VIBRATION META-MATERIALS FOR VIBRATION ABSORBER

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

Faculty of Mechanical Engineering

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DECLARATION

I declare that this project report entitled “Vibration Meta-materials for Vibration Absorber” is the result of my own work except as cited in references

Signature : ....

Name of Supervisor : ....

Date : ....

APPROVAL

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

Signature :.............................

Supervisor's Name :.............................

Date :..............................

DEDICATION

To my beloved mother and father

ABSTRACT

This project is about metamaterial vibration absorber where the designed vibration absorber being attached on cantilever beam model in a repetitive arrangement to create a metamaterial-like structure. The project is started by designing the shape of vibration absorber using Solidwork 2015 software which the design must consist of spring and mass system. After that, ANSYS software is used to determine the natural frequency and maximum principle stress on the designed vibration absorber for the lab testing requirement. There are four design of vibration absorbers and one design is chosen to be fabricated and tested on the cantilever beam model to study and analyse the ability of it in reducing vibration amplitude of the cantilever beam model that been excited random force. The chosen vibration absorber design will be fabricated for a few identical pieces using CubePro 3D printer machine with ABS plastic as its material. The 3D printed vibration absorber is added one by one on the cantilever beam model and the ability of the vibration absorber in reducing vibration amplitude been monitored as the number of vibration absorber applied on it increases. The data of vibration amplitude been collected using accelerometer and Data Physics which the data will be interpreted through a computer in graphical diagram which is amplitude versus frequency. It is found that, as the number of applied vibration absorber on the cantilever beam model increases, the resonance peaks will decrease and the distance between the resonance peaks will become further. Furthermore, to obtain a more positive result, the vibration absorbers should be applied on both side of the cantilever beam to get a better vibration suppression result.

ABSTRAK

Projek ini mengenai penyerap getaran metamaterial di mana penyerap getaran yang di reka akan di lekatkan pada model julur rasuk dalam susunan yang berulang untuk menghasilkan struktur seperti metamaterial. Projek ini di mulakan dengan merekabentuk penyerap getaran menggunakan perisian Solidwork 2015 di mana reka bentuk itu mesti mengandungi sistem kelenturan dan sistem jisim. Selepas it, perisian ANSYS di gunakan untuk mencari frekuensi semula jadi dan prinsip tekanan maksimum pada penyerap getaran yang di reka untuk keperluan ujian di makmal. Ada empat rekaan dan hanya satu yang di pilih untuk di hasilkan serta di uji pada model julur rasuk untuk di kaji dan analisis keupayaannya dalam mengurangkan getaran amplitude pada model julur rusuk yang telah di berikan daya rawak. Reka bentuk penyerap getaran yang dipilih telah dihasilkan dalam beberapa unit menggunakan "CubePro 3D printer" dengan menggunakan plastic ABS sebagai bahannya. Penyerap getaran bercetak 3D telah di tambah satu persatu pada model julur rasuk dan keupayaan penerap getaran mengurangkan amplitude getaran di pantau sebagai bilangan penyerap getaran bertambah. Data amplitude getaran di kumpul menggunakan "accelerometer" dan Data Fizik di mana data tersebut di tafsirkan dalam bentuk gambarajah amplitude melawan frekuensi. Ianya di dapati bahawa, apabila bilangan penyerap getaran bertambah pada model julur rasuk, ketinggian puncak resonans akan berkurang dan jarak antara puncak resonans semakin berjauhan. Selain itu,untuk mendapatkan hasil yang lebih baik, penyerap getaran yang di gunakan perlu di letakkan

pada kedua belah bahagian julur rasuk untuk mendapatakan hasil penindasan getaran yang lebih baik

ACKNOWLEDGEMENT

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Active vibration absorber	AVA
Active Dynamic Undamped Vibration Absorber	ADUVA
Dynamic Vibration Absorber	DVA
Single degree-of-freedom	SDOF
Particle Damping	PI
Particle Impact Damping	PID
Multiple dynamic vibration absorbers	MDVAs
Shape memory alloy	SMA
Adaptive tuned vibration absorber	ATVA
Magnetorheological elastomer	MRE
Centrifugal pendulum vibration absorbers	CPVAs
Piezoelectric vibration absorbers	PVAs
Guided mode resonance	GMR
Defense Advanced Research Projects Agency	DARPA
Carbon-fiber-reinforced polymer	CFRP

CHAPTER 1

INTRODUCTION

1.1 Background

A dynamic vibration absorber is a combination of spring-mass system, where its natural frequency is tuned to the vibration frequency of the host structure. The absorber can therefore be of any form, such as lumped system of mass-spring-damper like those installed at the Taipei 101 building in Taiwan and at Millennium bridge in London, or a continuous system such as the Stockbridge damper.

The most recent research is a study to create vibration absorber using the metamaterial. Metamaterial is a material engineered to have a property with combinations of multiple elements fashioned from composite materials such as plastics or metals. Furthermore, most of the metamaterial has a repetitive nanostructure which has its own application and used depending on the way of its repetitive arrangement.

Besides that, 3D printer machine technology becomes increasingly popular because its flexibility in printing any shape of structure into three dimensions. Thus, 3D printer technology also has be seen as an emerging technology of additive manufacturing and was seen as an easy way in producing any kind of desired structure using various kind of material.

In this study, a few pieces of identical vibration absorbers be produced using 3D printer technology because its capability in fabricating any size and shape of the designed structure. Then, all the 3D printed vibration absorbers be applied in a repetitive arrangement in order to imitate the metamaterial's nanostructure-like which able to reduce the vibration amplitude of the targeted structure.

1.2 Problem statement

Vibration amplitude of a system could be reduced by applying vibration absorber. The purposes of this project are to study and identify whether metamaterials are capable to be apply for vibration absorber through simulation and lab testing, this is because metamaterials are still new and not widely use in the industry or in engineering field. With the help of current technologies such as 3D printer, vibration absorber can be fabricated using metamaterials and the capability of metamaterials in reducing the vibration in a system can be studied.

1.3 Objective

The objectives of this project are as follows:

1. To design and simulate metamaterial vibration absorber that match the targeted natural frequency using ANSYS software.
2. To fabricate a vibration absorber using 3D printer.
3. To conduct a lab testing on the vibration absorber that have been fabricate in lab and doing the analysis on efficiency of the vibration absorber in reducing vibration amplitude.

1.4 Scope of product

The scopes of this project are:

1. Only results of ANSYS simulation and lab measurement data will be presented in this report. The results collected from the lab will be compared only with the simulation.
2. The vibration absorber only be design according to certain natural frequency that have been fixed for testing.
3. The vibration absorber will be fabricate using the material that have been set.
4. The vibration absorber test only will be used on cantilever beam model.
5. This project only focusing on supressing first mode of natural frequency on the cantilever beam model.

CHAPTER 2

LITERATURE REVIEW

2.1 Vibration absorber

2.1.1 Active vibration absorber (AVA)

Active vibration control is the active application of force in an equal and opposite fashion to the forces imposed by external vibration. AVA are mostly hybrid in the sense that passive flexible elements work alongside the active components to share the counter disturbance efforts. An active vibration absorber needs sensors such as servo-type accelerometer for detecting low-frequencies vibration range and pneumatic actuator which will influence the structural response of the system (Syed et al., 2018). AVA purpose is to reduce the vibration of a mechanical system which the absorber automatically tuned to the system's structural response (Vasques and Rodrigues, 2006). AVA is an effective method to suppress wide range vibration frequencies and this could be achieved by adapting the characteristics and parameters of the absorber according to the variation of excitation force of that particular system (Wang and Yang, 2017). A research by Wu and Shao shows that the stiffness, inertia and damping coefficient of an absorber could be adjusting by a software or via online which will able the absorber to work more efficiently in reducing the excitation vibration.

In some cases, Active Dynamic Undamped Vibration Absorber (ADUVA) able to suppress the rate of vibration fast and having a small steady state frequency error. The single-frequency and multi-frequency ADUVAs have programmable algorithms that consists of equivalent dynamic modelling equations and frequency estimator. ADUVA have two type which are nonlinear and linear, a nonlinear ADUVA is much better in accelerating the converging rate in vibration suppressing and achieve more decrement of oscillation attenuating (Wang et al., 2017).

A research done by Bein et al. (2007) in reducing noise and vibration in vehicle structures through the implementing of semi-active vibration absorber and smart interfaces is seen as another great innovation. This semi-active vibration absorber is based on the shunted piezoelectric patch actuator which able to reduce the vibration and noise effectively but very costly due to the materials used.

2.1.2 Passive vibration absorber

A Passive Vibration Absorber or Dynamic Vibration Absorber (DVA) is able to reduce vibration or sound radiation by attaching it to a primary dynamic structure. A conventional DVA consists of a single degree-of-freedom (SDOF) mass-spring-damper system (Hua et al., 2017). Normally, vibration is due to rotational imbalances in a rotating machine such as motors, engines and pump. Conventional passive vibration absorbers are preferably used in the industry because it cheaper than active vibration absorber. Furthermore, passive method of suppressing vibration is the most adapted due to its low energy consumption and simplicity which more likely used in the industry (Djemal et al., 2017).

However, the vibration suppression performance of the absorber is limited by the ratio between the absorber mass and the mass of the primary structure and DVA usually been implemented at the mechanical structure such as beam, machine, building or any system which it purposed is reducing the excited vibration frequency to an acceptable level. A good designated absorber should have the natural frequency almost the same as the excitation frequency. However, DVA exhibit low performance in vibration suppression away from the resonance point despite high performance around the resonance point. Figure 2.1 shows how the DVAs been applied on a cantilever beam structure.

DVA also important in improving the stability of certain machines such as milling tools machine. The used of DVA in milling tools machine is to improve the quality of product produced. In industry, in order to increase the productivity of the processes, higher cutting speed, larger feed and depth of cut is needed. On the other hand, to achieve such performance will cause the increase of self-excited vibrations or chatter which will damaging the tool and spindle bearing or poor result of surface finish and dimensional accuracy of the work piece. With the help of DVA in the milling tools machine, the problem could be overcome effectively (Wajih et al., 2016).

Vibration in a multi-storey structure also need to be focus on because it involved people lives. A Magnetic Vibration Absorber has been seen as a passive control vibration absorber that suitable to be implemented for multi-storey structure. This vibration absorber is very effective in controlling first vibration mode of the structure and effective in handling vibration with large amplitude (Feudo et al., 2018).

Inerter is a mechanical element with two terminals. Shen et al. (2014) has proposed the used of inerter in improving the DVA for vehicle body. Through a frequency-domain simulation, it is proved that the inerter able to improve the damping performance of the suspension system. From power spectral density result also showed that the damping performance of the suspension are much better than passive suspension.

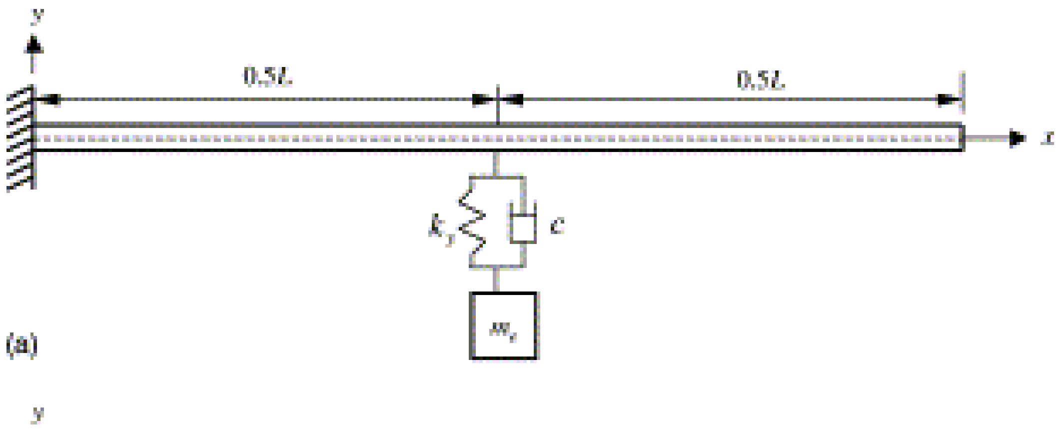

Figure 2.1: Dynamic vibration absorbers on cantilever beam.

2.1.3 Past research on vibration absorber

There are a lot of research done by past researchers that related to vibrator absorber, the purposes of those research are to improve the present vibration absorber and explore the possibility creating a much effective vibration absorber in certain industry and cases. Some of the research are done by Djemal et al. (2018) on Particle Damping (PD) or Particle Impact Damping (PID). This PID is believed to be able in reducing excessive wide range of vibration frequencies in mechanical systems and this PID consists in transferring a part of the vibration energy of the main system to the particles in the form of kinetic energy.

In automotive, multi-degree of freedom of vibration happen in powertrain system and because of that, implementation of vibration absorber is important. In order to overcome this problem, a study on semi-active dynamic vibration absorbers (adaptive tuned vibration absorbers) are done by Gao et al. (2017). Semi-active vibration absorbers able to vary it frequency which match with the external excitation frequency which resulting the absorbers to generates its own natural frequency based on the tuning absorber parameters to reduce the excitation vibration on the powertrain systems.

Some other research is on multiple dynamic vibration absorbers (MDVAs) which employ multiple aided masses that tuned to the frequencies near the structural frequency to reduce building motions. The MDVAs are more effective compared with DVA systems because MDVAs able to distribute the tuning of several auxiliary masses in the proximity of the resonance.

Some other method in controlling the vibration is by using a nonlinear structure which are the combination between isolator and absorber with a time-delayed coupling active control. The time-delayed nonlinear absorber can promote internal natural frequency between different modes, low frequencies of vibration energy could be sent to a high frequency mode and the range of fundamental frequency able to be suppressed (Sun and Xu, 2015).

In addition, shape memory alloy (SMA) also has been seen useful in adaptive tuned vibration absorber (ATVA). This could be achieved by the combination of magnetorheological elastomer (MRE) and SMA which will produce a smart spring-mass-damper system in tuned vibration absorber (Kumbhar et al., 2017). In some other cases, centrifugal pendulum vibration absorbers (CPVAs) could be applied to rigid rotor that have tilting, rotational and translational motions. This CPVAs could work effectively in reducing vibration on a rigid motor that free to translate, rotate and tilt with the help of gyroscopic modal analysis (Shi et al., 2016).

2.2 Vibration on structure

Structural phenomenon is a natural source, which occur due to repetitive movement and involves external forces acting on it. Commonly, vibration is not needed in everyday life because it could bring negative impact or result to any structure. Structural vibration is undesirable, wasting energy and leading to excessive deflections and structure failures. A common way to overcome this problem is by implementing vibration absorber system.

DVA able to reduce the vibration impact on the structure, thus been able to prevent any structural damage on it. In recent years, DVA have been increasingly used to enhance the structural ability performance such as in tall buildings, bridge, beam or any other structures. As the structures experiences a resonant response, DVA that have been designated properly will interact with the structure, altering its mechanical admittance function, and reducing the vibration frequencies response (Love et al., 2018). Figure 2.2 show on how DVA could be implement in a simple structure such as a washing machine, where this DVA system reduce the excite vibration due to the rotating motion from the washing machine.

Digitally controlled piezoelectric vibration absorbers (PVAs) is another type of absorber that has been found effective in reducing the vibration in truss structures. PVA is consists of DVA system, piezoelectric element and resistor-inductor (RL) circuit. This digitally controlled PVAs are proved to be effective in vibration-control method for adaptive structures (Yamada et al., 2018).

Floor vibrations are seen as another vibration problem that need to be overcome. Researchers found that vibration amplitude on the floor are due to the coincidence of the natural frequency and harmonics excitation due to walking activities, this could be avoided by keeping away the frequencies from each other. The solution to the problem is by embedding viscoelastic materials and tuned mass dampers under the floor (Saidi et al., 2011). Another method was proposed by Carmona et al. (2016) in reducing floor vibrations. They proposed a tuned mass damper with friction damping which damping mechanism is from friction. They found that this vibration absorber is effective in reducing vertical vibrations and impact forces due to human activities. Thus, it also needed a low manufacturing cost and able to be implement in a small space.

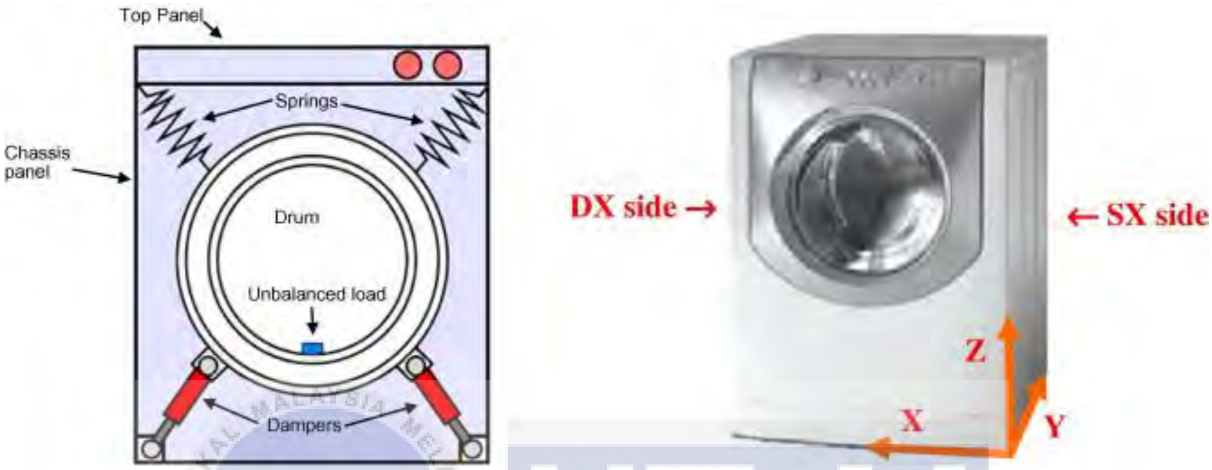

Figure 2.2: DVAs in washing machine.

2.3 Metamaterials study

Metamaterial is a material engineered to have a property that is not found in naturally occurring materials. They are made from combinations of multiple elements fashioned from composite materials such as plastics or metals. The unique properties of metamaterials have attracted many researchers to study about it more and try to implement its use in industry or in daily life. Some of the research and study about meta-materials are meta-materials as a superconducting material. Ricci et al. (2007) proposed that these meta-materials could be turned into a superconducting material because meta-materials have unique electromagnetic properties which its dielectric permittivity and magnetic permeability has values less than 1 or negative values. They found that this meta-material has the ability tuning its frequency according to the unique electromagnetic response that occur.

Besides that, meta-materials also been used in sensor. Tumkaya et al. (2018) has present a study about the use of meta-material-based sensor to differentiate different type of gasoline and diesel samples. The propose sensor is designed through the electromagnetic characterization of the samples. The samples will be experiment and the collected data will be used in the numerical analysis in order to come up with a suitable meta-material-based sensor. As a result, this sensor will have high capabilities to sense the fuel oil samples and differentiate it well.

Another used of metamaterials are discover by Vasudevan et al. (2018) where they studied the optical properties of non-circular metamaterials optical fibre. From the result that they get, implementing metamaterials in optic fibre will be able to increase in performance and the optic fibre could be a good use in sensor device because this metamaterial can increase the effectiveness permittivity and wavelength of the optic fibre.

Metamaterials in guided mode resonance (GMR) is another application that could bring changes to the resonance research. Applying metamaterials which consist of periodic array of conducting resonant structures in GMR, its able to boost up the sensitivity sensing from microwave, terahertz to optical frequencies (Liu et al., 2018). Furthermore, metamaterials open a new window for sensory application. This is because metamaterials are believed to have multi-functional of potential and have a wide range of applications due to their unusual electromagnetic properties. Besides, metamaterials have an extraordinary electrical and magnetic behaviours which useful in sensing, absorption, polarization rotation, imaging or source shifting and many more applications (Bakir et al., 2018).

2.4 Metamaterials in vibration absorber

Metamaterials are known as semi-active composited which has been proposed in 2011 by the Defense Advanced Research Projects Agency (DARPA), these metamaterials are unable to be observed in nature or in the constituent materials so a research and study on this new class of materials are important in order to develop new technologies (Frank et al., 2013). The size, orientation, shape and arrangement of the microstructure in metamaterials affect the transmission of light and create unconventional, unnatural material properties (Peng et al., 2014).

Recently, there are many researchers try to implement these metamaterials in vibration absorber. These metamaterials are being believed to improve vibration absorber into much better and much effective. According to Lee et al. (2018) a new vibration metamaterial is needed for solving vibration problems which cannot be easily solved by using a conventional materials and configurations. Vibration metamaterials which based on vibration absorbers and periodic acoustic/vibration composite materials are not a latest system, however, it is a new way interpreting of the well-known acoustic and vibration system for changing the characteristic of wave transmission.

A research done by Lee et al. (2018) using vibro-acoustic metamaterial for longitudinal vibration suppression, obtained a result that this type of vibration absorber is very effective in extremely low frequency range of longitudinal vibration. They find that, using vibro-acoustic metamaterial can be used as a connecting part for suppressing longitudinal vibration waves transmitted between two mechanical parts in a low frequency range. This show that by utilizing the used of metamaterials it could be able to improve the conventional materials vibration absorber into a much better and effective. The study and research related to metamaterials involving vibration absorber should be acknowledging and make as a reference in the future studies.

Besides that, He et al. (2017) has designed structural vibration suppression in laminate acoustic metamaterials which is composed of carbon-fiber-reinforced polymer (CFRP) and periodic array of mass-spring-damper subsystems with the laminates will acts as vibration absorbers. As a result, by integrating two parallel orthotropic laminates which consists of CFRP and mass-spring-damper subsystems, the stopband become more wider compared with a conventional vibration suppression.

Furthermore, Yang et al. (2017) has stated that meta-structure has vibration damping capability. An investigation on vibration reduction using meta-structures which composed of dynamic absorber that been employed by mass impacts have been done. Through propagation analysis, the reflection coefficients of meta-structure beam that have been attached with multiple absorbers been calculated using transfer functions. As a result, the meta-structure only effective when its natural frequency matched with the main system in reducing the structural vibration.

2.5 Cantilever beam model

To test the vibration absorber, cantilever beam model was used, and this is being done by clamping one side of a rectangular aluminium steel and let another end of the aluminium steel free so that it could act as cantilever beam structure as shown in Figure 2.3. The aluminium steel been set up at certain length which the natural frequency of the cantilever beam will match which the desired frequency for vibration absorber lab testing where the beam set up is bound to the equation of beam in Equation 1. According to Nirmall.T and Vimala.S (2013), natural frequency is the rate at which an object vibrates when it is not being disturbed by an outside force. While, S. Kale et al. (2016) stated that in analysis, the maximum deflection of cantilever beam will occur when the applied frequency matched with the natural frequency of cantilever beam when subjected to harmonic loading. In this project, the shaker will excite a random force on the cantilever beam model in order the cantilever beam model vibrates at its natural frequency. The stiffness of a cantilever beam is given by

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

Eq. 1

Where L is the length of the beam, E is the Young's modulus and I is the second mass moment of inertia.

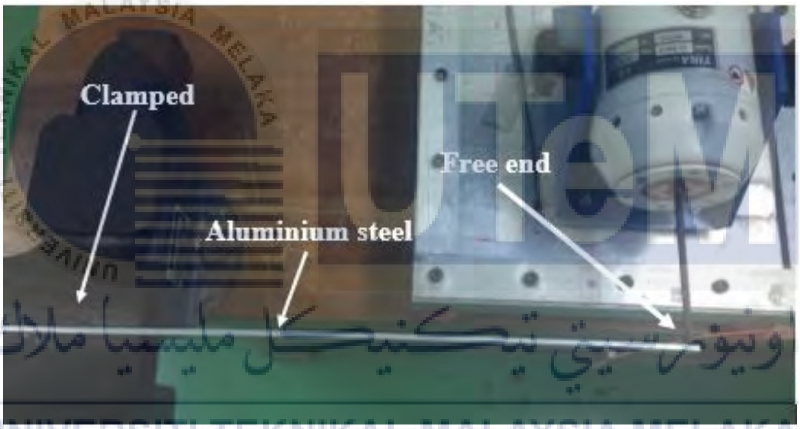

Figure 2.3: Cantilever beam model

The natural frequency of a mass, m attached at the free end of a cantilever beam as in Figure 2.4 is given by

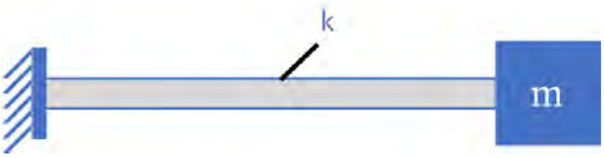

Figure 2.4: A mass attached at the free end of cantilever beam model

$$\omega_n = \sqrt{\frac{k}{m + 0.23m_b}}$$

Where m_b is the total mass of the beam, m is the mass attached at the free end of the beam and k is the stiffness of the beam.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the methodology used in this project to investigate the efficiency of metamaterial vibration absorber. This project starts by studying the literature review about metamaterials and vibration absorber. Through this study, its help to discover some research that have been done by past researcher that related to metamaterial and vibration absorber. Besides that, an analysis and simulation on designated absorber also was did for this project. The absorber for the project was designed by using Solidwork 2015 software. Where the simulation and analysis are done using ANSYS software. The designated absorber must achieve natural frequency in about 180$\pm$5 Hz to 220$\pm$5 Hz before can be used for the experimental testing. After achieving the desire natural frequency, the absorber has been fabricated for a few pieces using 3D Printer in the lab. The material used to print the absorber are ABS plastic. Then, all the 3D printed absorbers was attached on the cantilever beam in a repetitive manner to create a metamaterial-like structure. The effectiveness of the vibration absorbers in reducing the vibration on the cantilever been given attention and analysed. If the vibration absorber failed to reduce the excitation vibration, the process to design, simulate and fabricate of the absorber will be repeated until the absorber able to reduce the excitation vibration on the cantilever beam. The flowchart for this project will be shown in Figure 3.1.

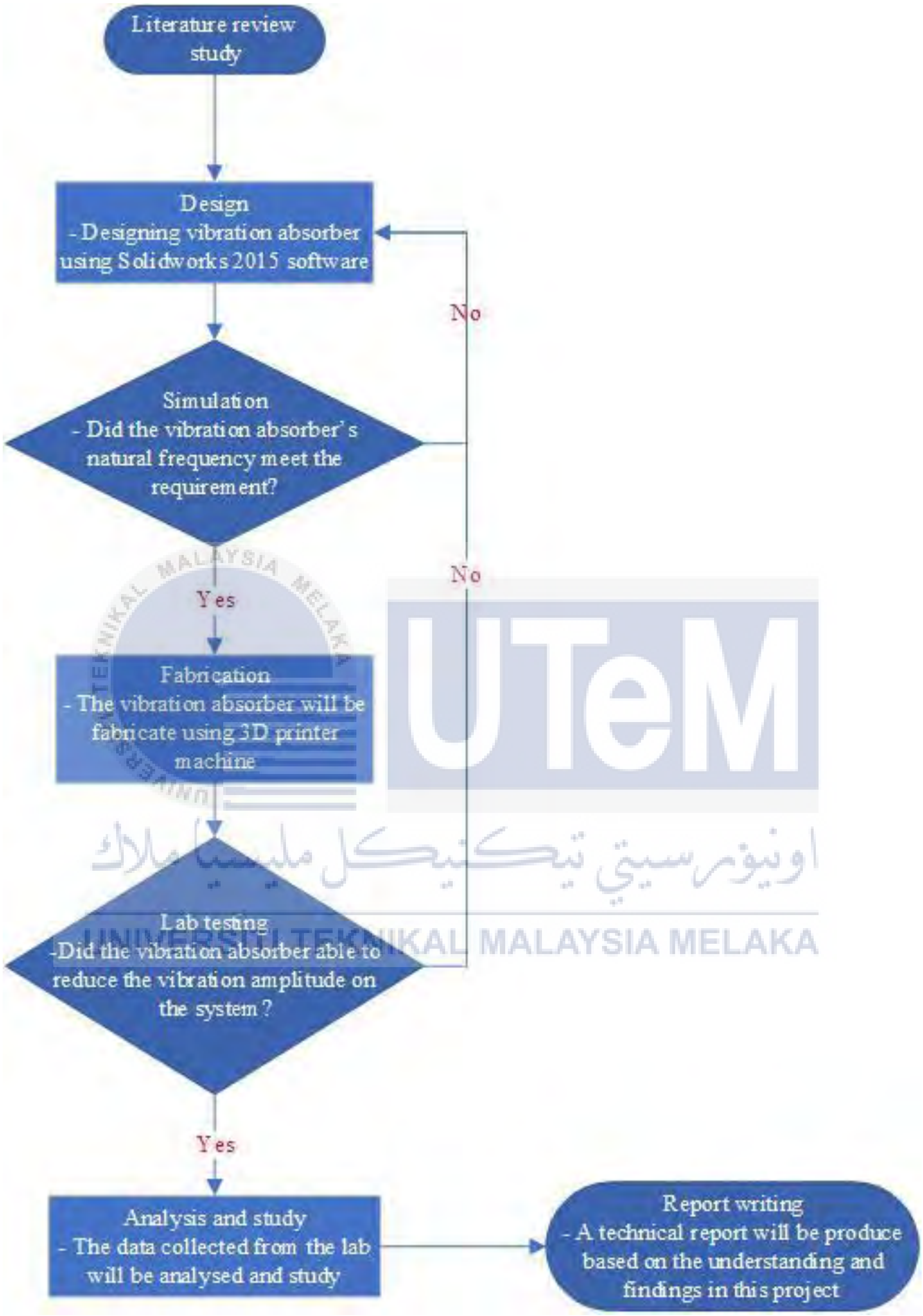

Figure 3.1: Flowchart for the project.

3.2 Design and simulation of vibration absorber

The design of the vibration absorber was done through the Solidwork 2015 software which the designated absorber consists of the combination of mass and spring system. There are four different designed of vibration absorbers have been proposed for this project which the design and dimension of all four vibration absorbers are shown in Figure 3.2. After designing the vibration absorber, the all the four vibration absorbers was exported to ANSYS software in order to find out the natural frequency of the absorber which needed to be in the range of 180 Hz to 220 Hz. The material of the absorber was set up as Acrylonitrile butadiene styrene (ABS) plastic in the ANSYS software. The analysis in the ANSYS software of the vibration absorber is done through modal analysis where the natural frequency for each of the designed vibration absorber obtained in total deformation simulation in the ANSYS modal analysis as shown in Figure 3.3 and Table 3.1.

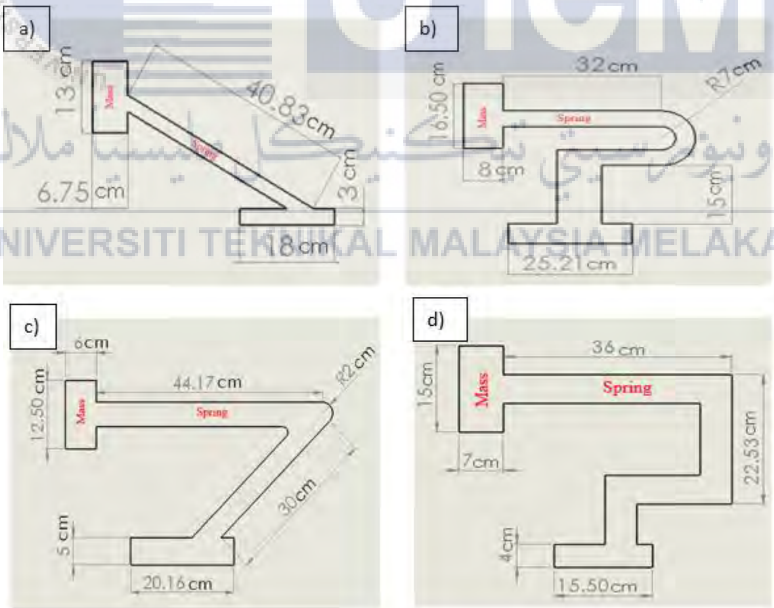

Figure 3.2: a) First design, b) Second design, c) Third design and d) Fourth design

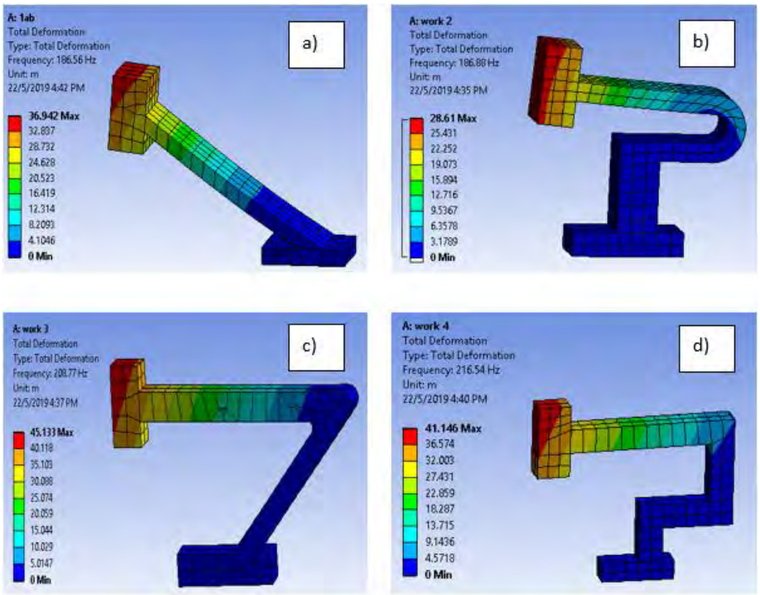

Figure 3.3: a) Modal analysis for first design, b) Modal analysis for second design, c) Modal analysis for third design and d) Modal analysis for fourth design

Table 3.1: Natural frequency for each of the proposed vibration absorber design from ANSYS

No	Vibration absorber	Natural frequency (Hz)
1	First design	186.56
2	Second design	186.88
3	Third design	208.77
4	Fourth design	216.54

After obtaining the natural frequency for each of the designed vibration absorber, all four designed of the vibration absorbers undergoes stress analysis simulation where a force of 10 Newton was applied to the vibration absorbers. The purposed of this analysis is to determine the most suitable designed of the vibration absorber to be use for the experimental testing in the lab by choosing the design with the highest value of maximum equivalent stress. The stress analysis is done via ANSYS simulation software as shown in Figure 3.4

and Figure 3.5, through static structural analysis, the data of maximum equivalent stress is obtained.

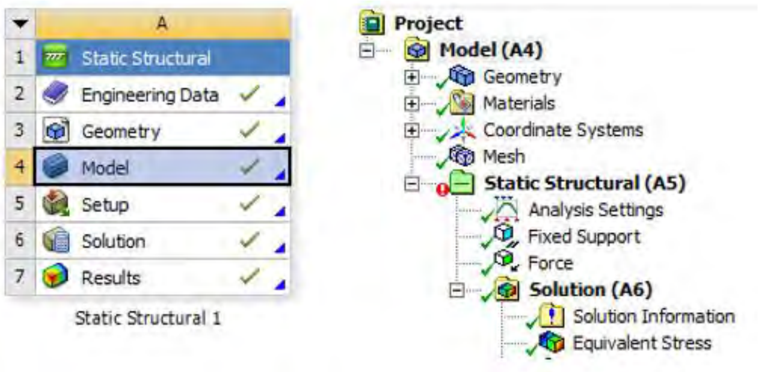

Figure 3.4: Stress analysis via ANSYS software

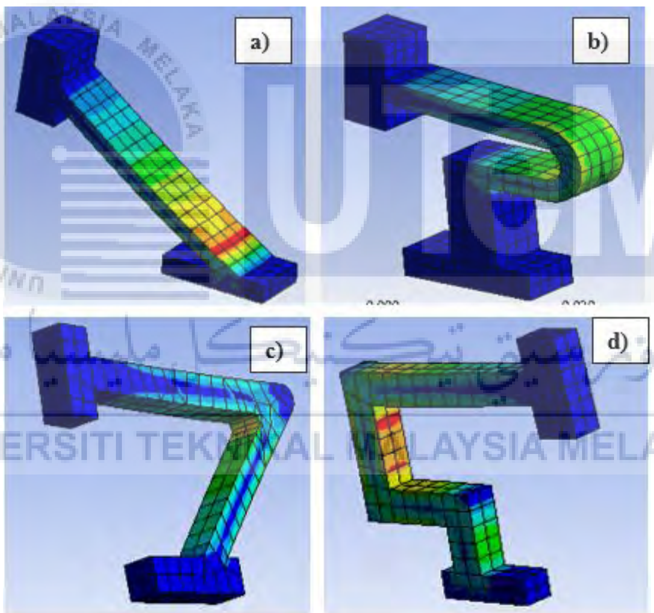

Figure 3.5: Stress analysis for a) First design, b) Second design, c) Third design and d) Fourth design

3.3 Fabrication

Then, vibration absorber that was been fabricated using 3D printer which is CubePro 3D Printer as shown as in Figure 3.6. The vibration absorber is printed using ABS plastic filament where the vibration absorber drawing from Solidwork drawing software are converted into STL file and transferred the file into the CubePro 3D printer. It takes 30 to 50 minutes for the 3D printer machine to produce a piece of vibration absorber.

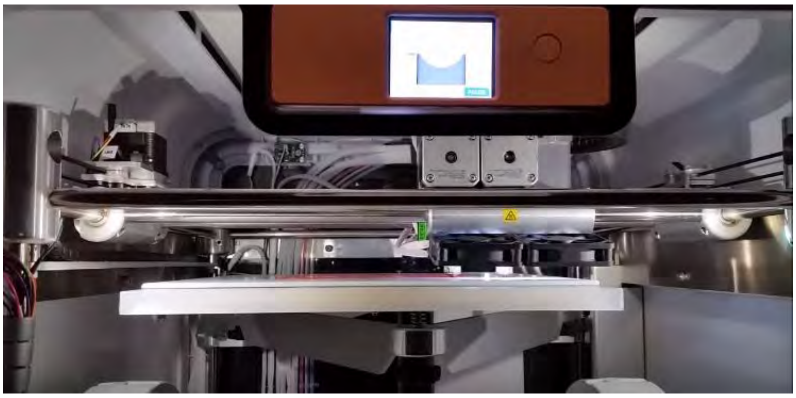

Figure 3.6: Printing the chosen vibration absorber using CubePro 3D Printer

3.4 Experimental testing

After the fabrication was done, the absorber undergoes an experimental testing in the lab to find the natural frequencies for each of the 3D printed vibration absorbers before it was attached on the cantilever beam structure to test its effectiveness in reducing vibration amplitude. The purpose in finding the natural frequency of each of the 3D printed vibration absorbers is to tune the natural frequency of the cantilever beam model same as the natural frequency of vibration absorbers. The experimental diagram to obtain the natural frequency of each of the vibration absorbers are shown in Figure 3.7.

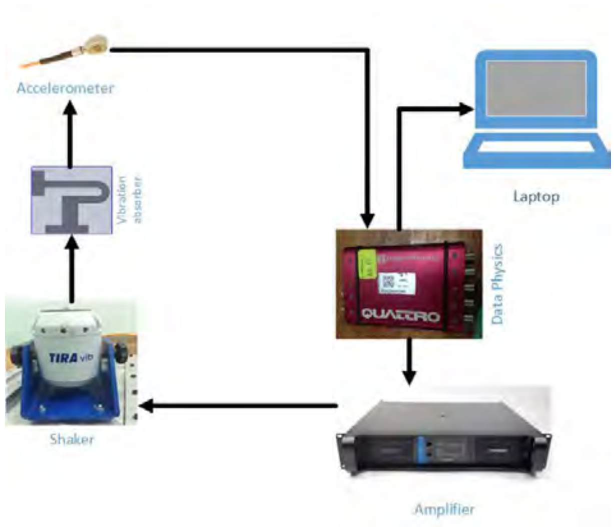

Figure 3.7: Experimental diagram to obtain the vibration absorber's natural frequency

Then, all the vibration absorbers that have been printed are applied on a cantilever beam model to test its effectiveness in reducing vibration. The experimental test was started by applying excitation forced at the cantilever beam by using a shaker. After that, the vibration absorber was placed one by one at the beam and the ability for the absorber to reduce the vibration been monitored with the help of accelerometer. The experimental diagram for the vibration absorber testing could be referred in Figure 3.8. The shaker applied a random vibration on the structure of the cantilever beam while the accelerometer will fetch vibration's frequency on the beam, the signal from the accelerometer been transferred to Data Physics to convert the signal into a graphical diagram that will been show up through the laptop connected to Data Physics. For this project, the data have been interpreted in term of amplitude versus frequency graph which easier to be analyse and study.

Table 3.2: List of equipment used for the project

No.	Type of equipment	Details of the equipment
1	Data Physics Analyzer	Read the signal from accelerometer and interpret it into graphical signal
2	Accelerometer	Measured the excitation vibration from the cantilever beam model
3	Amplifier	Controlled the excitation vibration from the shaker
4	Shaker	Excited vibration on the cantilever beam model
5	Laptop	Showed the graphical signal obtained from the Data Physic Analyzer

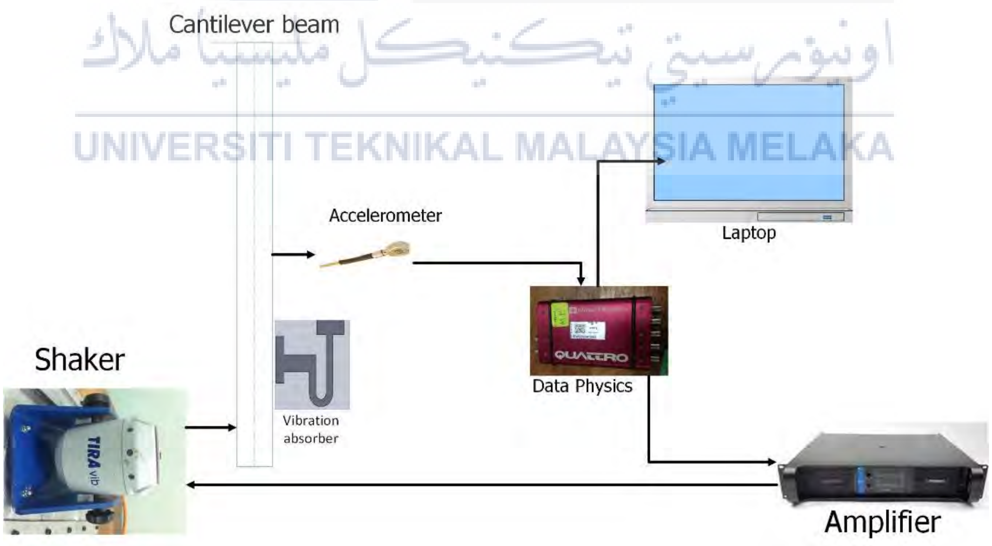

Figure 3.8: Experimental diagram for vibration absorbers testing

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

In this section, first, the stress analysis that have been done on all the proposed vibration absorber designed are evaluated. Next, the theoretical value of the vibration absorber was discussed and evaluated. Finally, the experimental procedure and results during the lab testing been analysed, discussed and evaluated.

4.2 Results from stress analysis from ANSYS software

In order to determine which design is the best for the vibration absorber from Figure 3.2, stress analysis been done on each of the vibration absorber design. The stress analysis results from ANSYS simulation are shown in Table 4.1.

Table 4.1: Values of maximum principle stress for each of the vibration absorber design

No	Vibration absorber	Maximum principle stress values (MPa)
1	First design of vibration absorber	24.56
2	Second design of vibration absorber	28.87
3	Third design of vibration absorber	26.72
4	Fourth design of vibration absorber	22.43

Since the second design of vibration absorber having the highest value of maximum principle stress, which is 28.87 MPa, the second design are been chosen for fabrication and the lab testing.

4.3 Experimental testing and results of vibration absorber

The experimental procedure started by fabricating the second design of vibration absorber into four pieces using 3D printer machine and obtaining the natural frequency for each of the vibration absorbers for the experimental process. Then, after obtaining natural frequency of each vibration absorber, all the vibration absorber was attached on the cantilever model to analyse the efficiency of the vibration absorbers in reducing the vibration amplitude on that particular cantilever beam model that has been tuned at certain frequency.

4.3.1 Determining vibration absorbers' natural frequencies

Before all the vibration absorbers been attached to a cantilever beam model structure, each of the vibration absorber's natural frequency are obtained by using a shaker, amplifier, accelerometer and Data Physics. The experimental set up to obtain the natural frequency of each of the vibration absorbers been showed in Figure 4.1. The chosen designed of the vibration absorber was printed into four pieces and each identical piece are labelled from

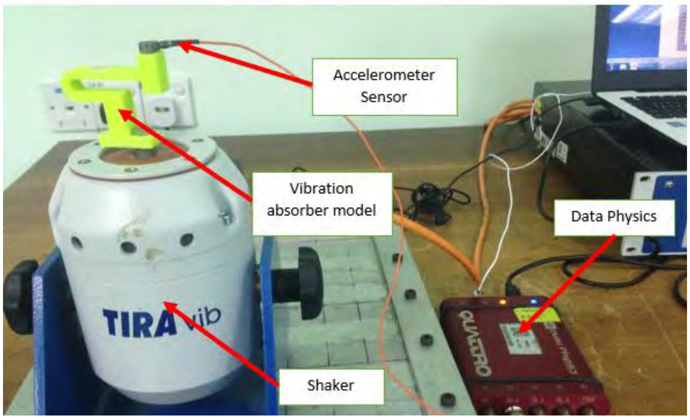

Figure 4.1: Experimental set up to determine vibration absorbers' natural frequency.

one to four in order to differentiate the natural frequency obtained for each of the identical vibration absorber as shown in Figure 4.2.

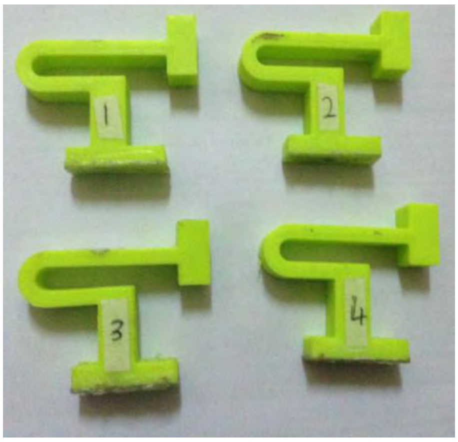

Figure 4.2: Four identical vibration absorber that been labelled from one to four

The shaker applied a random force on the vibration absorber model while the accelerometer fetched the frequency from the vibration absorber and the signal from the accelerometer are analysed through Data Physics and displayed in graphical diagram via the computer which is in amplitude versus frequency graph. The natural frequency of the vibration absorber is determined through the point where the highest peak of amplitude on the graph displayed. The results of each of the vibration absorbers are shown in Figures 4.3 and Table 4.2.

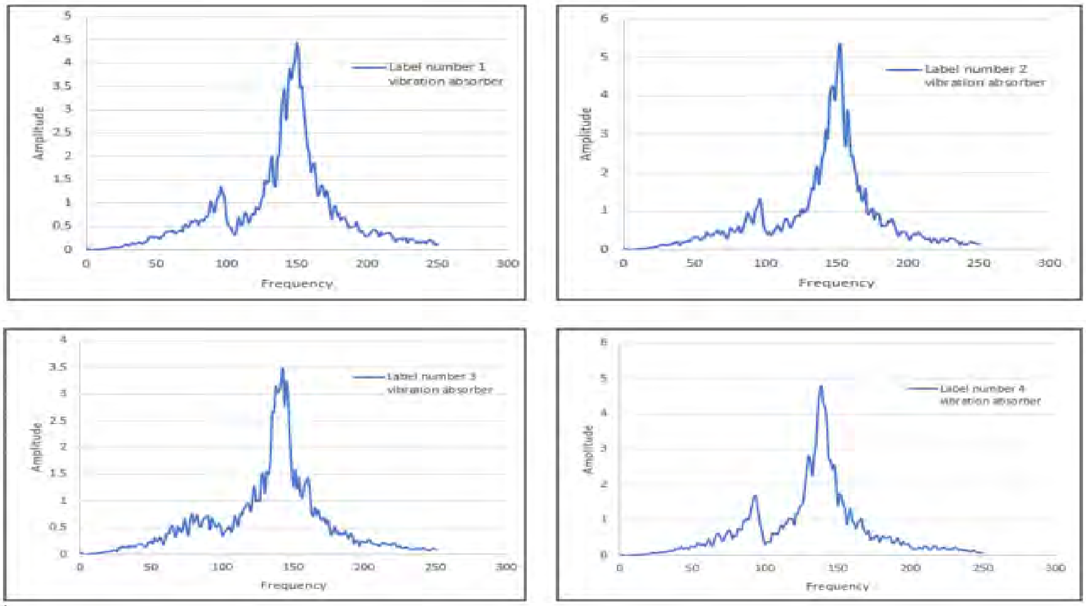

Figure 4.3: Amplitude versus frequency graph for determining natural frequency of each of the vibration absorber.

Table 4.2: Natural frequency of each of the vibration absorbers.

Absorber	Natural Frequency (Hz)
Absorber label number 1	150
Absorber label number 2	150
Absorber label number3	145
Absorber label number 4	143

Even absorber number 1, 2, 3 and 4 have the same shape, dimension and material, each of the vibration absorbers having a different natural frequency. According to the data from the simulation as in Table 3.1, the natural frequency for this chosen design should be around 186.88 Hz. However, the values of natural frequencies obtained from the lab are between 143 Hz to 150 Hz and this happened because the product from 3D printer model usually having inconsistent in term of the density and the fill inside the structure and also the layering of the material during printing not too compact which result the different of natural frequency of each of the vibration absorber models and different with the result from the simulation. Although the results are different from the expectation, as long the vibration absorber having a natural frequency lays in the range of 140 Hz to 160 Hz, it will be accepted for this project because having natural frequency lower than 220 Hz is easier to tuned the cantilever beam model's natural frequency in the lab.

4.3.2 Experimental testing of the vibration absorbers

The experiment was started by tuning the natural frequency of the cantilever beam model matched the desired frequency which is 143 ± 3 Hz which the experimental set up for the cantilever beam model could be referred in Figure 4.4. The cantilever beam model are tuned to 143 ± 3 Hz because it found that the vibration absorbers that are applied to that structure is more efficient in that particular range of frequency which in this experiment where the length of the aluminium steel have been set up at 27.8 cm in order to achieve the desired frequency.

A research done by Frank et al. (2013), presenting the idea of metamaterial beam based on multi-frequency vibration absorbers for a broadband vibration absorber has shown a positive result. Referring to Figure 4.5, the black line is the system without vibration absorber, where the red, green and blue line are the system with vibration absorber application. Through this past research result, this project should obtain an almost similar graphical representative data when applying the vibration absorbers.

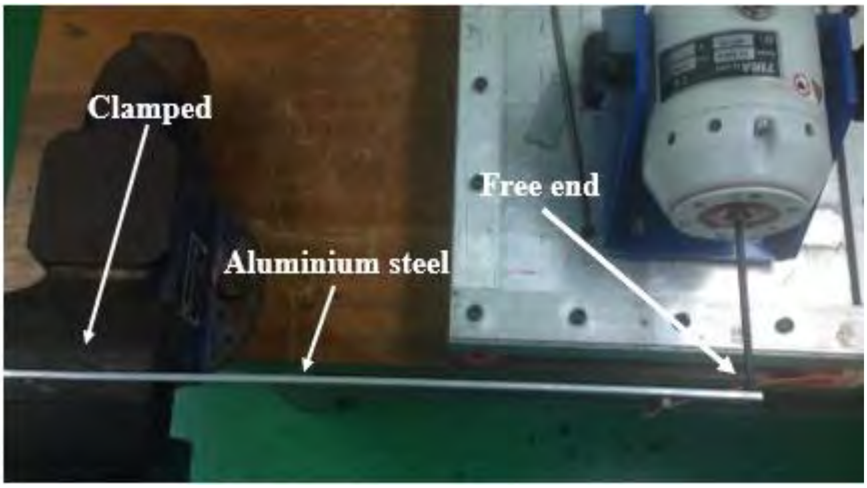

Figure 4.4: Experimental set up for cantilever beam model.

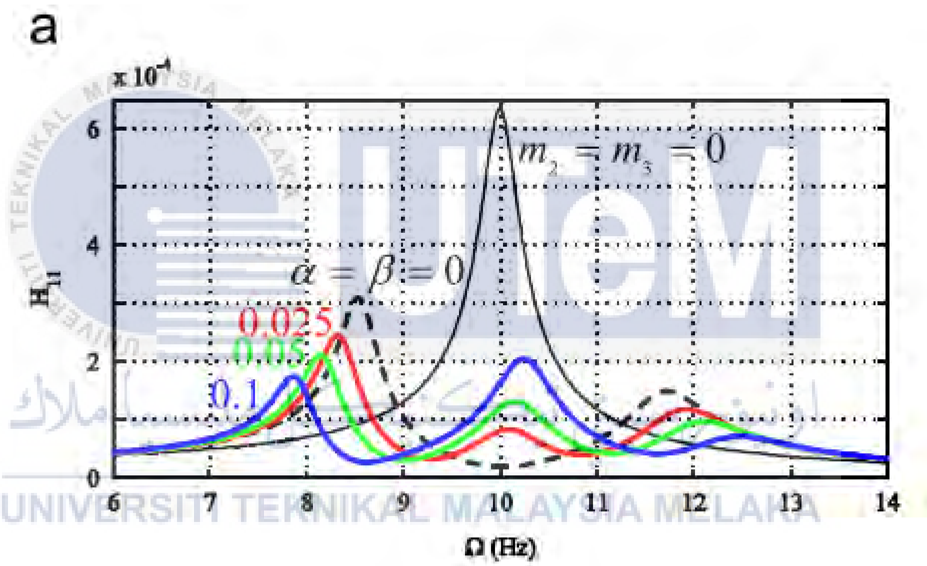

Figure 4.5: Result from Frank et al. research

There are four identical shape, size and material of vibration absorbers applied to the cantilever beam model structure. However, there are two ways on the arrangement of the vibration absorbers, first, all the four vibration absorbers are attached on the two side of the cantilever beam which two absorbers is on the left side and other two is on the right side of the beam. Second, all the four vibration absorbers are attached only on one side of the cantilever beam model. The purpose applying the vibrations absorbers in two different ways because to identify which arrangement of vibration absorber will be the best in reducing the vibration amplitude on the cantilever beam model. All the four vibration absorbers was attached on the cantilever beam model in a repeated arrangement which act as metamaterial structure like.

4.3.2.1 Applying vibration absorbers on two side of the beam

First experimental testing on the all four vibration absorber models is done by attaching two vibration absorbers on the left and right side of the cantilever beam model which are shown in Figure 4.6.

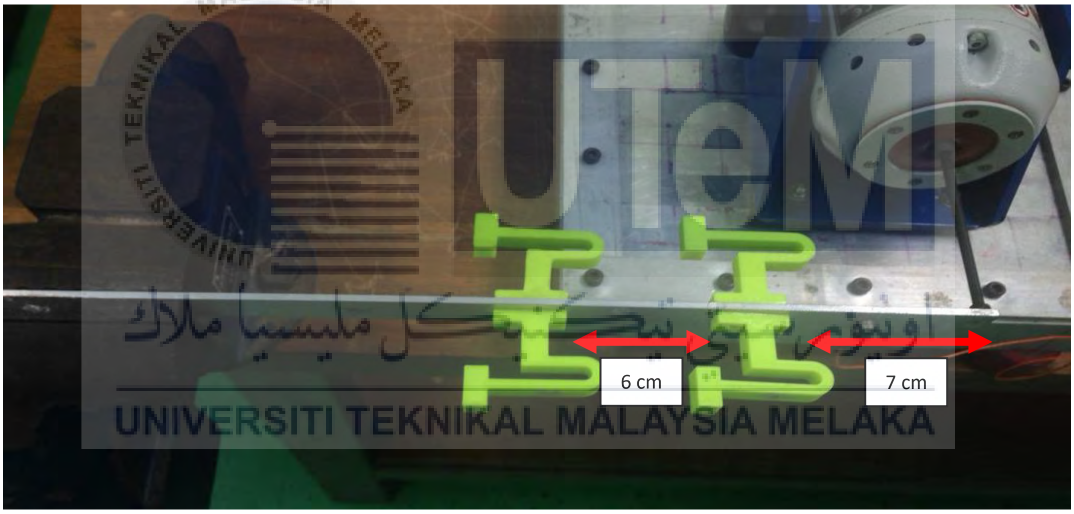

Figure 4.6: Experimental set up for side by side vibration absorber.

All the four vibration absorbers have been attached one by one at a single time and the data of amplitude versus frequency are taken on every time the vibration absorber been added on the cantilever beam model through the Data Physics that connected to accelerometer and amplifier. The results of the amplitude versus frequency are shown in Figure 4.7, 4.8, 4.9 and 4.10. Based on the results obtained, it could be concluded that when adding the number of vibration absorbers on cantilever beam, the two new peaks of resonances decreases and the distance between two resonances become further away.

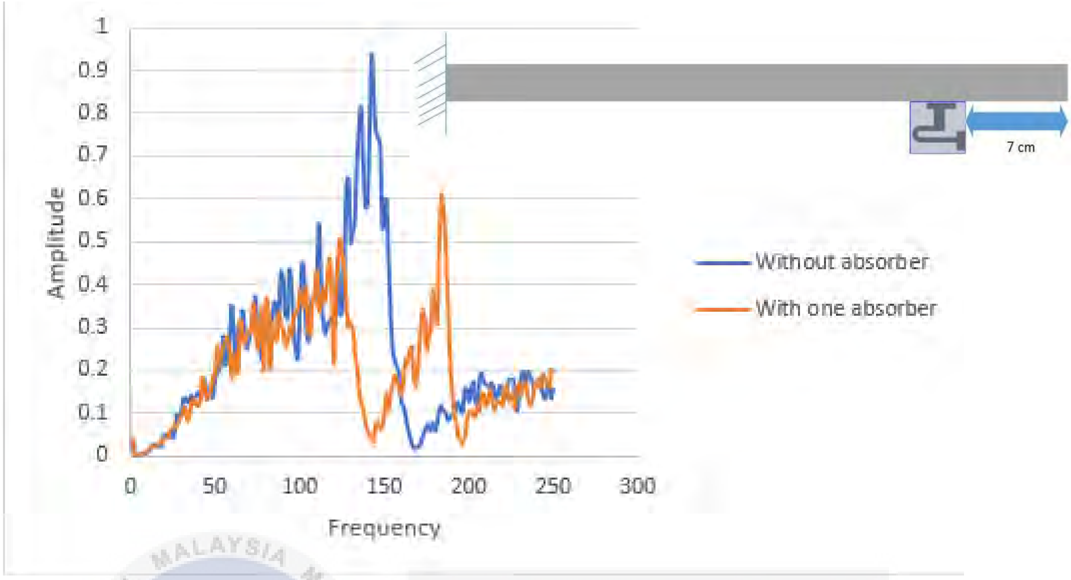

Figure 4.7: Applying one absorber

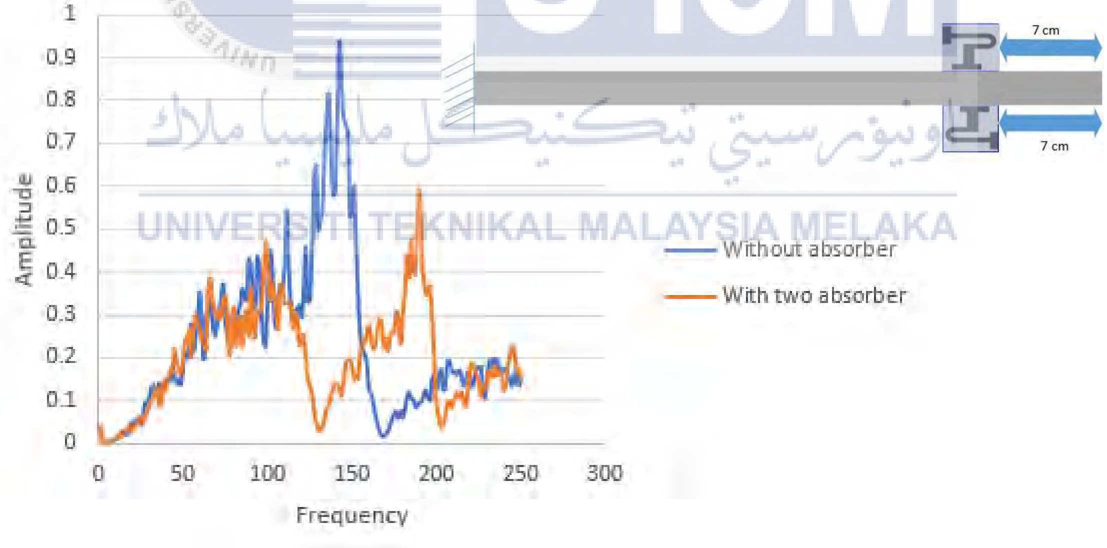

Figure 4.8: Applying two absorbers

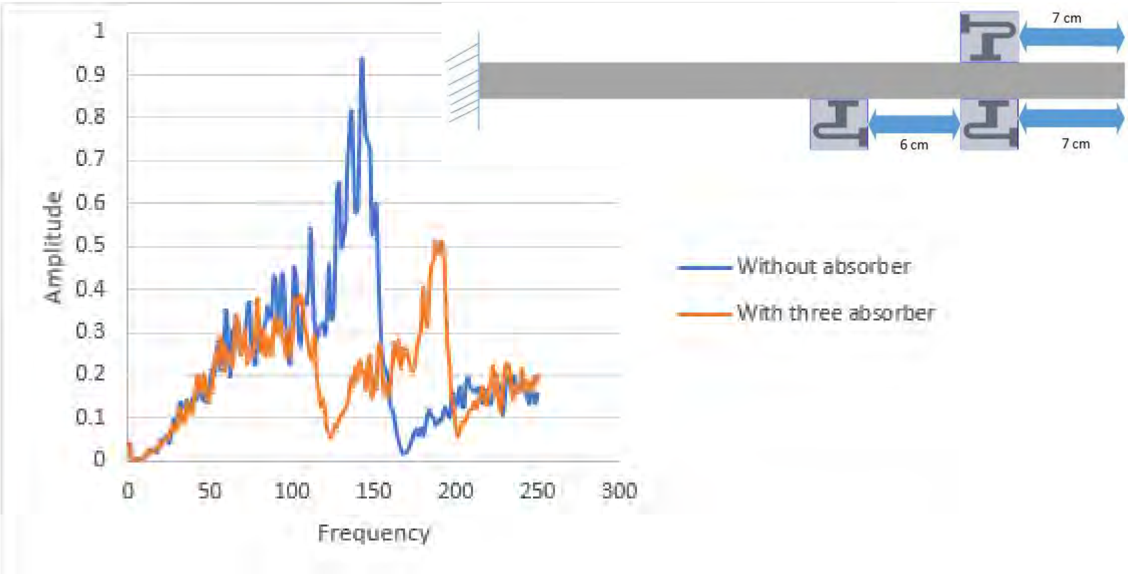

Figure 4.9: Applying three absorbers

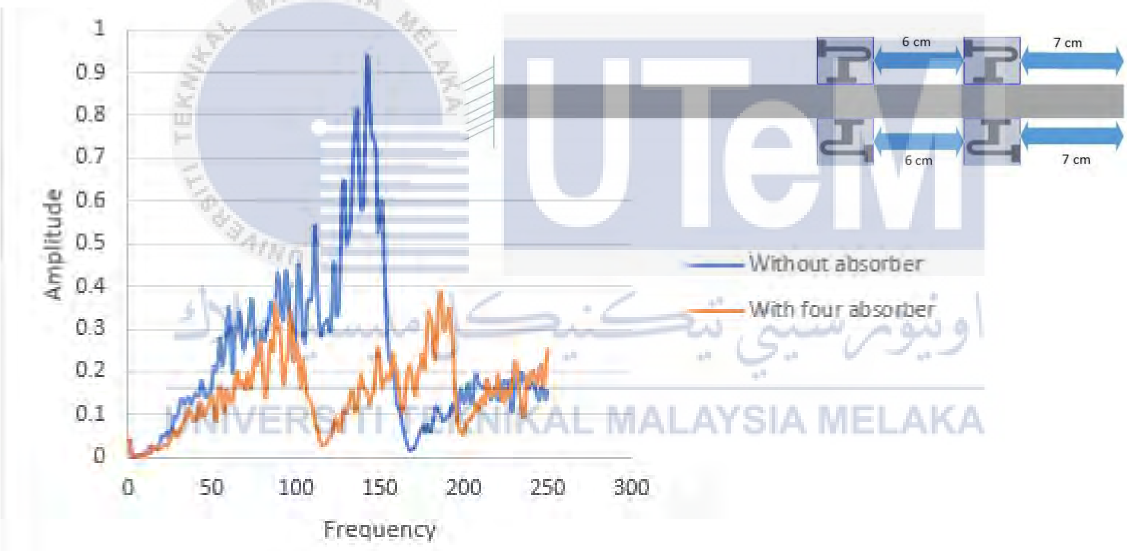

Figure 4.10: Applying four absorbers

4.3.2.2 Applying vibration absorbers on one side of the beam

Second experimental testing on the vibration absorber models is done by attaching all four of the vibration absorbers on one side of the cantilever beam model which are shown in Figure 4.11.

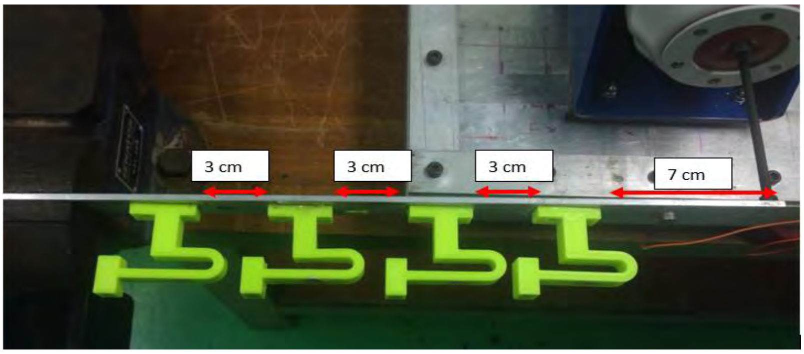

Figure 4.11: Experimental set up for one side vibration absorber.

All the four vibration absorbers have been attached one by one at a single time and the data of amplitude versus frequency are taken on every time the vibration absorber been added on the cantilever beam model through the Data Physics that connected to accelerometer and amplifier. The results of the amplitude versus frequency are shown in Figure 4.12, 4.13, 4.14 and 4.15. As can see on the results, when increase the number of vibration absorber attached to the cantilever beam model, the two new peaks of resonances decrease and the distance between the two of the new peaks of resonances become further away.

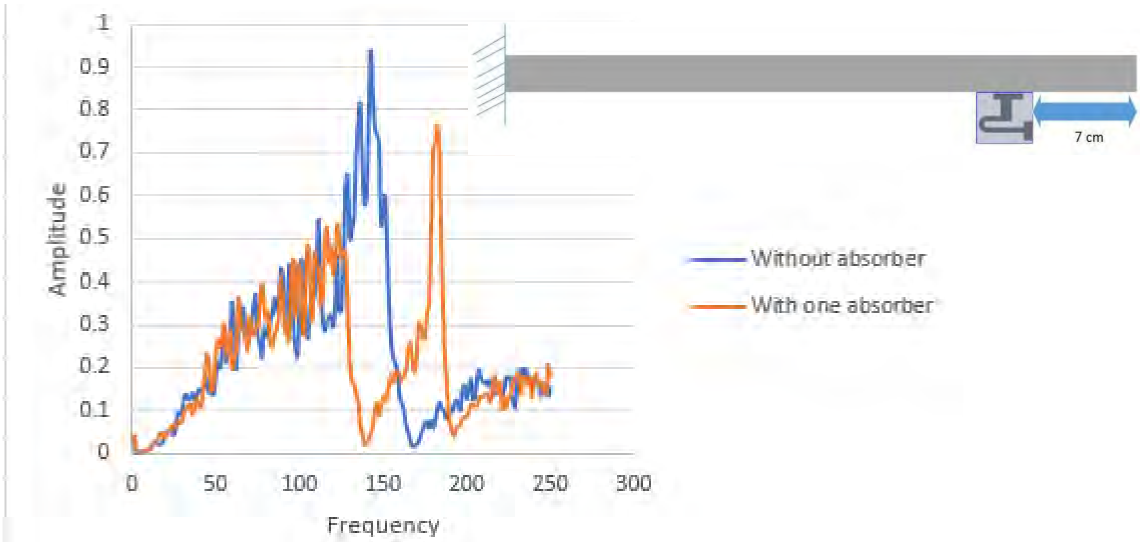

Figure 4.12: Applying one absorber

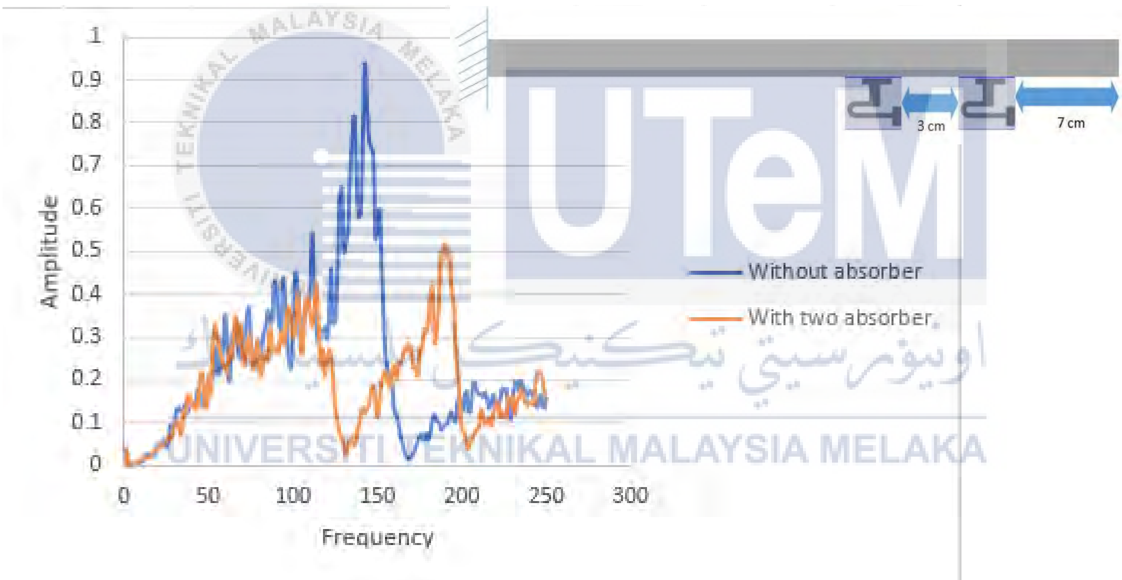

Figure 4.13: Applying two absorbers

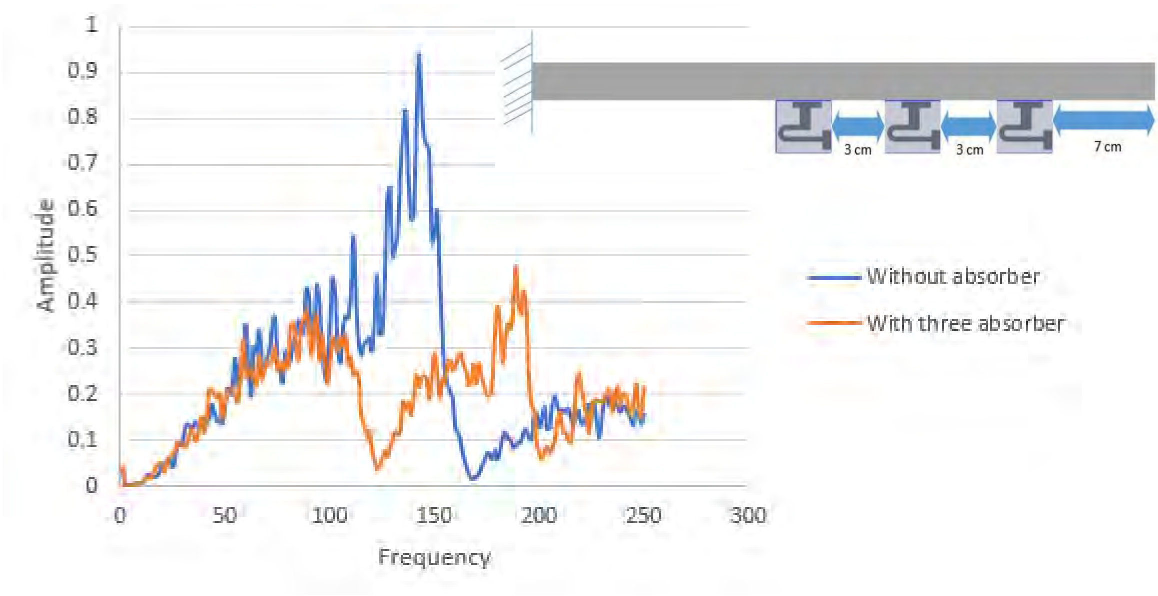

Figure 4.14: Applying three absorbers

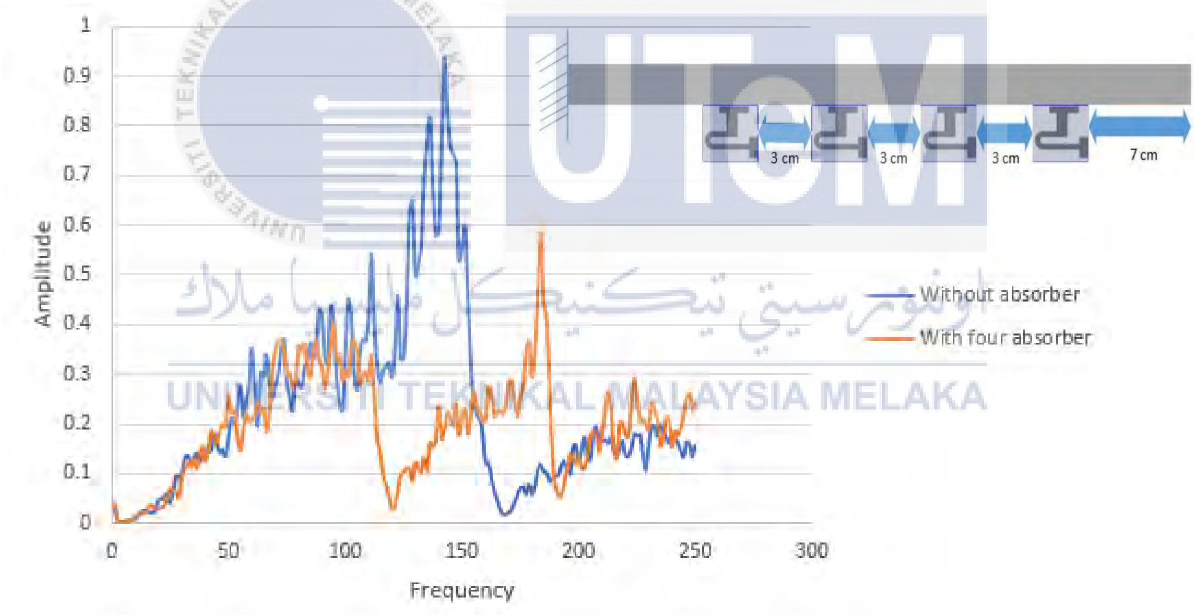

Figure 4.15: Applying four absorbers

4.3.2.3 Analysing two different arrangement of the vibration absorbers

During the experimental testing of vibration absorbers, they are two method of arrangement of the vibrations absorber which could be referred in Figure 4.16. In this section, it discussed on which method is the best applying the vibration absorber.

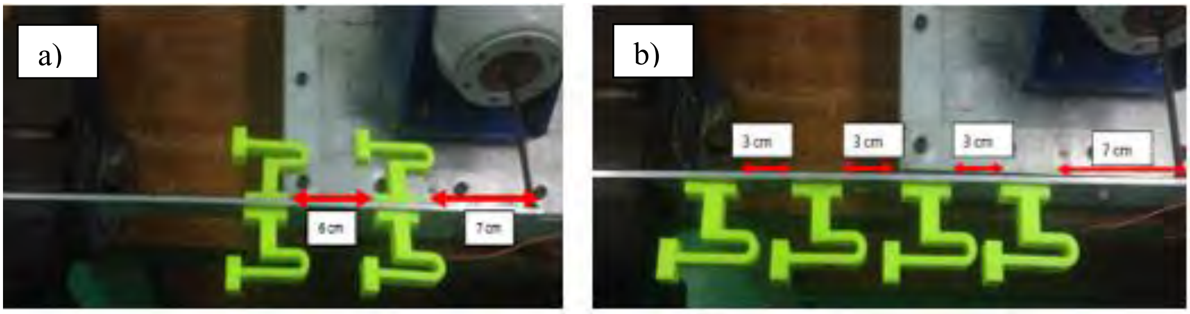

Figure 4.16: a) Side by side arrangement and b) One side arrangement

Referring to Figure 4.17, when all fours vibration absorbers are applied in two different arrangements, it was found that by applying the vibration absorbers on the two side of the beam is much effective compared with applying it on the one side of the beam. As can see in Figure 4.17, when applying the vibrations absorber on two side of the beam, the distance of the two new resonances is further away compared with applying it only at one side of the beam. Furthermore, the resonance peaks when applying the absorbers on the two side of the beam is much lower compared with the other method which showed that it is much effective in reducing the vibration amplitude on the beam.

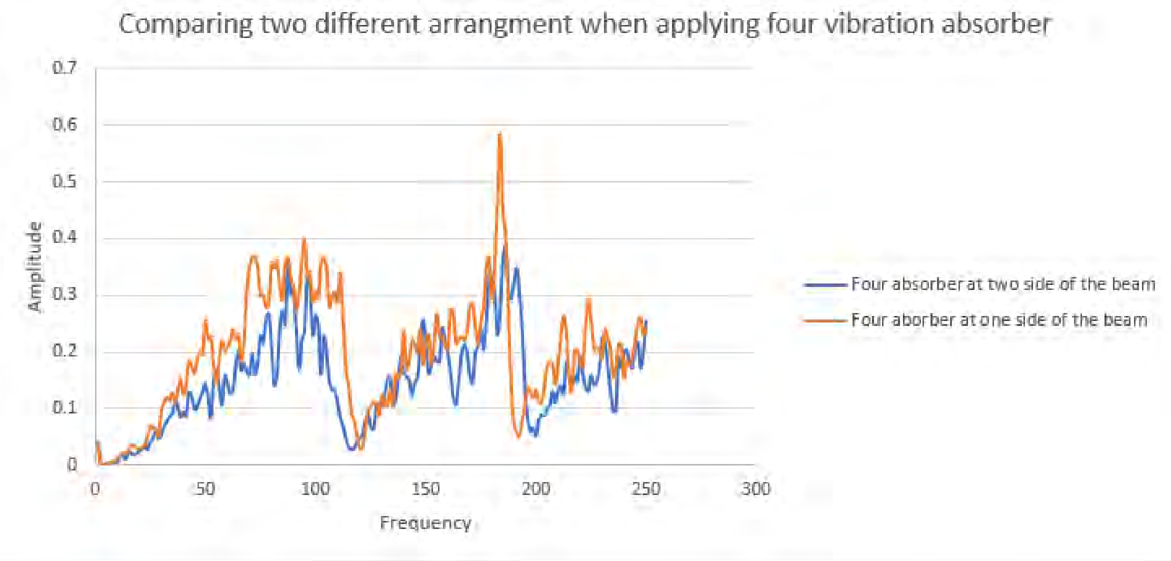

Figure 4.17: Comparing two different arrangement when applying four vibration absorbers.

CHAPTER 5

CONCLUSION

As conclusion for this project, first, producing vibration absorbers using 3D printer machine has been seen as a success because the capability of the 3D printed vibration absorbers in reducing the vibration amplitude have been proved through the data obtained from the experimental testing. In order to increase the effectiveness of the 3D printed vibration absorber in reducing the vibration amplitude, the number of vibration absorbers attached on the structure need to be increased which it causing the peaks of resonances decreasing as the number of vibration absorbers increases and the distance of the two new peaks of resonances are become further.

Second, during the experimental testing there are two method of arranging the vibration absorbers which are first, by applying the vibration absorber on the two-side of the beam and second, by applying only one-side of the beam. From the data and the analysis that have been through in result and discussion, arranging the vibration absorbers on two-side of cantilever beam is more effective compared with arranging it on one side of the beam. This is because, from the data obtained, the two peaks of resonances are much lower and the distance between the peaks of resonance are further when arranging the vibration absorbers on the two-side of the beam compared with arranging it only at one-side of the cantilever beam.

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