AN EXPERIMENTEL STUDY OF LAMINATED RUBBER-METAL SPRING ON AXIAL VIBRATION

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This report is submitted in fulfillment in fulfillment of the requirement for the degree of Bachelor of Mechanical Engineering (Design and Innovation)

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MAY 2017

DECLARATION

"I admit that this report is all written by myself except for the summary and the article which I have stated the source for each of them"

Signature : ……………………………………

Name : ……………………………………

Date : ……………………………………

APPROVAL

"I/We approve that we have read this thesis thoroughly and in my/our opinion, this thesis has fulfilled the criteria covering all the aspects of scope and qualify and satisfied to be awarded for Bachelor of Mechanical Engineering (Design and Innovation)"

Signature : ……………………………………….

Name of Supervisor: ……………………………………

Date : ………………………………………

DEDICATION

To beloved family, friends and lecture who supported throughout to finish this report

ABSTRACT

Laminated rubber-metal spring or rubber spring are used widely as isolator for heavy industries. In this study was to investigate natural frequencies of the metal that have be laminate in rubber to absorb any shock. This study also focus have to clamp correctly those plate due to the shape of this plate is circular. To get measurement data, I have use DEWESOFT software. And I need to compare those data with calculated data, which is using formula natural of fixe-free circular beam for various vibration mode. Due to more than one laminated of metal, I have to investigate five modes of vibration of those plate. If the percentage error of the result not more than 10% it consider the result was correct and clamped of the plated is correct. In this study I provide several concept design of the clamp and need to test it, which concept are get close result with calculated data.

ABSTRAK

Lapisan logam-getah digunakan secara meluas dalam industri berat. Dalam kajian ini untuk menkaji kekerapan semulajadi logam yang digunakn didalam getah yang digunakan sebagai penyarap hentakan. Kajian ini fokus kepada untuk mengapit dengan betulnya disebabkan bentuk logam itu bulat. Untuk mendapat data ukuran saya menggunakan perisian DEWESOFT dan saya perlu bandingkan data ukuran tersebut dengan data pengiraan yang menggunakan formula untuk mencari kekerapan semulajadi kepingan logam bulat tetap-bebas bagi pelbagai mod getaran. Oleh sebab lapisan logam lebih dari satu, saya perlu mencari lima mod getaran kepingan tersebut. Jika ralat peratusan tidak lebih daripada 10% ia mempertimbangkan keputusan itu adalah betul dan diapit dengan betul. Dalam kajian ini, saya menyediakan beberapa reka bentuk konsep pengapit dan perlu diuji, konsep pengapit yang mana mndapat hasil yang hampir dengan data pengiraan.

ACKNOWLEGMENT

All praise is due to Allah. May Allah’s peace and blessings be upon the one after whom there is no other prophet.

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First, I would like to thank Dr. Mohd Azli bin Salim, my wonderful supervisor. His unwavering patience, kindness and mentorship guided me through the process.

Needless to mention, experimental obstacles might not able to be coped without the assistance of the technical staff. Hereby I would like to express my sincere appreciation to technician for laboratory Measurement and Instruments, Mr.Hairul and other for their help and patience in providing me the resources in completing this report.

To my family and friends, my greatest treasures and gifts in my life, thank you. I am forever grateful to my big sister, Dr Zaleha Mustafa for instilling in me a desire to achieve my goals and a commitment to finish what I start, to the best of my ability, no matter what it takes.

With all my heart, I would like to thank my friends Muhammad Hafizuddin bin Zahar, Rosli bin Ronta, and Mohamad Hafifi bin Sarji who have supported me thorough this insightful journey

For myself, this dissertation has been a personal accomplishment, which I hope will benefit others as much as it has me.

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LIST OF ABBEREVATION

NR	Natural Rubber
DAQ	Data Acquisition
ICP	Integrated Circuit Piezoelectric
BNC	Bayonet Neill-Conselman
FTT	Fast Fourier transform

LIST OF SYMBOL

E = Young Modulus

I = Second moment of inertia

ρ = Density

f = frequency

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Spring are very suitable mechanical components to absorb shock and vibration. Condition of high vibration and shock in automobile, railway vehicles, heavy machinery, pipe suspension system at power plants and steel plants are the common phenomenon in engineering. Spring thus used to cope up with those problems. Rubber being an elastic medium is the most universal material used for vibration damping(Al 1986). Rubber element also absorb considerable amount of overloads for short time without suffering any damage. During dynamic loading rubber converts the absorbed energy into heat by internal molecular friction (Mukhopadhyay et al 2014).

This phenomenon is known as damping and is continuous. This property is particularly helpful when shock have to be reduced quickly. In rubber-metal spring, both rubber and metal plates are to be joined systematically. Such, assembly of rubber and metal can be accomplish in various ways. It is also possible to use disc spring or Belleville springs in place of metal plates. Disc spring give wide variety of load deflection curves not readily obtainable with conventional form of spring.

Several information on rubber-metal springs are different literature. Present paper research on the comparative studies of rubber-metal spring with pure metal spring.(Jafari-Talookolaei 2017). This research focus on five mode of vibration because the more complex of the mode of vibration the more close to the real phenomenon of the vibration. (Le 2017)

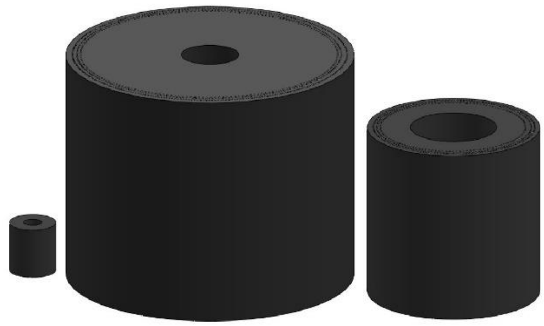


Figure 1-1: Rubber-Metal Springs
Sources :(http://www.antivibrationmethods.com/product/reinforced-rubber-springs)

1.1.1 Term terminology

Laminated is the technique of manufacturing a material in multiple layers, so that the material achieves improved strength, stability, sound insulation, appearance or other properties from the use of differing materials. This can apply to ensure that both material (metal and rubber) can combine their properties

Rubber is a latex from rubber tree. This latex is sticky, milky colloid drawn off by making incisions into the bark and collecting the fluid in vessels in a process called ‘tapping’. This material have high of elasticity and usually use as insulator and vibration absorber.

Metal is type of material that is typically hard. Metal can be hammered or pressed permanently out of shape without breaking or cracking and Vibration is phenomena oscillation occur about an equilibrium point.

Vibration come from Latin “*vibrationen*” (“shaking brandishing”). The oscillation may be periodic, such as the motion of a pendulum. Axial direction – a displacement that occur more than one direction such as axis-X and axis-Y.

1.2 PROBLEM STATEMENT

This laminated rubber isolator is an important product which has role of reducing the transmission of seismic forces in building load and flexibly transforming its shape into horizontal direction during apply of force such as earthquake. This isolator is formed using dies by setting rubber and metal sheets alternatively. Various inspections have been conducted in critical manufacturing processes to assure the quality of the products.

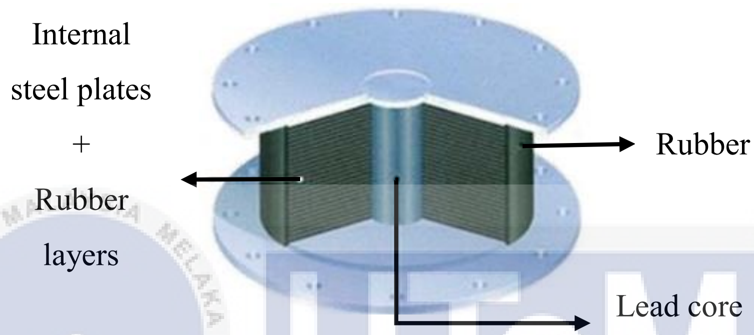


Figure 1-2: Structure of Laminated Rubber
Sources: (*https://structurae.net/products-services/lastolrb-lead-rubber-bearing)*

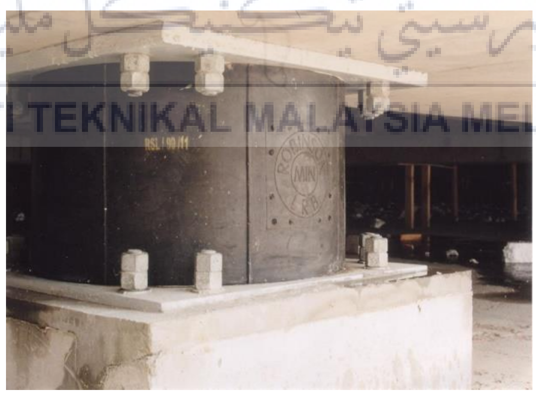


Figure 1-3: Application Rubber-Metal on Building
Sources: (*https://www.emaze.com/@ALTWWTRO/Flexible-Building)*

1.3 OBJECTIVE

I. To conduct an experimental study for laminated rubber-metal spring on axial loading

II. To investigated the natural frequencies of laminated rubber-metal spring for five modes of vibration

III. Study the five modes of vibration produce by the laminate rubber- spring metal spring

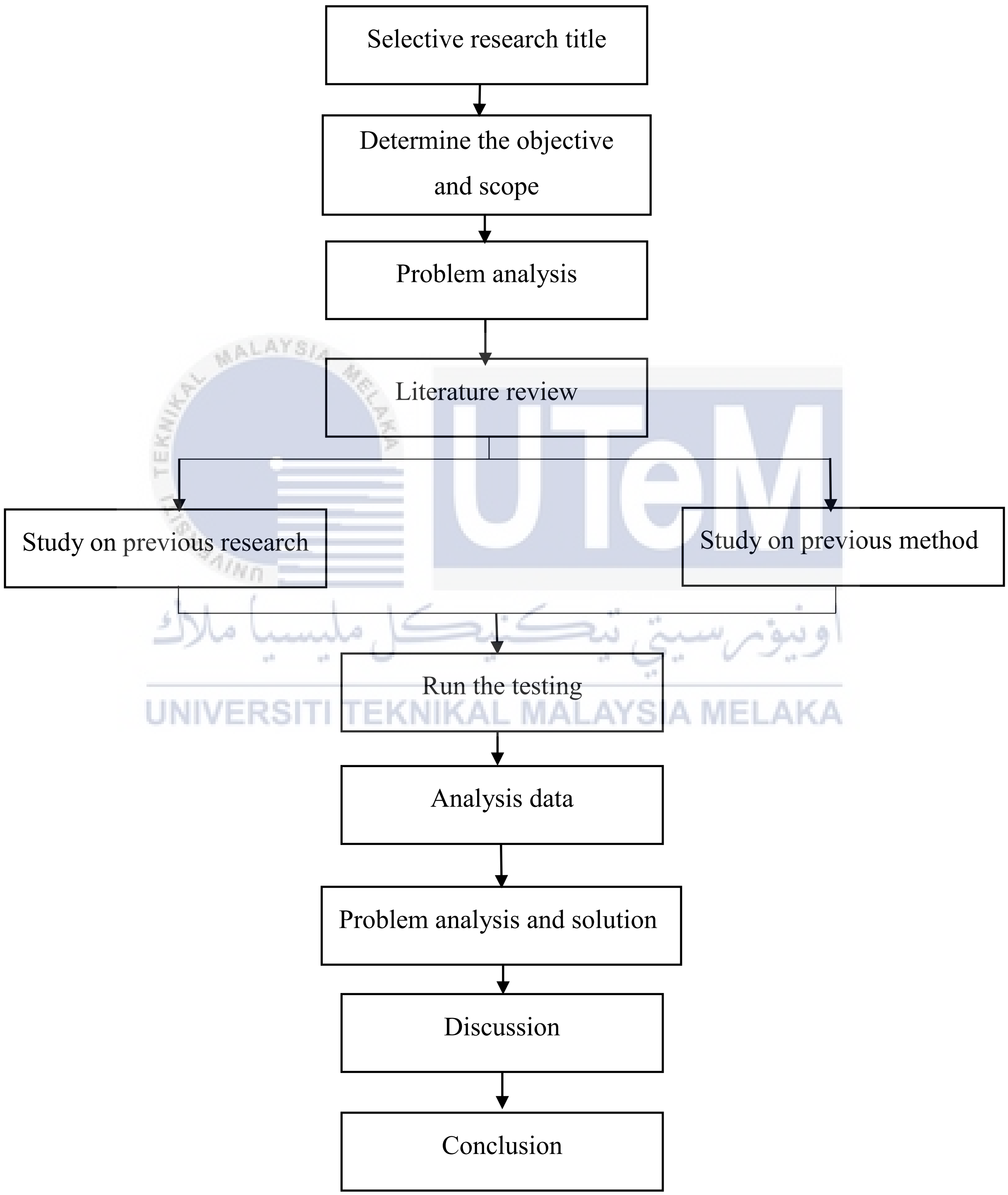
1.4 SCOPE OF PROJECT

I. Design the suitable clamp-base for laminated rubber-metal

II. Use Fourier series analysis to evaluate the free vibration sign at axial direction

III. Derive the five modes of vibration for natural frequencies of laminated rubber-metal spring

1.5 STUDY FLOW CHART



CHAPTER 2

LITERATURE REVIEW

This chapter is consisting of the previous research that has being carried out in the field of laminated rubber spring and axial vibration. All this information will provide more understanding but this study.

2.1 NATURAL RUBBER

Natural rubber (NR) is type of material which is have elasticity come from natural plant. To producing a natural rubber it come combination of chemical substance such as polyisoprene, unsaturated rubber, chemically active, intolerant aging(Zhao et al 2016). From all those combination it produce a substance widely used in medical and health industry, the transportation, industrial, agricultural, meteorological measurement. (Zhao 2014)

From other source, they definition the natural rubber is milky secretion or latex of various plants. Only one type of plant that commercial source of this rubber, this plant was call Hevea brasiliensis. To soften of the compound of rubber it was adding some ingredients and to overcome broken by mastication due to long polymer chain those rubber have through application mechanical shearing force by passing roller or rotating blades,(natural rubber, 2012)

Figure 2-1: latex of Hevea brasiliensis tree
Sources :(*http://treesandshrubs.about.com/od/treeshrubbasics/f/Where-Does-Latex-Come-From.htm*)

2.2 STAINLESS STEEL

To finish this research paper, I only focus on stainless steel to finding their natural frequencies, here have state some history of stainless steel. A stainless steel is resistant to stains, discoloration or loss of mass due to rusting. This is because it contains sufficient chromium to forma passive film of oxide on the surface, which isolates the substrate from the reactive environment. The film is able to reform in seconds in the event of damage. With an appropriate combination of alloying elements, stainless steels can be fully austenitic, a mixture of ferrite and austenite, fully ferritin or martensitic. (Al 2017)

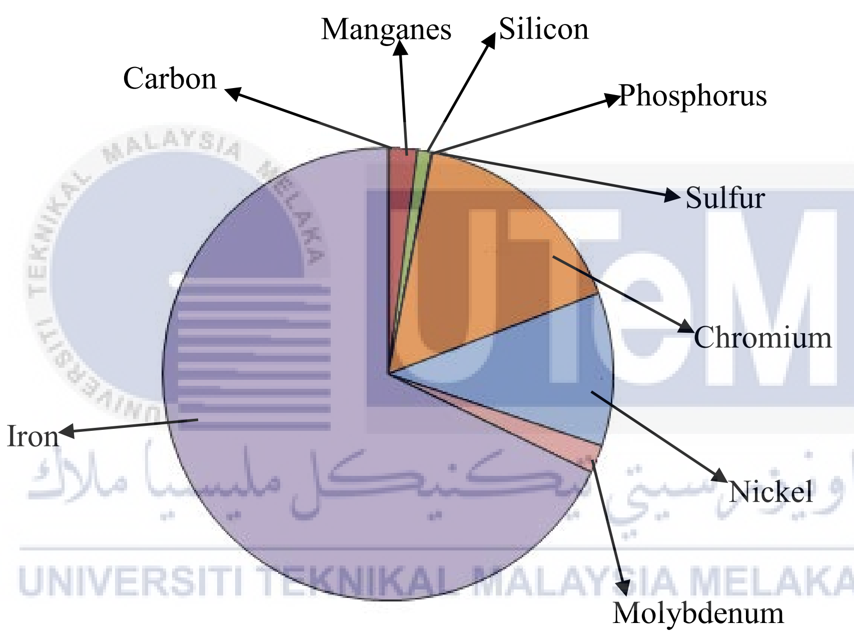


Figure 2-2: stainless steel composite

Sources: *(https://connecteddiscourse.wordpress.com/category/chemical-engineering/*

2.2.1 Background

The inverter of stainless steel was Harry Brearley. In 1904, French scientist Leo Guilet have document constitution of stainless steel. Brearly was investigated a ways to eliminated rusting in gun barrel, he found by accidently steel does not rusting and no dissolve in acid. Those steel have combination of chrome, and two months later on August 20, 1912 for first time. (History of steel, 2015)

Figure 2-3: Harry Brearly
Sources*: (http://www.bssa.org.uk/about_stainless_steel.php?id=31)*

2.2.2 Group of stainless steel

Have state that there was five stainless steel group: ferritin, martensitic, austenitic, and duplex and precipitation hardening. Ferritin consist of 12-18% of chromium and content of carbon is low. This type of steel is magnetic, thus it cannot be hardened by heat treatment. Martensitic was a commercially produces as cutlery. This type of steel consist of 0.1-1.2% of carbon, highest compare to other type of steel. It have 12-18% chromium. It can be hardened but quenching and tempering, it also can through heat treatment to increases strength with good ductility. Austenitic stainless steel a type of steel non-magnetic. It was added nickel as a result, their crystal structure changing to austenite. The basic composited of this steel, 18% chromium and 8% nickel. Austenitic are most common stainless steel production, up to 70%, their common grades are alloy 304, alloy 304L and alloy 316L.

Duplex are type of stainless steel which have high level of chromium (18-28%) and 8% amounts of nickel. The strength and capability of this stainless steel can be explained by their chemical composition. Example of this type of stainless steel is Alloys 2403 and 2205. Last group of stainless steel precipitation hardening can be through heat treatment to increases their hardness. These type of steel combine high strength and hardness also corrosion resistance higher than martensitic chromium steel. (History of steel, 2015)

2.3 NATURAL FREQUENCY

Natural frequency is a frequency of system at resonance state. As an example mass and beam, the natural frequency was determined by two factor; amount of the mass and stiffness of the material. Natural frequency inversely proportional to the mass and stiffness, if the value of mass and stiffness low than natural frequency will high and whereas (Silva 2017). Another example of phenomenon natural frequencies is a turning fork. This device was design to vibrate at particular natural frequency. If it vibrates at 440 Hz, natural frequency of those fork can be changed with a different spring rate of change of mass, and it can be altered by adding or reducing mass.(Fundamental of vibration, 2016)

2.4 FOURIES ANALYSIS

Fourier transformation are certain prelate spheroidal wave function. This Eigen functions properly extended properties that make them ideally suited for the study of certain questions regarding the relationship between functions and their Fourier transforms.(Slepian 1961)

Fourier series analysis one of method to investigated vibration on those plate. This method any signal may be represented by an infinite series of sine and cosine functions. Any time-varying signal can be produced by adding together sine waves of appropriate frequency, amplitude and phase. This technique was used to determine which sine waves give signal made up deconstruct the signal into constituent sine waves. Therefore we can get a result in sine wave amplitude as a function of frequency. If we get too small or amplitude approximated zero it consider not contribute to the signal. Those signal will have peak matching the frequency and amplitude of sine wave and zero contributions from all other frequencies. This all relative phase of the sine waves not commonly used in mechanical engineering application, but all this knowledge very useful to analysis any vibration phenomenal. For example if a machinery have unwanted vibration, those frequencies can be analysis by using Fourier analysis, and we can identify sources of the vibration. (Lawson 1997)

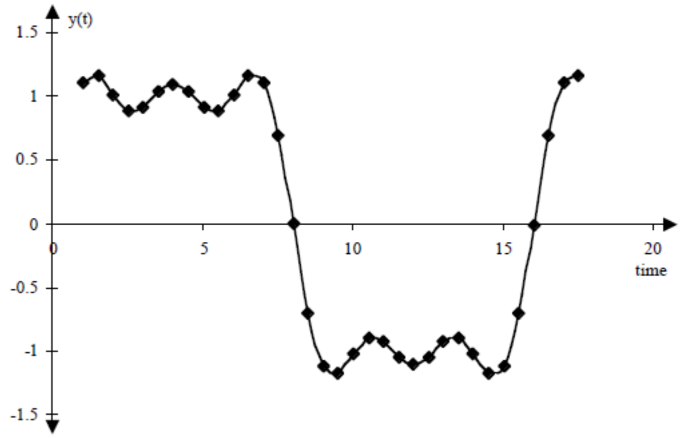


Figure 2-4: Fourier series representation of square wave

The Fourier series is defined as:

$$y = A_0 + \sum_{n=1}^{\infty} (A_n \cos nt + B_n \sin nt)\ y$$

Where

$$A_0 = \frac{1}{2\pi}\int_{-\pi}^{\pi} y(t)\, dt$$

$$A_n = \frac{1}{\pi}\int_{-\pi}^{\pi} y(t) \cos(nt)\, dt$$

$$B_n = \frac{1}{\pi}\int_{-\pi}^{\pi} y(t) \sin(nt)\, dt$$

2.5 LAMINATED RUBBER-METAL SPRING

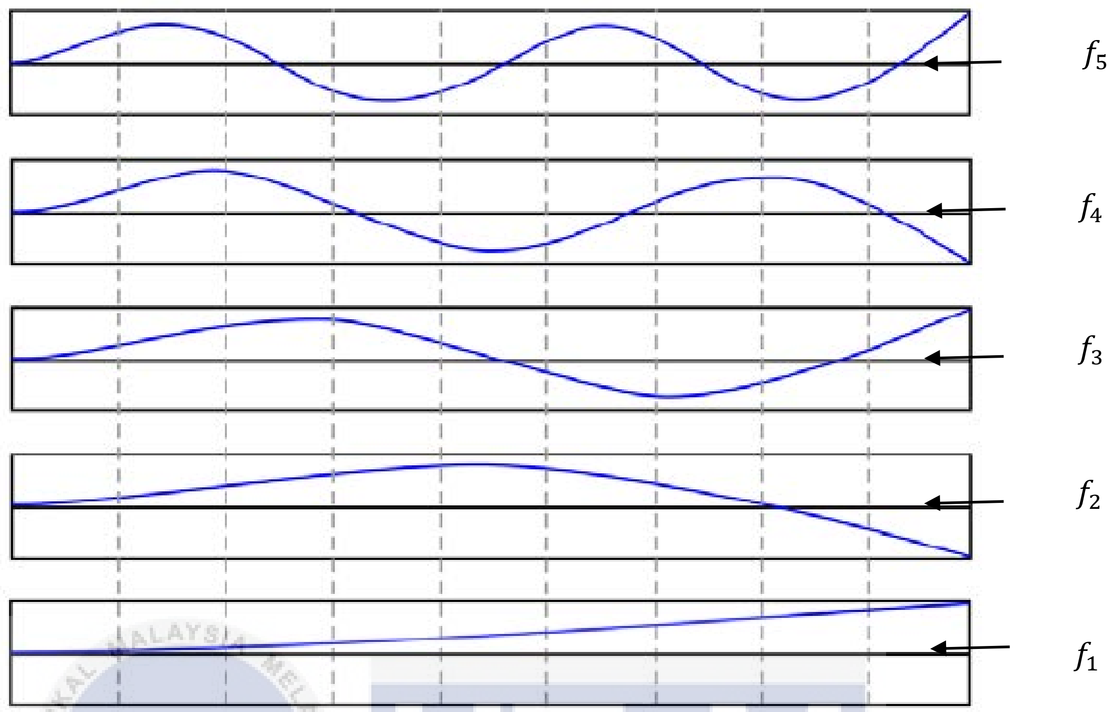
Rubber-metal is medium that have founded to overcome or reducing vibration on the system that involve bending, stretching, twisting, swinging, gesturing, rising, rotating and spinning this related to the(Salim 2015)Their studied have founded that shape factor is parameter that make the flexibility of the material to reduce or cut off unwanted energy transmitted in the system. There was three type of rubber spring that founded it is natural rubber (NR) bearing, lead rubber bearing and high damping rubber bearing. By testing all this type rubber bearing they have founded that natural rubber bearing is a better. (Salim 2015) Based on studies that have done, it have be proof that rubber-metal spring or rubber bearing was a best material that can be insulator to the axial vibration in the system.

In axial vibration it involve more than one direction of vibration. Until now rubber-metal is type of insulator in heavy industries that use to prevent any force transmit that can cause damage on the system. (Salim et al. 2016). Now rubber bearing also call laminated rubber-metal widely used as the stopper the vibration energy in longitudinal and rotational direction. This related to my studies which to study of laminated rubber –metal spring on axial vibration(Salim 2015).

There was also have previous researcher which doing their studies about uses of laminated rubber-metal spring also they call it rubber bearing. From this theory, we can say that any system that have higher vibration can use metal spring to overcome it. Therefore, the method that has being use have limitation due to the properties of metal that have less of elasticity and easily to occur fatigue. From the studies, rubber-metal spring device, his say that using of rubber lining on the metal spring can overcome breakage by fatigue. From the research, can be conclude that using rubber bearing or rubber –metal spring is the best way to block or reduce vibration(Fukahori 2014). Therefore, this studies can support that the studies about laminated rubber-metal spring on axial vibration.(Wang 2017)

2.6 MODE SHAPE OF VIBRATION

Prediction maintenance based on dynamic response information obtained by sensor is importance to determine the possibility damage of the structure. If the more modal points for the data structure responses are used, the more detail information of the structural status can be obtain. As a result of dynamic analysis the natural frequencies and mode shapes of the structure with dumping neglected can be defined. The natural frequencies of the structure are the frequencies at which structural vibrates if it is subjected to a disturbance. The deformed shape of structure at a specific frequency of the vibration is known as mode shape.(Mustakerov et Al 2014)



Sources: (*https://www.researchgate.net/figure/261145369_fig1_Fig-1-Cantilever-beam-vibration-mode-shape-functions*)

Figure 2-5: cantilever beam mode shape function

CHAPTER 3

METHODOLOGY

This chapter shall discuss the research method available for the study and what is applicable for it to use in response for the statement of the problem in Chapter 1 which is directed towards the ability laminated-rubber spring as isolator and reducing shock wave due to vibration during earthquake. Likewise, this chapter present the various procedure and strategies in identifying sources for need information on the study of laminated-rubber spring on axial vibration. Thus this part of the study specifies the method of research used, research design, data collection, instruments used and analysis of the gathered data. In this method was divide into three phase which is experiment equipment, testing or experiment phase and analysis phase.

3.1 EXPERIMENT EQUIMENT

. To run this experiment needed circular stainless steel as test subject, accelerometer, ICP type signal conditioning, PC Data Acquisition System, measurement tape and impact hammer and clamp. This part have shown experiment on cantilever beam, this to get first expression how this study have been conducted.

3.1.1 Testing material

A material that have been used to test and run analysis metal. As mention in previous chapter, laminated rubber-metal spring (RMS) was laminate between rubber and metal. Normally in making this type of absorber, they use stainless steel due to their properties which is strength, hardness, durability and resistance to rusting. (Figure 3-1)

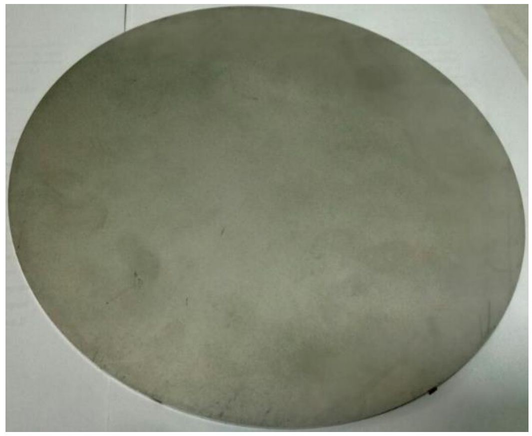


Figure 3-1: circular stainless steel
Source: (author)

3.1.2 Accelerometer

An accelerometer is an electromechanical device used to measure acceleration forces. Such forces may be static, such as continuous force of gravity. It used widely in mobile technologies, dynamic to sense movement or vibration. Accelerometer is the measurement of the change in velocity, or speed divide by time. An accelerometer look like a simple circuit for some larger electronic device, despite its appearance, the accelerometer consists of many different part and works in many ways, two of which are the piezoelectric and capacitance sensor. The piezoelectric effect is the most common form of accelerometer and uses microscopic crystal structures that become stressed due to accelerative forces. These crystal create a voltage from the stress, and accelerometer interprets the voltage to determine velocity and orientation. The capacitance accelerometer senses changes in capacitances between microstructures located next to the device. If an accelerative forces moves one of the structures, the capacitance will change and the accelerometer will translate that capacitance to voltage for interpretation. (Figure 3-2)

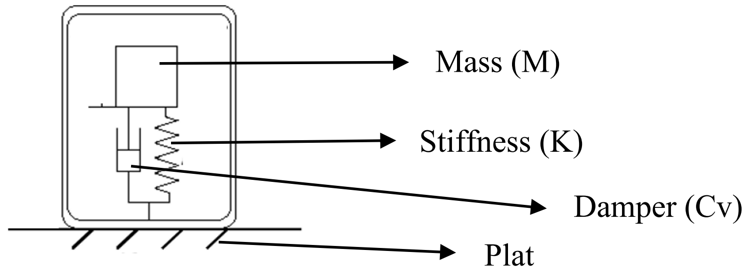


Figure 3-2: schematic diagram accelerometer.
Sources: (http://www.efunda.com/formulae/vibrations/sdof_eg_accelerometer.cfm)

3.1.3 ICP Type Signal Conditioning

Integrated circuit piezoelectric sensors (ICP) is type of device that use to measure any dynamic pressure, force, strain and acceleration. It consists element made up piezoelectric material, which can converts mechanical strain to an electrical signal and an electronic circuit to amplify this signal and transmit it to an external device. The process of ICP work shown in Figure 3.3

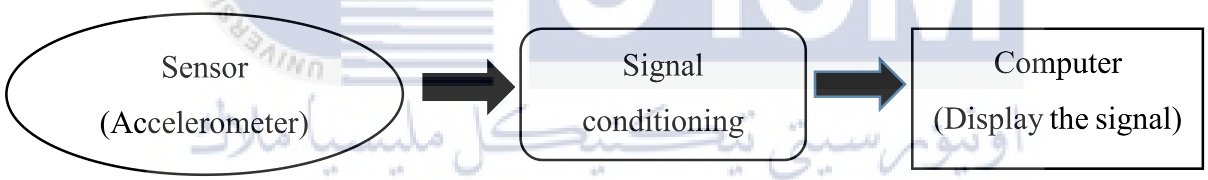


Figure 3-3 : how signal conditioning work

From the figure above, a signal was detected by sensor which is accelerometer read by ICP signal conditioning and display it on the computer using applicable software.

3.1.4 PC Data Acquisition System

Data acquisition (DAQ) is the process of measuring an electric of physical phenomenon such as voltage, current, temperature, or sound with a computer. A DAQ system consists of sensors, DAQ measurement hardware, and a computer with programmable software(Lisa Edelmann 2014). Compare to traditional measurements system, PC-based DAQ system exploits the processing power, productivity, display, and connectivity capabilities of industry-standard computer providing a more powerful, and flexible and cost-effective measurement solution. (Figure 3-4)

Figure 3-4: DEWESOFT programmable

Sources: (*http://www.dewesoft.com/products/dewesoft-x)*

3.1.5 Measurement Tape

The distance between sensors to clamping position it importance. This because distance can is a manipulated variable where vibration is responding variable. If the distance change it will effected to rate of vibration ether become higher amplitude or low amplitude. During setup the experiment, clamping position not too short because the vibration condition not in steady-state. (Figure 3-5)

Figure 3-5: measurement tape
Source: (author)

3.1.6 Clamp

A device that use to clamp a plate with base. As mention previously this device is main subject of this study. Fail or success of this research depends to the how to clamp those plate. (Figure 3-6)

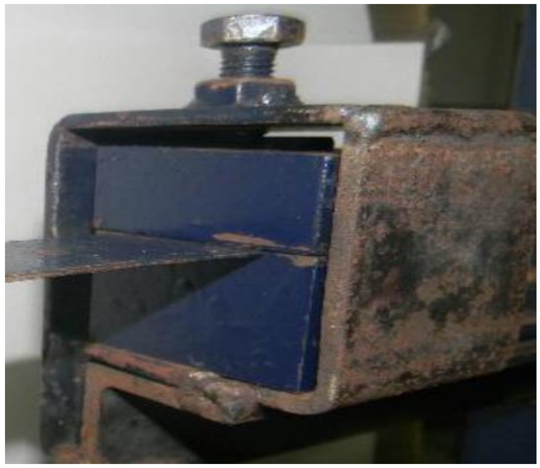


Figure 3-6: clamp
Source: (author)

3.2 EXPERIMENT PROCEDURE

An experiment was setup to test and compare the value of frequencies where get from calculation. This method require several skill such as how to clamp testing material, suitable apparatus and material to use. All this method need to try end error to get the correct method and ensure that error between two data (experiment and calculation) at low level (less than 10%).

3.2.1 Preparation Experiment

Step 1, a clamp was use to clamping testing material which is metal plate, this method call fixed-free experiment.

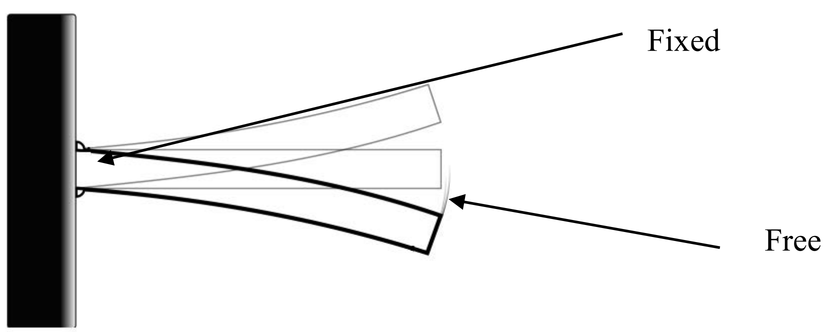


Figure 3-7: fixed and free diagram
Source: (*http://air.eng.ui.ac.id/tiki-index.php?page=FEM+-+Abdullah+Hawari)*

Step 2, Accelerometer have connect to input jack of second power unit a microdot-BNC cable. To transmitter data from the accelerometer to computer. During connected this cable, make sure that able in good condition which mean cable not broke, not any tool on the cable and cable must be straighter out. This all precaution step to ensure that not error during taking data.

Step 3, an accelerometer was place at end-mass and put some adhesive if necessaries. This because at the end of the mass is the position where input vibration was given.

Step 4, Power unit and DAQ system have turn on. Data acquisition (DAQ) a process of measuring any electrical or physical phenomenon such as voltage and temperature transfer to the application software for the system.

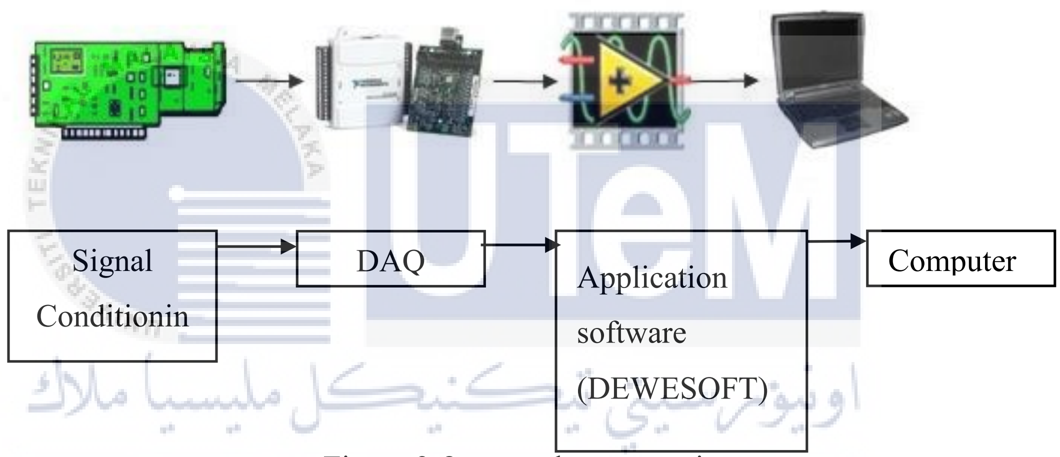


Figure 3-8: steps data transmit
Sources: (*http://sine.ni.com/cs/app/doc/p/id/cs-14099*)

3.2.2 Measurement of Natural frequency

Step 1, DEWESOFT program have run to enable the frequency measurement of the DAQ system.

Figure 3-9: DAQ system

Step 2, Load the save file if the file have save, or load new setup for run the testing. This to set properties of test material such as stainless steel.

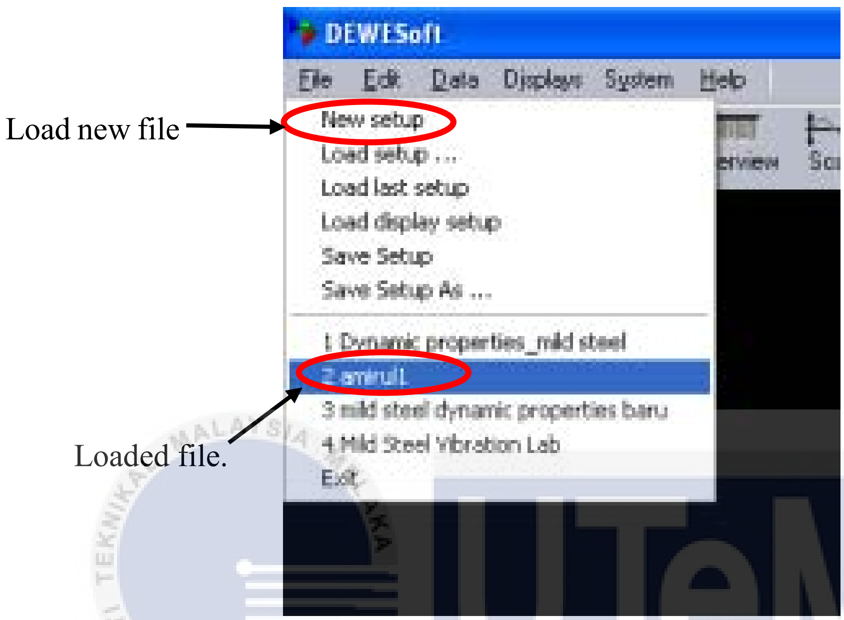


Figure 3-10: load file

Step 3, Set material properties in channel 3. Click on 'use' to apply those channel. Before that click Setting Channel to set the sensitivity according to sensitivity of device use.

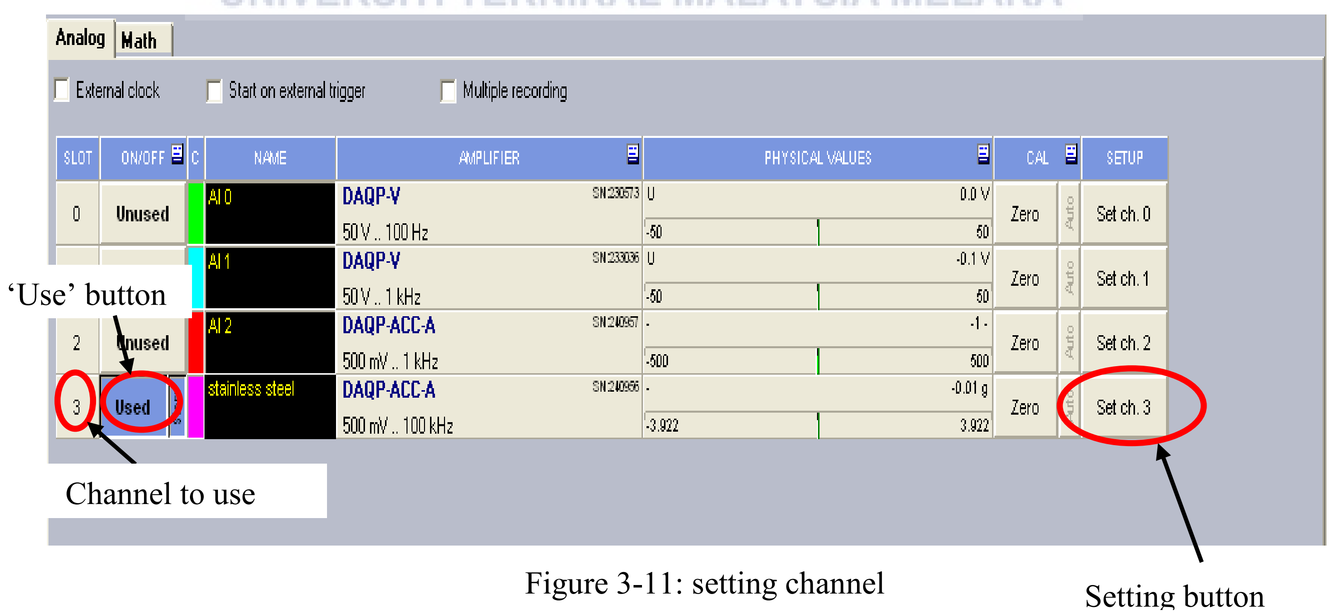


Figure 3-11: setting channel

Step 4, Sensitivity for the channels have been set according to sensitivity of the transduces. Select 'sensor' for sensor setting and click by function after that choose sensitivity. For the sensitivity the device that have being use is 101.6 mV/g

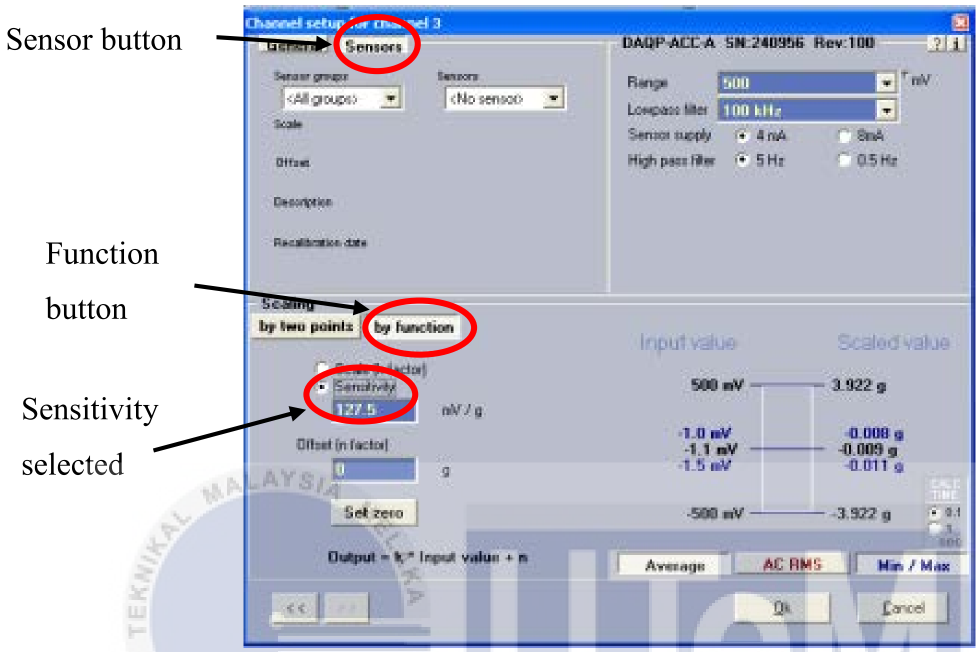


Figure 3-12: Setting sensitivity

Step 5, "FFT" button clicked to on the spectrum analyzer mode. This mode was use to analysis apply vibration on the plate.

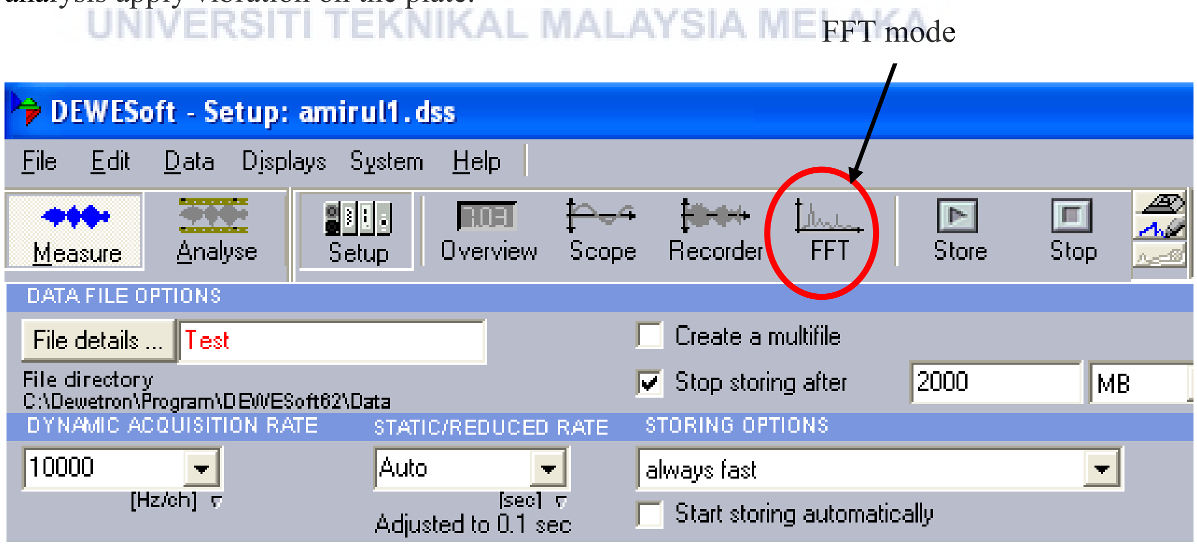


Figure 3-13: spectrum analyzer

Step 7, Rectangular window was select to compute Fourier Transforms and y-axis in unit 0dB

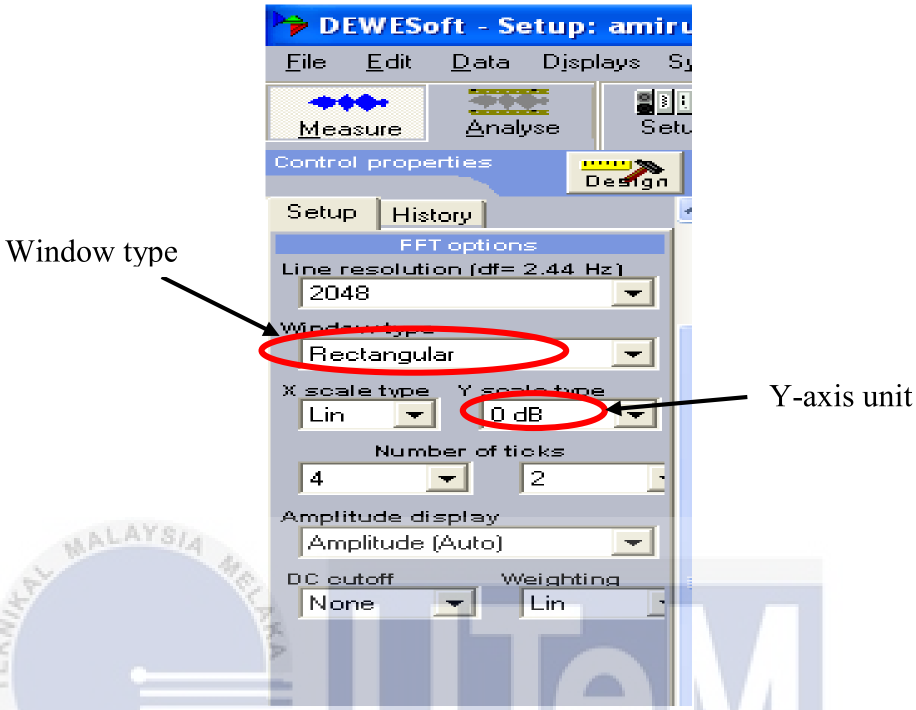


Figure 3-14: setting window type

Step 8, The upper lines will display a start frequency of 0 Hz and stop at frequency of 800 Hz with resolution of 2048 lines.

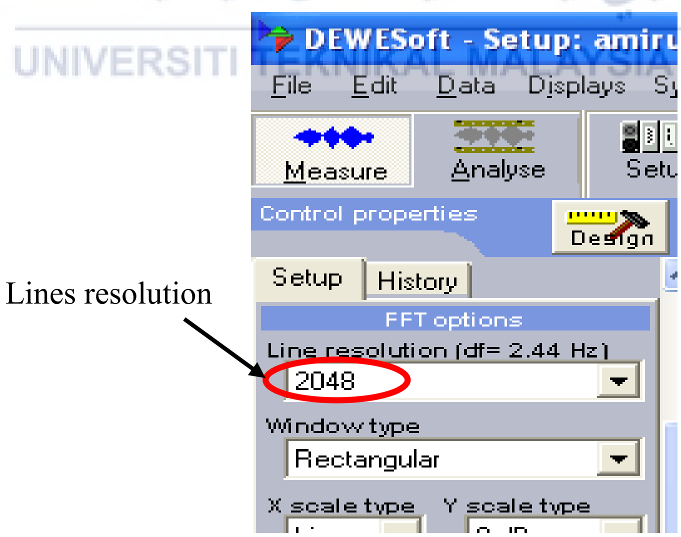


Figure 3-15: lines resolution

Step 9, the structure was hit lightly approximately once every several seconds at different position.

Step 10, Print those result that have display on the screen. The result should five peak which is represent five mode vibration of frequencies.

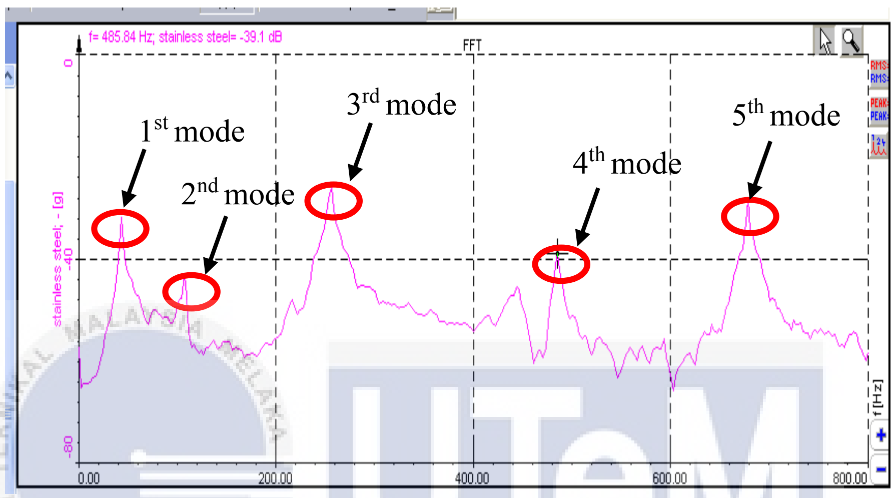


Figure 3-16: five mode vibration

3.3 ANALYSIS DATA

Analysis data is the process of comparison between two data, which is experimental data and calculation data or theoretical data. For experimental data, have being recorded from testing that have being run in Instrumentation Laboratory, for calculated data, Fourier series analysis have being use to generated formula.

3.3.1 Calculation for natural frequency

By using Fourier's series transformation as mention in previous chapter, the formula was generate and show in table 3-1 below. Those formula involve several importance variable such Young's modulus (E), moment of inertial (I), density (ρ), distance (l) and area (A).

Table 3-1: calculation for natural frequencies of fixe-free plate

Vibration mode	Formula (Hz)	Equation
f_1	$\left(\frac{1.875}{l}\right)^2 \frac{\sqrt{\frac{EI}{\rho A}}}{2\pi}$	3.1
f_2	$\left(\frac{4.694}{l}\right)^2 \frac{\sqrt{\frac{EI}{\rho A}}}{2\pi}$	3.2
f_3	$\left(\frac{7.855}{l}\right)^2 \frac{\sqrt{\frac{EI}{\rho A}}}{2\pi}$	3.3
f_4	$\left(\frac{10.996}{l}\right)^2 \frac{\sqrt{\frac{EI}{\rho A}}}{2\pi}$	3.4
f_5	$\left(\frac{1.875}{l}\right)^2 \frac{\sqrt{\frac{EI}{\rho A}}}{2\pi}$	3.5

Refer figure 2-5.

There was specific formula to calculate area and moment of inertia for the shape of testing material. In this research there was involve two different shape which is rectangular and circular.

Table 3-2: Variable for Calculation

Variable	Shape	
	Rectangular	Circular
Area	base x height Eq. 3.6	Π x radius^2 Eq. 3.7
Moment of Inertia	$\frac{base \times height^3}{12}$ Eq. 3.8	$\frac{\pi \times radius^4}{4}$ Eq. 3.9

The percentage of the measurement error during the experimental work and theoretical is calculated using Equation 3.10

Percentages of error $= \frac{theoritical - experimental}{theoritical} \times 100\%$

CHAPTER 4

RESULT AND DISCUSSION

In this chapter will provide and discuss all result from both method which experimental and calculation. After complete the testing method, the study continued with calculation method, all formula in chapter 3 will be apply.

4.1 EXPERIEMENT ON CANTILEVER BEAM

An experiment was run on rectangular shape. This experiment as the base line for this research. This type of experiment was normally conduct in finding mode of vibration

Figure 4-1: diagram of fix-free cantilever beam

4.1.1 Material properties

For cantilever beam, there was two type of material used for testing, those material is mild steel and copper. Therefore, both beam have same second moment of inertial (Equation 3.8) and area (Equation 3.6)

1. Second moment of inertia , I $= \frac{bh^3}{12}$

$$= \frac{(0.0285)(7e^{-3})^3}{12}$$

$$= 8.146e^{-10} \text{ m}^4$$

2. Cross section area, A $= bh$

$$= (0.0285) \times (7e^{-3})$$

$$= 1.995e^{-4} \text{ m}^2$$

Therefore, after done the calculation for second moment of inertia and area, the step continue with calculation with first mode of vibration until fifth.

Table 4-1: Material Properties

Properties	Mild Steel	Copper
Young Modulus, E	210GPa;	110GPa
2D Moment, I	$8.146e^{-10}$ m^4	$8.146e^{-10}$ m^4
Density, ρ	7800 kg/m^2	8800 kg/m^2
Cross section area, A	$1.995e^{-4}$ m^2	$1.995e^{-4}$ m^2

4.1.2 Modification

To reduce error of experimental, a modification have being apply to the method of clamping of plate.

Figure 4-2: without modification

Figure 4-3: different type clamp

Figure 4-4: with isolator

The reason of choose clamp-base as show in figure 4-3 is due to the type metal of making clamp-base. If using low strength of metal, the natural frequencies will also low. Therefore, for the first clamp (refer figure 4-2) is making from steel and change to second type of clamp which make from aluminum.

4.1.3 Mild Steel cantilever beam

In order to get the value of first peaks of the frequencies by using equation 3.1

$$\text{Frequencies } (f_1) = \left(\frac{1.875}{l}\right)^2 \frac{\sqrt{\frac{EI}{\rho A}}}{2\pi}$$

$$= \left(\frac{1.875}{0.6}\right)^2 \frac{\sqrt{\frac{(2.1^{11})(8.146^{-10})}{(7800)(1.995^{-4})}}}{2\pi}$$

$$= 16.28 \text{ Hz}$$

First peak of frequencies is 16.28 Hz, this mean frequencies for the first mode vibration is can achieve maximum at 16.28 Hz. Natural frequencies of the material is the highest value of the frequencies in the wave propagation. All value of the five peaks have shown in table 4-2 below.

Table 4-2: calculation data mild steel

Peak	Calculated frequencies [Hz]
f_1	16.28
f_2	102.03
f_3	288.71
f_4	559.89
f_5	925.44

From the table 4-2, the value of frequencies increases with the number mode vibration of frequencies. The measurement data was record from the applicable software which is DEWESOFT. The first' five peak was select as represent the five mode vibration.

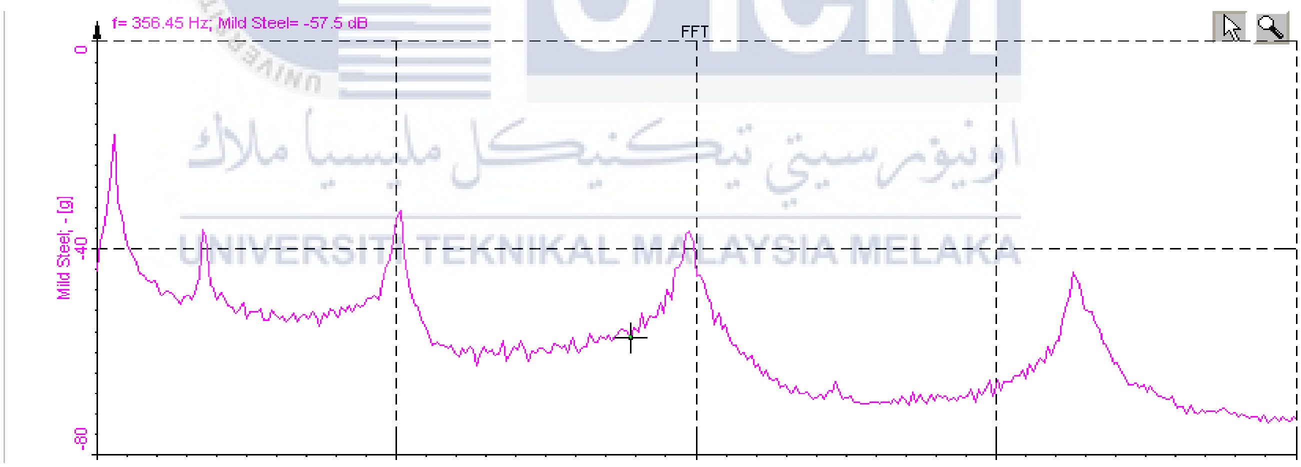


Figure 4-5: without modification

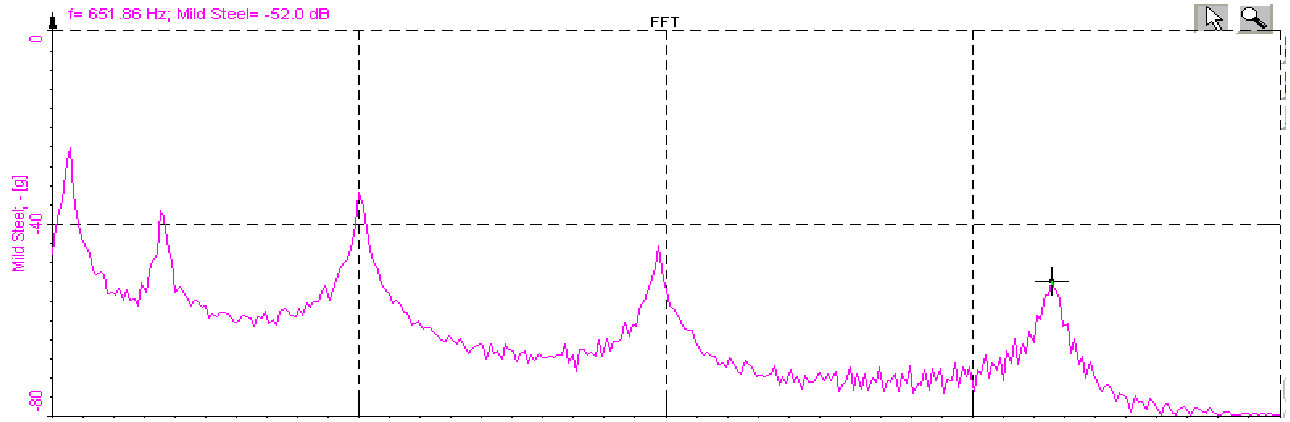


Figure 4-6: different type of clamp

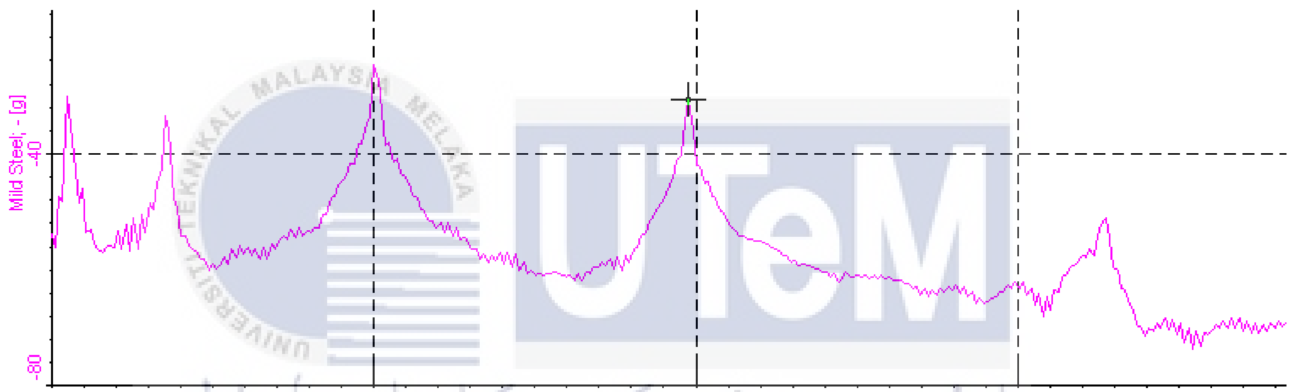


Figure 4-7: with isolator (rubber)

Table 4-3: Data measurement mild steel

Peaks	Data measurement ,[Hz]		
	Without modification (1)	different type of clamp (2)	With isolator (3)
f_1	12.21	13.23	14.23
f_2	78.13	79.35	89.34
f_3	214.84	254.5	263.73
f_4	422.36	490.88	502.67
f_5	698.24	798.58	864.43

Refer figure 2-5.

From the both data from table 4-2 and table 4-3, a graph was construct to show comparison both data. Those graph show in figure 4-5 below.

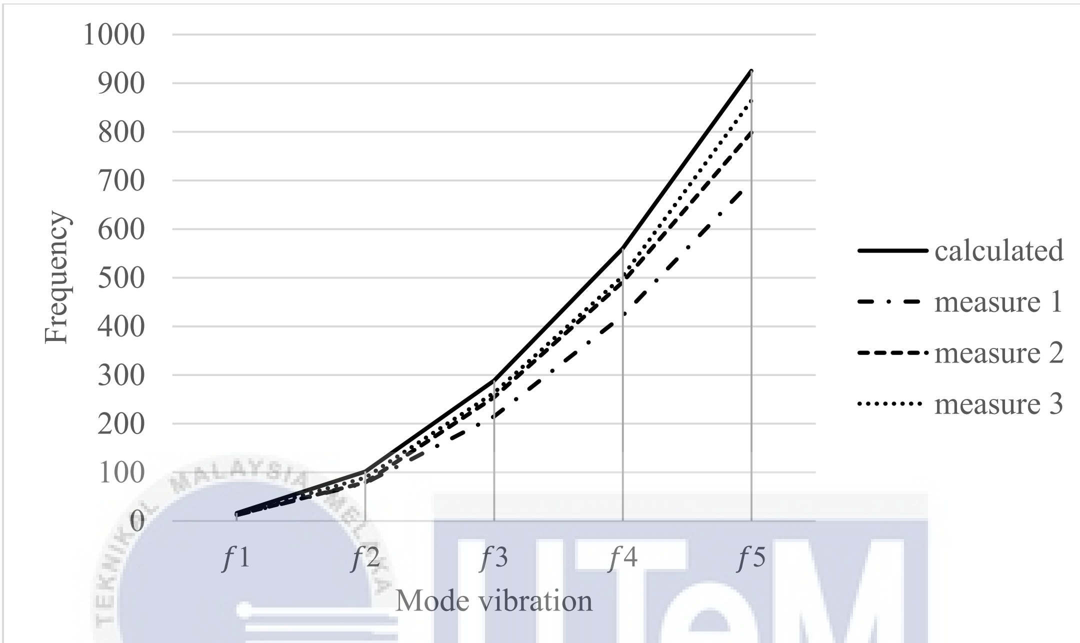


Figure 4-8: graph comparison between calculated with measurement data of mild steel

From graph above, error between measures 1st and calculated is 24.65% .Measure 1 was recorded from an experiment run without any modification. Equation 3.10

$$\text{Percentages of error} = \frac{1892.35 - 1425.78}{1892.35} \times 100\%$$

$$= 24.65\%$$

Therefore, experiment was continue with some of modification which is adding some isolator between plate and clamp base and try with other type of clamp base in other to reduce error and to find the most correct way clamping those plate.

First adjustment or modification on clamping is clamp with different type of clamp base. The result have shown in Measure 2nd, error from this second method is 13.52%.

$$\text{Percentage of error} = \frac{1892.35 - 1636.54}{1892.35} \times 100\%$$

$$= 13.52\%$$

From calculation percentages of error, the experiment still consider unsuccessful. Therefore, the modification on experiment which is adding isolator was tested for measure 3rd. The error reduce to 8.35%.

$$\text{Percentages of error} = \frac{1892.35 - 1734.4}{1892.35} \times 100\%$$

$$= 8.35\%$$

4.1.4 Copper cantilever beam

Copper was secondary testing for this shape of material. All calculation same from previous material. Equation 3.1

$$\text{Frequencies } (f_1) = \left(\frac{1.875}{l}\right)^2 \frac{\sqrt{\frac{EI}{\rho A}}}{2\pi}$$

$$= \left(\frac{1.875}{0.6}\right)^2 \frac{\sqrt{\frac{(1.1^{11})(8.146^{-10})}{(8800)(1.995^{-4})}}}{2\pi}$$

$$= 11.10 \text{ Hz}$$

Table 4-4: calculation data copper

Peak	Calculated frequencies [Hz]
f_1	110.10
f_2	69.59

f_3	194.87
f_4	381.88
f_5	631.21

After complete the calculation until five mode, the data was tabulate in table 4-4. For measurement data was show in table 4-5 below.

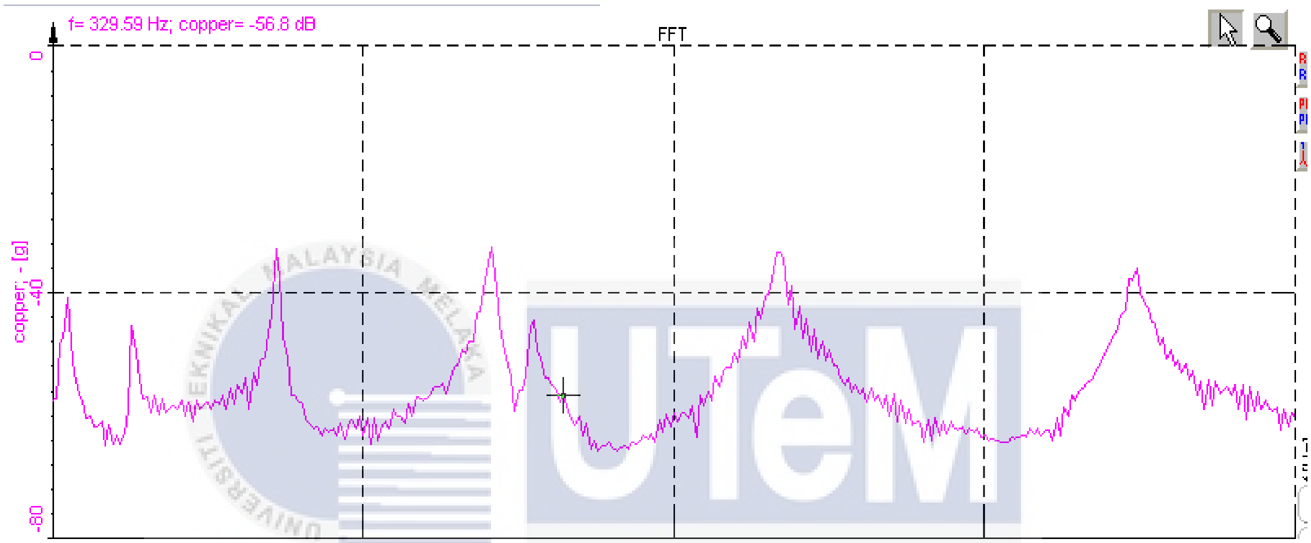


Figure 4-9: without modification

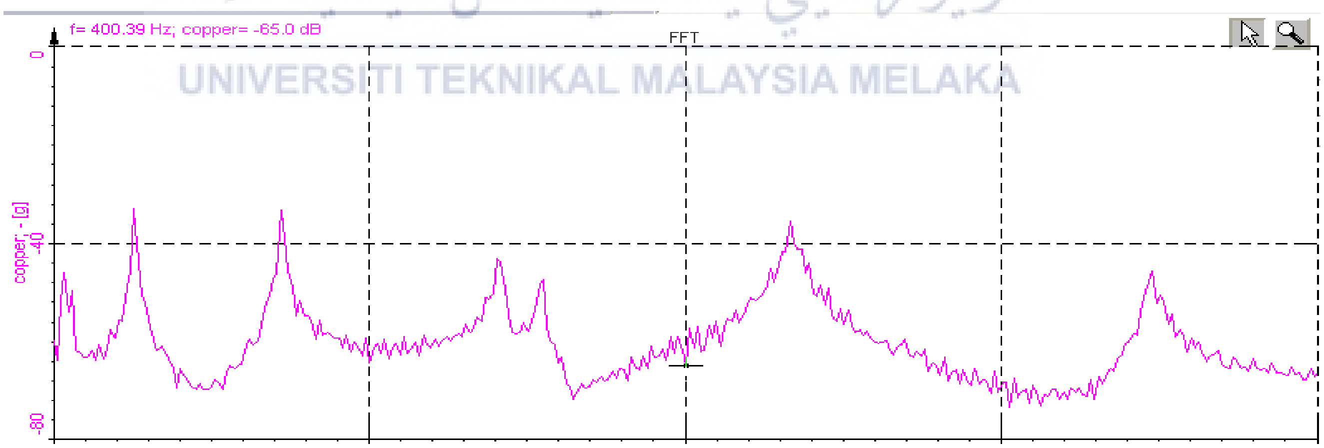


Figure 4-10: different type of clamp

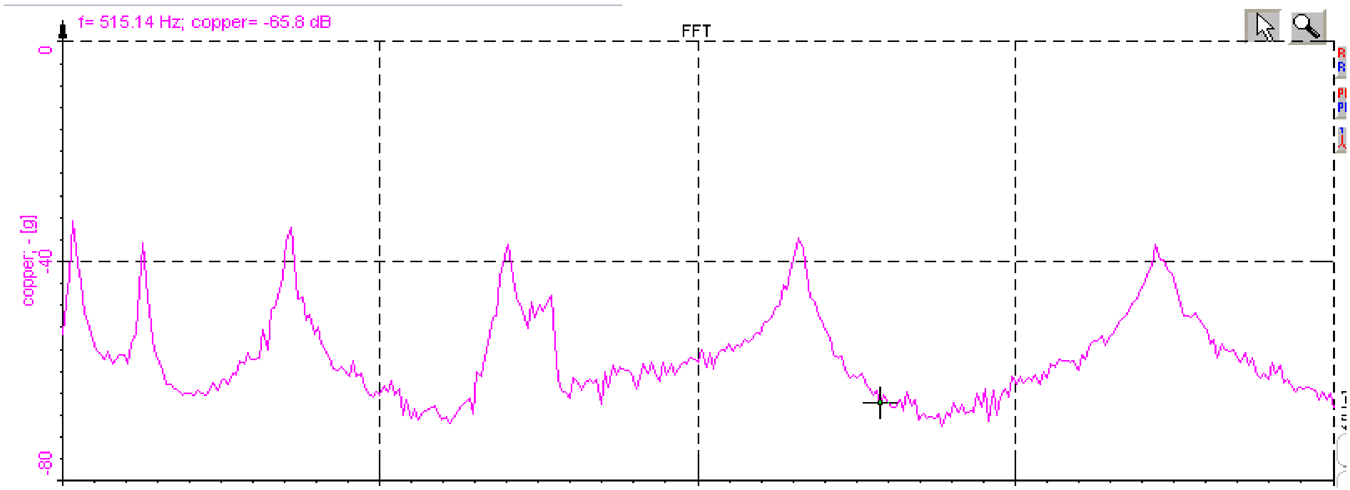


Figure 4-11: with isolator

Table 4-5: measurement data copper

Peaks	Data measurement ,[Hz]		
	Without modification (1)	different type of clamp (2)	With isolator (3)
f_1	9.77	10.81	11.0
f_2	61.04	63.45	68.65
f_3	168.46	178.43	189.57
f_4	329.59	365.88	374.56
f_5	546.88	589.67	615.55

Refer figure 2-5.

A graph was plot to show between calculation data with measurement data. Those comparison will show in figure 4-9.

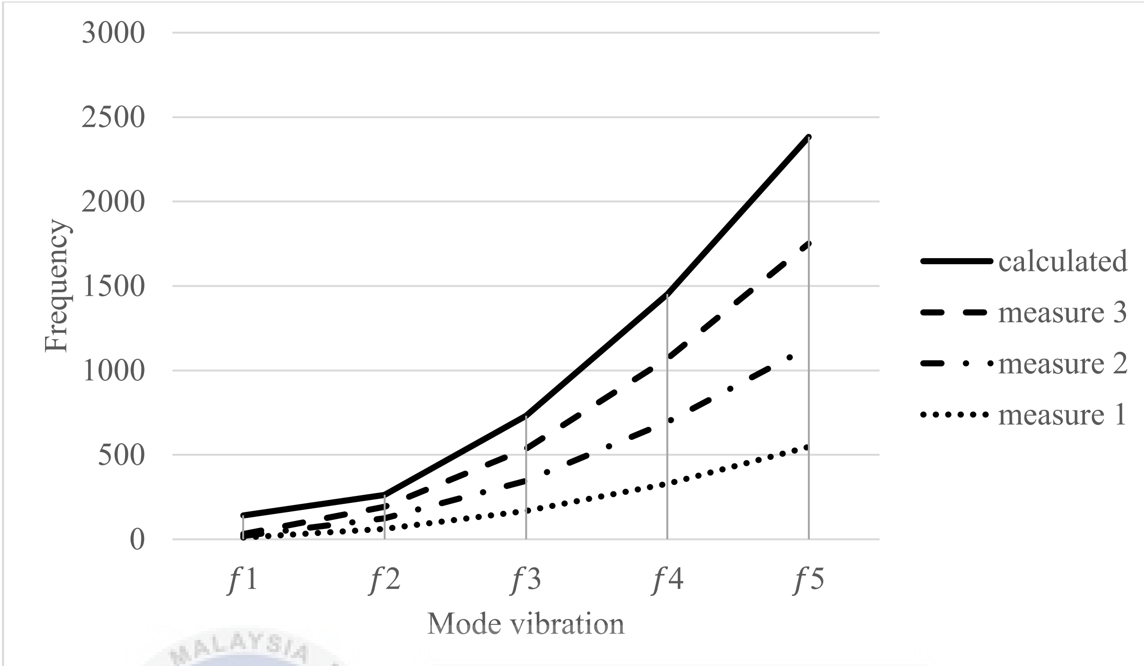


Figure 4-12: graph comparison between calculated with measurement data of copper

For the measure 1st represent without modification, show error between calculated 13.42%.

$$\text{Percentages of error} = \frac{1288.552 - 1115.74}{1288.552} \times 100\%$$

$$= 13.42\%$$

The modification of the clamping will run to standardize the research. The modification also same with previous testing which is try with different type clamp and place an isolating between plate and clamp base with rubber. For measure 2nd (different clamp) the percentages of error is 6.24%

$$\text{Percentages of error} = \frac{1288.552 - 1208.24}{1288.552} \times 100\%$$

$$= 6.24\%$$

The error for measure 3rd is 2.28%. The second testing was consider success but due to the value of error for third less than second test, thus this data was chose for final data measurement.

$$\text{Percentages of error} = \frac{1288.552 - 1259.33}{1288.552} \times 100\%$$

$$= 2.28\%$$

4.1.5 Summary

The purpose of adding isolator (rubber) is as absorber of any unwanted vibration such as natural frequencies from clamp base will influence data reading. From all three testing method, the third test which is was modified by insulated between clamp base and plate with rubber consider most successful testing. This due to percentages of error was lowest and below than 10%. The value of first peak frequencies for mild steel is 16. 28 Hz where for copper show that 11.01 Hz, this shown that mild steel harder compare to copper in term of strength.

4.2 EXPERIEMENT ON CIRCULAR PLATE

For second type experiment, was use same method and equipment but the different is testing material was changes to circular stainless steel metal plate. This research was include in study due to the laminated rubber-metal spring which use in this study have circular in shape.

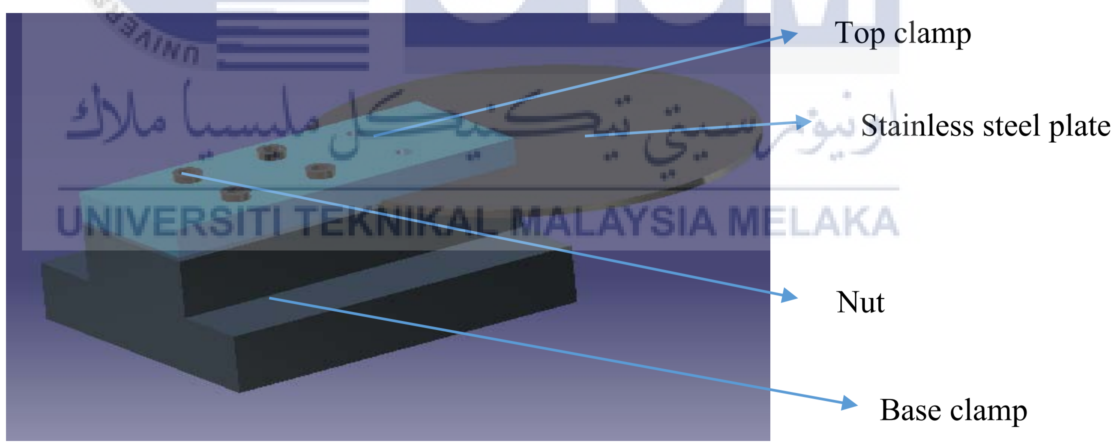


Figure 4-13: diagram of set of apparatus

The experiment was conduct same with previous experiment, which is run with normal testing and modification testing

4.2.1 Calculation

1. second moment of area, I

The second moment of area, I is also known as the moment o inertia of a shape the second moment of area is a measure of the ‘efficiency’ of a cross-section shape to resist bending caused by loading. For this research there was using formula moment of inertia for circular disk (Equation 3.9)

$$I = \frac{\pi R^4}{4}$$

Where;

R= radius

By apply the formula, the value of moment of inertia is:

$$I = \frac{\pi R^4}{4}$$

$$= \frac{\pi (0.112)^4}{4}$$

$$=1.2358e^{-4}\ m^4$$

2. Cross section area, A

From the figure 4-11 above show multi –cross section of the plate. There was five cross-section that have divide equally. Therefore, to calculated cross section area of this circular plate (equation 3.6), it need to plot a graph for distributed area and integral it. From figure 4-6 above, value of X represent length of cross-section and the thickness of the plate is 0.004015 m. To calculate the area each cross-section, formula of area rectangular was use.

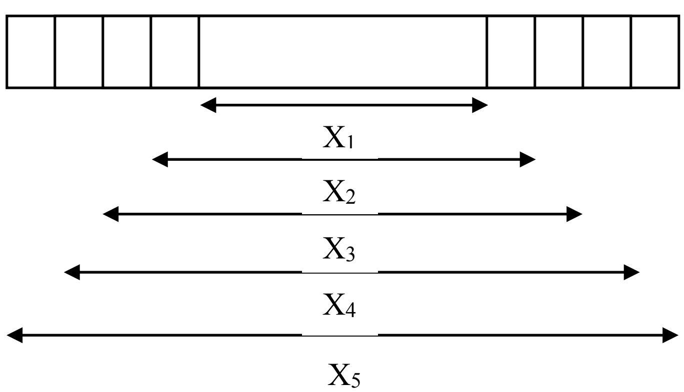


Figure 4-14:multi-cross section plate

Cross section area, $a_1 = t \times X_1$

$$= (0.004015) \times (0.016)$$

$$= 5.1295e^{-4} m^2$$

After apply formula of area, all the area until X_5 was tabulate in table 4-6.

Table 4-6: Distributed Area

No.	Length(X), m	Area (a),m^2
1	0.016	$5.1295e^{-4}$
2	0.040	$7.0664e^{-4}$
3	0.064	$8.1103e^{-4}$
4	0.088	$8.7928e^{-4}$
5	0.112	$8.9936e^{-4}$

A graph length against area was plot to show the distributed of area in figure 4-12.

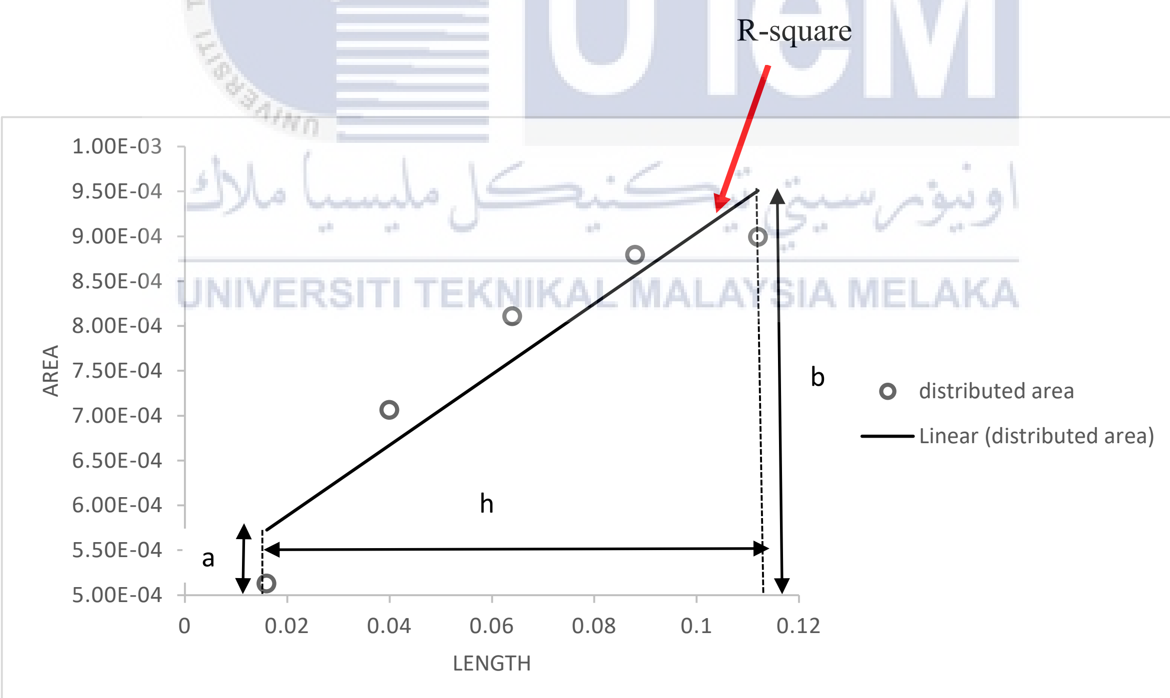


Figure 4-15: Graph Distributed Area

Regression line (R-square) is a line used to visually the relationship of two variable which is independent (X) and dependent (Y) in the graph. R-square also show statistical measure of how close the data to the fitted regression line. After plotting R-square, to get actual cross-section area of the plate the integration of the line was used. The integration is equal to area under the graph.

Distributed area, A $\quad$ = Area under the graph

Area under the graph, G $= \frac{1}{2}$[(sum of parallel side) (height)]

$$= \frac{1}{2}[(a+b)\times h]$$

$$= \frac{1}{2}\left[0.7e^{-4} + 4.5e^{-4}\right]\times 0.096$$

$$= 2.496e^{-5}\ \text{m}^2$$

All the properties of the plate will fill in to material properties table 4-7 below:

Table 4-7: Material Properties stainless steel

Properties	Stainless Steel
Young Modulus, E	203GPa
2D Moment, I	$1.2358e^{-4}$ m^4
Density, ρ	7990 kg/m^2
Cross section area, A	$2.496e^{-5}$ m^2

3. Mode vibration of frequencies

The formula that use to calculate the value of frequencies is same with rectangular (Equation 3.1)

$$\text{First mode, } f_1 = \left(\frac{1.875}{R}\right)^2 \frac{\sqrt{\frac{EI}{\rho A}}}{2\pi}$$

$$= \left(\frac{1.875}{0.112}\right)^2 \frac{\sqrt{\frac{(2.03^{11})(1.2358e^{-4})}{(7990)(2.496e^{-5})}}}{2\pi}$$

$$= 26.156$$

Table 4-8: Calculated Data for stainless steel

Mode	Formula	Value, (Hz)
f_1	$\left(\frac{1.875}{R}\right)^2 \frac{\sqrt{\frac{EI}{\rho A}}}{2\pi}$	26.156
f_2	$\left(\frac{4.694}{R}\right)^2 \frac{\sqrt{\frac{EI}{\rho A}}}{2\pi}$	163.927
f_3	$\left(\frac{7.855}{R}\right)^2 \frac{\sqrt{\frac{EI}{\rho A}}}{2\pi}$	459.048
f_4	$\left(\frac{10.996}{R}\right)^2 \frac{\sqrt{\frac{EI}{\rho A}}}{2\pi}$	899.571
f_5	$\left(\frac{14.137}{R}\right)^2 \frac{\sqrt{\frac{EI}{\rho A}}}{2\pi}$	1486.895

Refer figure 2-5

4.2.2 Experimental Data

a. 1st experiment

For the experiment data, an experiment have being conduct three time to ensure and conforming that accuracy of data.

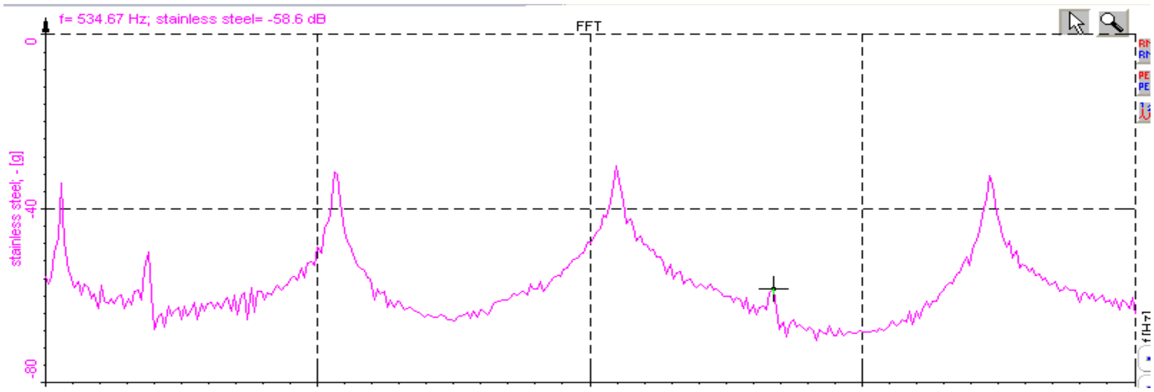


Figure 4-16: test 1

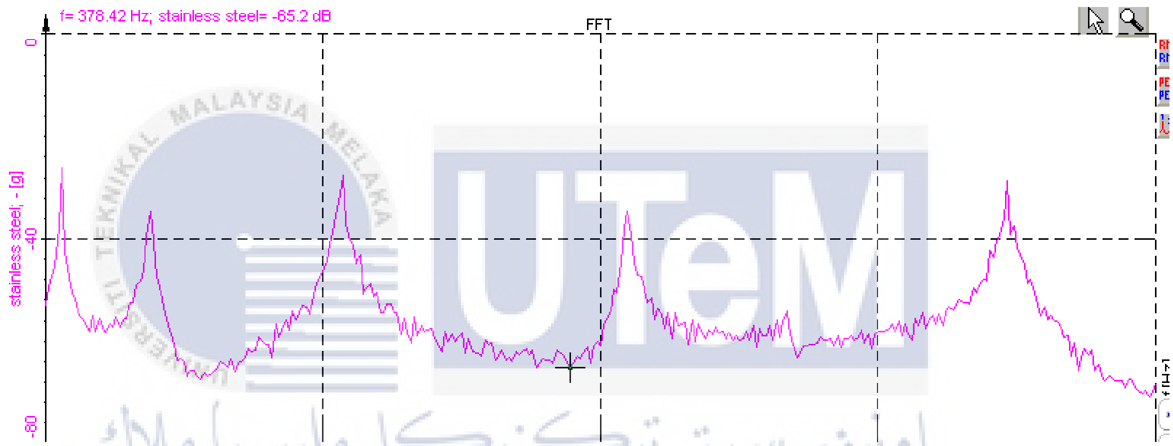


Figure 4-17: test 2

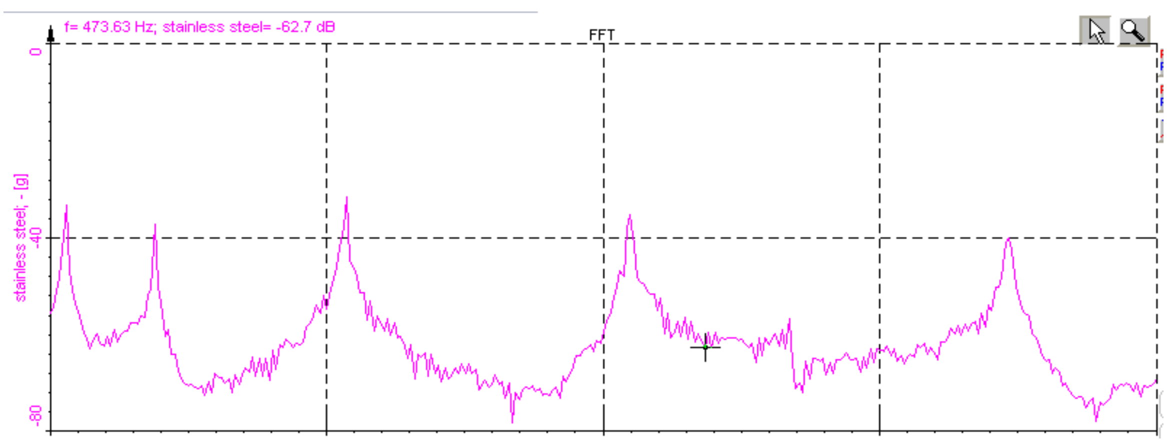


Figure 4-18: test 3

Table 4-9 : result experimental for stainless steel

Mode	Test 1	Test 2	Test 3	Average
f_1	78.125	78.125	78.125	78.125
f_2	141.60	141.60	141.60	141.60
f_3	307.62	307.62	307.62	307.62
f_4	640.97	644.58	646.97	644.17
f_5	698.24	700.68	700.68	699.87

Refer figure 2-5

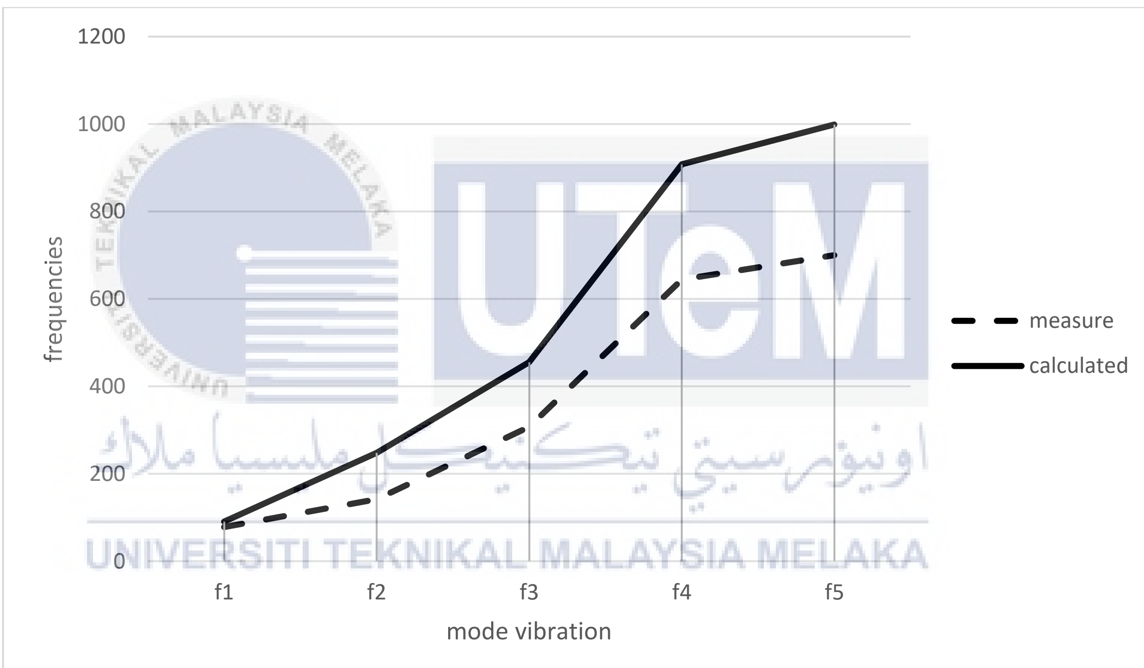


Figure 4-19: comparison data for stainless steel

From the graph above, the error of experimental is 38.38%. This error is due to the vibration of the plate not achieve steady-state condition. Therefore, the experiment was continued with testing different distance between clamp position and position of accelerometer.

$$\text{Percentages of error} = \frac{3035.597 - 1871.385}{3035.597} \times 100\%$$

= 38.38%

b. 2nd experiment

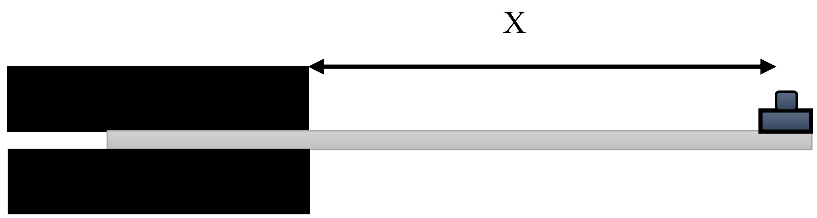


Figure 4-20: 2D diagram of clamping

For second experiment the distance of X will adjust until the vibration achieve steady-state condition. It is importance to get data of experiment when the condition of the testing material at steady-state because to avoid any error during taking data. (Al 1992)

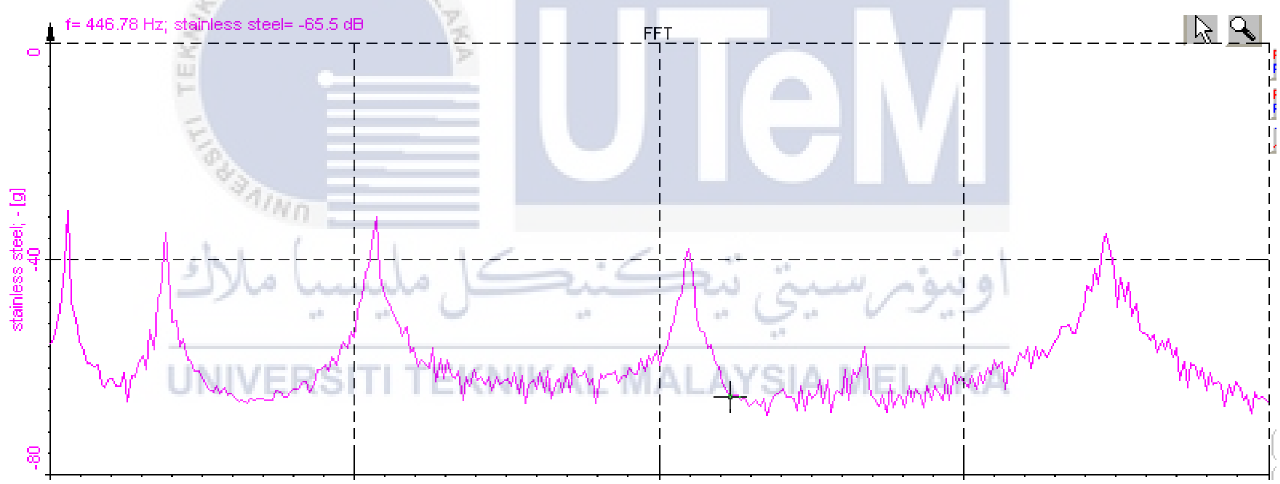


Figure 4-21: Distance 1

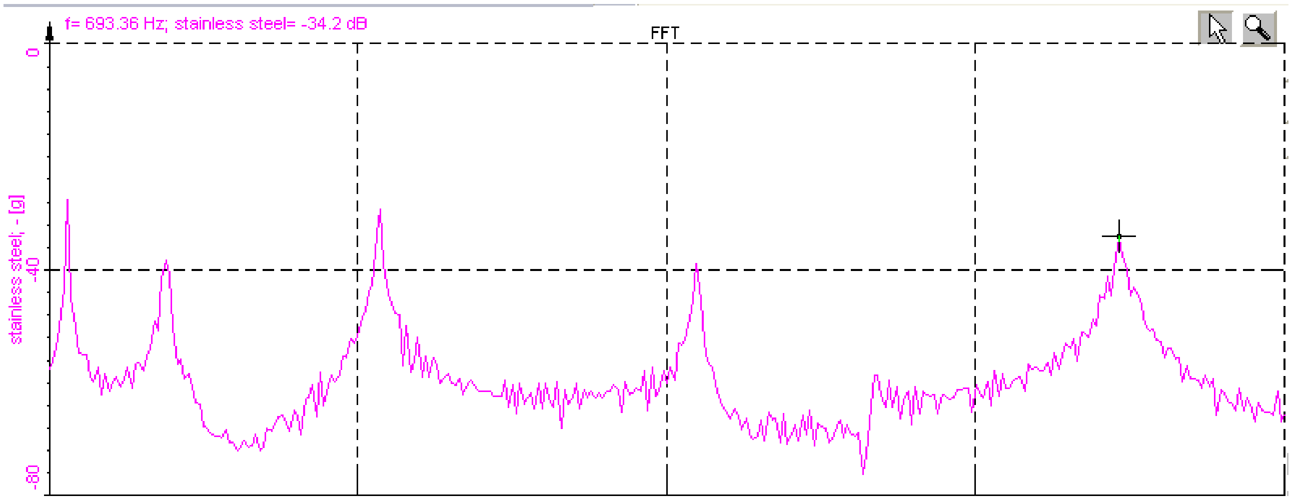


Figure 4-22: Distance 2

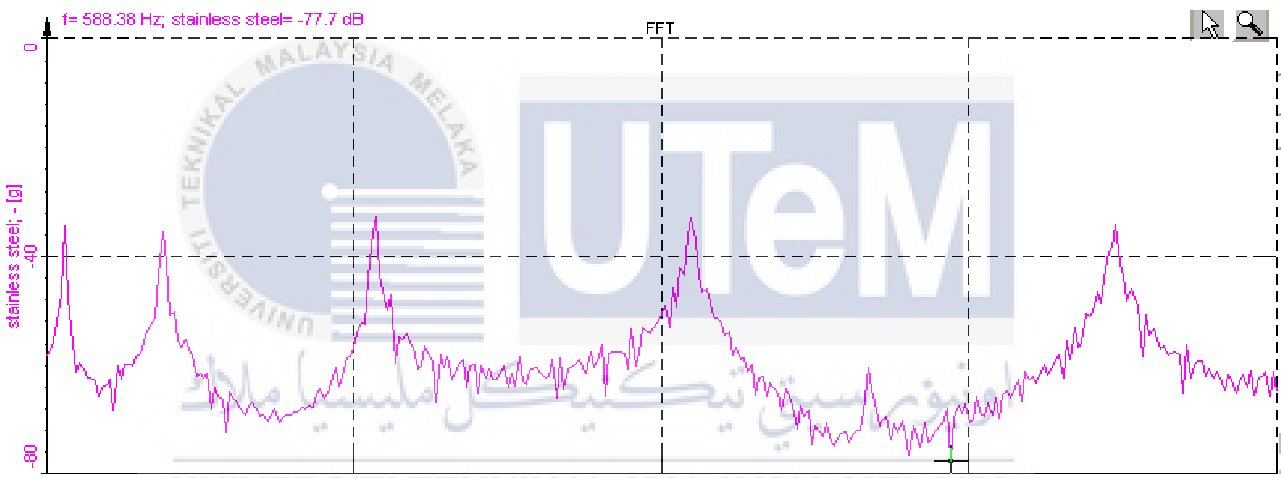


Figure 4-23: Distance 3

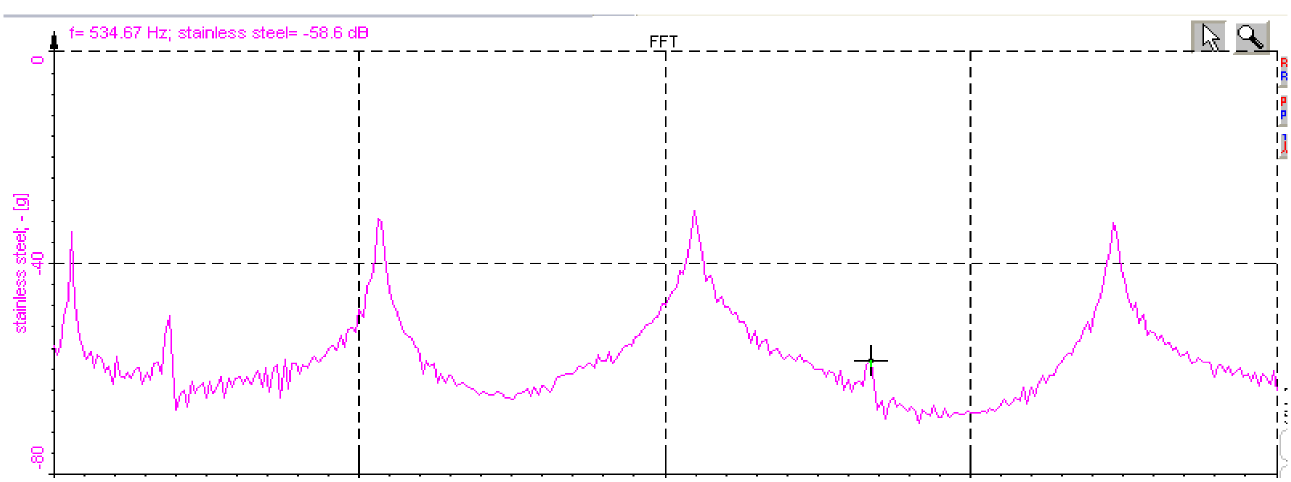


Figure 4-24: Distance 4

Table 4-10: frequencies with various distance

No	Distance, m	f_1	f_2	f_3	f_4	f_5
1	0.128	46.34	114.75	268.55	490.72	690.92
2	0.152	36.78	204.65	483.40	785.70	997.45
3	0.176	32.54	187.6	463.87	887.25	1045.92
4	0.200	28.96	154.78	461.46	897.78	1368.34

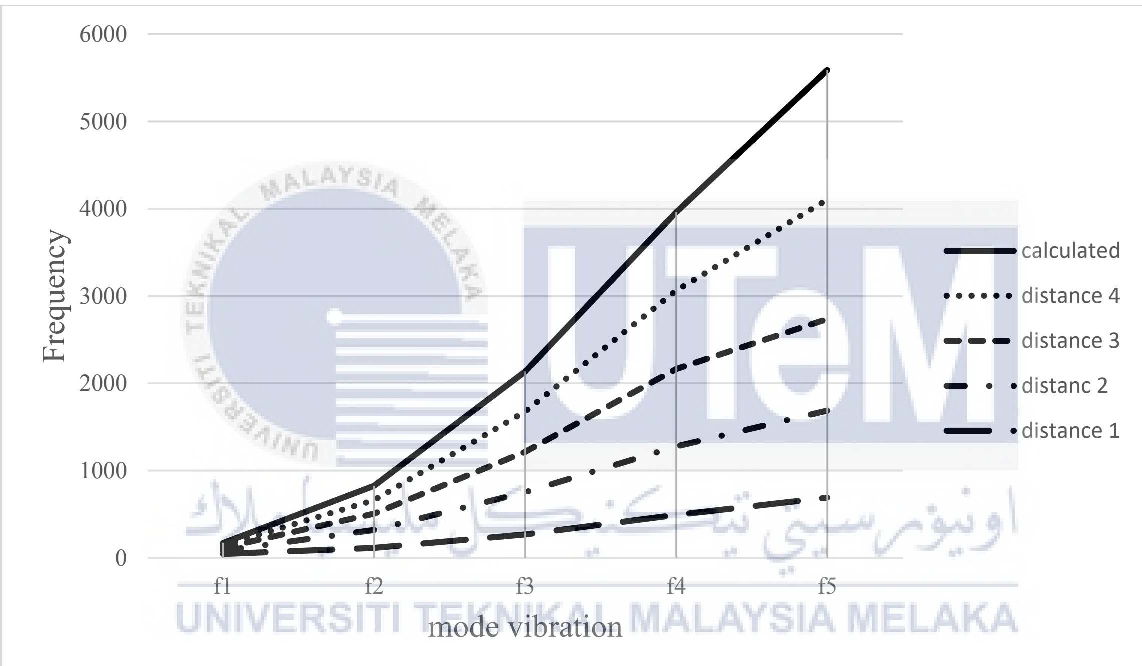


Figure 4-25: graph calculated with various distance data

From the graph above, the modification of distance indicated become more close to calculated data when achieve to distance 4. The distance was trigger by adding 0.024 m from distance 1 until distance 4. Error from distance 1 is 46.92%, distance 2 is 17.38%, distance 3 is 13.78% and distance 4 is 4.09%.

Percentages of error distance 1 = $\frac{3035.597 - 1611.28}{3035.597} \times 100\%$

$= 46.92\%$

$$\text{Percentages of error distance 2} = \frac{3035.597 - 2507.98}{3035.597} \times 100\%$$

$= 17.28\%$

$$\text{Percentages of error distance 3} = \frac{3035.597 - 2617.18}{3035.597} \times 100\%$$

$= 13.78\%$

$$\text{Percentages of error distance 4} = \frac{3035.597 - 2911.32}{3035.597} \times 100\%$$

$= 4.09\%$

From all modification, distance 4 was consider successful due to value of percentages of error less than 10%.

4.2.3 Summary

1st experiment was run three time and use average for comparison with calculated data, those testing was failed. This due the unsteady-state of plate during testing was run. Thus, second testing was run with modification (2nd experiment) to overcome the problem. This was run until reach the suitable distance.

CHAPTER 5

CONCLUSION AND RECOMMDETION

5.1 CONCLUSION

This study is to find mode vibration until five stage of vibration. The test was run on two different type of material for cantilever beam material which is copper and mild steel. Both testing as references of this research. After do some modification, those experiment was consider successful. The modification is changes the clamp-base with different type or design and adding isolator between plate. The successful method is using isolator due to the function of isolator to absorb any unwanted vibration acting on the plate. Those unwanted vibration will interface with input vibration and cause during run an experiment. In this research also cover a testing on circular shape of material. The reason of testing because circular shape is the shape of applicable laminated rubber-metal spring (LRMS). The material for this testing plate is stainless steel. When run the testing on this plate without any modification, the result was failed even the test was run three time. To reduce an error of the result, the plate must at steady-state condition. Thus, to archive that statement a modification have being apply to the method of testing. The modification is by adjusting the distance between clamping position with accelerometer. As the result, the experiment was successful when achieve fourth distance, this distance is the longest distance. This mean, to archive steady-state condition, the distance or position of accelerometer must be far enough and not too close with clamping position. In this study was successfully run an experiment on LRMS an find their five mode vibration of frequencies. Lastly, a study have done on five mode of frequencies through Fourier series analysis.

5.2 RECOMMENDATION

5.2.1 Clamping

To clamp the material on the clamp-base, it necessary to ensure that the condition of clamp-base in good condition and can be applicable to testing material. It is necessary to adjust the clamping method to get the correct data and reducing the error of experiment. It also require some modification of clamping, in this study the successful modification is isolated the plate with isolator such as rubber before clamping it at clamp-base. This due the high elasticity of the rubber can absorb unwanted vibration which can trigger and influent when taking data.

5.2.2 Calculation

In this study, there was including two method of finding frequencies of metal, those two method is running an experiment and using calculation method which is application of Fourier series transformation. During do calculation, there was need to alert all the variable involve in the formula. This because some variable cannot get straight by the formula, it need to trigger it. For example, to find cross-section area of circular plate, it need to plot a graph distributed of area and find the area under the graph which is consider as cross-section area of circular shape in this study.

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DEWESOFT programmable
(*http://www.dewesoft.com/products/dewesoft-x)*

Data acquisition (DAQ)

(http://sine.ni.com/cs/app/doc/p/id/cs-14099)

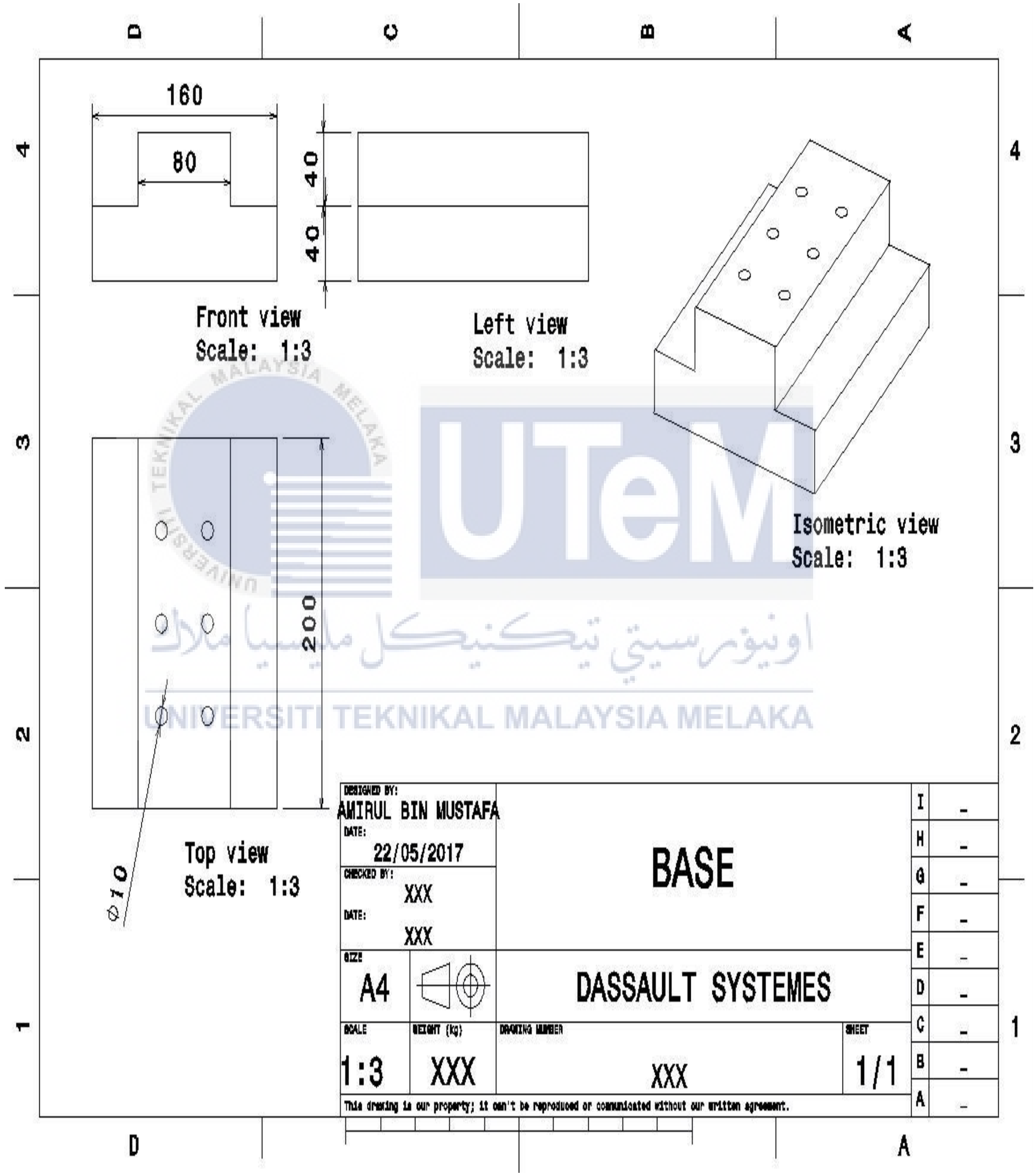
Application Rubber-Metal on Building
(https://www.emaze.com/@ALTWWTRO/Flexible-Building

Illusion Fixed and Free
(http://air.eng.ui.ac.id/tiki-index.php?page=FEM+-+Abdullah+Hawari)

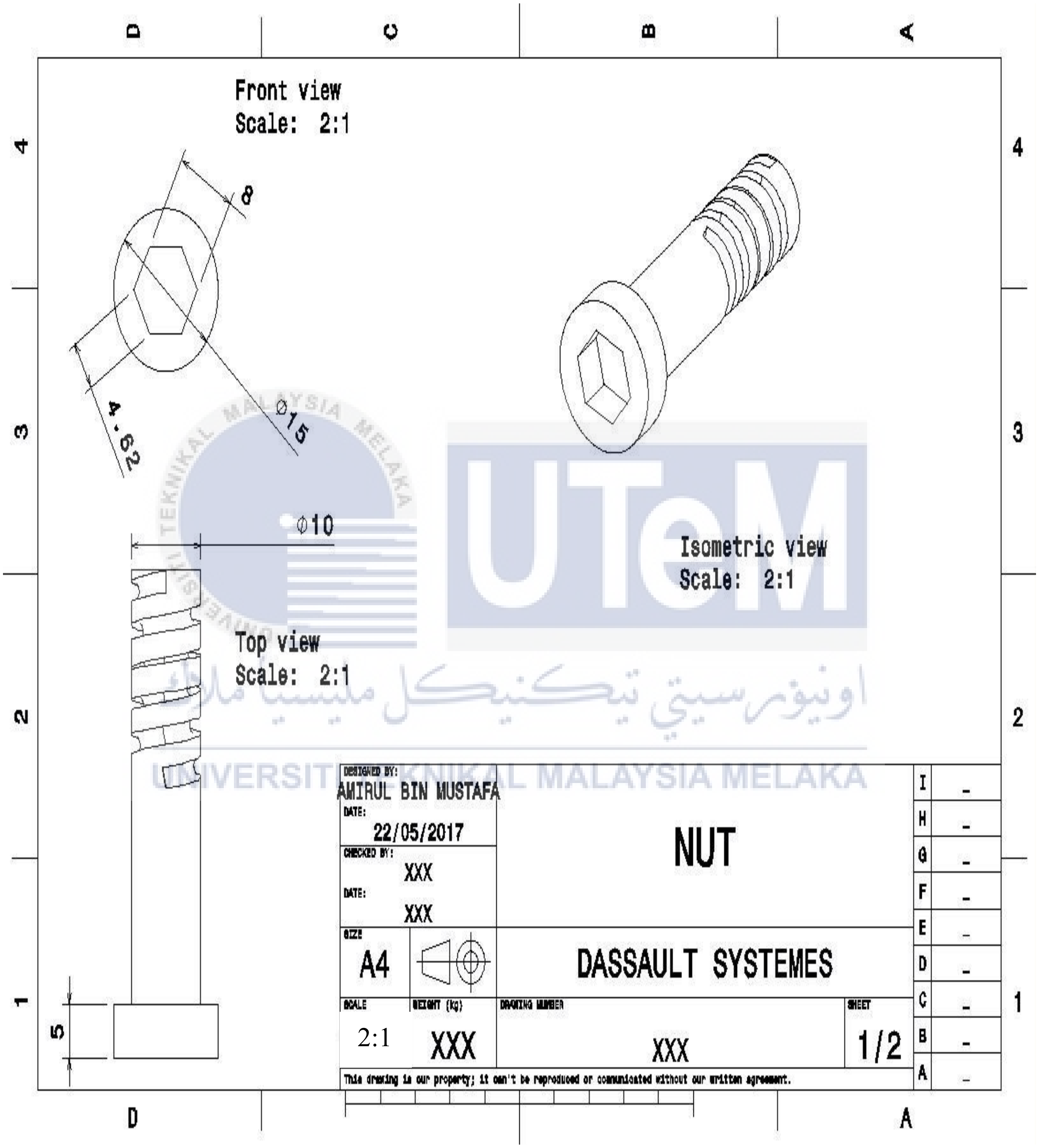
Natural rubber, 2012
(http://treesandshrubs.about.com/od/treeshrubbasics/f/Where-Does-Latex-Come-From.htm)

APPENDIX

Appendix A (1)

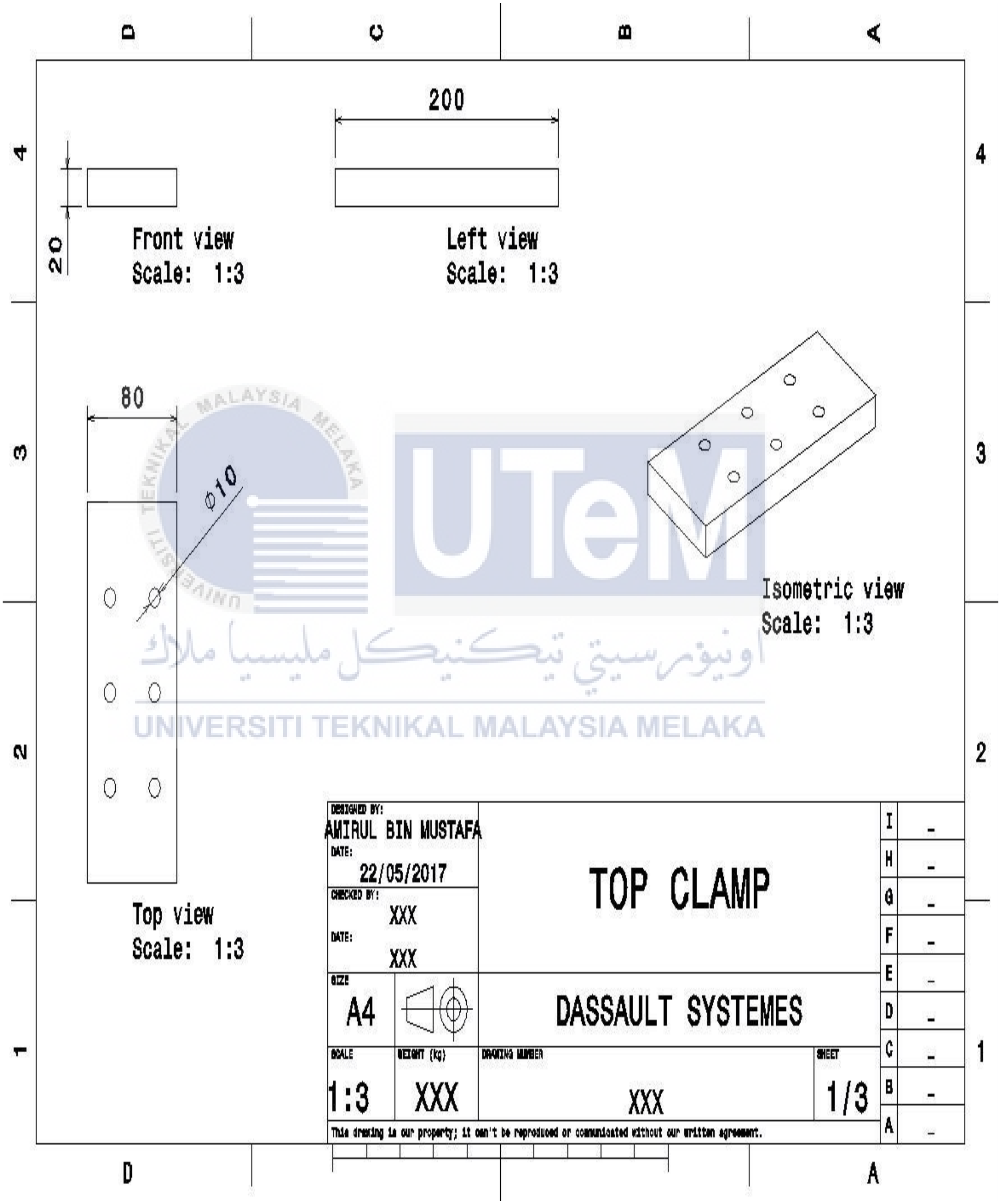

160
80
40
40
Front view
Scale: 1:3
Left view
Scale: 1:3
Isometric view
Scale: 1:3
200
⌀10
Top view
Scale: 1:3
DESIGNED BY:
AMIRUL BIN MUSTAFA
DATE:
22/05/2017
CHECKED BY:
XXX
DATE:
XXX
SIZE
A4
BASE
DASSAULT SYSTEMES
SCALE
1:3
WEIGHT (kg)
XXX
DRAWING NUMBER
XXX
SHEET
1/1
This drawing is our property; it can't be reproduced or communicated without our written agreement.
D
C
B
A
4
3
2
1
I
H
G
F
E
D
C
B
A

Appendix A (2)



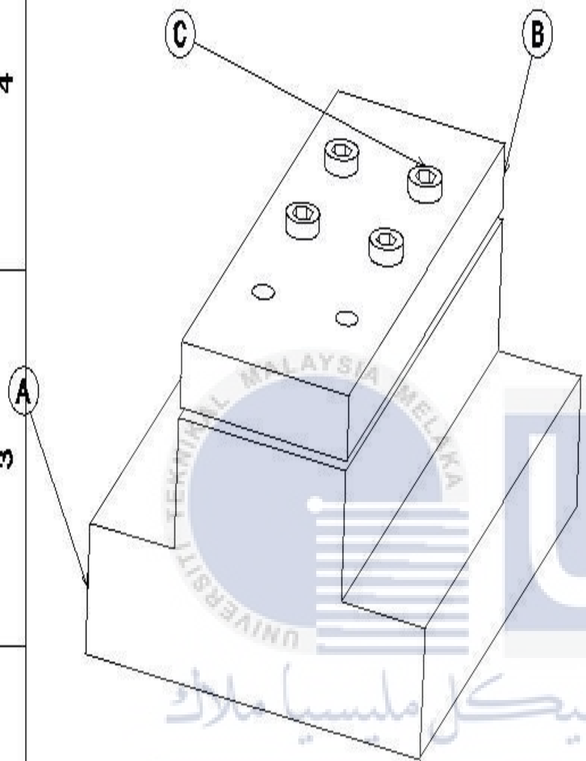
Front view
Scale: 2:1
8
4.62
Ø15
Ø10
Isometric view
Scale: 2:1
Top view
Scale: 2:1
5
DESIGNED BY:
AMIRUL BIN MUSTAFA
DATE:
22/05/2017
CHECKED BY:
XXX
DATE:
XXX
NUT
SIZE
A4
DASSAULT SYSTEMES
SCALE
2:1
WEIGHT (kg)
XXX
DRAWING NUMBER
XXX
SHEET
1/2
This drawing is our property; it can't be reproduced or communicated without our written agreement.

Appendix A (3)



200
20
Front view
Scale: 1:3
Left view
Scale: 1:3
80
⌀10
Isometric view
Scale: 1:3
Top view
Scale: 1:3
DESIGNED BY:
AMIRUL BIN MUSTAFA
DATE:
22/05/2017
CHECKED BY:
XXX
DATE:
XXX
TOP CLAMP
SIZE
A4
DASSAULT SYSTEMES
SCALE
1:3
WEIGHT (kg)
XXX
DRAWING NUMBER
XXX
SHEET
1/3
This drawing is our property; it can't be reproduced or communicated without our written agreement.

Appendix A (4)



Bill of Material: Product1

Quantity	Part Number	Type
1	base	Part
1	top	Part
4	nut	Part

Recapitulation of: Product1

Different parts: 3

Total parts: 6

Quantity	Part Number
1	base
1	top
4	nut

Isometric view

Scale: 1:2

DESIGNED BY: AMIRUL BIN MUSTAFA

DATE: 22/05/2017

CHECKED BY: XXX

DATE: XXX

SIZE: A4

ASSEMBLY

DASSAULT SYSTEMES

SCALE: 1:2

WEIGHT (kg): XXX

DRAWING NUMBER: XXX

SHEET: 1/4

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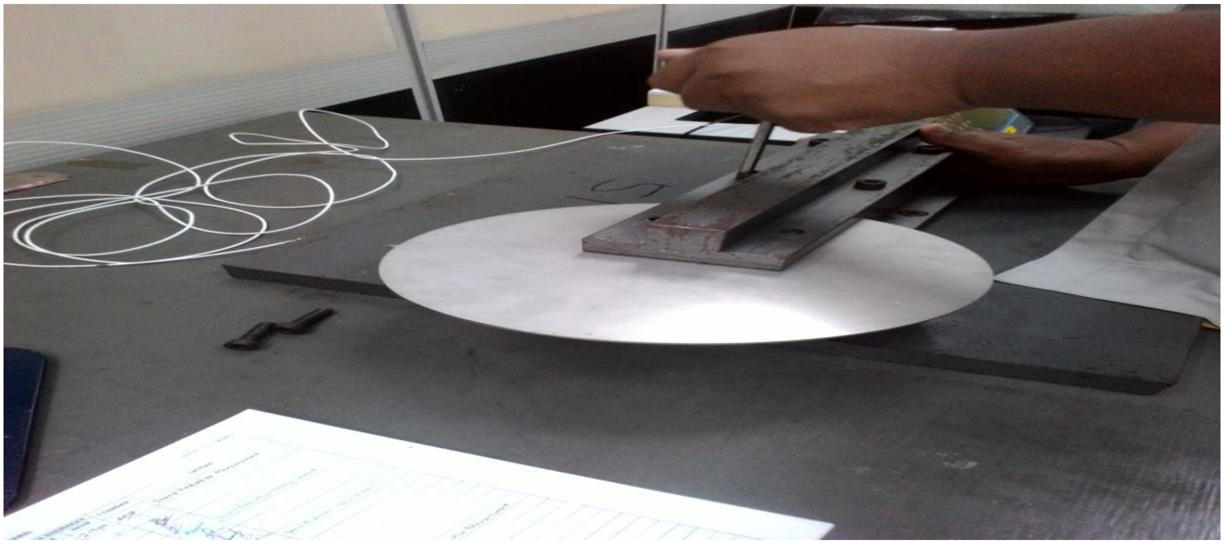
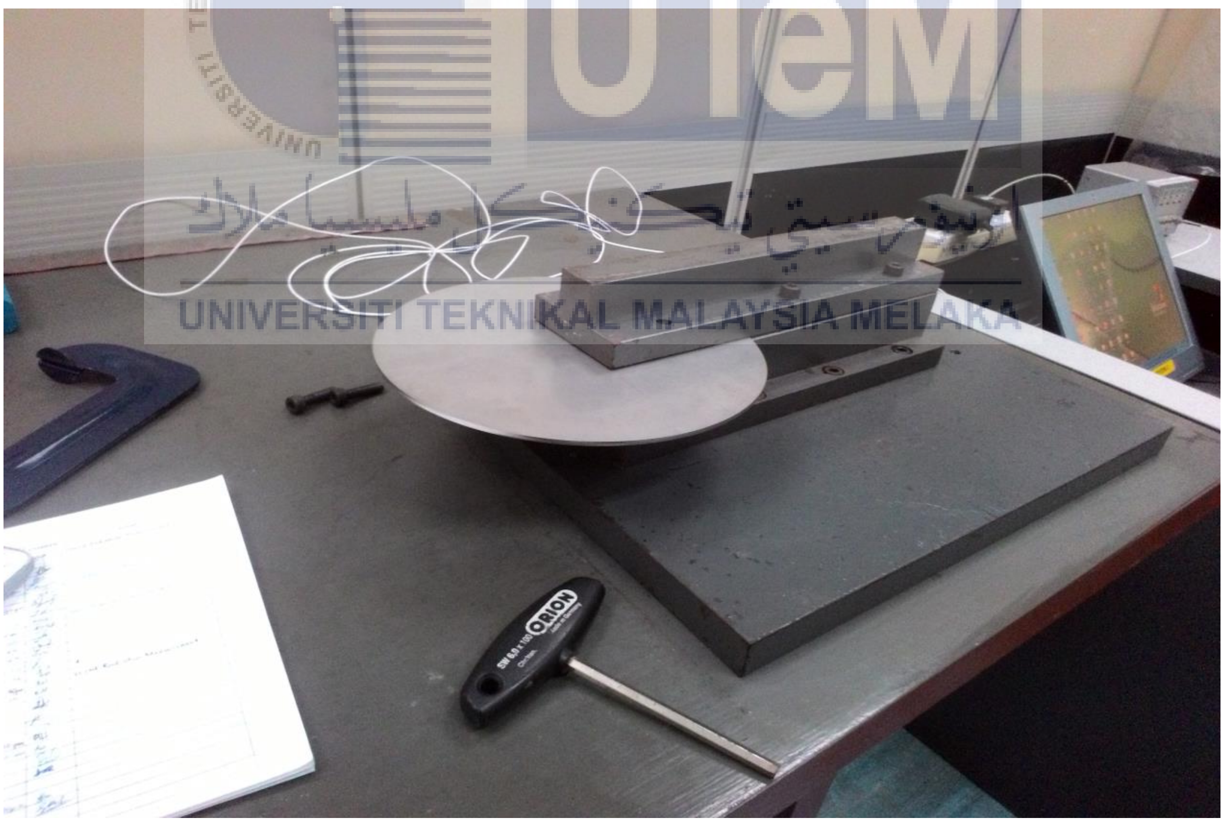
Appendix B (1)



Appendix B (2)



Appendix B (3)

Appendix B (4)