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JUDUL: MODAL ANALYSIS ON CNC MILLING CUTTING TOOL

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MODAL ANALYSIS ON CNC MILLING CUTTING TOOL

NIK MUHAMAD FIRDAUS B NIK SALAHUDDIN

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

Faculty of Mechanical Engineering
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JANUARY 2013

UNIVERSITI MALAYSIA PAHANG

FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled "*Modal Analysis on CNC Milling Cutting Tool*" is written by *Nik Muhamad Firdaus B Nik Salahuddin*. I have examined the final copy of this project and in our opinion, it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering.

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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 : NIK MUHAMAD FIRDAUS B NIK SALAHUDDIN
ID Number : MA08138
Date : 30 JANUARY 2013

Dedicated to my father, Mr. Nik Salahuddin bin Nik Othman, my beloved mother, Mrs. Wan Narimah binti Wan Abd Rahman, and last but not least to all my fellow friends

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ABSTRACT

To date, milling is one of the most common manufacturing process for manufacturing sectors, aerospace, and tool and dies industries. In this project, the main objective is to study the dynamic properties and behaviour of the CNC milling cutting tool. The method used is using finite element analysis and the validation of results obtained using experimental modal testing. Firstly, the structural three-dimensional solid modelling of the selected CNC cutting tool draw before analysed using the linear modal analysis approach. After that, the experimental modal testing was performed using Modal Impact Hammer Testing method. The natural frequency of the mode shape is determined and comparative study was done from both method results. The results of this project shown the mode shape simulation of experimental data are totally not same but generally is in agreement with the finite element analysis. It is concluded that the experimental method uses vertical milling machines as test rig and the difference mass of cutting tool affected the result.

ABSTRAK

Sehingga kini, pengilangan adalah salah satu proses pembuatan yang paling biasa untuk sektor pembuatan, aeroangkasa, dan industri alat dan acuan. Dalam projek ini, objektif utama adalah untuk mengkaji sifat dinamik dan perilaku alat pemotong CNC. Kaedah yang digunakan adalah dengan menggunakan analisis elemen secara teori dan pengesahan keputusan yang diperolehi menggunakan ujian modal secara eksperimen. Pertama, pemodelan struktur tiga-dimensi alat pemotong CNC yang telah dipilih dilukis menggunakan perisian melukis sebelum dianalisis menggunakan pendekatan analisis linier modal. Selepas itu, ujian modal secara eksperimen telah dilakukan dengan menggunakan kaedah kesan ketukan. Frekuensi dan bentuk mod ditentukan dan kajian perbandingan telah dilakukan dari kedua-dua keputusan kaedah. Keputusan projek ini telah menunjukkan bahawa simulasi bentuk mod daripada data uji kaji secara keseluruhannya tidak sama tetapi secara umumnya adalah sama dengan simulasi daripada elemen secara teori. Ia menyimpulkan bahawa kaedah eksperimen menggunakan mesin pengilangan menegak sebagai pelantar ujian dan perbezaan jisim alat pemotong juga boleh menjejaskan hasilnya.

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LIST OF SYMBOLS

º	Degree
dB	Decibel
k	Kilo
&	And
"	inch
TiN	Titanium Nitride
TiCN	Titanium Carconitride
TiAIN	Titanium Aluminum Nitride
AlTin	Aluminum Titanium Nitride
mm	Milimeter
N	Newton
%	Percent
volt	Voltan
Hz	Hertz
kHz	Kilohertz

LIST OF ABBREVIATIONS

CNC	Computer Numerical Control
EMA	Experimental Modal Analysis
FE	Finite Element
FFT	Fast Fourier Transform
USB	Universal Serial Bus
TCP/IP	Transmission Control Protocol/Internet Protocol
FEA	Finite Element Analysis
FEM	Finite Element Method
DOF	Degree Of Freedom
ODS	Operating Deflection Shape
IRF	Impulse Response Functions
SDOF	Single Degree Of Freedom
MDOF	Multi Degree Of Freedom
FRF	Frequency Response Function
NC	Numerical Control
HSS	High Speed Steel
DAQ	Data Acquisition
CAD	Computer Aided Diagram
2D	Two Dimensional
3D	Three Dimensional
ASCII	American Standard Code for Information Interchange
SI	International System of Units

CHAPTER 1

INTRODUCTION

1.1 GENERAL INTRODUCTION

CNC stands for Computer Numerical Control. CNC machine is a milling machine that can perform the functions of drilling and also turning. CNC milling machine has been commonly used in industrial field nowadays. CNC have various types of cutting tools and one of the common cutting tools is end mill. In CNC machines, end mills are used to cut metal and other materials. Roughing end mills used to remove large amounts of raw material to create the rough shape of the part itself. Moreover, finishing end mill used to complete and surface finished the part to size as defined in the blueprint. Vibration occurring on machine tools has been being a serious limitation for engineers since a long time ago. Undesired relative vibrations between the tool and the work-piece reduced the quality of the machine surfaces during cutting. Machine tool chatter is a self-excited vibration problem occurring in large rates of material removal, resulting from the unavoidable flexibility between the cutting tool and workpiece. In addition, chatter causes rougher surface finish and dimensional inaccuracy of the workpiece, along with unacceptably loud noise levels and accelerated tool wear. Generally, chatter is one of the most critical limiting factors, which is considered in designing a manufacturing process (Erol Turkes et al, 2010). Modal analysis is the study of the dynamic properties of structures under vibrational excitation. The dynamic behaviour of a structure in a given frequency range can be modelled as a set of individual modes of vibration. The parameters that describe each mode are natural frequency or resonance frequency (modal) damping mode shape are called the modal parameters. By using the modal parameters to model the structure, vibration problems caused by these resonances or modes can be examined and understood. To better understand any structural vibration problem, the resonances of a structure need to be identified and quantified. A common way of doing this is to define the structure's modal parameters. Static and dynamic deformations of cutting tool play an important role in tolerance integrity and stability in a machining process affecting part quality and productivity. It is an experimental approach for solving technical problems which are a means to estimate or evaluate modal properties of a mechanical structure. Modal analysis is vital to understanding and optimizing the inherent dynamic behaviour of structures, leading to lighter, stronger, and safer structure to better performance.

In this project, we will investigate the stability and identify the vibration that occurred in the cutting tool of CNC machine. The result of vibration obtained is validate by performing dynamic analysis using ANSYS Finite Element Analysis (FEA).

1.2 OBJECTIVE OF STUDY

The purpose of this research is to study the dynamic properties and behaviour of CNC milling cutting tool by using modal analysis and comparison with the finite element analysis (FEA).

1.3 SCOPE OF PROJECT

This project focuses on the following points:

i. Choosing and draw CNC milling cutting tool. Difficulties in modelling the cutting tool with the dimension precise with the original one.
ii. The theoretical data for dynamic analysis using FEA ANSYS. Some problem with importing files and setting the model parameter.
iii. Experimental analysis using modal testing on cutting tool. Difficulties in choosing the right test rig for the experiment and getting the best result.
iv. Comparative study between numerical and experimental analysis.

1.4 PROBLEM STATEMENT

There are several factors that can potentially influence the quality of the final product of a machining. Some of these include the condition of the machine tool itself, the condition of the cutter, and the dynamics of the process. The structural dynamics of the machine tool, the dynamics of the cutting process and workpiece-tool interactions all affect the quality of the surface profile. Finite element method commonly used to analyze the instability of machining process. The tool's natural frequencies and the shape of their vibration modes were obtained from modal testing results. Thus, this project is focused on dynamic properties of a CNC cutting tool at the resonance frequencies and vibration shapes. The machine tool vibration was excited by impulse force and a response of excited vibration was recorded. The measurement points for vibration were selected at the different location of cutting tool.

The frequency of vibration of the CNC cutting tool is directly related to the stiffness and the mass of it while the mode shapes are related to the defect location. Therefore vibration testing needs to be carried out to obtain the data of those dynamic properties. The parameters that describe each mode are natural frequency or resonance frequency (modal) damping mode shape; these are called the modal parameters. By using the modal parameters to model the structure, vibration problems caused by these resonances or modes can be examined and understood. Vibration is a frequent problem that affecting the result of machining and cutting tool life. The last shape of workpiece will wavy surface during machining operation. This is showing the vibration problem occurs and affects the surface finish. Before going further on optimization of cutting tool or active suppression on chatter, initial study on the structural analysis need to be conducted.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter is reviewed about the preliminary of vibration in the CNC machine cutting tool, the dynamic properties and structural behaviour with the cutting tool using different type of cutting tool. Modal analysis or vibration analysis was done using two methods that is by experimental of modal analysis and simulation using ANSYS finite element analysis.

2.2 MODAL ANALYSIS OF MILLING MACHINE

This chapter aims to investigate the vibration phenomena occurring occasionally at the different components of milling machine. Moreover, it will involve the previous analytical and experimental modal analyses performed. The study focused on extracting the mode shape of the dominating cutting tools of the milling machine in order to ensure resonance phenomena as a cause of chatter. In a first step the significant eigen-frequencies with corresponding mode shapes were obtained by means of an experimental modal analysis (EMA). Subsequently, the dynamic behaviour of the machine components was simulated using an ABAQUS FE model by Anayet U. Patrawi et al., 2009. However, ANSYS FE model is used in this project. The comparison of the eigenfrequencies based on FE calculations with their experimental counterparts proved in general quite a satisfactory correlation. (Anayet U. Patrawi et al., 2009)

2.2.1 Experimental Modal Analysis

Understanding of experimental modal analysis and knows how this method works on this project can give explanation to investigate the way to get dynamic properties that is modal parameter**.** Figure 2.1 below shown how is the experimental modal analysis test setup.

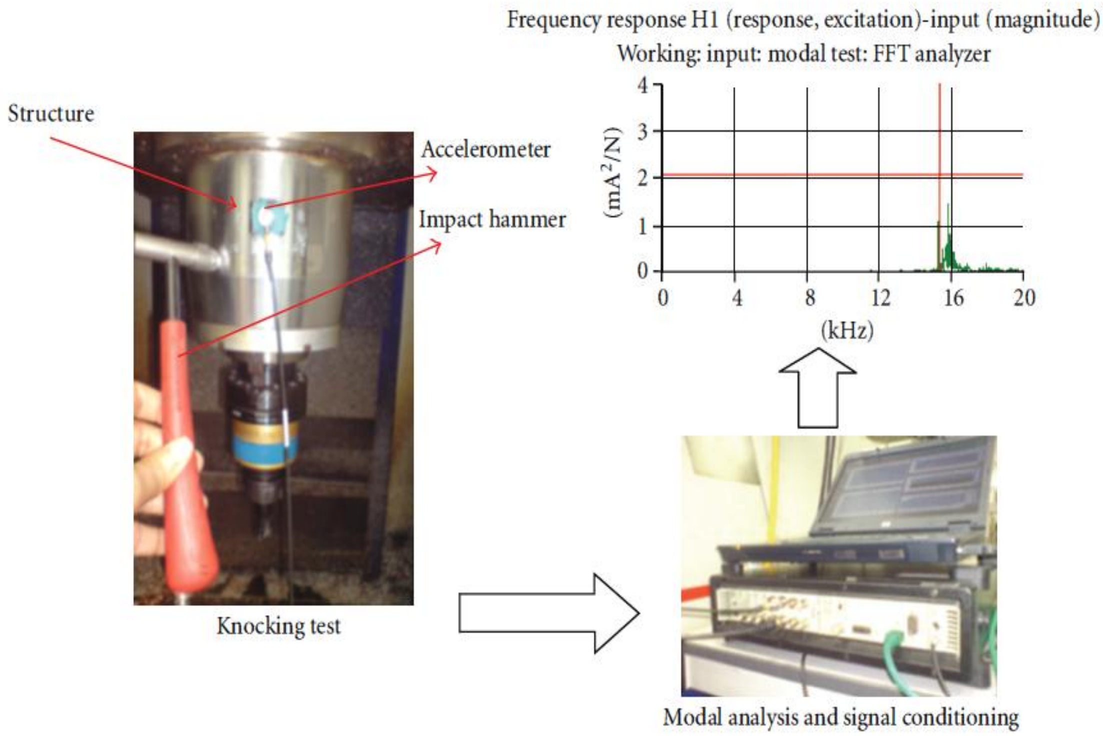


Figure 2.1: Test Set Up

Source: Anayet U. Patrawi et al., 2009

(a) Measurement Hardware.

A vibration measurement generally requires several hardware components. The basic hardware elements required consist of a source of excitation, called an exciter (Impulse hammer), for providing a known or controlled input force to the structure, a transducer to convert the mechanical motion of the structure into an electrical signal, a signal conditioning amplifier, and an analysis system in which modal analysis program resides. The schematic diagram of hardware used to perform in a vibration test is shown in Figure 2.1. The different equipments that have been used are listed as follows: Pulse Front-end (Data Acquisition), Impact Hammer, USB Dongle, Accelerometers, Impact Hammer cable, Accelerometer cables, Pulse Front-End Power Supply, TCP/IP Cross Cable, and Bee's wax.(Anayet U. Patrawi et al., 2009)

(b) Test Procedures.

The different milling machine components were identified which play a dominating role in the chatter generation. The natural frequency of the different components was measured using modal analysis and consequently the different mode shapes were identified. Initially excited frequencies were monitored during the operational mode. It is easy to record a response in vibration during machining but almost impossible to measure the mentioned dynamic force. Therefore, the force measurement was replaced by measurement of the impulse response to the impact force excited by a hammer, whose tip was fitted with a force sensor. As the goal of these measurements was to evaluate frequency transfer function, the responses at various machine points with respect to a reference point were recorded and analysed. The reference point was selected at the different location shown in Figure 2.2. (Anayet U. Patrawi et al., 2009)

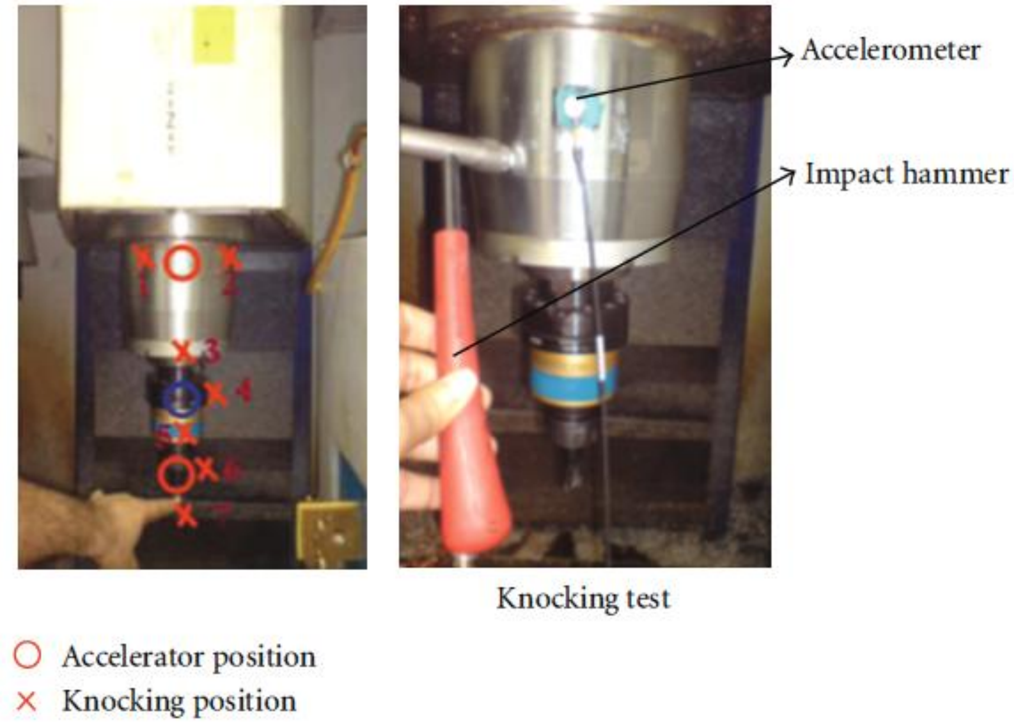


Figure 2.2: Accelerometer and knocking point position

Source: Anayet U. Patrawi et al., 2009

(i) Knocking test.

The natural frequencies of the different components were extracted from the recorded FFT diagram. One accelerometer was connected to the component; the natural frequency data from the FFT graph was recorded by knocking the different components using the impact hammer. (Anayet U. Patrawi et al., 2009)

Experimental Modal Analysis is based on determining the modal parameters by testing, unlike Analytical Modal Analysis, where the modal parameters are derived from Finite Element Models (FEMs). There are two ways of doing Experimental Modal Analysis: Classical Modal Analysis and Advances in Acoustics and Vibration.(Anayet U. Patrawi et al., 2009)

2.3 MACHINING PROCESS DYNAMICS

The machining process is considered from the perspective of complex interrelated dynamics of the machine tool mechanical structure and workpiece-cutting interactions. This approach was initially proposed by Merritt HE,1965; Kegg RL,1965; Minis et al.,1990; and Tlusty and Moriwaki T,1976 and was extended by Bordatchev EV and Orban PE,1999 to deal with the dynamics of the machine tool spindle only. The concepts expand upon in this paper to include the dynamics of the cutting tool and thus create a more complete dynamic model of this important machine tool subsystem.(Adam G. Rehorn et al., 2004)

2.3.1 Variables Influencing The Machining Process

A simple way of envisioning and discussing machining is to consider the process as a black box (Rehorn AG, 2001; Bordatchev and Orban, 1999). There are three main parts associated with this model: the input variables, the output variables and the process itself. The output of the machining operation is a workpiece with a given surface profile and geometry. This surface profile can be quantified by a product quality vector (Bordatchev and Orban, 1999). The quality vector includes measurements of ovality, cylindricity and dimensional accuracy as well as some quantification of the roughness of the surface finish. The main input variables are of two types: controlled variables and characteristic variables. The controlled variables represent factors that can be independently controlled and altered by the operator of the machine tool, either before or at any time during machining. Controlled variables include spindle speed and feed rate, the cutting and feed motions, depth of cut, cut geometry, immersion and direction of rotation of the tool (Altintas Y, 2000). Characteristic variables are those over which there is little or no control once selected and which are primarily processed specific. Some typical examples include the cutter type and geometry, the physical and mechanical properties of the workpiece and the cutting tool and the chemical affinities between these two materials. Even though very little control can be exercised over the characteristic variables, they can have a dramatic impact on the quality of the product.(Adam G. Rehorn et al., 2004)

The machining process itself can be considered as a series of interactions among several dynamic processes. These processes represent different sets of dynamics that comprise the constituent parts of the machining process. Some of these dynamics, namely the machine tool's natural structural dynamics and the dynamics of the cutting process, result in workpiece-tool relative displacements. These displacements then affect the dynamics of the surface profile formation. Thus, the dynamics can be seen to directly influence the quality of the final product. .(Adam G. Rehorn et al., 2004)

2.3.2 Interrelation Among Different Variables In Machining Processes

The machining process and the interrelations among the dynamic processes mentioned in the previous section can be considered in terms of a dynamic feedback system, which is a further development of previously presented models (Bordatchev,1996; Zakovorotny et al.,1995). Each block represents a key dynamic process in the overall machining operation. The dynamic processes are represented as functions of the differential operator.(Adam G. Rehorn et al., 2004)

2.4 FUNDAMENTAL OF VIBRATION

2.4.1 Natural Frequencies

Bridges, aircraft wings, machine tools, and all other physical structures have natural frequencies. A natural frequency is the frequency at which the structure would oscillate if it were disturbed from its rest position and then allowed to vibrate freely (Tom Irvine,2000). All structures have at least one natural frequency. Nearly every structure has multiple natural frequencies. Resonance occurs when the applied force or base excitation frequency coincides with structural natural frequency. During resonant vibration, the response displacement may increase until the structure experiences buckling, yielding, fatigue, or some other failure mechanism.(Tom Irvine,2000)

(a) Dynamic Analysis

Engineers performing dynamic analysis must:

1. Determine the natural frequencies of the structure.
2. Characterize potential excitation functions.
3. Calculate the response of the structure to the maximum expected excitation.
4. Determine whether the expected response violates any failure criteria.

Based on the steps above, this report related to the first step. The natural frequencies can be calculated via analytical methods during the design stage. The frequencies may also be measured after the structure, or a prototype, is built. Each natural frequency has a corresponding damping ratio. Damping values are empirical values that must be obtained by measurement. (Tom Irvine,2000)

(b) Frequency Response Function Overview

There are many tools available for performing vibration analysis and testing. The frequency response function is a particular tool. A frequency response function (FRF) is a transfer function, expressed in the frequency domain. Frequency response functions are complex functions, with real and imaginary components. They may also be represented in terms of magnitude and phase. A frequency response function can be formed from either measured data or analytical functions. A frequency response function expresses the structural response to an applied force as a function of frequency. The response may be given in terms of displacement, velocity, or acceleration. Furthermore, the response parameter may appear in the numerator or denominator of the transfer function. (Tom Irvine,2000)

(c) FRF Model

Consider a linear system as represented by the diagram in Figure 2.3:

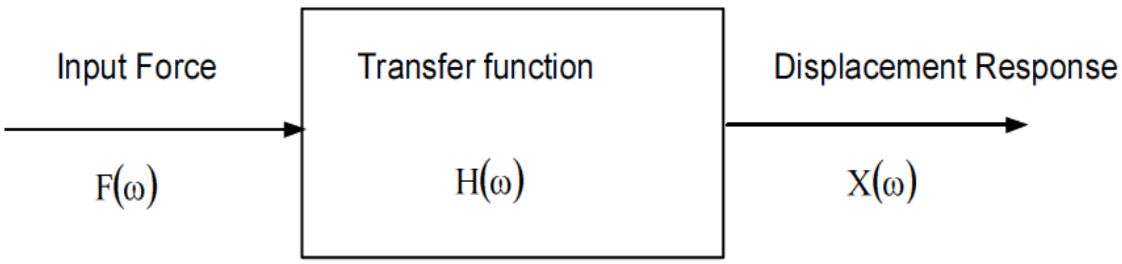


Figure 2.3: linear system of FRF

Source: Tom Irvine,2000

The function above is a complex function and also can be represented in terms of phase and magnitude. F(w) is the input force in function of angular frequency w, H(w) is the transfer function and X(w) is the displacement response function.

(d) FRF Measurements

The Frequency Response Function (FRF) is a fundamental measurement that isolates the inherent dynamic properties of a mechanical structure. Experimental modal parameters (frequency, damping, and mode shape) are also obtained from a set of FRF measurements. The FRF describes the input-output relationship between two points on a structure as a function of frequency, as shown in Figure 2.3. Since both force and motion are vector quantities, they have directions associated with them. Therefore, an FRF is actually defined between a single input DOF (point & direction), and a single output DOF. An FRF is a measure of how much displacement, velocity, or acceleration response a structure has at an output DOF, per unit of excitation force at an input DOF.(Brian J. Schwarz et al,1999)

Figure 2.4 shows that an FRF is defined as the ratio of the Fourier transform of an output response X(w) divided by the Fourier transform of the input force F(w) that caused the output.

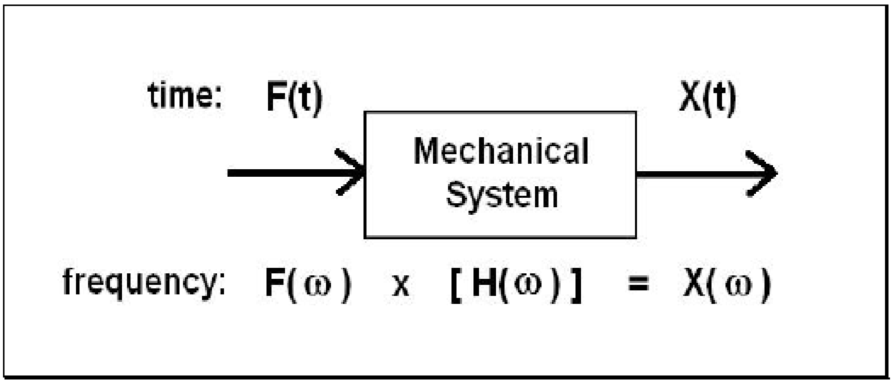


Figure 2.4: Block Diagram of FRF

Source: Brian J. Schwarz et al,1999

Response motion can be measured as displacement, velocity, or acceleration, and the FRF and its inverse can have a variety of names such as,

i. Compliance (displacement / force)
ii. Mobility (velocity / force)
iii. Inertance or Receptance (acceleration / force)
iv. Dynamic Stiffness (1 / Compliance)
v. Impedance (1 / Mobility)
vi. Dynamic Mass (1 / Inertance)

2.4.2 Modes

Modes (or resonances) are inherent properties of a structure. Resonances are determined by the material properties (mass, stiffness, and damping properties), and boundary conditions of the structure. Each mode is defined by a natural (modal or resonant) frequency, modal damping, and a mode shape. If either the material properties or the boundary conditions of a structure change, its modes will change.

For instance, if mass is added to a vertical pump, it will vibrate differently because its modes have changed. At or near the natural frequency of a mode, the overall vibration shape (operating deflection shape) of a machine or structure will tend to be dominated by the mode shape of the resonance. An operating deflection shape (ODS) is defined as any forced motion of two or more points on a structure. Specifying the motion of two or more points defines a shape. Stated differently, a shape is the motion of one point relative to all others. Motion is a vector quantity, which means that it has both a location and a direction associated with it. Motion at a point in a direction is also called a Degree Of Freedom (DOF). “All experimental modal parameters are obtained from measured ODS’s.” That is, experimental modal parameters are obtained by artificially exciting a machine or structure, measuring its operating deflection shapes (motion at two or more DOFs), and post-processing the vibration data. (Brian J. Schwarz et al, 1999)

(a) Kinds of Modes

Modes are further characterized as either rigid body or flexible body modes. All structures can have up to six rigid body modes, three translational modes and three rotational modes. If the structure merely bounces on some soft springs, its motion approximates a rigid body mode. (Brian J. Schwarz et al,1999)

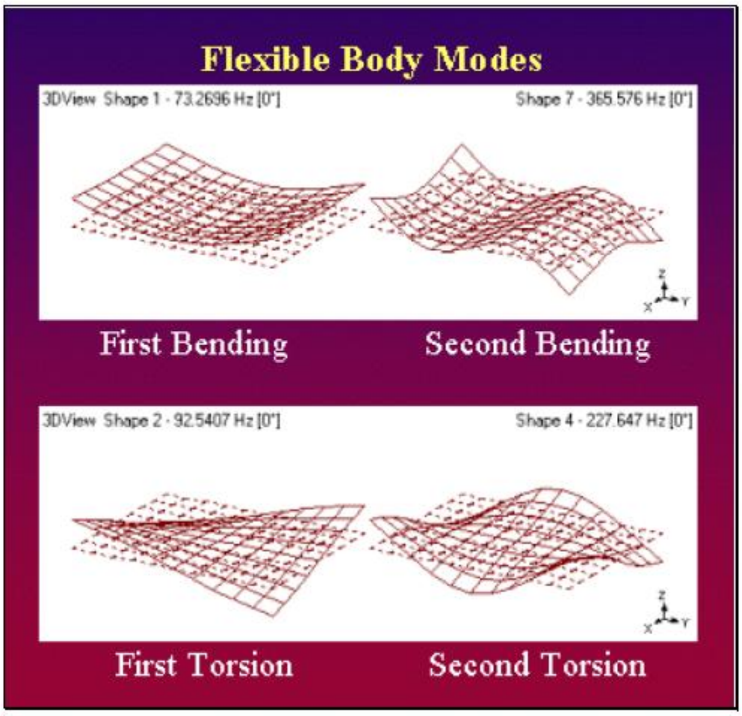


Figure 2.5 : Flexible Body Modes

Source: Brian J. Schwarz et al,1999

Vibration problems are caused, or at least amplified by the excitation of one or more flexible body modes. Figure 2.5 shows some of the common fundamental (low frequency) modes of a plate. The fundamental modes are given names like first and second bending, and first and second torsion. The higher or larger frequency mode shapes are usually more complex in appearance and do not have common names.

(b) Understanding Vibration in Terms of Modes

Modes are actually very related to vibration and we can understanding it in terms of mode. Figure 2.6 shows the reason why vibration is easier to understand in terms of modes of vibration. It is a plot of the Log Magnitude of an FRF measurement (the solid curve), but the dotted lines below the FRF magnitude plotted as resonance curves. Each of these resonance curves is the response of structural due to a single mode of vibration. The overall response of structural is in fact, the summation of resonance curves. In other means, at any frequency, the overall response of a structure is a summation of responses due to each of its modes. The response of one mode will dominate the frequency response is the evidence that close to the frequency of one of the resonance peaks.

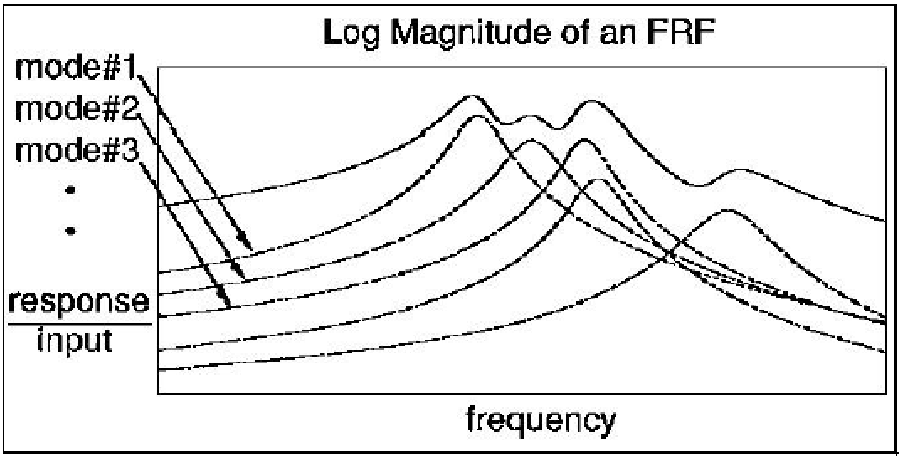


Figure 2.6: Response as Summation of Modal Responses

Source: Brian J. Schwarz et al,1999

2.5 MODAL TESTING

Modal testing is a form of vibration testing of an object where the natural (modal) frequencies, modal masses, modal damping ratios and mode shapes of the object determined under test. A modal test consists of an analysis phase and an acquisition phase. The complete process is referred to as a Modal Analysis or Experimental Modal Analysis.

2.5.1 Impact Testing

Modal testing that is impact testing use in this project and was developed during the late 1970's with the ability to compute FRF measurements in an FFT analyzer, and has become the most popular modal testing method used today. Impact testing is a fast, convenient, and low cost way of finding the modes of machines and structures such as cutting tool.

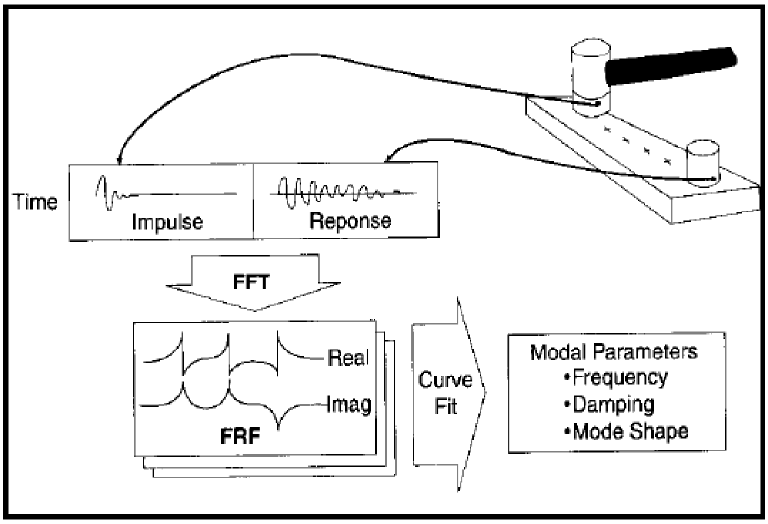


Figure 2.7: Impact Testing.

Source: Brian J. Schwarz et al,1999

Impact testing is shown in Figure 2.7 and the following equipment is required to perform an impact test as approach by Brian J. Schwarz et al,1999,

i. To measure the input force, an impact hammer with a load cell attached to its head.
ii. To measure the response acceleration at a fixed point & direction by using an accelerometer.
iii. To compute FRFs by using a 2 or 4 channel FFT analyzer.
iv. Identifying modal parameters and displaying the mode shapes in animation by post-processing modal software.

From the four main equipments stated above, a wide variety of structures and machines can be impact tested and to provide the appropriate impact force, different sized hammers are required depending on the size of the structure; large hammers for large structures, small hammers for small structures. The steps and test in impact testing are important especially to get the best result and the testing is part of the important initial work on this project.

(a) Roving Hammer Test

A roving hammer test is the most common type of impact test. In this test, the accelerometer is fixed at a single DOF, and the structure is impacted at as many DOFs as desired to define the mode shapes of the structure. Using a 2-channel FFT analyzer, FRFs are computed one at a time, between each impact DOF and the fixed response DOF. (Brian J. Schwarz et al, 1999)

(b) Roving Tri-axial Accelerometer Test

The only drawback to a roving hammer test is that all of the points on most structures cannot be impacted in all three directions, so 3D motion cannot be measured at all points. Reactions, so 3D motion cannot be measured at all points. When 3D motion at each test point is desired in the resulting mode shapes, a roving tri-axial accelerometer is used and the structure is impacted at a fixed DOF with the hammer. Since the tri-axial accelerometer must be simultaneously sampled together with the force data, a 4-channel FFT analyzer is required instead of a 2-channel analyzer. (Brian J. Schwarz et al,1999)

(c) Impact Testing Requirements

Even though impact testing is fast and convenient, there are several important considerations that must be taken into account in order to obtain accurate results. They include, pretrigger delay, force and exponential windowing, and accept/reject capability. (Brian J. Schwarz et al,1999)

(d) Pre-Trigger Delay

Because the impulse signal exists for such a short period of time, it is important to capture all of it in the sampling window of the FFT analyzer. To insure that the entire signal is captured, the analyzer must be able to capture the impulse and impulse response signals prior to the occurrence of the impulse. In other words, the analyzer must begin sampling data before the trigger point occurs, which is usually set to a small percentage of the peak value of the impulse. This is called a pre-trigger delay. (Brian J. Schwarz et al,1999)

(e) Force & Exponential Windows

Two common time domain windows that are used in impact testing are the force and exponential windows. These windows are applied to the signals after they are sampled, but before the FFT is applied to them in the analyzer. The force window is used to remove noise from the impulse (force) signal. Ideally, an impulse signal is non-zero for a small portion of the sampling window, and zero for the remainder of the window time period. Any non-zero data following the impulse signal in the sampling window is assumed to be measured noise. The force window preserves the samples in the vicinity of the impulse, and removes the noise from all of the other samples in the force signal by making them zero. The exponential window is applied to the impulse response signal. The exponential window is used to reduce leakage in the spectrum of the response. The FFT assumes that the signal to be transformed is periodic in the transform window. (The transform window is the samples of data used by the FFT). To be periodic in the transform window, the waveform must have no discontinuities at its beginning or end, if it were repeated outside the window. Signals that are always periodic in the transform window are,

i. Signals that are completely contained within the transform window.
ii. Cyclic signals that complete an integer number of cycles within the transform window.

If a time signal is not periodic in the transform window, when it is transformed to the frequency domain, a smearing of its spectrum will occur. This is called leakage. Leakage distorts the spectrum and makes it inaccurate. Therefore, if the response signal in an impact test decays to zero (or near zero) before the end of the sampling window, there will be no leakage, and no special windowing is required. (Brian J. Schwarz et al,1999)

On the other hand, if the response does not decay to zero before the end of the sampling window, an exponential window must be used to reduce the leakage effects in the response spectrum. The exponential window adds artificial damping to all of the modes of the structure in a known manner. This artificial damping can be subtracted from the modal damping estimates after curve fitting. But more importantly, a properly applied exponential window will cause the impulse response to be completely contained within the sampling window, thus leakage will be reduced to a minimum in its spectrum. (Brian J. Schwarz et al,1999)

(f) Accept/Reject

Because accurate impact testing results depend on the skill of the one doing the impacting, FRF measurements should be made with spectrum averaging, a standard capability in all modern FFT analyzers. FRFs should be measured using 3 to 5 impacts per measurement. Since one or two of the impacts during the measurement process may be bad hits, an FFT analyzer designed for impact testing should have the ability to accept or reject the result of each impact. An accept/reject capability saves a lot of time during impact testing since you don’t have to restart the measurement process after each bad hit. (Brian J. Schwarz et al,1999)

(g) Obtaining Modal Parameter

Figure 2.8 shows the different ways in which modal parameters can be obtained, both analytically and experimentally. A growing amount of finite element modeling, with extraction of modal parameters from the finite element model, is being done in an effort to understand and solve structural dynamics problems. Experimental modal analysis is also done for this same purpose.

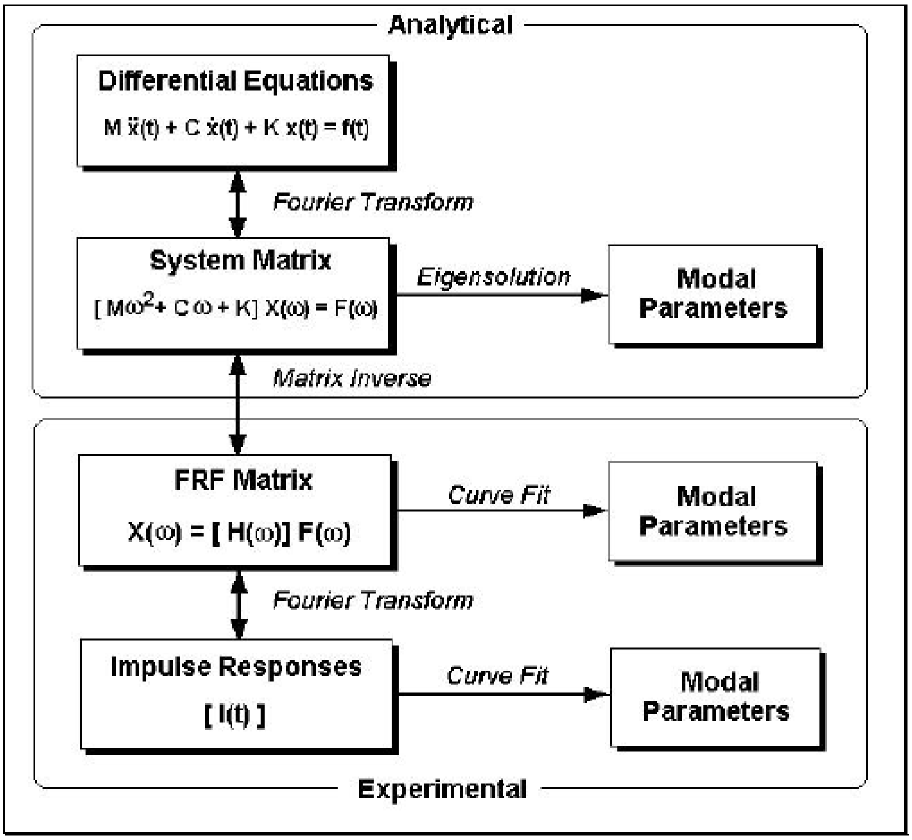


Figure 2.8: Sources of Modal Parameters.

Source: Brian J. Schwarz et al,1999

From figure 2.8 above, the majority of modern experimental modal analysis relies upon the application of a modal parameter estimation (curve fitting) technique to a set of FRF measurements. As indicated in Figure 2.8, the FRFs can also be inverse FFT'd and curve fitting techniques applied to their equivalent Impulse Response Functions (IRFs). (Brian J. Schwarz et al,1999)

2.5.2 Obtaining Modal Parameters From Curve Fitting

Curve fitting and also known as regression analysis is used to find the curve or the best fit line for a series of data points. Modal parameters are commonly identified by curve fitting a set of FRFs and can also be identified by curve fitting an equivalent set of Impulse Responses, or IRFs. In general, curve fitting is a process of matching a mathematical expression to a set of empirical data points. This is done by minimizing the squared error between the analytical function and the measured data. There are have four curve fitting methods.

The methods are listed in order of increasing complexity. SDOF is short for a Single Degree Of Freedom, or single mode method. Similarly, MDOF is short for a Multiple Degree Of Freedom, or multiple mode method. SDOF methods estimate modal parameters one mode at a time. MDOF, Global, and Multi-Reference methods can simultaneously estimate modal parameters for two or more modes at a time. Local methods are applied to one FRF at a time. Global and Multi-Reference methods are applied to an entire set of FRFs at once. Local SDOF methods are the easiest to use, and should be used whenever possible. SDOF methods can be applied to most FRF data sets with light modal density (coupling). MDOF methods must be used in cases of high modal density. Global methods work much better than MDOF methods for cases with local modes. Multi-Reference methods can find repeated roots (very closely coupled modes) where the other methods cannot. (Brian J. Schwarz et al,1999)

(a) Local SDOF Methods

These are referred to as SDOF (single degree of freedom, or single mode) methods. Even though they do not look like curve fitting methods (in the sense of fitting a curve to empirical data), all three of these methods are based on applying an analytical expression for the FRF to measured data. (Richardson, M. H., 1975)

(i) Modal Frequency as Peak Frequency

The frequency of a resonance peak in the FRF is used as the modal frequency. This peak frequency, which is also dependent on the frequency resolution of the measurements, is not exactly equal to the modal frequency but is a close approximation, especially for lightly damped structures. The resonance peak should appear at the same frequency in almost every FRF measurement. It won’t appear in those measurements corresponding to nodal lines (zero magnitude) of the mode shape. (Brian J. Schwarz et al,1999)

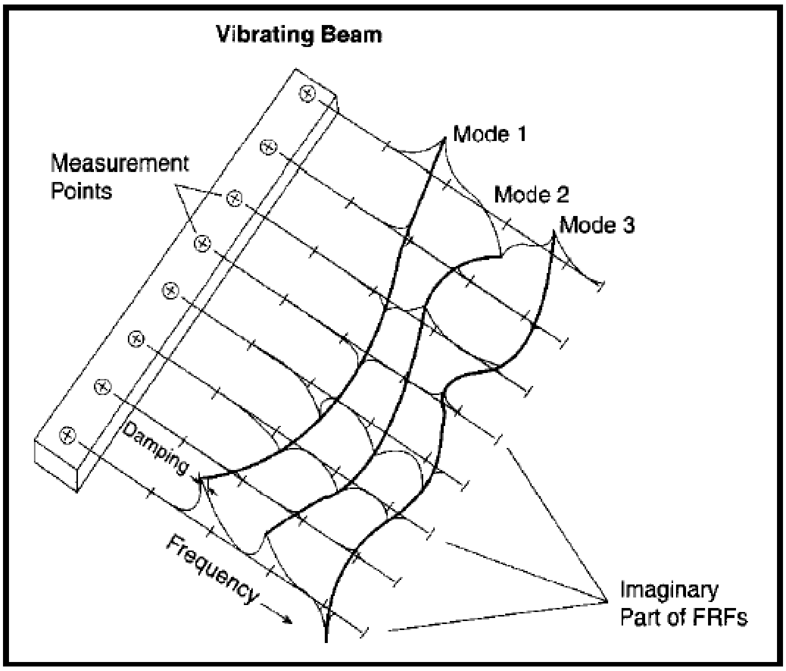


Figure 2.9: Curve Fitting FRF Measurements.

Source: Brian J. Schwarz et al,1999

(ii) Modal Damping as Peak Width

The width of the resonance peak is a measure of modal damping. The resonance peak width should also be the same for all FRF measurements, meaning that modal damping is the same in every FRF measurement. The width is actually measured at the so-called half power point, and is approximately equal to twice the modal damping (in Hz). Mode Shape From Quadrature Peaks From (displacement/force) or (acceleration/force) FRFs, the peak values of the imaginary part of the FRFs are taken as components of the mode shape. This is called the Quadrature method of curve fitting. From (velocity/force) FRFs, the peak values of the real part are used as mode shape components. Hence, using the simplest Local SDOF curve fitting methods, all three modal parameters (frequency, damping, and mode shape) can be extracted directly from a set of FRF measurements. (Brian J. Schwarz et al, 1999)

(b) Local MDOF Methods

The Complex Exponential and the Rational Fraction Polynomial methods are two of the most popular Local MDOF curve fitting methods. Complex Exponential (CE) This algorithm curve fits and analytical expression for a structural impulse response to experimental impulse response data. A set of impulse response data is normally obtained by applying the Inverse FFT to a set of FRF measurements. The leakage (wrap around error) caused by the inverse FFT, which distorts the impulse response data. This portion of the data cannot be used because of this error. (Brian J. Schwarz et al, 1999)

(i) Rational Fraction Polynomial (RFP)

This method applies the rational fraction polynomial expression directly to an FRF measurement. Its advantage is that it can be applied over any frequency range of data, and particularly in the vicinity of a resonance peak. Not only can the RFP method be used to estimate modal parameters, but it also yields the numerator & denominator polynomial coefficients, as well as the poles & zeros of the FRF. (Brian J. Schwarz et al, 1999)

(c) Global and Multi-Reference Methods

Both the CE and RFP algorithms have been implemented as Global and Multi-Reference methods also.

2.6 CNC MACHINE CUTTING TOOL

In this project, the material used are CNC cutting tools. So, the information about this CNC machine and their types of cutting tool helpful in understanding about their use or function. CNC means or stands for Computer Numerical Control and has been around since the early 1970's. Prior to this, it was called NC, for Numerical Control. (In the early 1970's computers were introduced to these controls, hence the name change.).

CNC has touched almost every form of manufacturing process in one way or another while people in most walks of life have never heard of this term. It is likely that you will be dealing with CNC on a regular basis if you will be working in manufacturing field. Computer Numerical Control (CNC) Milling is the most common form of CNC. CNC mills can perform the functions such as drilling and often turning. CNC Mills are classified according to the number of axes that they possess and the axes are labeled as x and y for horizontal movement, and z for vertical movement.

2.6.1 Classification Of Milling Cutters

Milling cutters are usually made of high-speed steel and are available in a great variety of shapes and sizes for various purposes. You should know the names of the most common classifications of cutters, their uses, and, in a general way, the sizes best suited to the work at hand. More understanding on milling cutter, below are the milling cutter nomenclature.

i. The pitch refers to the angular distance between like or adjacent teeth.
ii. The pitch is determined by the number of teeth. The tooth face is the forward facing surface of the tooth that forms the cutting edge.
iii. The cutting edge is the angle on each tooth that performs the cutting.
iv. The land is the narrow surface behind the cutting edge on each tooth.

v. The rake angle is the angle formed between the face of the tooth and the centerline of the cutter. The rake angle defines the cutting edge and provides a path for chips that are cut from the workpiece.

vi. The primary clearance angle is the angle of the land of each tooth measured from a line tangent to the centerline of the cutter at the cutting edge. This angle prevents each tooth from rubbing against the workpiece after it makes its cut.

vii. This angle defines the land of each tooth and provides additional clearance for passage of cutting oil and chips.

viii. The hole diameter determines the size of the arbor necessary to mount the milling cutter.

ix. Plain milling cutters that are more than 3/4 inch in width are usually made with spiral or helical teeth. A plain spiral-tooth milling cutter produces a better and smoother finish and requires less power to operate. A plain helical-tooth milling cutter is especially desirable when milling an uneven surface or one with holes in it.

The CNC milling cutting tools have so many types and below are the types of the cutting tools.

(a) (b)

(c) (d)

(e) (f)

Figure 2.10: (a) End Milling Cutter, (b) Edge Finder, (c) Woodruff Keyslot, (d) Drill, (e) Tapper, (f) Centre Drill

Since the CNC cutting tools chosen in this project is end mill, we will focus on the end mill cutter. The end milling cutter, also called an end mill, has teeth on the end as well as the periphery. The smaller end milling cutters have shanks for chuck mounting or direct spindle mounting. End milling cutters may have straight or spiral flutes. Spiral flute end milling cutters are classified as left-hand or right-hand cutters depending on the direction of rotation of the flutes. If they are small cutters, they may have either a straight or tapered shank.

The most common end milling cutter is the spiral flute cutter containing four flutes. Two-flute end milling cutters, sometimes referred to as two-lip end mill cutters, are used for milling slots and keyways where no drilled hole is provided for starting the cut. These cutters drill their own starting holes. For milling both soft or tough materials, straight flute end milling cutters are generally used, while for cutting steel, spiral flute cutters are used mostly.

Large end milling cutters (normally over 2 inches in diameter) are called shell end mills and are recessed on the face to receive a screw or nut for mounting on a separate shank or mounting on an arbor, like plain milling cutters. The teeth are usually helical and the cutter is used particularly for face milling operations requiring the facing of two surfaces at right angles to each other.

2.7 FEM ANALYSIS

Finite element analysis as computational analysis is the main part in this project. A FEA commercial package was used to find the natural frequencies and the corresponding mode shapes of the model. The FE analysis was done to find the targeted eigen frequencies and corresponding eigen modes. (Jahangir Ansari, 2006)

2.7.1 FE Modeling Procedures

A three-dimensional geometrical model of machine's structure with SOLIDWORK software has been developed in order to make a finite element model, and then converted to igs. format for further analysis by FEA ANSYS software as approach by Anayet U. Patrawi et al, 2009. This model provides natural values and response frequency extraction. The observation of vibration modes of machine cutting tool is three-dimensional shapes which provides better capability to the analysis of vibration model. The different cutting tool of CNC machine were measured and designed by SOLIDWORK software and the designed models were three dimensional (3D) models. The necessary input data as material properties such as modulus of elasticity, Poisson ratio, and density are applied after modeling selection. The elements used in the FEM model for mesh generation is quadratic tetrahedral element. The element dimensions are finer and controlled. Afterwards, boundary conditions on supporting are applied on the earth connection of machine tool and finally modal analysis has been done to obtain natural frequencies. In continuation, fine screening of the finite element model is accomplished to match the natural frequencies results from experimental modal analysis. (Anayet U. Patrawi et al, 2009)

2.7.2 Finite Element Modal Analysis

Modal analysis of finite element has been done on the three different cutting tools of CNC machine using finite element model to determine the natural frequency of cutting tool structure elements and to discrete them from each other. The models for this project are as follows:

(i) model number 1: End Mill 3 flute
(ii) model number 2: End Mill 4 flute
(iii)model number 3: End Mill 4 flute Variable Helix

Finite element analysis is a computerized procedure for the analysis of structures. Rapid engineering analyses can be performed because the structure is represented (modelled) using the known properties of standard geometric and the finite element method. Finite element analysis used in this manner provides the dynamic properties of structures, including mode shapes and corresponding natural frequencies. (Neville F. Rieger).

2.7.3 ANSYS Software

ANSYS 13.0 is the software recommended for this project and includes a great number of new and advanced features that make it easier, faster and cheaper for customers to bring new products to market, with a high degree of confidence in the ultimate results they will achieve. ANSYS 13.0 builds on the foundation of previous ANSYS releases, taking development to the next level by continuing the evolution of Smart Engineering Simulation. By compressing design cycles, optimizing product performance across multiple physics, maximizing the accuracy of virtual prototypes, and automating the simulation process, ANSYS is making it easier and faster than ever to bring innovative new products to market which has become imperative in today's difficult economy. The software suite delivers new benefits in three major areas:

i. Greater accuracy and fidelity: As engineering requirements and design complexity increase, simulation software must produce more accurate results that reflect changing operating conditions over time.
ii. Higher productivity: ANSYS 13.0 includes dozens of features that minimize the time and effort product development teams invest in simulation.
iii. More computational power: For some engineering simulations, ANSYS 13.0 can provide speedup ratios that are five to 10 times greater than previous software releases. Even complex multiphysics simulations can be accomplished more quickly and efficiently, speeding up product development and market launch initiatives.

The ANSYS 13.0 software have the ability function to obtain the frequencies and mode shapes for finite element analysis that is one of the scope on this project.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

Methodology is important that can be the guide for this project. In general, methodology means a set or system of methods. This chapter is about the about how the research is carried out. The research is to study about the dynamic properties and behaviour of CNC machine cutting tool that is Square End Mill (3,4 and 4 Variable Helix flute) by doing the experimental modal analysis and performing ANSYS (FEA) method. All the result and data from the ANSYS will be compared with the data collected from the experimental modal analysis. The flow chart of the methodology is as shown in figure 3.1.

This study begins with the problem statement, determine the project objectives and scopes, literature review on previous work and theoretical study on CNC cutting tools and modal analysis. After gathering the information, the model of End Mill cutting tool sketch using SOLIDWORK software. Then a simulation is conducted to observe the dynamic properties of End Mill cutting tools such as natural frequency and mode shape. In this project, the simulation is performed using ANSYS Finite Element Analysis software. After that, identification and selection of CNC cutting tools and an experimental modal analysis is performed. Lastly, after gathering information from both results, a comparative study will be done and discussed on all of the cutting tools selected.

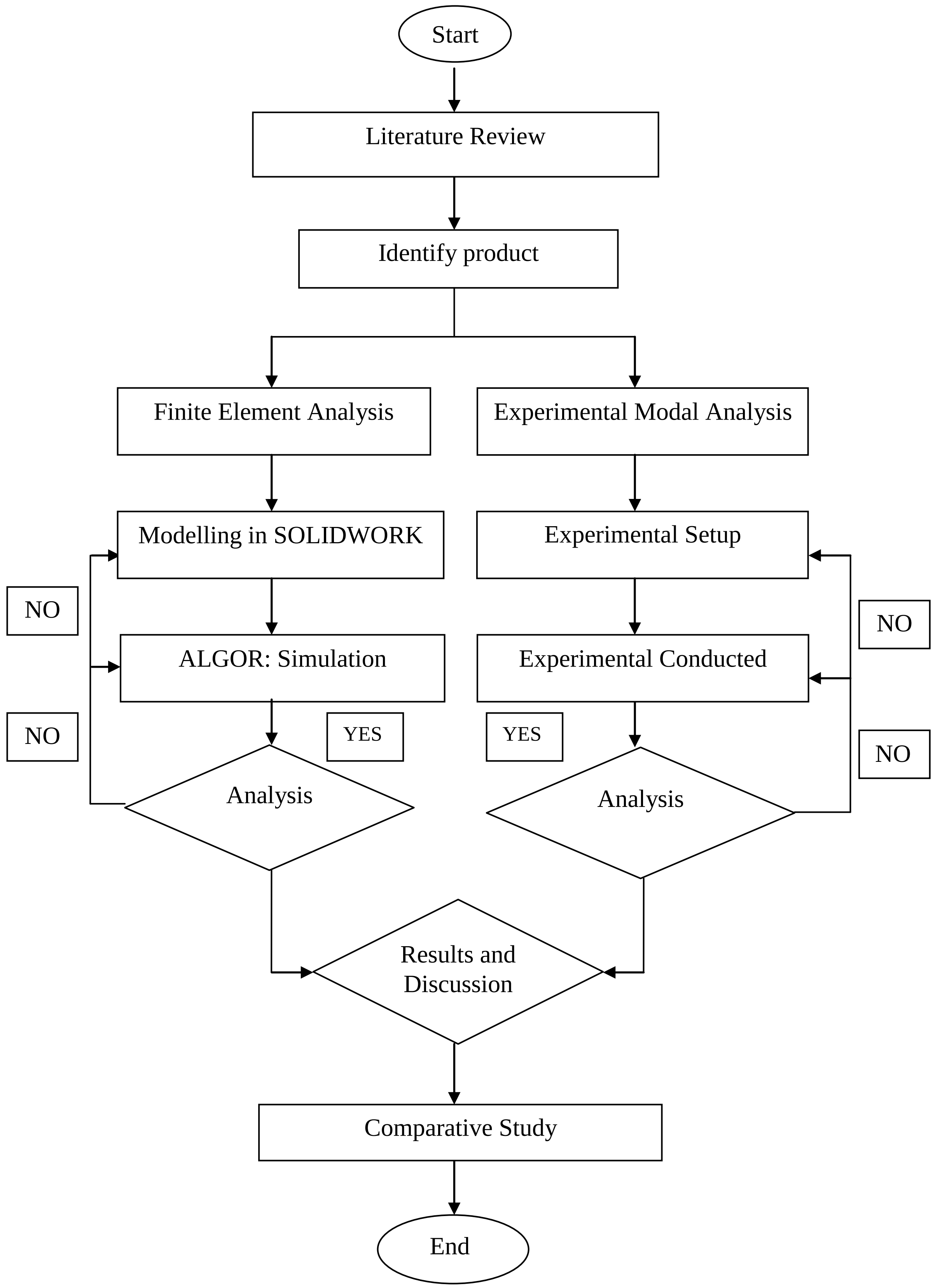


Figure 3.1: Methodology Flowchart

3.2 MATERIAL

Materials choosing in this project are End Mill 3 flute, End Mill 4 flute and End Mill 4 flute Variable Helix and material type is carbide end mills.

3.2.1 End Mills For CNC Machines

The material choosing for this project is end mill and knowing about this material will help. End mills actually come in a variety of materials and in various sizes as well as materials including high-speed steel, cobalt and carbide. Carbide end mills are the hardest and are used for finishing end mills, while cobalt end mills are used mostly for roughing models. The hardness of end mills determines the material to be cut and the cost of the end mill.

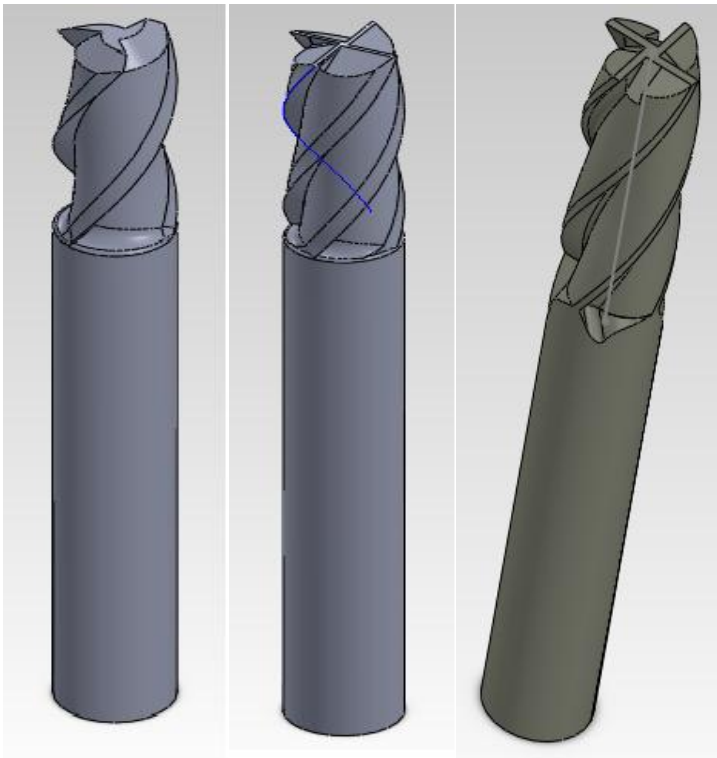
Solid materials for end mills are HSS (High Speed Steel) and Carbide. Carbide is the harder of the two, will last longer and can handle faster feedrates. To make carbide even better, there are various coating material applied such as gold coating Titanium Nitride and TiN is a very resilient material that can withstand higher heat and provides a bit more hardness. Other coatings include: TiCN (Titanium Carconitride) which is great for various metals, TiAIN (Titanium Aluminum Nitride) which is even better for metals (not aluminum which is in the coating itself), AITiN (Aluminum Titanium Nitride) with similar characteristics as TiAIN, and finally Diamond. The shapes of end mills vary extremely widely and is the most important aspect of your application. The shape of the end mill will determine the shape of the final cut and even on the material being cut.

3.3 MODELLING

Modelling the CNC cutting tools for finite element analysis actually not easy since the model must same as the real one. The dimension for the cutting tools was taken by using vernier calipers.

3.3.1 Modelling Method

From the real model of cutting tools, the cutting tools are drawn using SOLIDWORK. The design of the model is shown in the figure below. The cutting tools that want to draw are End Mill 3 flute and End Mill 4 flute and End Mill 4 flute Variable Helix. The dimension from real cutting tools measured so that can be modelled on SOLIDWORK for further analysis.



(a) (b) (c)

Figure 3.2: (a) End Mill 3 flute, (b) End Mill 4 flute, (c) End Mill 4 flute Variable Helix

3.4 SIMULATION

3.4.1 Simulation Method

The finite element analysis is carried out is using ANSYS SOFTWARE 13.0 is capable of generating meshes automatically because it support for multi-CAD environment and also an extensive finite element modelling tools that help manufacturers study initial design intent and accurately predict product performance. It also allows user to validate and optimize design before manufacturing which can increase efficiency, minimizing reliance on physical prototypes, reducing costs, and decreasing errors. It also allows complex geometries to be generated easily and support mesh types for 2D and 3D simulation.

ANSYS SOFTWARE 13.0 software is used to conduct the analyzing of End Mill CNC Machine cutting tools. ANSYS Finite Element Analysis (FEA) uses a complex system of point called nodes which make grid called mesh. Natural frequency (modal analysis) in ANSYS determined a part’s natural frequencies and mode shape to avoid frequencies that are disruptive or harmful in the design. The software use studies of oscillating modes to determine if a part resonates at the frequency of an attached power- driven device. It makes design changes to reduce the amplitude of oscillations and account for stiffening effects from applied loads.

The 3D model of cutting tools by is transferred into the ANSYS software in type of IGS file. IGS file is a 2D/3D vector graphics format based on the Initial Graphics Exchanger Specification (IGES) used by many CAD programs as a standard ASCII text- based format for saving and exporting vector data which can store wireframe models, surface or solid object representation, circuit diagram and other object. The mesh was constructed using three parts that represent End Mill 3 flute and End Mill 4 flute and End Mill 4 flute Variable Helix. The element type for the End Mill is set to carbide. The experiment is carried out by setting the analysis type to Natural Frequency (modal), change the units from metrics mks (SI) to custom unit and change the length to millimeter (mm) and force to Newton (N). The element definition is set to tetrahedron and defines the mesh size to 70%. The result will be better if a higher percentage of mesh size is set up it need a supercomputer to perform the analysis. For this experiment, 5 mode shapes were analyzed and there are no loading and boundary condition were imposed on the test specimen. The free boundary condition is simulated by supporting the structure with soft material such as sponge. The simulation is done part by part so then it can be compared to the experimental analysis later.

3.5 MODAL TESTING

3.5.1 Impact Hammer Testing

In the experiment, impact hammer is used to run modal testing. The component is interfaced with a host computer allowing for coordination of the operation of the overall system and enhancing the data processing capabilities. An impact hammer test is the most common method of measuring FRFs (Frequency Response Functions).the hammer impacts a transient impulsive force excitation to the device. The impact is intended to excite a wide range of frequencies so that the DAQ (Data Acquisition) can measure the vibration of the device across this range of frequencies. In the experiment, Accelerometer is used as the sensor to connect with the DAQ. The accelerometer is a device for measuring vibration of a structure, producing an output signal proportional to acceleration. They work by having some kind of force measuring sensor, with a mass attached to it so that when the device is forced to vibrate a force is produced by Newton's law, proportional to acceleration. The frequency content of the excitation input depends on the size and type of impact hammer and Accelerometer that is used. The dynamic force signal is recorded by the DAQ. After the impact, the device vibration is measured with Accelerometer recorded by the DAQ. The DAQ then computer the FRF by comparing the force excitation and the response acceleration signals.

There are important when performing impact testing. The selection of the hammer tip can have a significant effect on the measurements obtained. The Input frequency of the excitation controlled mainly by the hardness of the tip selected. The harder the tip, the wider the frequency range that is excited by the excitation force. The tip needs to be selected such that all the modes of interest are excited by the impact force over the frequency range to be considered. Figure 3.8 shows a typical set-up for a measurement system.

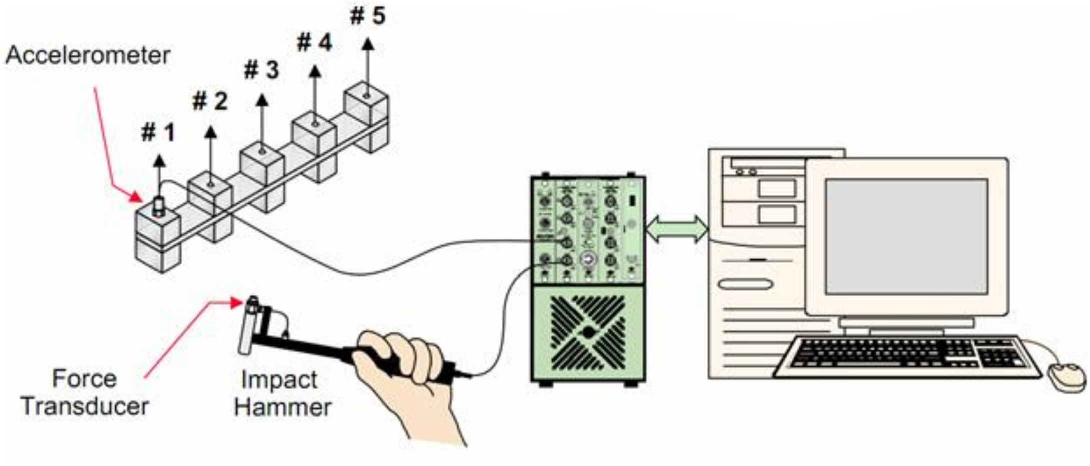


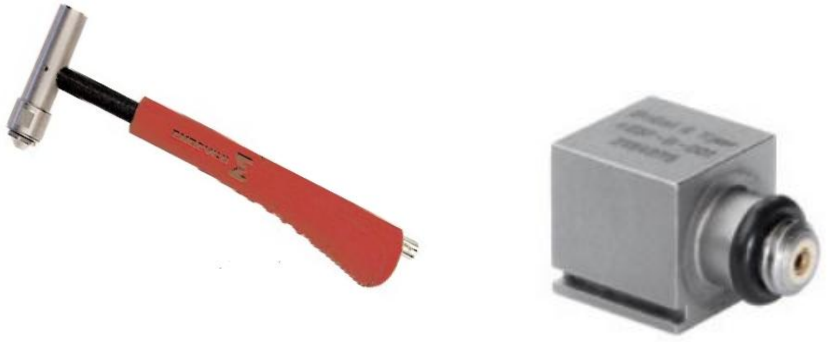
Figure 3.3: Modal testing systems

Source:Brüel & Kjær, Denmark, 2003

The apparatus using on modal testing such as modal hammer, accelerometer, FFT analyzer shown in the table and figure below.

Table 3.1: List of apparatus

No	Apparatus	Function
1	Modal Hammer Model: Endevco Type: 2302-10	i. Excites the system. Impact all the DOF's point on the SWG.
2	FFT Analyzer	i. Collect time data and convert it to FRF measurement. ii. Response will displayed in PC
3	Computer with PULSE-Lite software version 10.2, ME'scope version 4.0	i. PULSE-Lite – display the collected data ii. ME'scope – simulate or analyzer the data converted from the analyzer.
4	Tri-Axial Accelerometer Model: Bruel & Kjaer Type: 4507B	i. Measure signal respone in each DOF from impact hammer test. Measurement includes 3 axis (X,Y,Z)



(a) **(b)**

Figure 3.4: (a) Modal hammer, (b) Accelerometer

3.5.2 Modal Analysis Procedures

Practical modal analysis, or modal testing, involves the following operations:

I. The structural response amplitude is acquired in digital format throughout a prescribed frequency domain.
II. The modal mini-computer automatically develops and stores this digitized frequency response data in a designated memory for subsequent processing.
III. Curve-fit routines are applied to the frequency response data to identify the natural frequencies within the given frequency range. The corresponding mode shapes are extracted from the digitized amplitude data at the natural frequencies.
IV. The mode shapes may be animated in terms of the simplified structural model, corresponding to those locations at which the response has been determined.
V. The modal damping is estimated from the magnitude of the response at each natural frequency. This is often the most approximate structural parameter obtained by modal testing.
VI. Modal matrix data are identified for the structure. Output is developed for mass, stiffness, and damping matrices suitable for further computations,

based on the structural modal properties. These data are printed out for subsequent use.

VII. Some software packages permit modifications to be made to the matrix data, to evaluate the influence of possible changes on the natural frequencies and mode shapes. These packages can be run on certain commercially available modal analyzers.

3.5.3 Step Of Experimental Modal Analysis

From the Measurement & Automation software, the sensitivity of the accelerometer and hammer set up. Sensitivity is the sensitivity of the sensor. This value is in the units you specify with the sensitivity unit's input. Refer to the sensor documentation to determine this value. The sensitivity of the hammer is 2.27 mvolts/g and sensitivity of the accelerometer is 5 mvolts/g. The setting of the sensitivity is shown in figure 3.5. This graph displays the analog signals acquired or generated by the device.

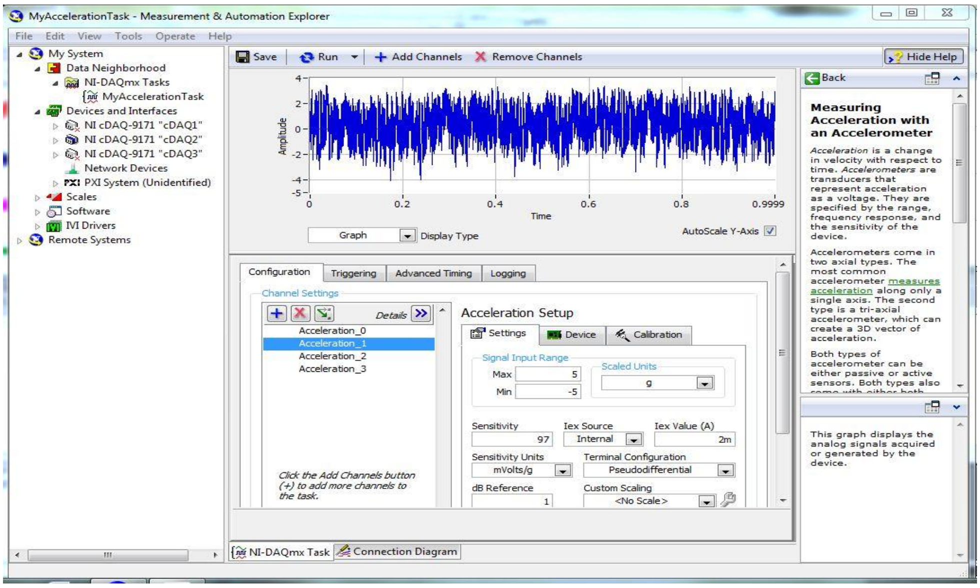


Figure 3.5: Setting of sensitivity

The experimental modal analysis is carried out by using DASYlab 10.0 software. The figure 3.6 is show draw schematic diagram.

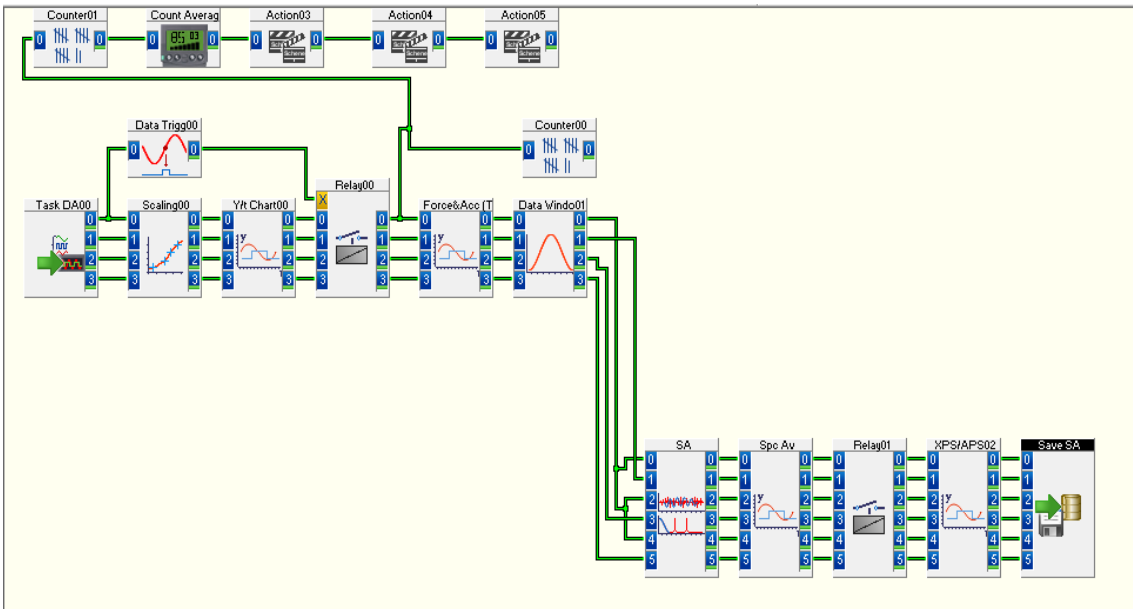


Figure 3.6: Schematic diagram at DASYlab 10.0

The data experimental modal analysis from DASYlab 10.0 is carried out by using ME'scope software. 3D models with simple are easily built in ME'scopeVES by using the Drawing Assistant. More complex models can be built by repeatedly using the Drawing Assistant to model the structure using several simpler Substructures. Substructures choose is cylinder and a grid of Points with 4 points in the Global X direction of 360^o for 4 flute and with 3 points in the Global X direction of 360^o for 3 flute. The setting of the dimension is shown in figure 3.7.

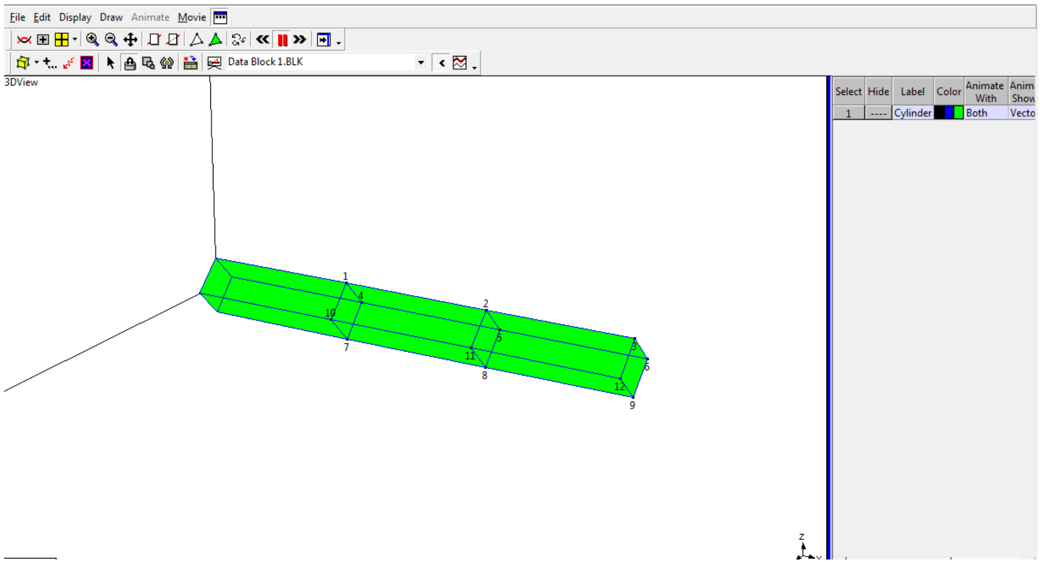


Figure 3.7: Dimension of plate

In ME'scopeVES, each Point on a 3D model is animated using Animation Equations. Each Point has its own Animation Equations. Measured Points (Points were measurements were made) are animated using Measured Animation Equations. Before that, the Points on the 3D model must be numbered to match the Point numbers in the Roving DOFs of the FRF Traces. Structure Points are numbered by editing their Point Labels. Figure 3.8 shows 3D views during point numbering.

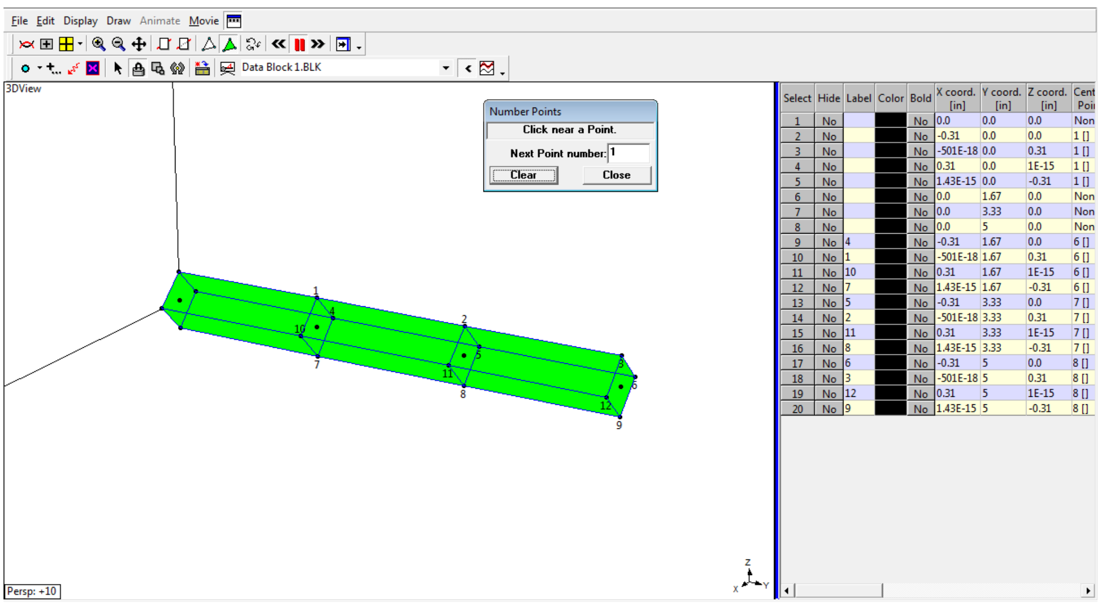


Figure 3.8: 3D View during point numbering.

ME'scopeVES contains SDOF (single mode), MDOF (multiple modes) and Multiple Reference curve fitting methods for estimating modal parameters from experimental data. Since ME'scopeVES displays both ODS's & mode shapes, can see the differences and correlate the two. The figure 3.9 shows curves fitting of number frequency for choose number of modes. With the UMM result can be animated a plate model for getting modes shape.

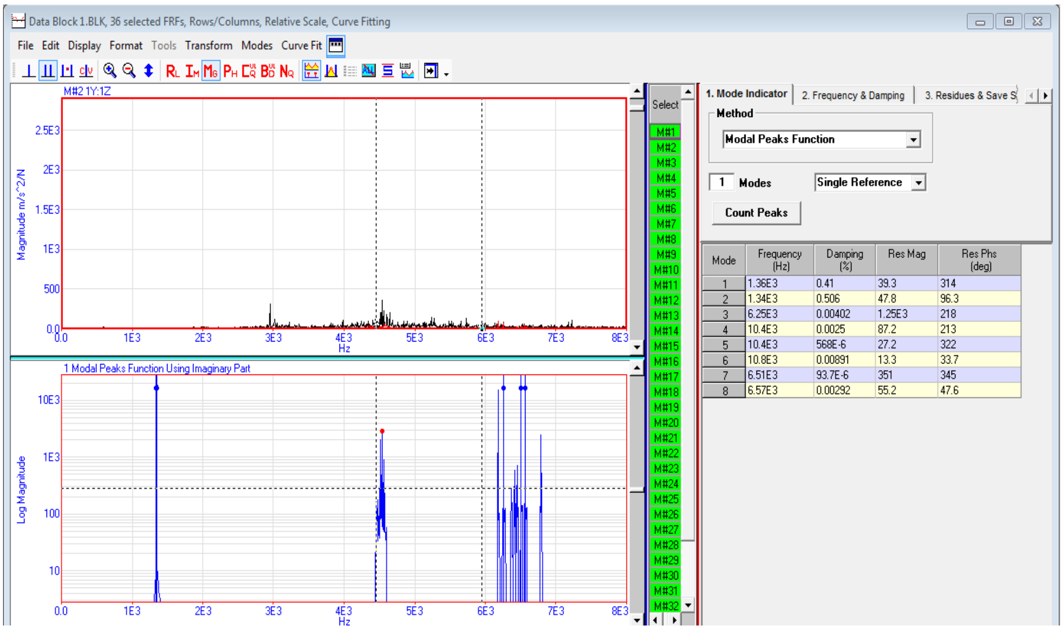


Figure 3.9: Curve fitting of number frequency

3.5.4 Modal Testing Test Rig

Test rig for this project was conducted by using vertical milling machine. The cutting tools were attached to the vertical milling machine and doing modal testing to get the results as shown in figure 3.10 below.

Figure 3.10: Vertical Milling Machine as test rig

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

In this chapter, the results from the computational and experimental will be compared and discussed. The study was carried out using ANSYS software for the finite element analysis (FEA) and experimental analysis using impact hammer testing. There will be discussion about dynamic properties and behaviour and comparative study between experimental and numerical analysis.

There are three types of cutting tools through this modal analysis that is 3flute End Mill, 4flute End Mill and 4flute Variable Helix End Mill. Since there is having two types of 4flute End Mill, variable helix once and the other not, the comparison made between these two for the difference in their result. The comparison also made between 3flute and 4flute End Mill.

4.2 RESULT OF MODAL ANALYSIS OF CNC MACHINE CUTTING TOOLS

CNC machine cutting tools have many different types. So, choosing the several types of cutting tools for modal analysis made by using the common cutting tools of CNC machines. The cutting tools choose for the modal testing shown in the figures below.

(a) (b) (c)

Figure 4.1: (a) 3flute End Mill, (b) 4flute End Mill, (c) 4flute Variable Helix End Mill

4.3 RESULT OF NATURAL FREQUENCY

Natural frequency was an excitation frequency that produces one exaggerated response. This is important because resonant frequency a structure will often produce adverse effects which involve excessive vibration leading to potential fatigue failures, damage to the most delicate parts of the structure or, in extreme cases, complete structural failure.

4.3.1 Natural Frequency Of Finite Element Analysis (Fea)

Modal analysis is done by using ANSYS finite element analysis (FEA) to determine the natural frequency of CNC machine cutting tools. From the natural frequencies, damping in the system can be neglected. The table 4.1 until 4.3 shows the frequency, max displacement and min displacement of each mode. Range of frequency between 800Hz to 8000Hz for 3 flute and 4 flute End Mill, and 1000Hz to 11000Hz for 4 flute Variable Helix End Mill.

Table 4.1: Frequency and displacement of 3 flute CNC cutting tool (Finite Element Analysis)

Mode	Mode Frequency (Hz)	Max. Displacement (Mm)
1	886.9	5.6112
2	887.44	5.6123
3	4468.1	7.1999
4	4472.2	7.2316
5	7709.6	5.8250

Table 4.2: Frequency and displacement of 4 flute CNC cutting tool (Finite Element Analysis)

Mode	Mode Frequency (Hz)	Max. Displacement (Mm)
1	829.97	5.2491
2	830.7	5.2495
3	4412.3	6.2706
4	4417.5	6.2692
5	7296.2	5.4911

Table 4.3: Frequency and displacement of 4 flute Variable Helix CNC cutting tool (Finite Element Analysis)

Mode	Mode Frequency (Hz)	Max. Displacement (Mm)
1	1278.2	5.6328
2	1282.2	5.6061
3	6236.8	6.5282
4	6452.1	6.4312
5	10080	6.3201

4.3.2 Natural Frequency Of Experimental Modal Analysis

Experimental modal analysis is done by using impact hammer testing to determine mode shape of CNC machine cutting tools. From the experimental analysis, a set data is collected during the impact hammer testing. The testing is made within 3 points selected at every angle of 90^o for 4flute End Mill and within 3 points selected at every angle of 120^o for 3flute End Mill. The total of points at every angle is 12 points on the 4flute End Mill and 4flute Variable Helix End Mill each, and 9 points on the 3flute End Mill. The table 4.4 until 4.6 shows frequency and displacement of CNC machine cutting tools of each mode. Range of frequency between 800Hz to 8000Hz for 3flute and 4flute End Mill, and 1000Hz to 11000Hz for 4flute Variable Helix End Mill.

Table 4.4: Frequency and displacement of 3 flute CNC machine cutting tools (Experimental Modal Analysis)

Mode	Frequency (Hz)	Max. Displacement (Mm)
1	901	110
2	928	108
3	4470	249
4	4580	5820
5	7770	2290

Table 4.5: Frequency and displacement of 4 flute CNC machine cutting tools (Experimental Modal Analysis)

Mode	**Frequency (Hz)**	**Max. Displacement (Mm)**
1	840	0.226
2	861	11.07
3	4480	130
4	4510	269
5	7370	182

Table 4.6: Frequency and displacement of 4 flute Variable Helix CNC machine cutting tools (Experimental Modal Analysis)

Mode	**Frequency (Hz)**	**Max. Displacement (Mm)**
1	1340	196
2	1360	267
3	6250	1570
4	6510	2300
5	10800	6650

Below are the graph comparison of natural frequency versus mode for all the cutting tools. The graph including the theoretical and experimental data and from this graph showing the closest result between them.

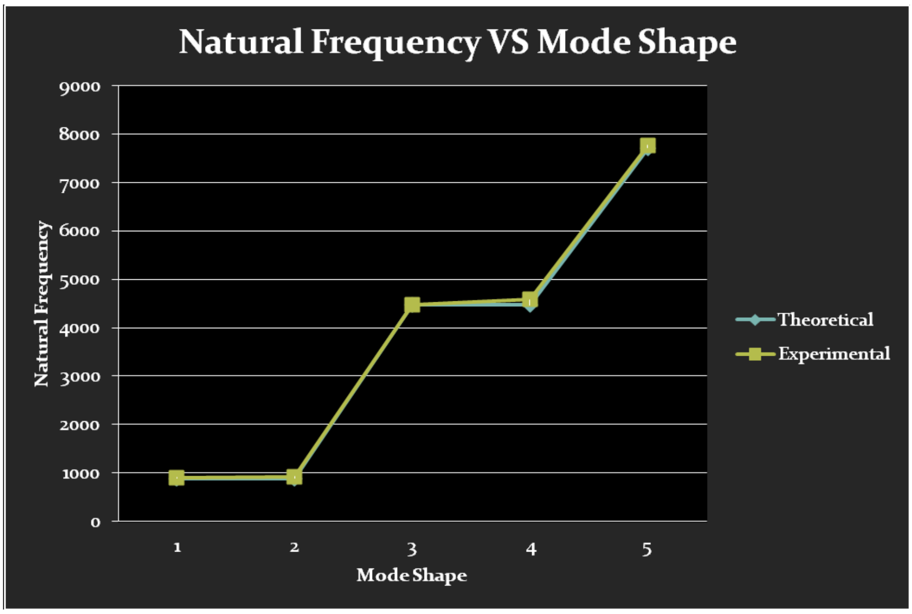


Figure 4.2: Graph 3flute End Mill

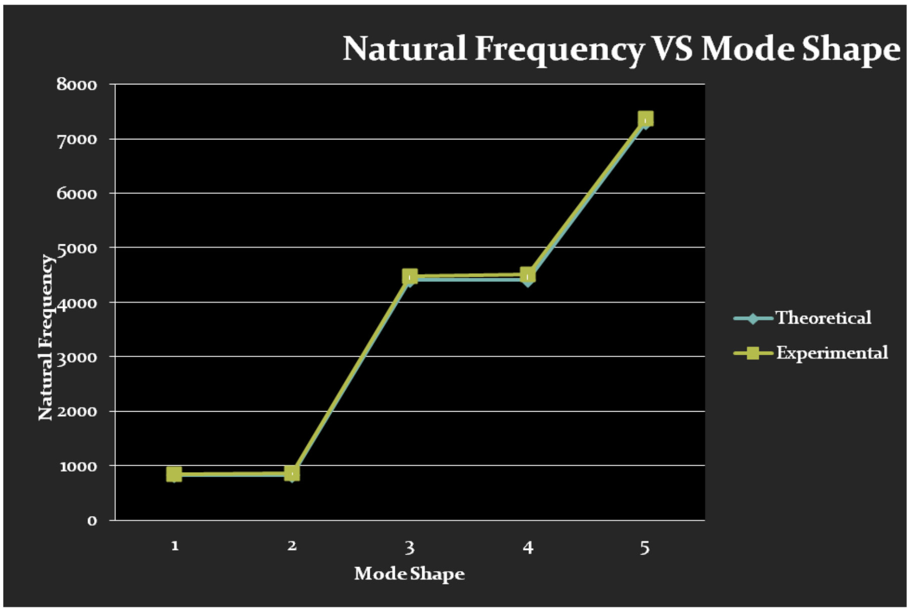


Figure 4.3: Graph 4flute End Mill

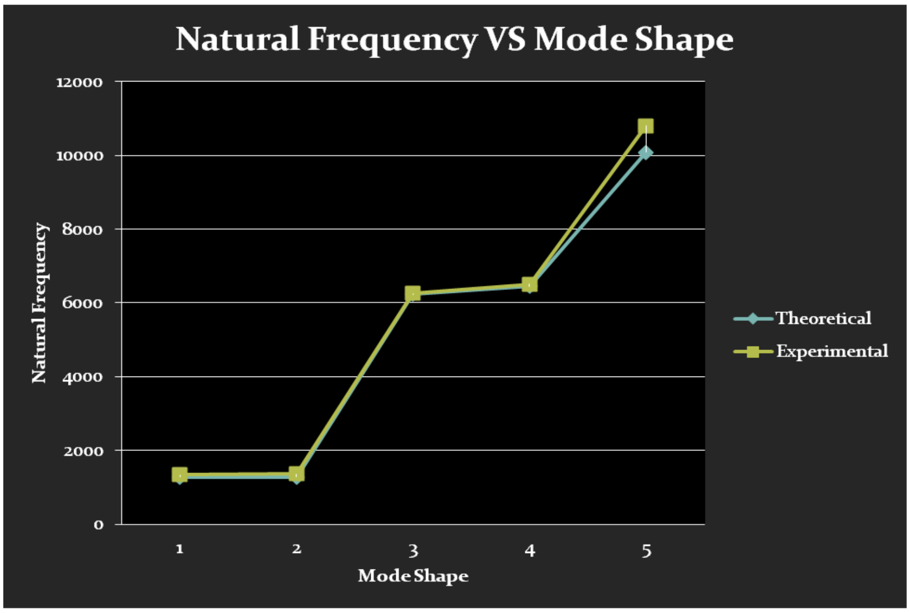


Figure 4.4: Graph 4flute Variable Helix End Mill

4.3.3 Comparative Study On Result For Both Experiments

Table 4.7 until 4.9 shows natural frequencies obtained from the finite-element models and experimental modal testing of CNC machine cutting tools and the amount percentage of their errors in the different cases. For 3flute End Mill, mode shape 3 had the lowest percentage error while mode 2 had the highest percentage error in the result. For 4flute End Mill, mode shape 5 had the lowest percentage error while mode 2 had the highest percentage error in the result. For 4flute Variable Helix End Mill, mode shape 3 had the lowest percentage error while mode 5 had the highest percentage error in the result. The highest percentage error is because of the differences natural frequencies are bigger and the lowest percentage error is because of the differences natural frequencies is smaller.

Table 4.7: Comparison of natural frequency analysis Between FEA and Experimental Modal Analysis for 3flute End Mill

Mode Shape	**Theoretical**	**Experimental**	**Error (%)**
1	886.9	901	1.59
2	887.44	928	4.57
3	4468.1	4470	0.04
4	4472.2	4580	2.41
5	7709.6	7770	0.78

Table 4.8: Comparison of natural frequency analysis Between FEA and Experimental Modal Analysis for 4flute End Mill

Mode Shape	**Theoretical**	**Experimental**	**Error (%)**
1	829.97	840	1.21
2	830.7	861	3.65
3	4412.3	4480	1.53
4	4417.5	4510	2.09
5	7296.2	7370	1.01

Table 4.9: Comparison of natural frequency analysis Between FEA and Experimental Modal Analysis for 4flute Variable Helix End Mill

Mode Shape	**Theoretical**	**Experimental**	**Error (%)**
1	1278.2	1340	4.83
2	1282.2	1360	6.07
3	6236.8	6250	0.21
4	6452.1	6510	0.89
5	10080	10800	7.14

4.4 RESULT OF MODE SHAPES

Mode shapes were deformation patterns at resonant frequencies. At these resonant frequencies take on a variety of different shapes depending on the excitation force frequency. These deformation patterns are referred to as the structure's mode shapes.

4.4.1 Mode Shapes Of ANSYS Finite Element Analysis

Modal analysis is done by using ANSYS finite element analysis (FEA) to determine mode shape of CNC machine cutting tools. From the mode shapes, damping in the system can be neglected since there is no damping effect on FEA. The figure shows the deformation patterns that will result when the excitation coincides with one of the natural frequencies of the system.

4.4.2 Mode Shapes Of Experimental Analysis

From the experimental analysis, a set data is collected during the impact hammer testing. The testing is made within 3 points selected at every angle of 90^o for 4flute End Mill and within 3 points selected at every angle of 120^o for 3flute End Mill. The total of points at every angle is 12 points on the 4flute End Mill and 4flute Variable Helix End Mill each, and 9 points on the 3flute End Mill. This pattern deformation referred to as mode shape structure and this pattern of deformation very close to the mode shapes.

4.5 COMPARISON OF MODE SHAPES BETWEEN FEA AND EXPERIMENTAL MODAL ANALYSIS

Accelerometers distributed on the plate and measure the amplitude of the response of the plate with different excitation frequencies. The figure 4.5 shows the deformation patterns that will result when the excitation coincides with one of the natural frequencies of the system. At the first natural frequency, there is a first bending deformation pattern in the plate shown in blue (mode 1). At the second natural frequency, there is a first twisting deformation pattern in the plate shown in red (mode 2). When dwell at the third and fourth natural frequencies, the second bending and second twisting deformation patterns are seen in green (mode 3) and magenta (mode 4), respectively. These deformation patterns are referred to as the mode shapes of the structure. In this project, the result of pattern deformation in mode shape valid with Peter Avitabile, University of massachusetts Lowell.

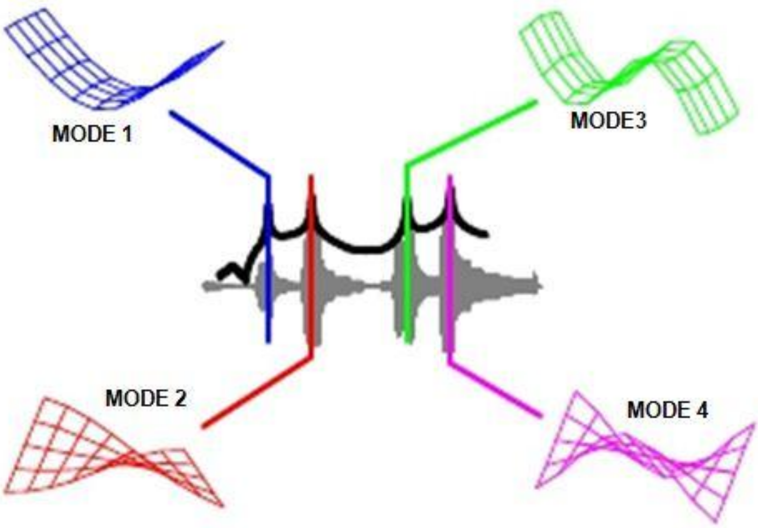
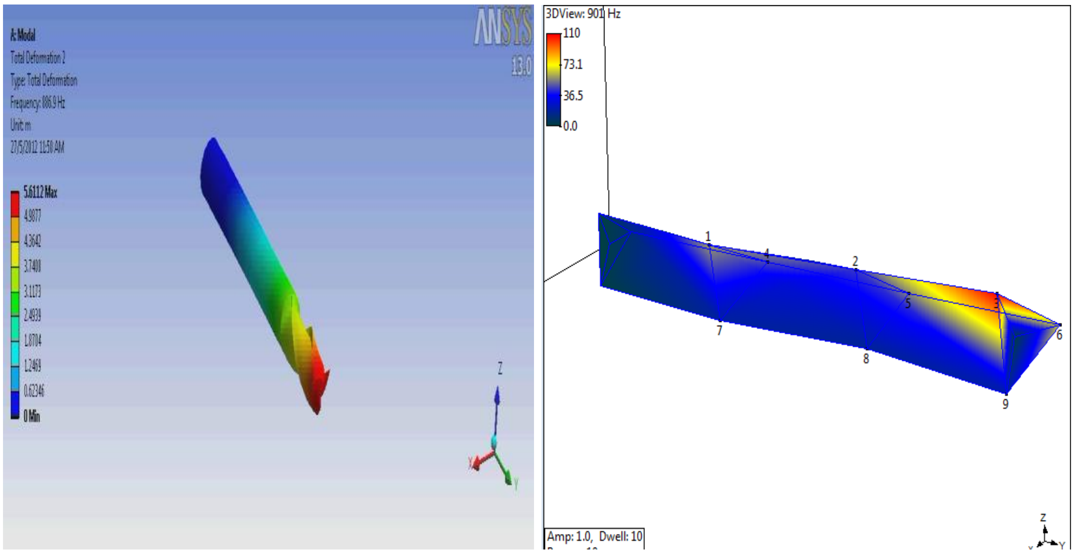


Figure 4.5: Simple plate sine dwell response

Source: Peter Avitabile, 2001

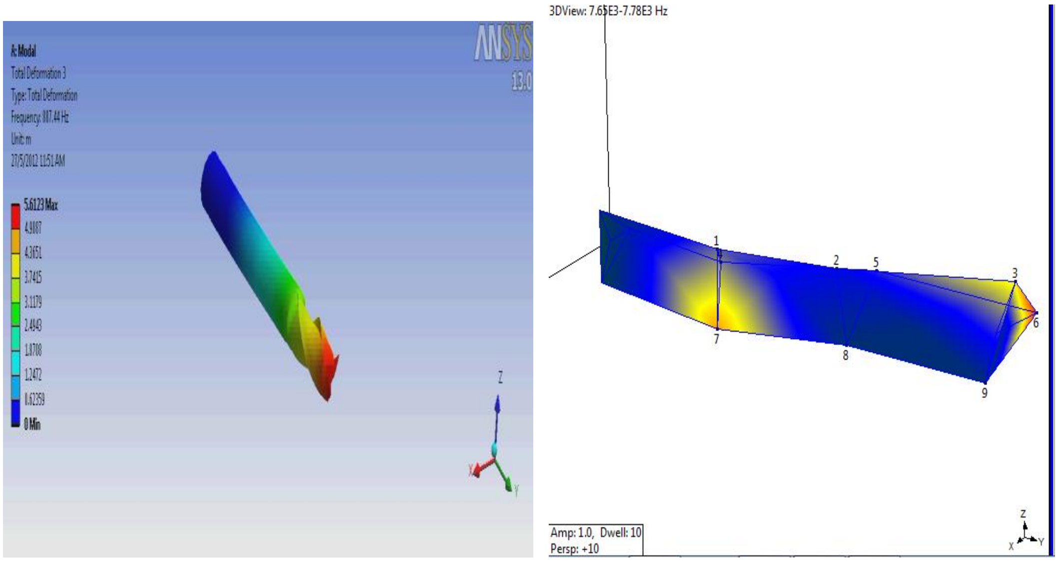
4.5.2 Result Of 3flute End Mill



(a) (b)

Figure 4.6: First mode shape of 3flute End Mill, (a) Finite element analysis, (b) Experimental modal analysis

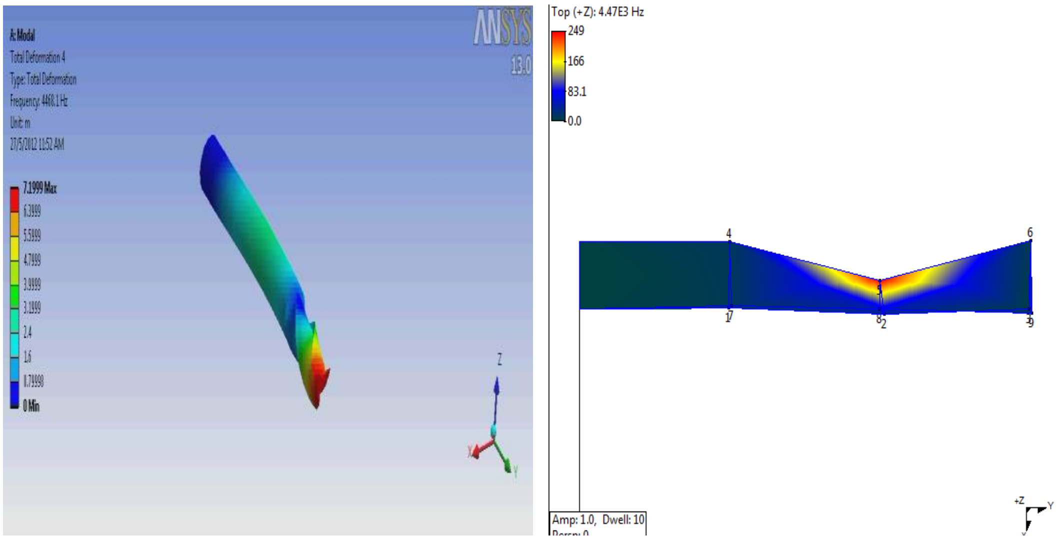
Figure 4.6 shows the first mode of 3flute End Mill is first bending one deformation pattern of the plate. The frequency of mode in finite element analysis (FEA) is 886.9 Hz which the maximum shift mode is 5.6112mm and minimum shift 0mm. The frequency of mode in experimental modal testing is 901 Hz which the maximum shift mode is 110mm and minimum shift 0mm. The red colour represented as the maximum displacements occur in the mode and the colour blue is a minimum shift. The one end of the simulation has been always in blue colour and have a minimum displacement with 0mm because the end of the cutting tool is fixed. This is same to all cutting tool simulation.



(a) (b)

Figure 4.7: Second mode shape of 3flute End Mill, (a) Finite element analysis, (b) Experimental modal analysis

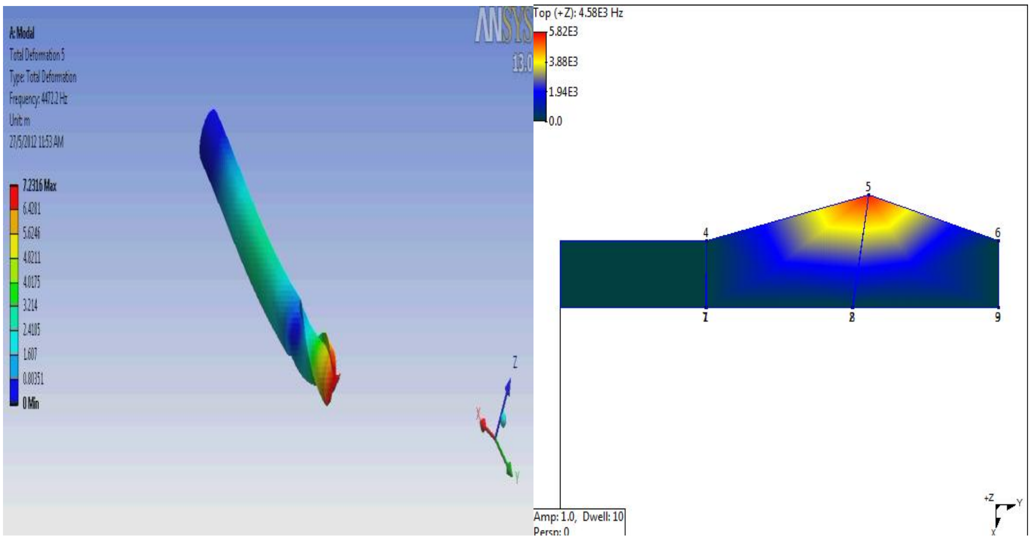
Figure 4.7 shows the second mode of 3flute End Mill is first bending two deformation pattern of the plate. The frequency of mode in finite element analysis (FEA) is 887.44 Hz which the maximum shift mode is 5.6123mm and minimum shift 0mm. The frequency of mode in experimental modal testing is 928 Hz which the maximum shift mode is 108mm and minimum shift 0mm.The red colour represented as the maximum displacements occur in the mode and the colour blue is a minimum shift.



(a) (b)

Figure 4.8: Third mode shape of 3flute End Mill, (a) Finite element analysis, (b) Experimental modal analysis

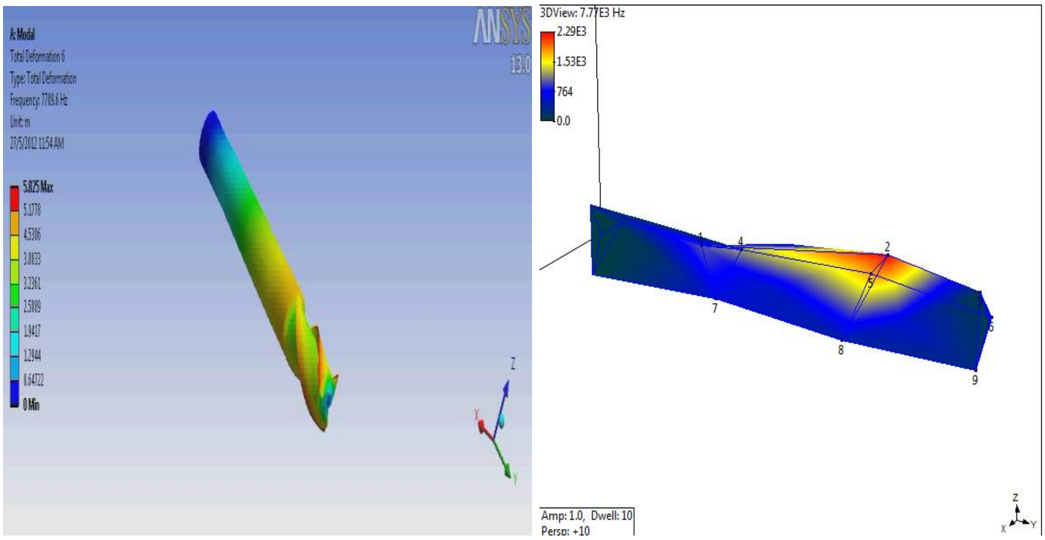
Figure 4.8 shows the third mode of 3flute End Mill is second bending one deformation pattern of the plate. The frequency of mode in finite element analysis (FEA) is 4468.1 Hz which the maximum shift mode is 7.1999mm and minimum shift 0mm. The frequency of mode in experimental modal testing is 4470 Hz which the maximum shift mode is 249mm and minimum shift 0mm.The red colour represented as the maximum displacements occur in the mode and the colour blue is a minimum shift.



(a) (b)

Figure 4.9: Fourth mode shape of 3flute End Mill, (a) Finite element analysis, (b) Experimental modal analysis

Figure 4.9 shows the fourth mode of 3flute End Mill is second bending two deformation pattern of the plate. The frequency of mode in finite element analysis (FEA) is 4472.2 Hz which the maximum shift mode is 7.2316mm and minimum shift 0mm. The frequency of mode in experimental modal testing is 4580 Hz which the maximum shift mode is 5820mm and minimum shift 0mm.The red colour represented as the maximum displacements occur in the mode and the colour blue is a minimum shift.



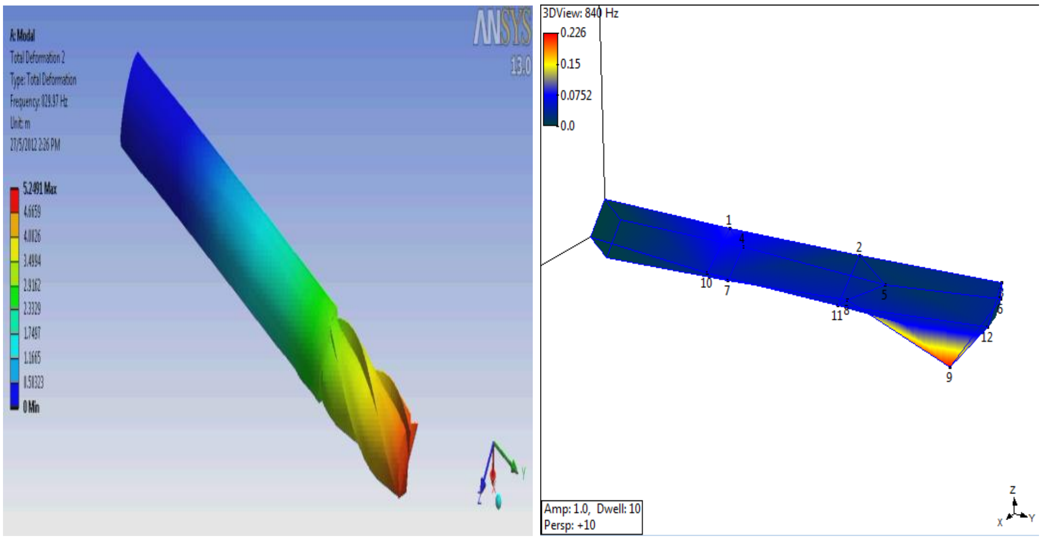
(a) (b)

Figure 4.10: Fifth mode shape of 3flute End Mill, (a) Finite element analysis, (b) Experimental modal analysis

Figure 4.10 shows the fifth mode of 3flute End Mill is a twisting deformation pattern of the plate. The frequency of mode in finite element analysis (FEA) is 7709.6 Hz which the maximum shift mode is 5.825mm and minimum shift 0mm. The frequency of mode in experimental modal testing is 7770 Hz which the maximum shift mode is 2290mm and minimum shift 0mm.The red colour represented as the maximum displacements occur in the mode and the colour blue is a minimum shift.

From all the mode shapes, the stiffness dynamic behaviour for 3flute End Mill is smaller and almost similar to the 4flute End Mill because the mass of this cutting tool is the second heavier after 4flute End Mill. The stability of this cutting tool is the low stable compared to 4flute Variable Helix but stable compared to 4flute.

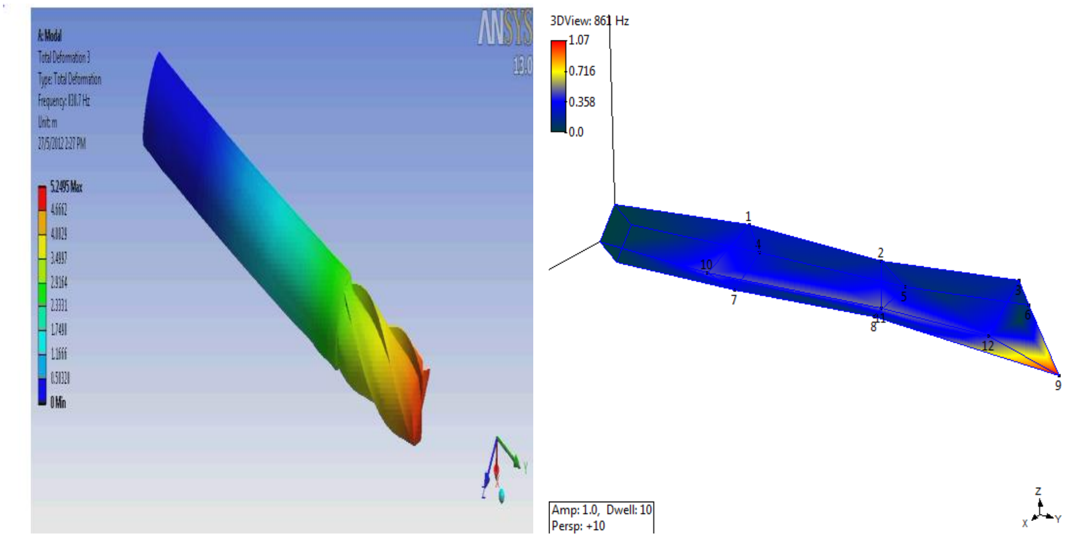
4.5.1 Result Of 4flute End Mill



(a) (b)

Figure 4.11: First mode shape of 4flute End Mill, (a) Finite element analysis, (b) Experimental modal analysis

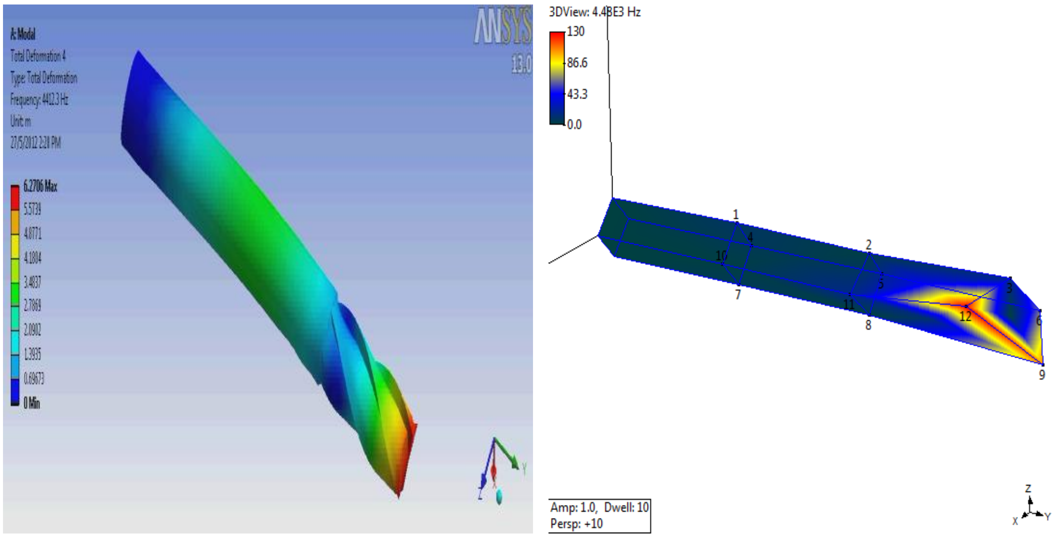
Figure 4.11 shows the first mode of 4flute End Mill. The first mode is first bending one deformation pattern of the plate. The frequency of mode in finite element analysis (FEA) is 829.97 Hz which the maximum shift mode is 5.2491mm and minimum shift 0mm. The frequency of mode in experimental modal testing is 840 Hz which the maximum shift mode is 0.226mm and minimum shift 0mm.The red colour represented as the maximum displacements occur in the mode and the colour blue is a minimum shift.



(a) (b)

Figure 4.12: Second mode shape of 4flute End Mill, (a) Finite element analysis, (b) Experimental modal analysis

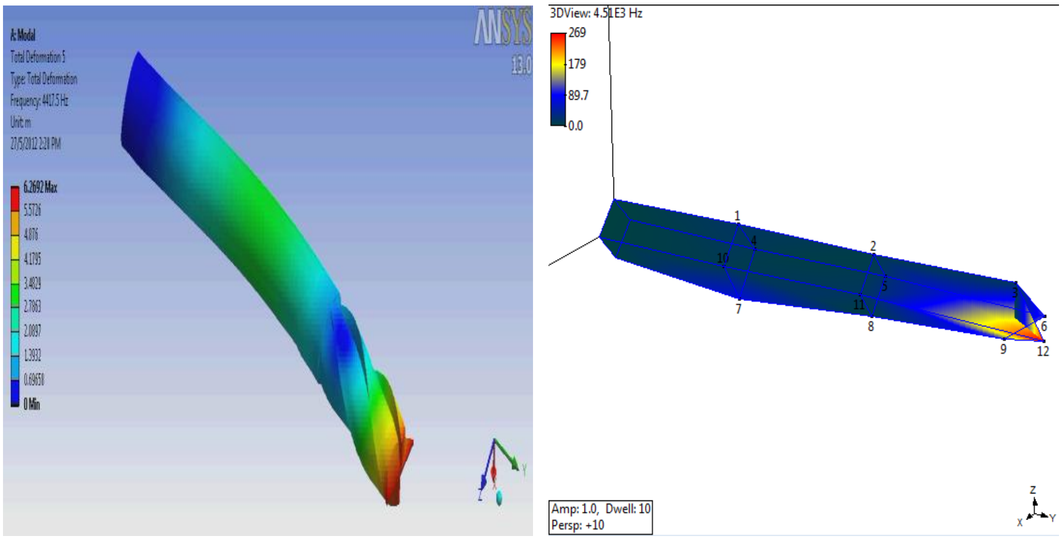
Figure 4.12 shows the second mode of 4flute End Mill is first bending two deformation pattern of the plate. The frequency of mode in finite element analysis (FEA) is 830.7 Hz which the maximum shift mode is 5.2495mm and minimum shift 0mm. The frequency of mode in experimental modal testing is 861 Hz which the maximum shift mode is 11.07mm and minimum shift 0mm.The red colour represented as the maximum displacements occur in the mode and the colour blue is a minimum shift.



(a) (b)

Figure 4.13: Third mode shape of 4flute End Mill, (a) Finite element analysis, (b) Experimental modal analysis

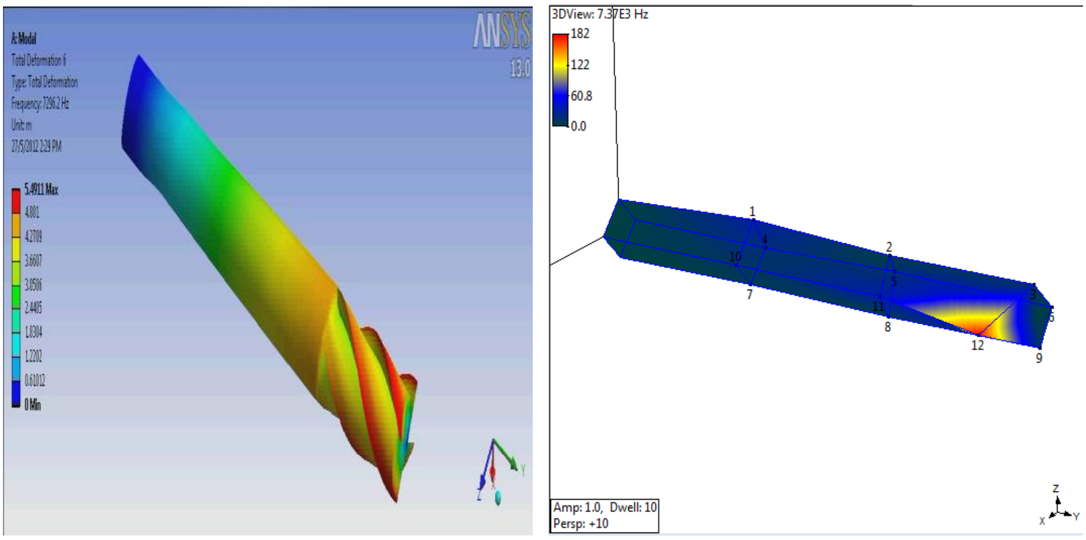
Figure 4.13 shows the third mode of 4flute End Mill is second bending one deformation pattern of the plate. The frequency of mode in finite element analysis (FEA) is 4412.3 Hz which the maximum shift mode is 6.2706mm and minimum shift 0mm. The frequency of mode in experimental modal testing is 4480 Hz which the maximum shift mode is 130mm and minimum shift 0mm.The red colour represented as the maximum displacements occur in the mode and the colour blue is a minimum shift.



(a) (b)

Figure 4.14: Fourth mode shape of 4flute End Mill, (a) Finite element analysis, (b) Experimental modal analysis

Figure 4.14 shows the fourth mode of 4flute End Mill is second bending two deformation pattern of the plate. The frequency of mode in finite element analysis (FEA) is 4417.5 Hz which the maximum shift mode is 6.2692mm and minimum shift 0mm. The frequency of mode in experimental modal testing is 4510 Hz which the maximum shift mode is 269mm and minimum shift 0mm.The red colour represented as the maximum displacements occur in the mode and the colour blue is a minimum shift.



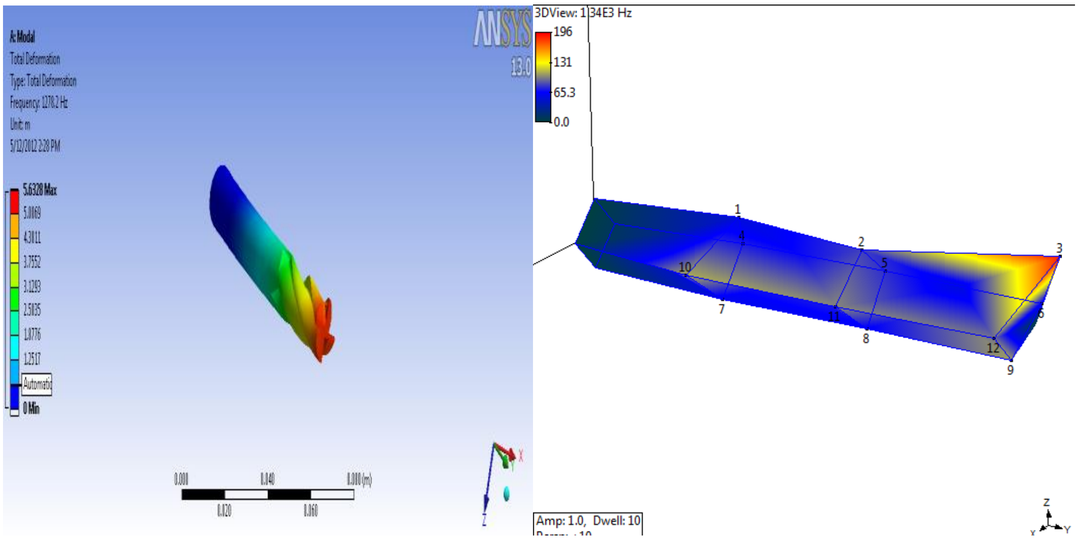
(a) (b)

Figure 4.15: Fifth mode shape of 4flute End Mill, (a) Finite element analysis, (b) Experimental modal analysis

Figure 4.15 shows the fifth mode of 4flute End Mill is a twisting deformation pattern of the plate. The frequency of mode in finite element analysis (FEA) is 7296.2 Hz which the maximum shift mode is 5.4911mm and minimum shift 0mm. The frequency of mode in experimental modal testing is 7370 Hz which the maximum shift mode is 182mm and minimum shift 0mm.The red colour represented as the maximum displacements occur in the mode and the colour blue is a minimum shift.

From all the mode shapes, the stiffness dynamic behaviour for 4flute End Mill is smaller because the mass of this cutting tool is the heaviest and the stability of this cutting tool is the lowest stable compared to the other two cutting tools.

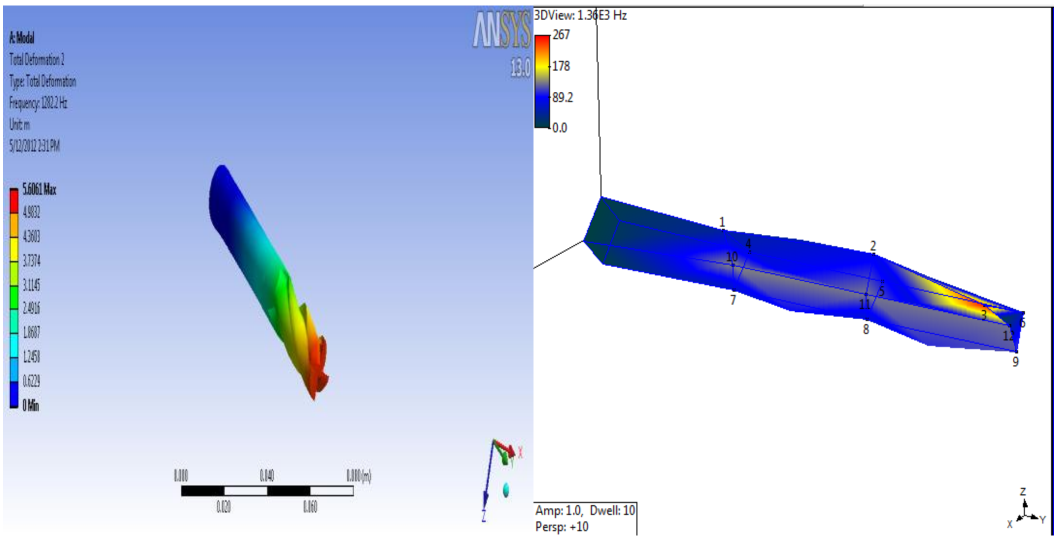
4.5.3 Result Of 4flute Variable Helix End Mill



(a) (b)

Figure 4.16: First mode shape of 4flute Variable Helix End Mill, (a) Finite element analysis, (b) Experimental modal analysis

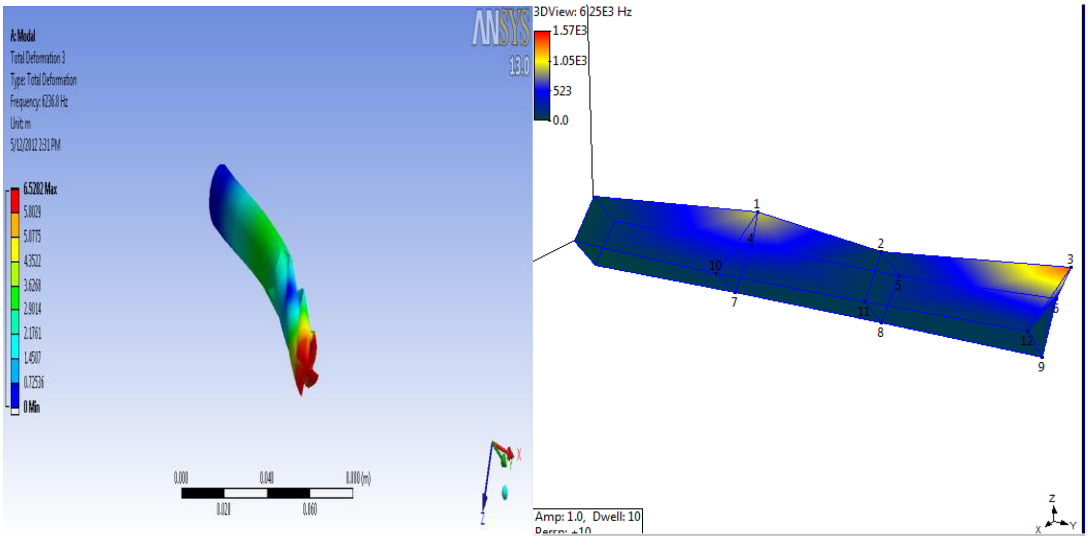
Figure 4.16 shows the first mode shape of 4flute Variable Helix End Mill, there is a first bending one deformation pattern. For finite element analysis (FEA), the frequency of the mode is 1278.2 Hz. The maximum displacement of the mode is 5.6328 mm and minimum displacement is 0mm. For experimental modal testing, the frequency of the mode is 1340 Hz. The maximum displacement of the mode is 196 mm and minimum displacement is 0 mm. The red colour indicates the maximum displacement occurred in the mode and blue colour is minimum displacement.



(a) (b)

Figure 4.17: Second mode shape of 4flute Variable Helix End Mill, (a) Finite element analysis, (b) Experimental modal analysis

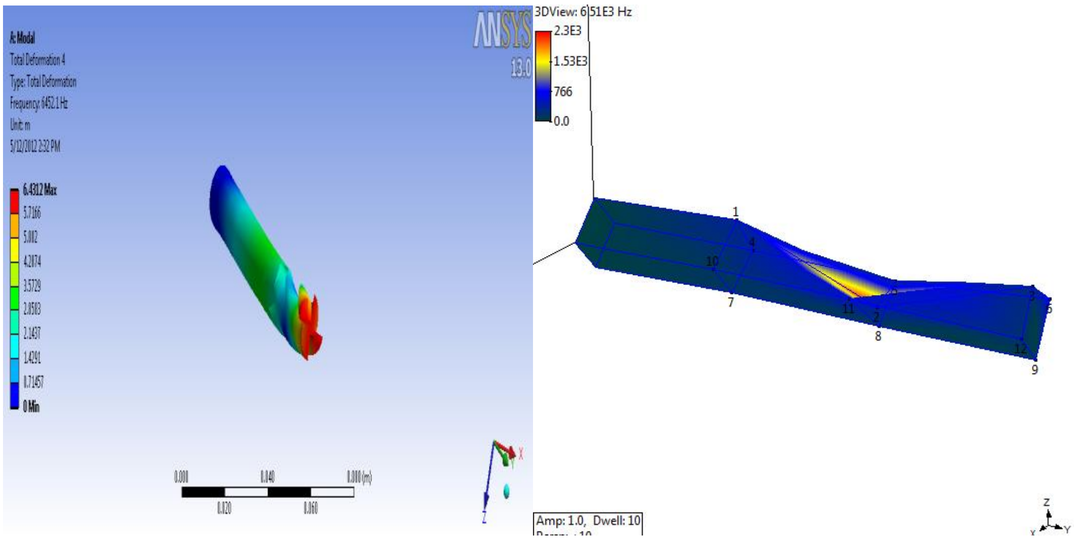
Figure 4.17 shows the second mode shape of 4flute Variable Helix End Mill, there is a first bending two deformation pattern. For finite element analysis (FEA), the frequency of the mode is 1282,2 Hz. The maximum displacement of the mode is 5.6061 mm and minimum displacement is 0 mm. For experimental modal testing, the frequency of the mode is 1360 Hz. The maximum displacement of the mode is 267 mm and minimum displacement is 0 mm. The red colour indicates the maximum displacement occurred in the mode and blue colour is minimum displacement.



(a) (b)

Figure 4.18: Third mode shape of 4flute Variable Helix End Mill, (a) Finite element analysis, (b) Experimental modal analysis

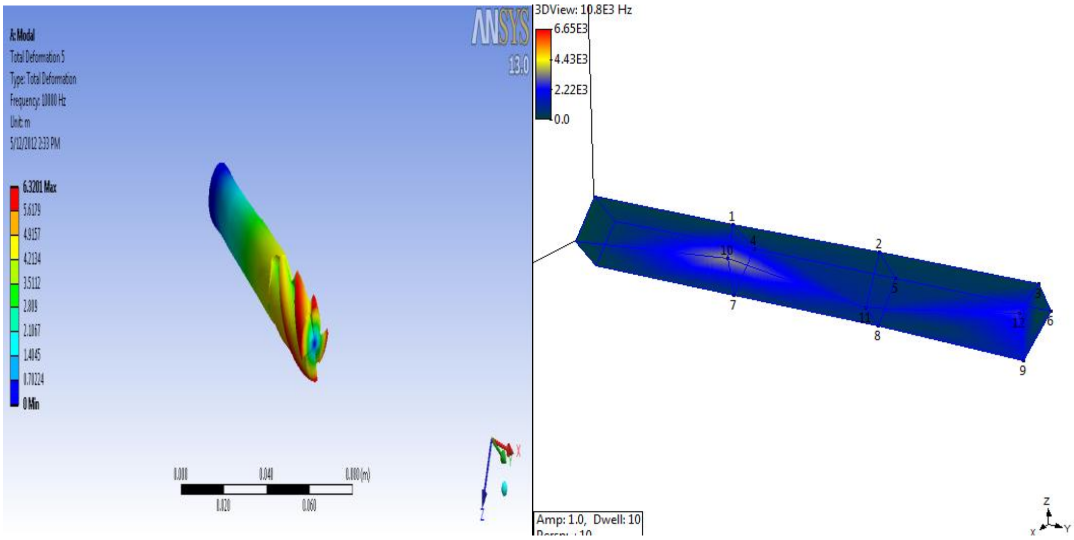
Figure 4.18 shows the third mode shape of 4 flute Variable Helix End Mill, there is a second bending one deformation pattern. For finite element analysis (FEA), the frequency of the mode is 6236.8 Hz. The maximum displacement of the mode is 6.5282 mm and minimum displacement is 0 mm. For experimental modal testing, the frequency of the mode is 6250 Hz. The maximum displacement of the mode is 1570 mm and minimum displacement is 0 mm. The red colour indicates the maximum displacement occurred in the mode and blue colour is minimum displacement.



(a) (b)

Figure 4.19: Fourth mode shape of 4flute Variable Helix End Mill, (a) Finite element analysis, (b) Experimental modal analysis

Figure 4.19 shows the fourth mode shape of 4flute Variable Helix End Mill, there is a second bending two deformation pattern. For finite element analysis (FEA), the frequency of the mode is 6452.1 Hz. The maximum displacement of the mode is 6.4312 mm and minimum displacement is 0 mm. For experimental modal testing, the frequency of the mode is 6510 Hz. The maximum displacement of the mode is 2300 mm and minimum displacement is 0 mm. The red colour indicates the maximum displacement occurred in the mode and blue colour is minimum displacement.



(a) (b)

Figure 4.20: Fifth mode shape of 4flute Variable Helix End Mill, (a) Finite element analysis, (b) Experimental modal analysis

Figure 4.20 shows the fifth mode shape of 4flute Variable Helix End Mill, there is a twisting deformation pattern. For finite element analysis (FEA), the frequency of the mode is 10080 Hz. The maximum displacement of the mode is 6.3201 mm and minimum displacement is 0 mm. For experimental modal testing, the frequency of the mode is 10800 Hz. The maximum displacement of the mode is 6650 mm and minimum displacement is 0 mm. The red colour indicates the maximum displacement occurred in the mode and blue colour is minimum displacement.

From all the mode shapes, the stiffness dynamic behaviour for 4flute Variable Helix End Mill is bigger because the mass of this cutting tool is the lighter. The stability of this cutting tool is the stable one compared to the other two cutting tools.

The stability of the cutting tool because of the distortion of the cutting tool. The order of distortion significantly from the most to the less is followed by 4flute, 3flute and 4flute Variable Helix End Mill.

4.6 DISCUSSION OF COMPARISON

A comparison of calculating modes with their measured counterparts is very helpful in general to verify the quality of an FE model for dynamic simulation purposes and to detect any possible improvements. The objective of modal analysis in structural mechanics is to determine the natural mode shapes and frequencies of an object or structure during free vibration. From the obtained result of this study it showed the comparison between FEA and experimental is showing the closeness result and also have slight differences. The vibration modes of 3 flute End Mill are almost similar to the vibration modes of 4 flute End Mill, respectively. The ranges are between 800Hz to 8000Hz for both. The vibration frequency region of 4 flute Variable Helix End Mill between 1000Hz to 11000Hz is much higher than the vibration frequencies of 4 flute End Mill. The percentage error levels for all the cutting tools are within the accepted range and the high error in some of them might be referred to the boundary conditions specification, because it is not easy to simulate the realistic boundary conditions for such complicated system comparison. Suitable frequency ranges for end milling will be up to 12000Hz said by Anayet U. Patwari et al, 2009. So, all the frequency ranges for all the cutting tools are within the suitable ranges for end milling.

From the results of mode shape, distortion of 4 flute End Mill is more significant than the 3 flute End Mill and distortion of 4 flute End Mill also more significant than the 4 flute Variable Helix End Mill. In therm of physics, the mass of 4 flute that optimize lighter than the other two cutting tools. Another reason that may be causing the high percentage error levels in the comparative study is the experimental modal analysis is conducted with fix condition of the cutting tools by using vertical milling machine as test rig and the effect of damping. The vibration on the machine and the noise from environment since the machine has at wide area also affected the result. While doing the experiment, the room is also not completely silent. Even though the room is soundproofed, but the door is left open and there will be noise come from the outside by accident and affect the result of the experiment.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 INTRODUCTION

This chapter will conclude the project and briefly discussed about the recommendation that can be applied in the future work. The conclusion obtained according to the result from chapter 4. In order to study the dynamic properties and behaviour of CNC milling cutting tool, other aspects of future work also will be discussed.

5.2 CONCLUSIONS

The aim of this project is to determine the dynamic properties and behaviour of CNC milling cutting tool using experimental modal analysis and comparison with the finite element analysis (FEA).

In this project a finite element model is used to analyse the mode frequencies and shapes of CNC cutting tools and hence compare the results with the experimental one. This model is produced in SOLIDWORK software based on the real dimensions of the End Mill cutting tool of CNC machine and analysis was done by ANSYS software. According to the model analysis, the natural frequencies and vibration modes shape of the model in all three types of cutting tool cases were determined and evaluated. The comparison between natural frequencies of finite element modeling and model testing shows the closeness of the results. Based on this study, the following conclusion can be drawn.

i. Natural frequency and mode shape between 4 Flute and 4 Flute Variable Helix showing big difference.
ii. Natural frequency and mode shape between 3 Flute and 4 Flute showing small difference.
iii. Comparison natural frequency shows the closeness of the result and mode shape between experimental and FEA.
iv. The natural frequency range from highest to lowest followed by 4 Flute Variable Helix, 3 Flute and 4 Flute End Mill.
v. The percentage error is occur because there are some errors occur during the experimental modal analysis. The experimental modal analysis is conducted with fix condition of CNC milling cutting tools and the effect of damping which effect test rig by vertical milling machine as a cutting tool holder is a factor of the percentage error.

This research work will help to find out the natural frequencies of the CNC milling cutting tool and hence predicting the chatter formation zone as resonance phenomena.

5.3 RECOMMENDATIONS

For the recommendation, there are few improvements need to be done for the future research. This is to improve the accuracy of the predicted dynamic properties of CNC milling cutting tool. Some of the recommendations are:

i. Choosing the other CNC milling cutting tool that has been optimized and common used as model of modal analysis.
ii. Use CNC machine or other as a test rig to minimize the effect of damping and get the best signal of vibration.
iii. The research is carried out in a completely soundproofed room and only the person doing the experiment is allowed to be in the room while doing the experiment.

iv. The tool to hold the cutting tool for experimental modal analysis must not affect the mass of cutting tool while doing experiments since the mass can give effect to the result of the experiment.

REFERENCES

Anayet U. Patwari, Waleed F. Faris, A. K. M. Nurul Amin, and S.K.Loh, *Dynamic 'Modal Analysis of Vertical Machining Centre Components'*, Advances in Acoustics and Vibration, Volume 2009,doi: 10.1155/2009/508076,2009.

Jahangir Ansari, '*Finite Element Vibration Analysis and Modal Testing of Bells'*, Virginia State University, Engineering and Tevhnology Learning Center,2006.

Brian J. Schwarz & Mark H. Richardson, '*Experimental modal analysis'*, Vibrant Technology, Inc. Jamestown, California 95327, 1999.

Shibabrat Naik, Wrik Mallik, '*Experimental Modal Testing For Estimeting The Dynamic Properties Of A Cantilever Beam'*, Department of Civil Engineering, Jadavpur University, Kolkata-700 032.

Dr. Sinan Badrawy, *'Dynamic Modeling And Analysis Of Motorized Milling Spindles For Optimizing The Spindle Cutting Performance'*, Engineering Manager Moore Nanotechnology Systems, LLC.

F. Bossens, R.A de Callafon, and R.E. Skelton, *'Modal Analysis of a Tensegrity Structure–an experimental study'*, Mechanical and Aerospace Engineering, Dynamic Systems and Control Group, University of California, San Diego, 9500 Gilman Drive, La Jolla, CA 92093-0411, U.S.A.

Patrick Guillaume, *'Modal Analysis'*, Department of Mechanical Engineering,Vrije Universiteit Brussel, Pleinlaan 2, B-1050 Brussel, Belgium.

Adam G. Rehorn, Jin Jiang, Peter E. Orban, and Evgueni Bordatchev, *'Modelling and experimental investigation of spindle and cutter dynamics for a high precision machining center'*, Int J Adv Manuf Technol 24: 806–815 DOI 10.1007/s00170-003-1794-8, 2004.

D J Ewins, *'Basics and state-of-the-art of modal testing'*, Department of Mechanical Engineering, Imperial College of Science, Technology and Medicine, London, UK, Vol. 25, Part 3, pp. 207-220, June 2000.

Peter Avitabile, *'Experimental Modal Analysis (A Simple Non-Mathematical Presentation'*, Modal Analysis and Controls Laboratory, Mechanical Engineering Department, University of Massachusetts Lowell, Lowell Massachusetts USA, Rev 052700, January 2001.

Teo Wei Heng, *'Theoretical and Experimental Modal Analysis on Selected Structures Using Forced Vibration Method'*, Faculty of Civil Engineering, University Technology of Malaysia, PSZ 19:16 (Pind. 1/97), April 2007.

R.M. Lin and J. Zhu, *'Model updating of damped structures using FRF data'*, Mechanical Systems and Signal Processing 20 (2006) 2200–2218, Mechanics of Micro-system (CMMS), School of Mechanical & Aerospace Engineering, Nanyang Technological University, 50 Nanyang Avenue, Singapore 639798, Singapore.

B. Peeters, LMS International, Interleuvenlaan 68, B-3001 Leuven, Belgium. Email:bart.peeters@lms.be and C. E. Ventura, Department of Civil Engineering, The University of British Columbia, 2324 Main Mall, Vancouver, BC, Canada. V6T-1Z4. E-mail:ventura@civil.ubc.ca, *'Comparative Study Of Modal Analysis Techniques For Bridge Dynamic Characteristics'*, Mechanical Systems and Signal Processing (2003) 17(5), 965–988 doi:10.1006/mssp.2002.1568

Neville F. Rieger. (2003). *'The Relationship Between Finite Elemen Analysis And Modal Analysis'*. 79 (2003) 405

APPENDICES

APPENDIX A1

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PROJECT ACTIVITIES		WEEK																											
		PSM 1														PSM 2													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11	12	13	14
INTRODUCTION (collect data and information)	PLAN	X																											
	ACTUAL	X	X	X																									
LITERATURE REVIEW (about the project)	PLAN		X	X	X	X	X	X	X	X	X																		
	ACTUAL		X	X	X	X	X	X	X	X	X	X																	
REVIEW OF MATERIAL AND EQUIPMENT	PLAN		X	X	X	X	X	X	X	X	X																		
	ACTUAL			X	X	X	X	X	X	X	X	X	X	X															
ANALYSIS USING FEA-ANSYS	PLAN								X	X	X	X	X	X	X														
	ACTUAL								X	X	X	X	X	X	X														
EXPERIMENTAL MODAL ANALYSIS	PLAN															X	X	X	X	X	X								
	ACTUAL															X	X	X	X	X	X	X	X						
COMPARATIVE BETWEEN FEA AND EXPERIMENTAL	PLAN																					X	X	X	X	X	X		
	ACTUAL																					X	X	X	X	X	X	X	
REPORT WRITING	PLAN		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	ACTUAL		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
PRESENTATION	PLAN														X														X
	ACTUAL														X														X

PLAN ACTUAL