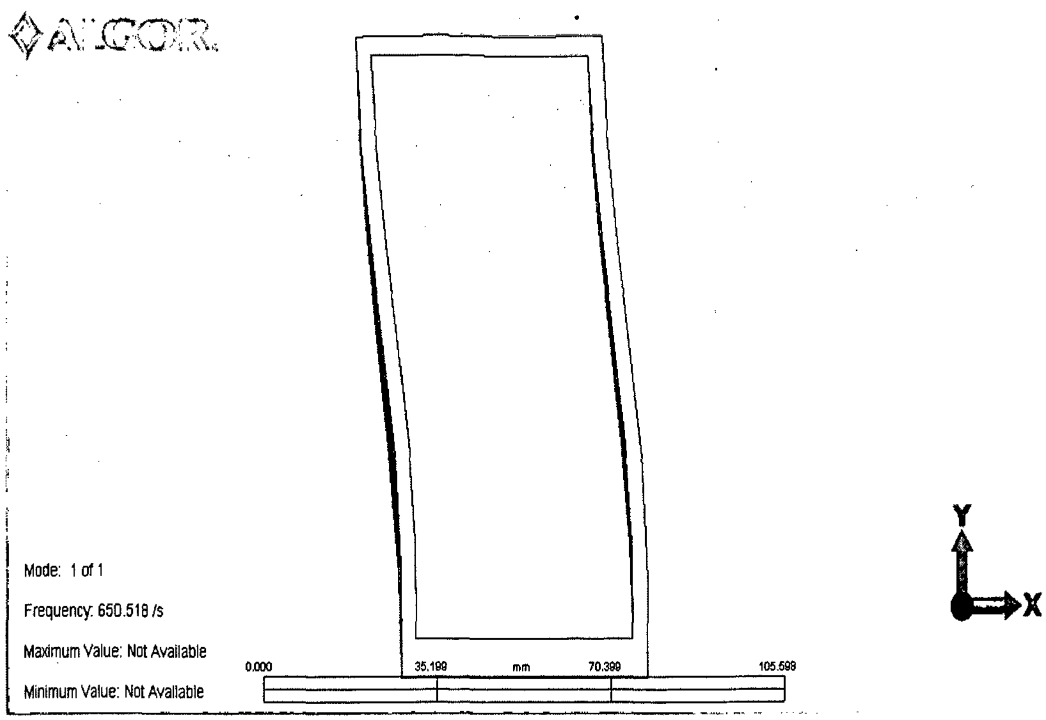

Figure 4.1: Height of 10cm

Number of node points : 360

Final mesh size : 16.275

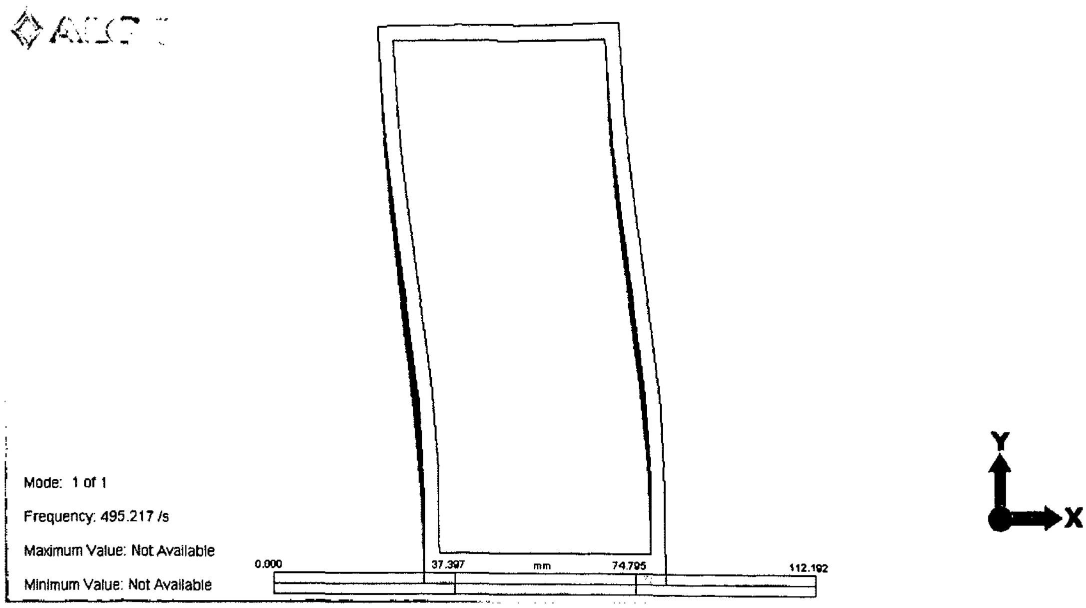

Figure 4.2: Height of 11cm

Number of node points : 360

Final mesh size : 17.325

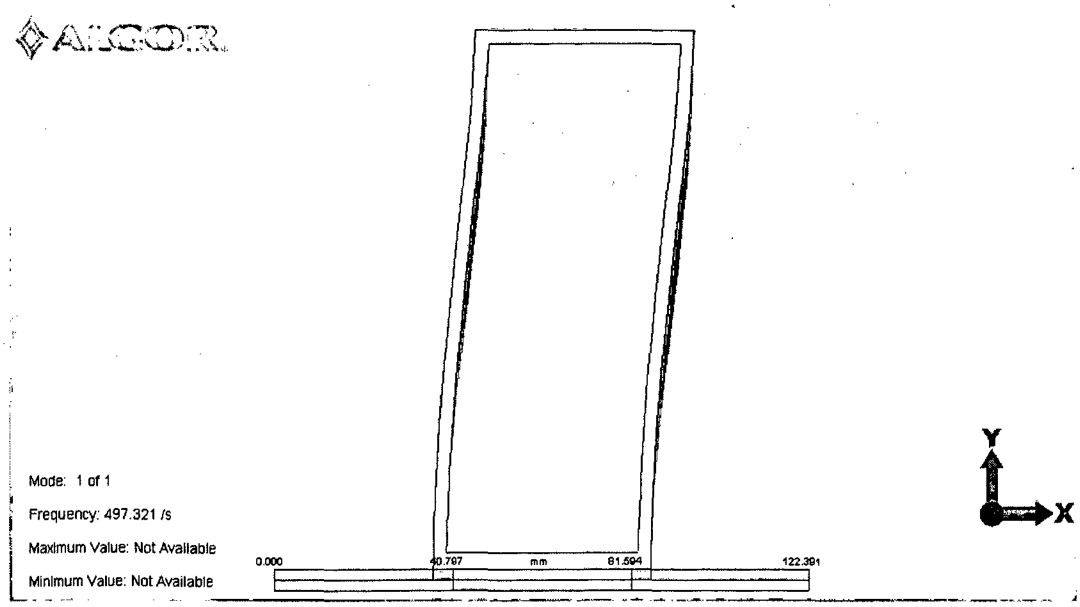

Figure 4.3: Height of 12cm

Number of node points : 324

Final mesh size : 18.375

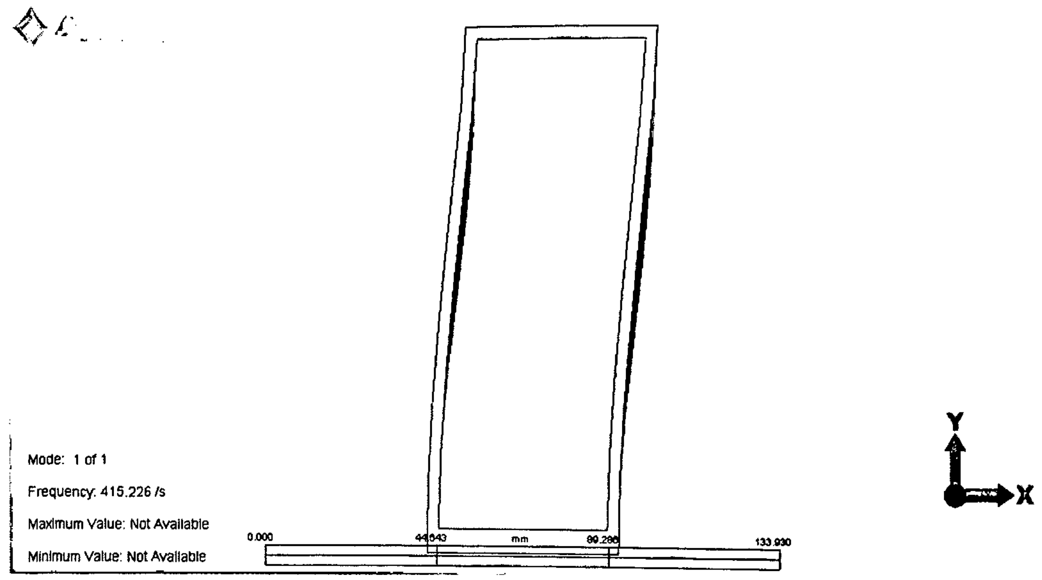

Figure 4.4: Height of 13cm

Number of node points : 324

Final mesh size : 19.425

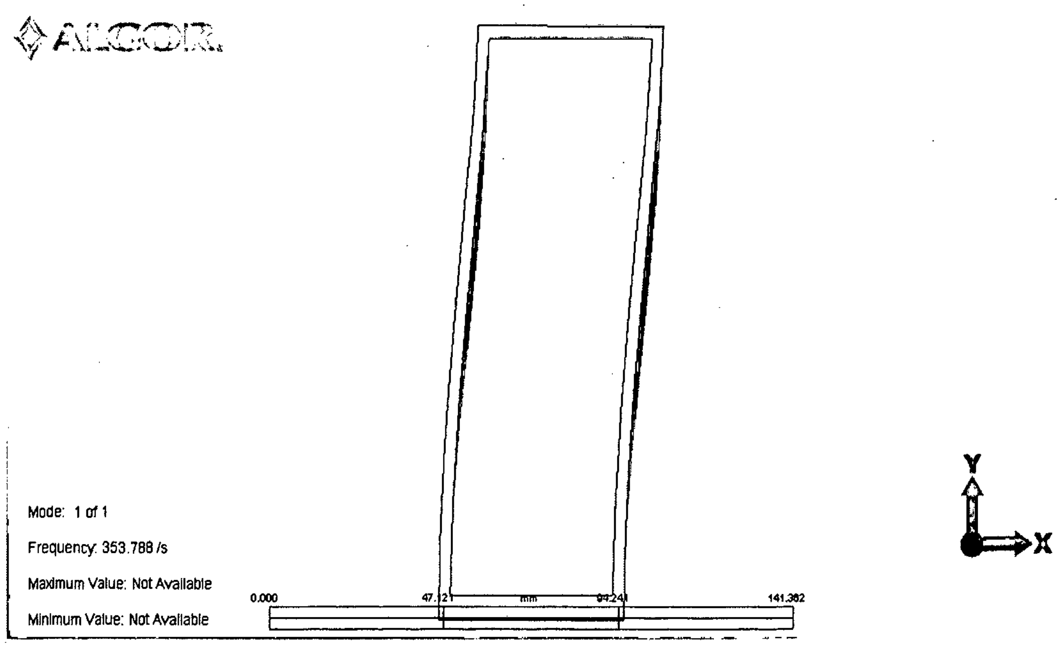

Figure 4.5: Height of 14cm

Number of node points : 272

Final mesh size : 20.475

Table 4.2: Data Analysis using Algor Software

NO	Height,h (cm)	Natural Frequency,ω_n (Hz)
1	10	650.518
2	11	495.217
3	12	497.321
4	13	415.226
5	14	353.788

4.4 RESULTS FOR MODAL ANALYSIS

The experimental then was proceeded with modal analysis testing. The impact hammer was applied to measure the FRF of flexural. An impact hammer is applied to the flexural and the response was measured by the accelerometer that located opposite with the applied force point of impact hammer. Figure 4.6, 4.7, 4.8, 4.9 and 4.10 show the peak position for natural frequency of flexure at different height. Table 4.3 shows the results summarize of flexure that tested from height of 10cm-14cm.

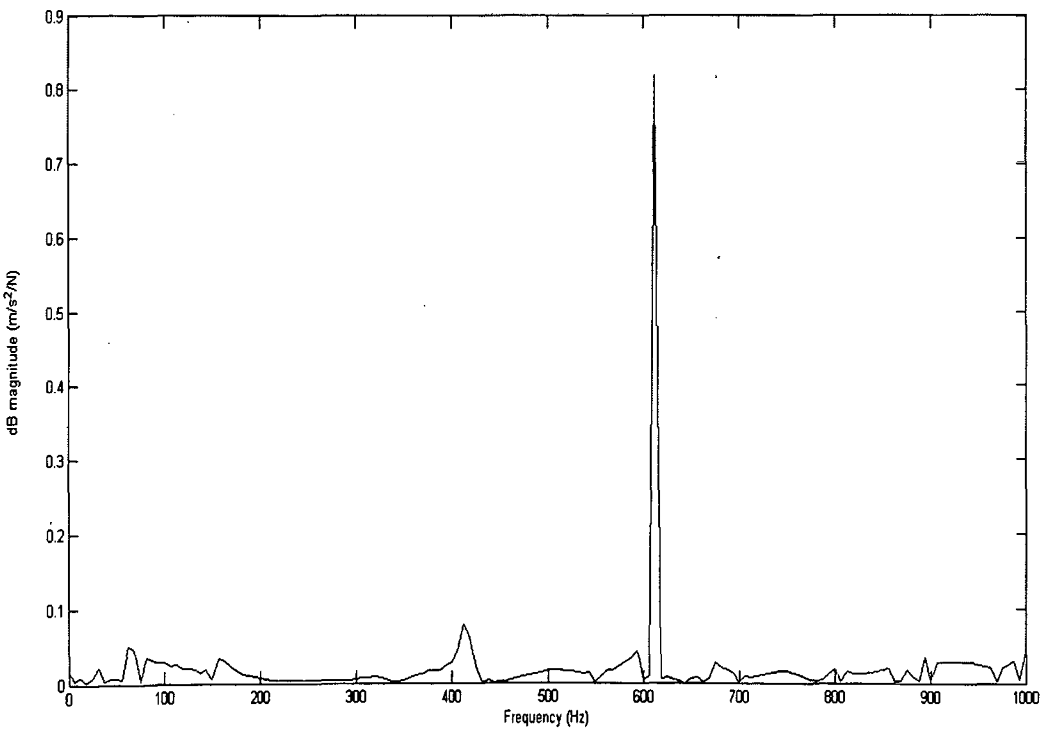

Figure 4.6: Height of 10cm

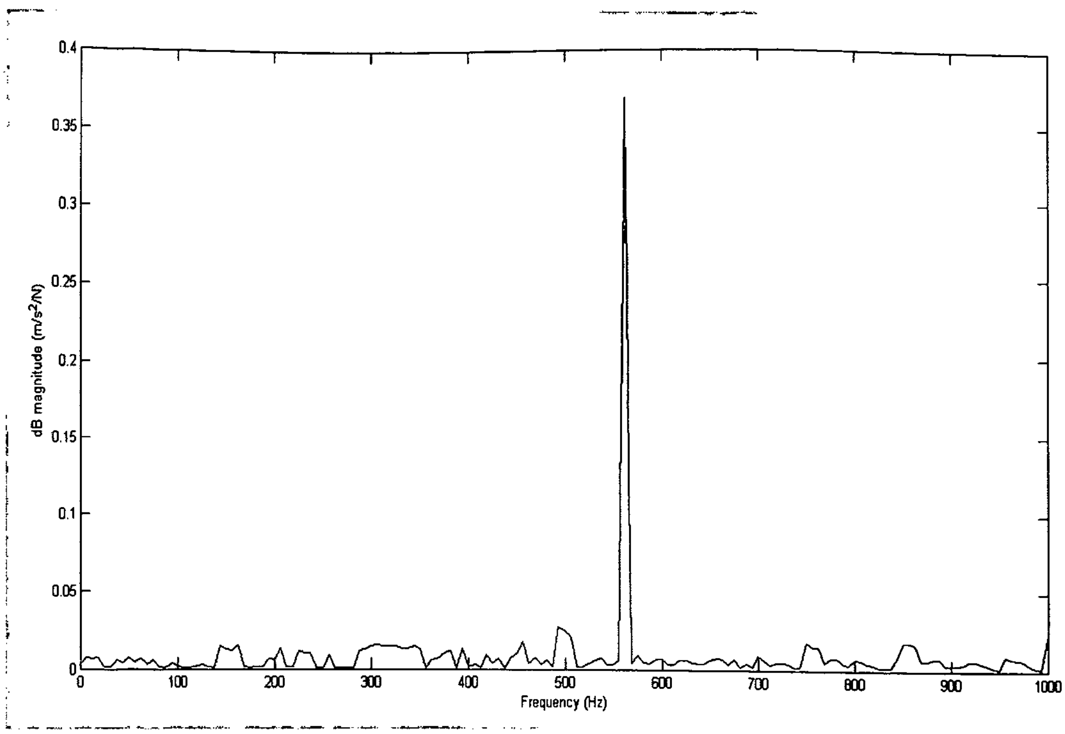

Figure 4.7: Height of 11cm

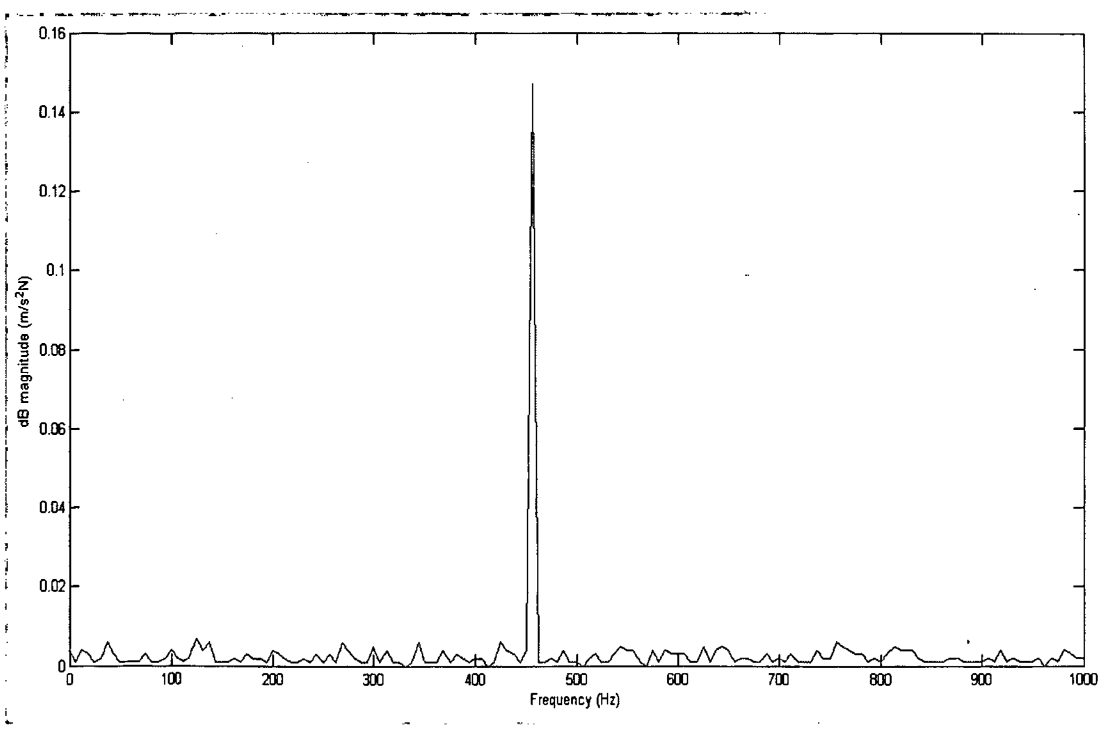

Figure 4.8: Height of 12cm

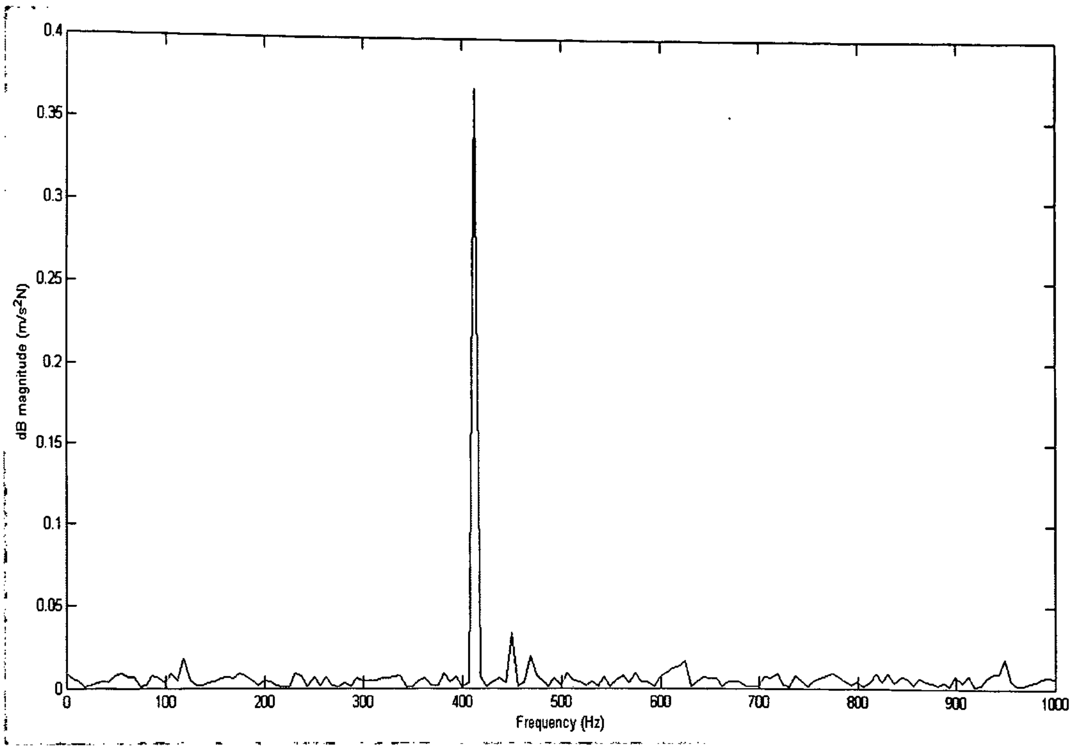

Figure 4.9: Height of 13cm

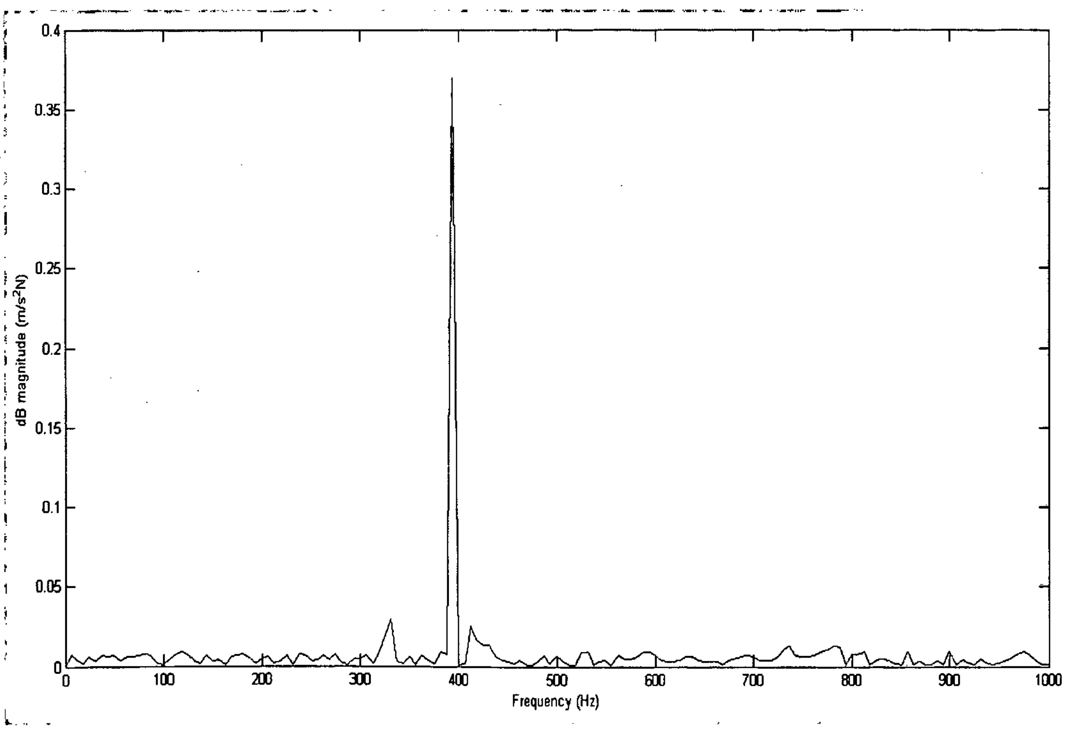

Figure 4.10: Height of 14cm

Table 4.3: Results of Modal Analysis

NO	Height,h (cm)	Natural Frequency, ω_n (Hz)
1	10	612.5
2	11	562.5
3	12	456.25
4	13	412.5
5	14	393.75

The flexural has been test with initial height of 10 cm until 14 cm and tested with the increment of 1cm. The data measured by National Measurement has displays the data in real time and provides a graphical user interface and then data has been plotted using MatLab software for analyze.

As expected, the earlier estimation of natural frequency using analytical method and FEA is quite similar with the modal analysis result. For each peak of the response graph produced can be take and from the graph. It is because the frequency response is a function of frequency that reaches it maximum value at the maximum natural frequency. The dominant frequency can see through the highest peak on graph. Frequency response is measured in decibels (dB) versus frequency in Hertz (Hz).

The graph shows the reading of natural frequency is increasing due to decreasing of flexure height. Refer to the analytical method, natural frequency is increasing directly proportional with the increasing of material stiffness. In this situation, the stiffness of the mild steel tends to change of smaller value due to the increasing of height.

Although there is a little bit different between the methods used, the efficiency during actual condition by using modal analysis should be considered due to the inefficiency of equipment used.

All the three methods used give a bit different value due to the method used to run the experiment. From the analytical method followed by FEA and finally with modal analysis test have their own assumption to avoid from the inaccuracies result and will be discussed at the end of this chapter.

4.5 RESULT ANALYSIS BETWEEN THREE METHODS

The graph between analytical method, FEA and modal analysis is compared. The different method used results in a little bit different data obtained based on some reason whether before and after the flexure is build. The different has been plotted and shown as Figure 4.11, 4.12, 4.13, 4.14 and 4.15. The percentage error is calculated by using equation 4.3 between the estimation value and actual value obtain.

$$\frac{|\,Estimation\ -Actual\ |}{Actual}\ X\ 100 \tag{4.3}$$

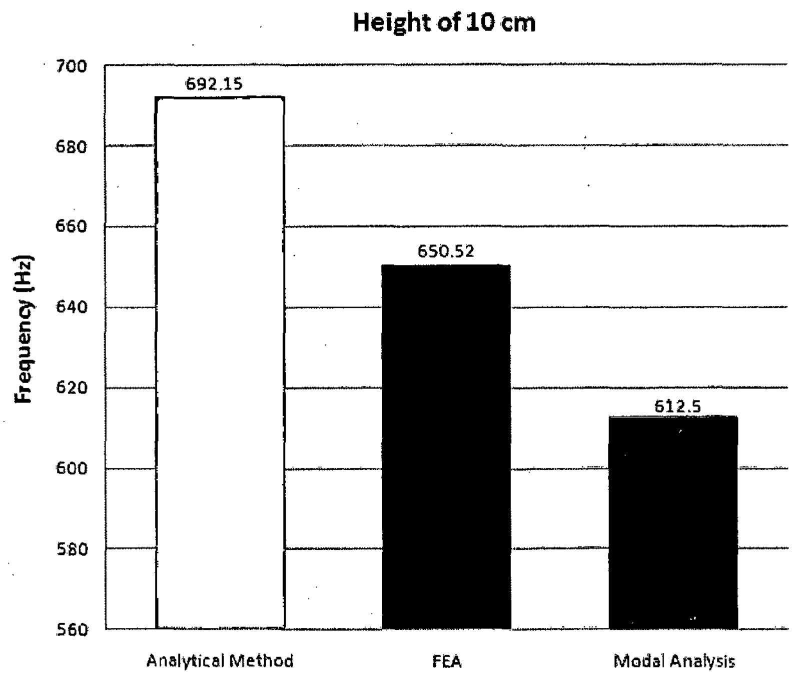

Figure 4.11: Height of 10 cm

Percentage of error:

Analytical method and FEA : 5.84 %

FEA and Modal Analysis : 6.21%

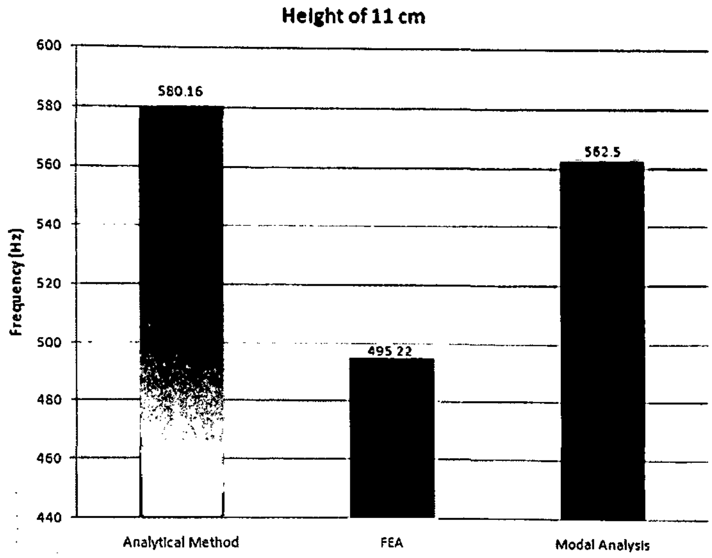

Figure 4.12: Height of 11 cm

Percentage of error:

Analytical Method and FEA : 17.15 %

FEA and Modal Analysis : 11.96 %

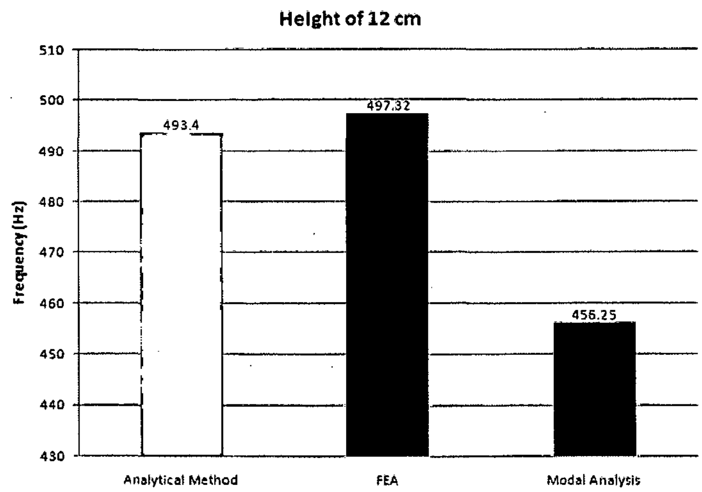

Figure 4.13: Height of 12cm

Percentage of error:

Analytical Method and FEA : 0.80 %

FEA and Modal Analysis : 9.0 %

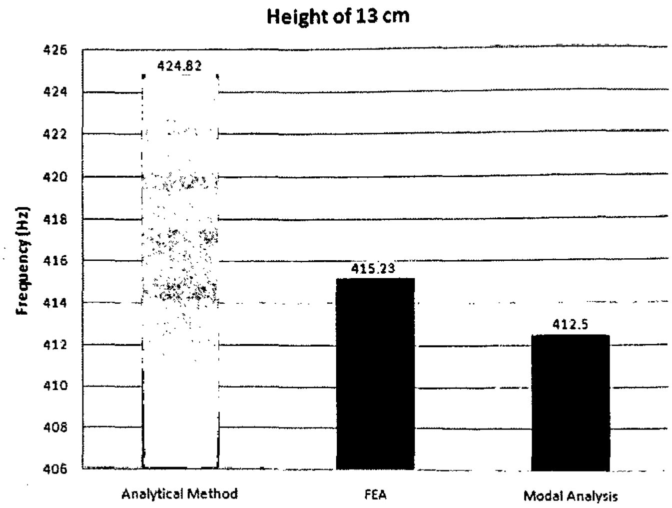

Figure 4.14: Height of 13 cm

Percentage of error:

Analytical Method and FEA : 2.31 %

FEA and Modal Analysis : 0.66 %

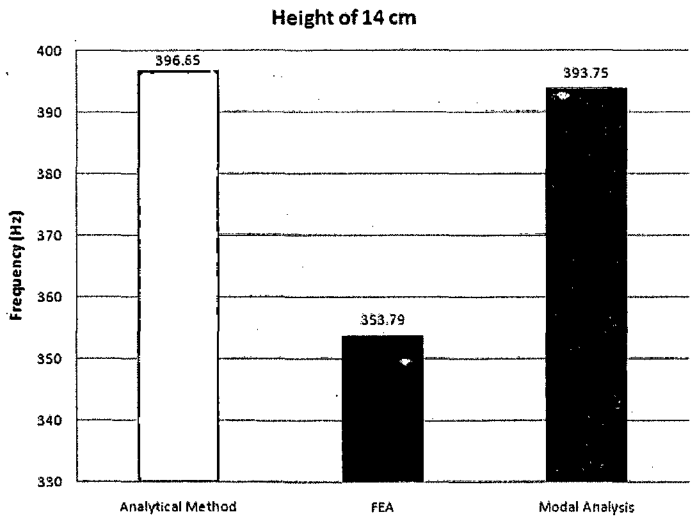

Figure 4.15: Height of 14cm

Percentage of error:

Analytical Method and FEA : 12.16 %

FEA and Modal Analysis : 10.15 %

From the graph as shown between analytical method, FEA and modal analysis, there is a little bit different from the value of natural frequency obtained. The analytical method frequently shows with the highest value follow by FEA and modal analysis. This differentiation value obtained because the analytical method is about applies the parameter to the equation. It has no any influence factor consideration and the material is to be assumed as solid material with no inaccuracies.

For FEA, the flexural is applied in 2D analysis with generating mesh model on flexural. The modal analysis has been performed with the real situation which the flexural is tested on the CNC milling machine. Flexural build during FEA also is ignoring the bolt connection with assumption that there is no movement during analysis and flexure is considerably rigid.

For modal analysis, the possibility for the error during analysis to occur is high. The accelerometer that measured the acceleration has a very high sensitivity and any vibration during experiment can disturb the graph reading. Furthermore, when estimate the frequency response function on measurement model, the data is measured from the input (impact hammer) and output (FRF) in the presence of noise or error. The error can be categorized like leakage or aliasing from Digital Signal Processing error of National Instrument and also calibration error.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

All the work progress has been show clearly in the previous chapter including the analysis of earlier invention of flexural, the methodology, result and analysis. In this chapter, all of the research and experiment carried out will be summarized. The observation, result experiment and discussion will be concluded. The recommendation will be proposed for better improvement for the next invention.

5.2 CONCLUSION

The main point in HSM is to increase material removal rate. It then can reduce the production cost and increasing production rate. But, the limitation in achieving HSM operations is process instability known as self excited vibration or chatter. Tool begins to vibrate when flexible tool engages a workpiece because vibrations are cut into the new surface leaving a wavy surface. In this research, it requires to develop a flexure that adjustable in high with natural frequency of 400Hz-600Hz. The role of SDOF of flexure is choose because as the workpiece is mounted to a SDOF flexure, it exhibited higher flexibility than the cutting tool so the tool could be consider rigid. The benefit of this setup, multiple geometries could be compared without influences of changing dynamics. Flexural are used to perform stability test to predict the presence of chatter.

In this experiment, the fabrication of flexural is built in three stages. Firstly, the natural frequency is calculated during the design stage. In this stage, the height of the flexural been manipulated in order to determine the natural frequency. At height of 13cm the natural frequency value is 424.82 Hz and 580.16 Hz at height of 11 cm. Then, FEA is used to analyze the flexural and validate the analytical method. From the data analyzing, it shows that at height of 13cm the natural frequency is 415.23 Hz and 495.22 Hz at height of 11cm. Finally, the modal analysis is used to verify the data and shows that at height of 13cm the natural frequency is 412.5 Hz and 562.5Hz at height of 11 cm. From the all three methods used the best data can be accepted is by using modal analysis because it represents the test in real situation and the analytical method and FEA as a satisfied value that can be use before the flexural is developed. The different data obtained by all of the three methods because for analytical method the calculation is based on equation without considering the inefficiencies. Meanwhile, during FEA the flexure design is not connected with bolt with assumption there is no movement during analysis. For modal analysis the flexure is tested on CNC milling machine and the possibility of errors to occur is high such the loosing of securing bolt connection between flexure and CNC table during test, the external vibration detected by the highly sensitivity accelerometer thus will influence the graph reading, the leakage of data signal processing and others. However, since the results of the three methods obtained are still in range of 400-600 Hz, the data could be accepted and all of the three methods used can be said is achieved with the project objective.

5.3 RECOMMENDATIONS

As the experiment is done, there is also a space of discussion to give an improvement for this flexure invention. From this experiment, there are several suggestions that could be implanted for further improvements especially in reducing error during experiment. At glance, flexural seem well as substantial product that fit with it applications and functions due to simple to build and low in cost. Thus it is important to design a very high performance flexure with an effective way technology.

A flexural actually should not consist of multiple parts because it can suffer in low cross-axis, torsional stiffness, limited load capacity and very sensitive to dimensional tolerance. From aspect of material selection, the material should not possess a high stiffness. It is because it can generate to unwanted heating and will damage the cutting tool during machining. When designing the flexural, the material should also be considerably in strength and toughness because the transient high loads may cause buckling and permanent deformation.

Lastly, as we know the accelerometer is a device that measures the acceleration and has a high sensitivity. Thus, during the experiment of modal analysis, the experiment should be run at location with a minimum or zero disturbances so it is not exposed to the external vibration thus will influence the graph reading.

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APPENDICES A1: GANTT CHART FYP 1

No.	ACTIVITIES	WEEK														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Searching Literature Review															
2	Preparing Gantt Chart															
3	Reading and Understanding Literature Review															
4	Writing Proposal															
5	Submit Proposal															
6	Final Presentation to Panel															

Plan

Actual

APPENDICES A2: GANTT CHART FYP 2

No.	ACTIVITIES	WEEK 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Determine Parameter Using Analytical Method	■	■													
2	Development Model Using Solidwork Software			■												
3	Perform FEA Using Algor Software				■											
4	Fabricate The Flexural					■	■	■	■	■						
5	Determine The Natural Frequency Using Modal Analysis										■					
6	Final Report Preparation										■	■	■	■	■	■
7	FYP 2 Presentation														■	

■ **Plan**

☐ **Actual**

APPENDICES B1: SOLIDWORK DRAWING