ON THE WIDEBAND DYNAMIC VIBRATION ABSORBER USING MAGNETIC PIECE-WISE STIFFNESS MECHANISM

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**A report submitted
in fulfilment of the requirements for
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SUPERVISOR'S DECLARATION

I have checked this report and the report can now be submitted to JK-PSM to be delivered back to the supervisor and the second examiner.

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 the degree of Bachelor of Mechanical Engineering with Honours.

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

Name of Supervisor :...................................

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

DEDICATION

To my beloved mother and father

ABSTRACT

A passive dynamic vibration absorber is a device that requires manual adjustment to adapt the natural frequency to the requirements of the structure. To modify the natural frequency, it is necessary to adjust mass and stiffness. Constant retuning is bad for structure because it is not ideal for time-varying applications. A wideband DVA was created to tackle this problem. However, wideband DVA is affected by the jump-down point based on the frequency response. Many things influence this point, one of which is damping. The contact between the stopper and the beam causes the damping element of the beam, which might limit the jump-down point's extension. Using a non-contact mechanism, the damping element should be reduced and the jump-down point should be extended. Therefore, this study aims to investigate the static and dynamic properties of the proposed mechanism by comparing with a traditional piece-wise mechanism linear stiffness study and effect of repulsive.

ABSTRAK

Penyerap getaran dinamik pasif adalah peranti yang memerlukan penyesuaian manual untuk menyesuaikan frekuensi semula jadi dengan kehendak struktur. Untuk mengubah frekuensi semula jadi, perlu menyesuaikan jisim dan kekakuan. Penyambungan berterusan tidak baik untuk struktur kerana ia tidak sesuai untuk aplikasi yang mengikut masa. DVA jalur lebar telah dibuat untuk mengatasi masalah ini. Walau bagaimanapun, DVA jalur lebar dipengaruhi oleh titik lompatan berdasarkan tindak balas frekuensi. Banyak perkara mempengaruhi titik ini, salah satunya adalah redaman. Hubungan antara penyumbat dan balok menyebabkan elemen redaman pada rasuk, yang mungkin menghadkan peluasan titik lompat turun. Dengan menggunakan mekanisme tidak bersentuhan, elemen redaman harus dikurangkan dan titik lompatan harus dilanjutkan. Oleh itu, kajian ini bertujuan untuk mengkaji sifat statik dan dinamik mekanisme yang dicadangkan dengan membandingkan dengan kajian kekukuhan linear mekanisme kepingan tradisional dan kesan tolakan.

ACKNOWLEDGEMENT

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LIST OF ABBREVIATIONS

DVA	Dynamic Vibration Absorber
SDOF	Single Degree of Freedom
EST	Equivalent Stiffness Technique
NDVA	Nonlinear Dynamic Vibration Absorber
FRF	Frequency Response Function

LIST OF SYMBOLS

m_p	=	Mass plate
$f(x)$	=	Restoring force
ω_n	=	Natural frequency
A	=	Amplitude
m	=	Mass
k	=	Cantilever stiffness
ω	=	Operating frequency
E	=	Modulus of Elasticity
I	=	Second moment of inertia
L	=	Length
b	=	Breath
d	=	Thickness
y_i	=	Vertical gap between stopper and beam
x_i	=	Horizontal gap between the stopper and stand block
F	=	Force
X_i	=	Tip deflection

CHAPTER 1

INTRODUCTION

1.1 Background

Vibration can be performed in machines and structures. In general, vibration usually affects the performance of a machine. Vibration also leads to fatigue failure or even damage to the machine and structure by causing an excessive stress level (Bonsel et al., 2004). Therefore, prevention of the problem needs to be considered by controlling the machine vibration by changing the machine's stiffness and adding a damping element to the machine. Commonly, there are two methods to control unwanted vibration. The first is by isolating the vibration and the receiver, which is termed vibration isolation. The second term is vibration absorption by suppressing the vibration of the source using a dynamic vibration absorber (DVA).

DVA is initially invented by Frahm a century ago as an ideal device for vibration control in specific frequencies (Zhu et al., 2018). DVA is a device for vibration control that involves them to be tuned to a particular resonance frequency of a single degree of freedom system (SDOF system) (Ladipo & Muthalif, 2012). The working mechanism of DVA is by tuning the structure's natural frequency to negate the vibrations so that it meets the frequency of the structure. However, DVA is only effective in a limited frequency range, and mistuning could intensify vibrations and cause damage. (Ramlan et al., 2010).

There are three common types of DVA, which is passive, semi-active and active. This study is focused on passive DVA where it needs manual tuning to adjust the absorber frequency so that it matches the excitation frequency. It is required in adjusting mass and its stiffness to vary the natural frequency. Constant retuning is not good for structure because it is not suitable for application that varies with time. To solve this problem, a wideband DVA was produced. Wideband DVA can be applied by using piecewise linear stiffness and magnetic stiffness.

Piecewise linear stiffness mechanism worked by placing any stopper which acts to limit motion of the oscillating mass (Pun & Liu, 2000). By the presence of the stopper, the stiffness of the systems will be hardened. This can have a similar impact as the solidify stiffness, which is good for DVA requirement, especially when employed with a wideband absorber. This mechanism, on the other hand, worked in terms of the upstanding gap between the beam and the limit block, resulting in frequency response with a jump-down point where we required it to be higher to enhance bandwidth. To improve the point, there is a need to improve the damping element of the beam which is the contact of the beam and the stopper. The surface contact can be reduced by replacing the stopper with a magnet.

1.2 Problem Statement

Based on past research, the jump-down point based on the frequency response affected the bandwidth which is, the higher the jump-down point the wider the bandwidth. This point is affected by many factors, one of them is damping. The damping element of the beam is caused by the contact between the stopper and the beam, so it can limit the extension of the jump-down point (Li et al., 2014). To improve the situation, a repulsive magnet could replace the stopper. By using a non-contact mechanism hopefully, could reduce the damping element and extend the jump-down point.

1.3 Objective

The objectives of this project are as follows:

1. To generate a piecewise linear stiffness mechanism with repulsive magnetic stiffness.
2. To investigate the static and dynamic properties of the proposed mechanism based on previous set-up.

1.4 Scope of Project

The scope of this project are:

1. Modify the existing device.
2. Focus on comparative study only.
3. Focus on static and dynamic properties of the mechanism only with no performance in terms of vibration absorption.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, its describe the further understanding about the characteristic of the parameter testing of the device that will be studied. The literature review is mainly about the understanding of dynamic vibration absorber, wideband dynamic vibration absorber, piece-wise linear stiffness and magnetic piece-wise linear mechanism.

2.2 Dynamic Vibration Absorber (DVA)

Vibration might present at any machine or structure where could affect the performance of the machine such as fatigue failure or damage to the system where can cause an excessive level of stress. Vibration can be controlled by using two different methods. The first is by isolating the vibration and the receiver, which is termed vibration isolation. The second term is vibration absorption by suppressing the vibration of the source using a dynamic vibration absorber (DVA).

DVA was initially invented by Frahm in 1911 which he used to reduce rolling ships. As stated as DVA under vibration absorption, there are three main types of DVA which are passive tuned DVA. This type of application contains an auxiliary mass-spring system that acts to neutralise the vibration of the structure. It works based on operation out of phase with the vibration of the structure by applying a counteracting force (Bonsel et al., 2004). This application necessitates careful tuning to match the DVA's inherent frequency to the structure frequency. To achieve natural frequency, constant changes need to be done to the stiffness of the instead of mass. However, passive DVA is unable to absorb vibrations that deal with multi-frequency and shift-frequency.

The second is the semi-active DVA. Semi-active vibration can change its parameter which is inertia, damping and stiffness to come after the frequency of the external excitation. The performance of absorbing vibration is the same as passive (Liu et al., 2017). The advantages of semi-active control are it consume less energy which requires lower cost and is much simpler when compared with the active system.

The third is an active DVA. This mechanism can tune based on the device required to satisfy the desired requirements and features. Active DVA consume actuators which are mechanical mechanisms, piezoelectric actuators, pneumatic springs, cylinders, electromagnetic motors and electrical linear motors. By using electromagnetic and electrical linear motors, it will speed up the response and provide higher precision. However, it is complex to control them due to the magnetic force was belong to the unstable nonlinear system, and electromagnetic motors need the addition of gear transmission to convert the rotational motion into translational motion (Chen et al., 2005).

2.3 Wideband Dynamic Vibration Absorber

A passive vibration absorber was founded to be optimum in reducing vibration at a narrow band (Flatau et al., 2004). Narrow-band vibration required basic parameters of damping value, stiffness and mass. However, constant retuning of the system might be not good for the system. There is a need for higher bandwidth to solve the problem.

A paper that proposed that designs a passive vibration absorber to attenuate wideband vibration, used a cantilever beam as a primary system because it is a continuous system and has a large degree of freedom (Fai & Hao, 2019). It is started by experimental modal analysis of the cantilever which is to identify the first four natural frequencies and set those frequencies as target frequencies. This was done by using the impact testing method and measurement from each attachment point which was analysed by using the LMS test lab. After gaining the analysis, they starter to calculate the first four modes of the cantilever and each mode has a mass and stiffness that can be tuned. After several steps of modification, they came out with a new set of mode shapes and modal frequencies. Lastly, the parameter is determined by comparing the reduction of overall vibration absorber level over the first four frequencies.

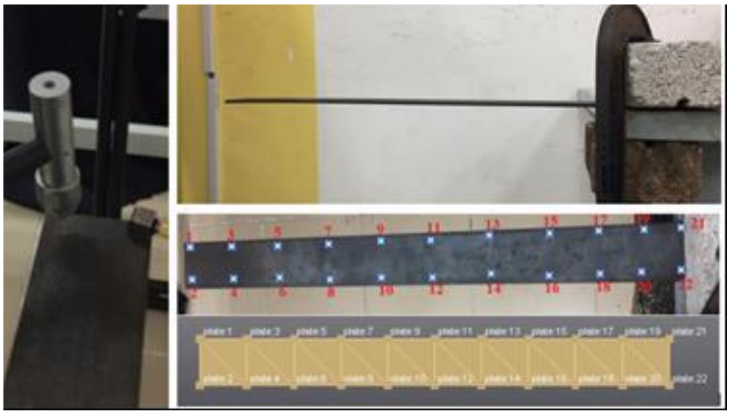

Figure 1: Cantilever Beam Experimental Modal Analysis Setup.

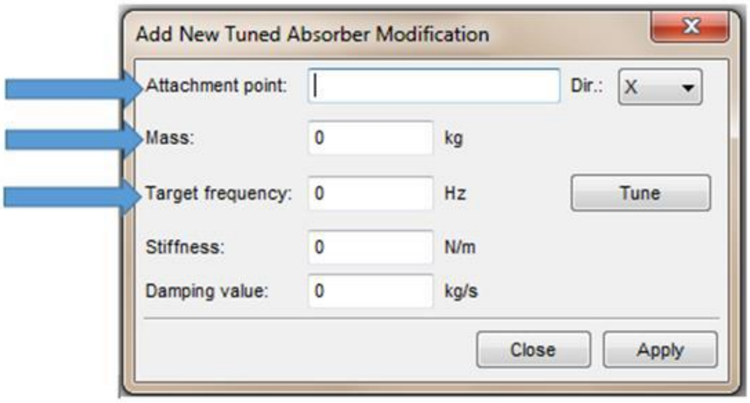

Figure 2: LMS Test Lab Modal Analysis Modification Prediction to simulate the attachment of vibration absorber on experimental modal analysis results.

Throughout the demanding technological development, there are many types of high power rotating machinery that were proposed to the world. Those modern rotating machineries require vibration suppression devices with simple structure and wideband effective vibration suppression frequency range (Yao et al., 2019). This could happen because the machine required other levels of vibration absorber to function precisely and longer life so that cost on maintainability can be reduced. The use of such springs will greatly increase the attractiveness of using passive dynamic vibration absorbers to reduce excessive vibration amplitudes to acceptable levels (Hunt, 1982).

2.4 Piecewise-linear stiffness

The absorber's adjustable piecewise-linear stiffness needed the use of a slider with two stop-blocks to constrain the elastic support's bilateral deflections, which required the use of a slider with two stop-blocks. An analytical approach had been proposed named as equivalent stiffness technique (EST) and then engaged to gain the analytical relations of the frequency, amplitude and phase with revealing a more comprehensive feature of the absorber (Shui & Wang, 2018).

Shui and Wang proposed a paper where it is about mechanical vibration absorber with tunable piecewise-linear stiffness, where they construct a primary structure consisting of a mass plate m_p, four springs for the blade and a base plate as stated in figure 3. Two elements make up the tunable stiffness absorber which is the mass-spring system and the restriction system. The former is a blade spring with one end connected to the mass of tunable stiffness absorber and another end clamped to the m_p mass plate. The above consists of a guide rail, a slider and two symmetrically connected stop-blocks to the slider with a slider.

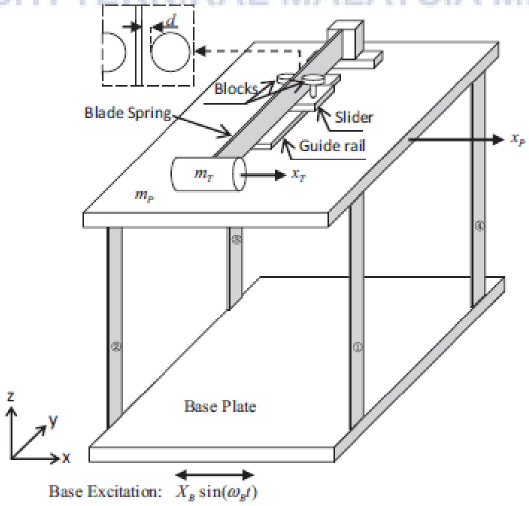

Figure 3. Schematic illustration of the experimental test setup.

They used the EST technique which is straightforward but the systematic analytical perspective to determine the fundamental actions of the system with nonlinear restoring force. It is well-known that system mass m, the nonlinear restoring force f(x) cause a frequency ω_n(A) as the amplitude is A. This EST offers a solution of constructing a linear stiffness k(A) where it fulfils $k(A) = m\omega_n^2(A)$. Therefore, the linear restoring force k(A)x can be used to substitute the nonlinear f(x) in the equation of motion, consequently changing the nonlinear equation to a linear and obtain an analytical result. It has been proven that the analytical result has a smaller error when comparing with numerical simulation with the original equation. The idea of linear stiffness construction is where the nonlinear restoring force f(x) is presumed to act as a concave function which is a hard spring (Shui & Wang, 2018).

2.5 Magnetic Piecewise Linear Mechanism

The nonlinear element usually used as a mechanical system has different performance demands based on its position. Piecewise linear system is commonly used to study and estimate nonlinear elements. Today, the accuracy of mass production industries demand is increasing inaccuracies and productive toward top-notch production and measurement equipment, which need positioning systems with critical reliability over measurement ranges. To achieve wideband DVA, it requires a higher jump-down point as stated in frequency response which illustrates in figure 4, where bandwidth increases linearly with the jump-down point.