VIBRATION META-MATERIALS FOR VIBRATION ABSORBER

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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

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVATIONS

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.

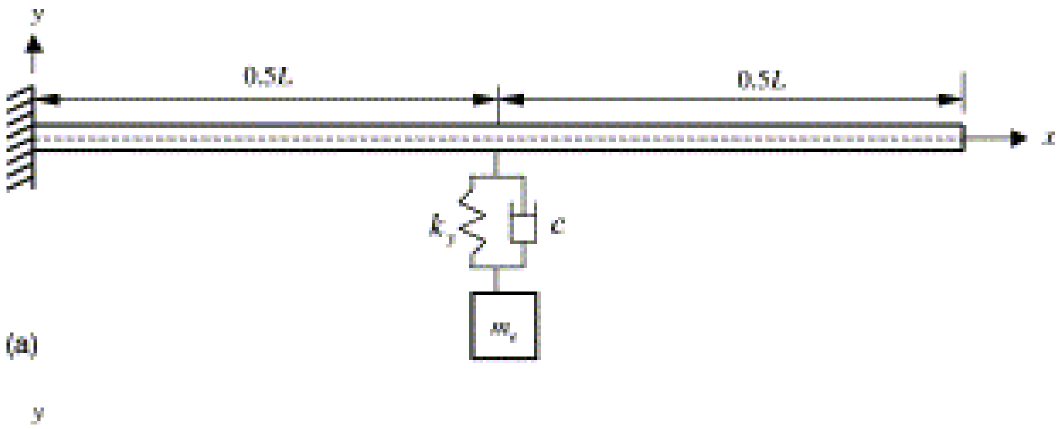

Figure 2.1: Dynamic vibration absorbers on cantilever beam.

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.