ACTIVE TUNING OF DYNAMIC VIBRATION ABSORBER (DVA) FOR SUPPRESING STRUCTURAL VIBRATION

LOH SHERN TIEN

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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A report submitted
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APPROVAL

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

Signature : ……………………………………...

Supervisor’s Name : PROF. MADYA DR. ROSZAIDI BIN RAMLAN

Date : ……………………………………...

DECLARATION

I declare that his project report entitled “Active Tuning of Dynamic Vibration Absorber (DVA) for suppressing structural vibration” is the result of my own work except as cited in the references.

Signature : ………………………….

Name : ………………………….

Date : ………………………….

DEDICATION

To my beloved mother and father

ABSTRACT

The dynamic vibration absorber (DVA), also called the tuned vibration absorber (TVA), is commonly used in engineering applications. It can be used to suppress vibrations of structures, either globally for rigid structures or locally for flexible structures. DVAs can be divided into passive DVAs, active DVAs and semi-active DVAs. The passive DVA consists of a mass, a spring, and a damper. The mechanical simplicity of the passive DVA gives it good stability and it can suppress undesired vibrations of primary structures excited by harmonic forces. However, the passive DVA is only effective over a very narrow frequency range. To increase the effective frequency range, there is the invention of active DVA. The active DVA is also called the active–passive vibration absorber. It can be considered as a DVA with an active element attached. By controlling the activation force, the vibration reduction performance of the active DVA can be improved. In this project report, active tuning of dynamic vibration absorber on suppressing the structural vibration was studied. An active dynamic vibration absorber system was constructed. Frequency detection method was discussed. An electric motor was used as the active element to the system. The vibration amplitude of the primary system can reduce effectively when active vibration absorber is added to the system.

ABSTRAK

Dynamic Vibration Absorber (DVA), juga disebut sebagai tuned vibration absorber (TVA), biasanya digunakan dalam aplikasi kejuruteraan. Ia boleh digunakan untuk menekan getaran struktur, baik secara global untuk struktur tegar atau secara tempatan untuk struktur fleksibel. DVA boleh dibahagikan kepada DVA pasif, DVA aktif. DVA pasif terdiri daripada jisim, pegas, dan peredam. Kesederhanaan mekanikal DVA pasif memberikannya kestabilan yang baik dan dapat menekan getaran struktur primer yang tidak diingini oleh daya harmonik. Walau bagaimanapun, DVA pasif hanya berkesan pada julat frekuensi yang sangat sempit. Untuk menyelesai masalah tersebut, terdapat penciptaan DVA aktif. DVA aktif juga dipanggil active–passive vibration absorber. Ia boleh dianggap sebagai DVA dengan elemen aktif terpasang. Dengan mengawal daya pengaktifan, prestasi pengurangan getaran DVA aktif dapat ditingkatkan. Dalam laporan projek ini, penalaan aktif penyerap getaran dinamik untuk menekan getaran struktur telah dikaji. Sistem active dynamic vibration absorber telah dibina. Kaedah pengesanan frekuensi telah dibincangkan. Motor elektrik digunakan sebagai elemen aktif kepada sistem Amplitud getaran sistem primer dapat berkurang dengan berkesan apabila penyerap getaran aktif ditambahkan kepada sistem..

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CHAPTER 1

INTRODUCTION

1.1 Background

It is well accepted to be said that earthquakes will not stop to occur in the future, and it will cause critical social structural building and economic damage if we are not prepared. Engineer strategies need to be improved and earthquake risks need to be assessed to diminish the damage that are caused by the vibration from the earthquake. Intellectual such as geologists, seismologist and engineers are doing their best to improve the earthquake zoning maps, create reliable databases of earthquake processes and the consequences of it, increase on the understanding of the earthquake area characteristic and design the earthquake resistant buildings. Moreover, the alternative yet effective way to reduce the vibration from the earthquake is to install dynamic vibration absorber to the structure or system.

Dynamic vibration absorber (DVA), also called as tuned vibration absorber (TVA) is invented by Frahm to suppress the vibration from a system. It consists of spring-mass system, where its natural frequency is tuned to the vibration frequency of the host structure in order to reduce the vibration of the structure.

In recent research, several improvements to the traditional DVA are to be studied and mainly relate to the adjustability of DVA in order to increase the narrow effective frequency area. DVA will loses its efficiency on reducing vibration when the resonant frequency is out of the effective bandwidth. Worse come to worst, the DVA will increases the vibration to the structure and cause more damage. The improvements to the traditional DVA are introduced over the last 100 years, ranging from passive, semi-active, hybrid or adaptive to active dynamic systems.

In this paper, active tuning of dynamic vibration absorber on suppressing the structural vibration is to be studied. An actuator is attached to the structure and it will be controlled by microcontroller. The actuation force from the actuator need to be matched with the natural frequency of the primary in order to reduce the vibration.

1.2 Problem Statement

Vibration amplitude of a system can be reduced by applying vibration isolation or vibration absorber to the system. Vibration isolation is a control scheme taken to minimize the amount of force transmitted to the system. In another words, the purpose of the vibration isolator is to block the vibration energy being transfer to the system. While vibration absorber is to absorb the vibration energy of the source or directly from the target receiver. It is in the form of another vibrating system and it is attached on the target structure to absorb the vibration energy. For a forced vibration, the frequency of the attached vibration absorber needs to be same with the excitation frequency of the system in order to reduce the vibration amplitude. Installing a vibration absorber to a single degree of freedom (SDOF) system will changes the system to 2-DOF system. Thus, the system will have two new natural frequencies. If the operating speed of the system or machine is not stable, either reduce or increase, the system will suffer resonance. In another word, the effective bandwidth of the traditional vibration absorber is narrow. Therefore, the purpose of this research is to widen the narrow frequency range of DVA by active tuning system.

1.3 Objectives

The objectives of this project are as follows:

1. To design a frequency detection system.

2. To design and implement a system to control the speed of actuator.

3. To conduct the performance testing of the DVA on suppress the vibration of the primary structure.

1.4 Scopes of Project

The scopes of this project are:

1. The system is to be assumed as linear system.

2. The data measured from the accelerometer is in term of frequency spectrum and time domain waveform

3. The primary system is a rotating motor and to be assumed there is no vibration from the structure.

CHAPTER 2

LITERATURE REVIEW

2.1 Vibration Phenomenon

Structural vibration is a serious threat to our environment nowadays. According to Hartog (1985), Vibration is basically a periodic motion and this motion will be repeating even after certain of time interval, see in Figure 2.1. In most of the cases, the presence of the dynamic load is the most important and common that contributed to the vibration of structures. Human activity is a common contributor of the dynamic loading and the structures that normally be affected are stadiums, staircases, bridges, floors and any other spaces that can be occupied. (Pearce and Cross, 2011). Moreover, other sources of vibration include compressors, pumps, and engines and these equipment will generate dynamic forces thus result in structural vibration. These generated dynamic forces are then led to bigger problems such as piping failures, secondary damages, poor equipment reliability, and safety concerns. The vibration is caused by the mechanical resonant in the structure. The resonant occurs when the frequency of the dynamics forces as mentioned above coincide with the building natural. At resonance, the vibrating forces can be amplified up to 20 times and this will cause the whole structure or deck beams to vibrate beyond its safety operating limits. To solve the problem above, a suitable approach to overcome the vibration is to add a dynamic vibration absorber to the structure.

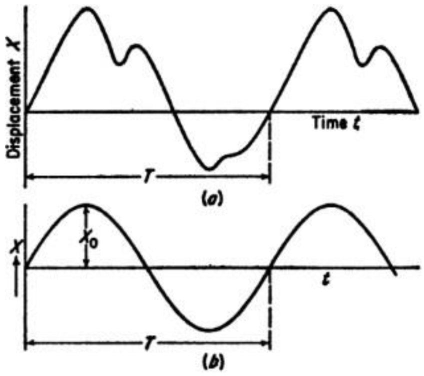

Figure 2. 1 A periodic and a harmonic function (Hartog, 1985)

2.2 Vibration Isolator

Vibration isolation is a technique commonly used in structures and machines to reduce or suppress unwanted vibrations. By inserting a resilient member or isolator, the device or system of interest is isolated from the source of the vibration (Yang, Li and Cheng, 2011). Valeev & Kharisov (2016) studied about the application of vibration isolators with a low Stiffness for the strongly vibrating equipment. The design of their vibration isolator is shown in figure 2.2. The isolator was installed between the vibrating equipment and the foundation. The steel rings are assembled to the frame of the equipment by welding to allow the isolators to hold the frame with stable position as shown in figure 2.3.

Figure 2. 2 The design of Vibration Isolator by Valeev and Kharisov (2016)

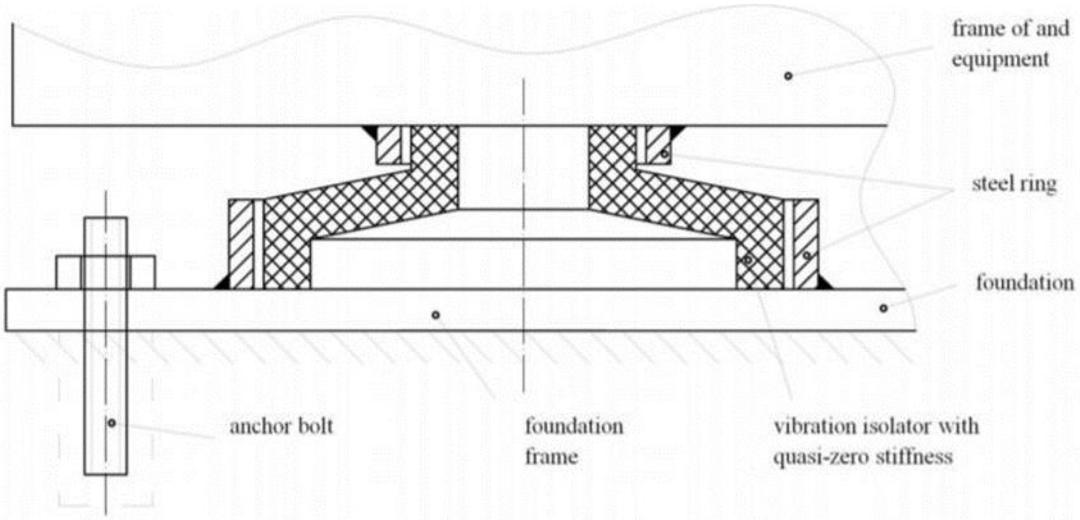

Figure 2. 3 The scheme of installation of vibration isolator (Valeev and Kharisov, 2016)

2.3 Vibration Absorber

Frahm (1911) invented the theory of undamped and damped dynamic vibration absorber (DVA). this device is also called as tuned vibration absorber (TVA). DVA consists of a mass, a damper, and a spring, and it is connected to the primary system to absorb the vibration of the primary system, see in Fig. 2.4. DVA need to be attached at the location where the maximum vibration in the primary system is acting on. The normalized amplitude of the primary system (m) can be calculated by, see in Equation 1.

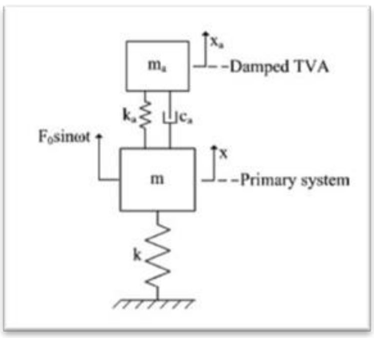

Figure 2. 4 Primary system (m) with damped tuned vibration absorber (ma) (Franchek, Ryan and Bernhard, 1996)

$$\frac{xk}{F_0} = \sqrt{\frac{(2\zeta r)^2 + (\beta^2 - r^2)^2}{(1-(1+\mu)r^2)^2(2\zeta r)^2 + ((1-r^2)(\beta^2 - r^2) - \mu\beta^2 r^2)^2}} \tag{1}$$

$$\omega_p = \sqrt{\frac{k}{m}} \qquad \omega_a = \sqrt{\frac{k_a}{m_a}} \qquad \zeta = \frac{c_a}{2m_a\omega_p} \qquad r = \frac{\omega}{\omega_p} \qquad \beta = \frac{\omega_a}{\omega_p} \qquad \mu = \frac{m_a}{m_p}$$

As noted from Equation 1, the natural frequency of the primary system, m_p, can be altered by changing the stiffness (k) or mass (m) of the primary system. The natural frequency of the primary can also be altered by adding a DVA to the system and to change its stiffness (k_a) or mass (m_a) so that the natural frequency of the whole system will be different. Naturally, the stiffness or mass of the primary system is difficult to change in the existing machine, whereas the absorber is simple enough to install to the primary system, and its stiffness can be modified so that the natural frequency of the whole system can be changed. The main purpose for adjustability of DVAs is to increase the small effective frequency area of DVAs, see in figure 2.5. The narrow effective frequency area will cause DVA loses its efficient damping characteristic easily and it can increase vibrations of the primary system and produce more damage to the system. Therefore, a lot of studies have been carried out intensively to widen the narrow frequency area of DVA or to alter the resonant frequency of the DVA as the operating conditions or parameters of the primary system may vary over time (Liu and Liu, 2005). Adjustable DVAs are also applicable to machines that operate close to the natural frequency of the primary system or machines, and it must operate without disturbing the vibrations over a wide frequency range.

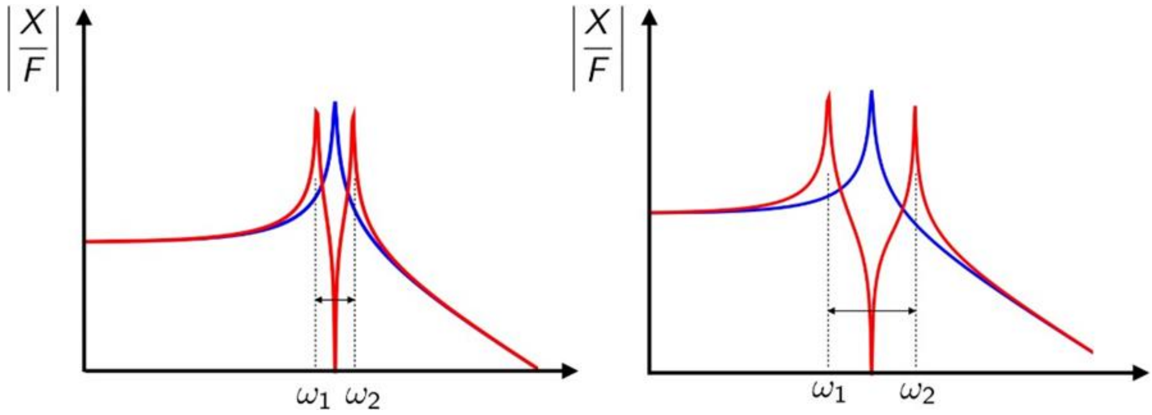

Figure 2. 5 The effective frequency area of DVAs

The mechanism of suppressing structural vibrations by attaching a DVA to the structure is to transfer the vibration energy of the structure to the DVA and to dissipate the energy in the damper of the DVA. In other words, the frequency of the damper is tuned to a structural frequency so that when that frequency is excited, the DVA will resonate out of phase with the structural motion. The ultimate performance of the DVA system is limited by the size of the additional mass, where is typically 0.25~1.0% of the building's weight in the fundamental mode.

2.4 Hybrid, Semi-Active, Passive & Active Vibration Absorbers

DVA or TVA is an over 100-year-old invention, and its adjustability has also been extensively studied by many researchers. DVAs are traditionally categorized into four classes: passive, active, hybrid, and semi-active absorbers. Nowadays, smart materials and adjustable dampers have confused the traditional classification. Resistive or reactive devices, which absorb vibration energy or load the transmission path of the harmful vibrations, are passive absorbers. Active vibration absorbers feed additional energy to the system to absorb its harmful vibrations, and at least a part of the actuator's force is used directly to damp external force. Hybrid absorbers are a combination of active and passive absorbers, and semi-active absorbers are passive absorbers, which are adjusted to optimize their effectiveness. The control parameters of the adjustable DVA includes of adjustment of different type of flexible elements: the effective coil numbers of a mechanical spring (Franchek, Ryan and Bernhard, 1996), the length of threaded flexible rods by stepping motors (Hill and Snyder, 2002), the shape of a flexible beam (Kidner and Brennan, 2001), the curvature of two parallel beams (Bonello et al., 2005), and the effective length of a flexible beam by a moving support (Brennan, 2006).

2.4.1 Hybrid Vibration Absorber

A hybrid vibration absorber is formed when an additional actuation force is added to the DVA. Its actuation force determines the performance of the hybrid vibration absorber (Yuan, 2001). Generally, a simple hybrid vibration absorber absorbs vibration at a certain frequency. Yuan (2001) widened the frequency range by inserting n pieces of simple hybrid vibration absorbers to the system. Thus, it absorbs vibrations at a specific frequency range. Simple hybrid vibration absorber represents a hybrid vibration absorber, which consumes sensor signals directly without recovering modal states (Yuan, 2001). This simple hybrid vibration absorber normally absorbs vibration at a single point; therefore, a simulation had been carried out by Yuan (2011), adding n pieces of HVAs to a cantilever beam, see in figure 2.6. The stimulation result in figure 2.7 shown that the vibration is absorbed by the HVAs n wide frequency range.

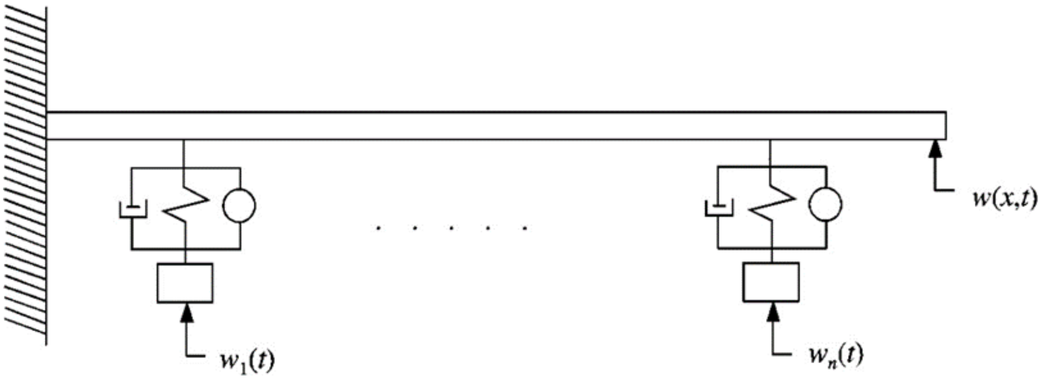

Figure 2. 6 A cantilever beam coupled with n HVAs

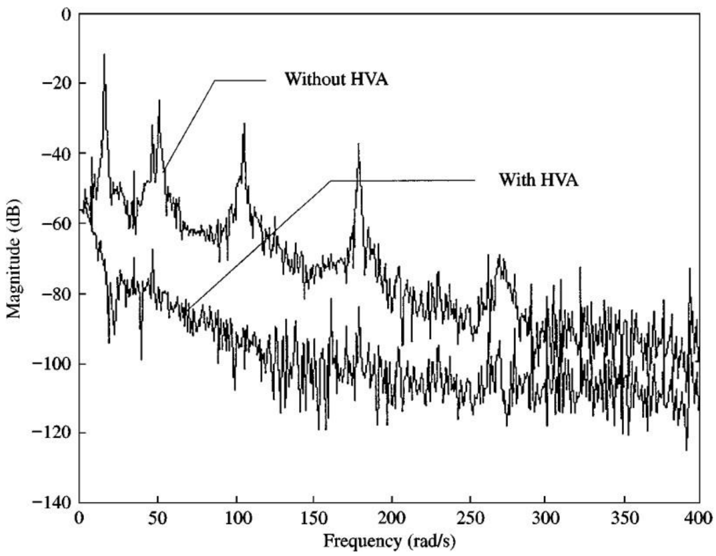

Figure 2. 7 Stimulation Result of proposed HVA by Yuan (2011)

2.4.2 Semi-Active Tuned Vibration Absorber

It has been reported that ATMDs can provide better suppression of structural vibrations than PTMDs. However, ATMDs have the disadvantages of added complexity, high operational and maintenance costs, and high-power requirements. Hence, they are considered less reliable than passive systems, limiting implementation of two special certain cases. (Setareh, 2001) proposed a semi-active tuned mass damper which is called ground hook tuned mass dampers (GHTMD), see in figure 2.8. The stiffness or damping of semi-active TVAs can be different, and they vary from original TVAs by an adjustable damper, which is located between primary system and vibration absorber. This is not an ATVA because only damping or level of amplitudes can be controlled, but not the natural frequencies of the system.

However, the damping factor can be different, for instance, with time, so that a vibrating system with GHTMD is a nonlinear dynamic system. (Setareh, 2001) also did numerical studies for the GHTMD. he noted that the primary system must be lightly damped so that the TVA worked effectively.

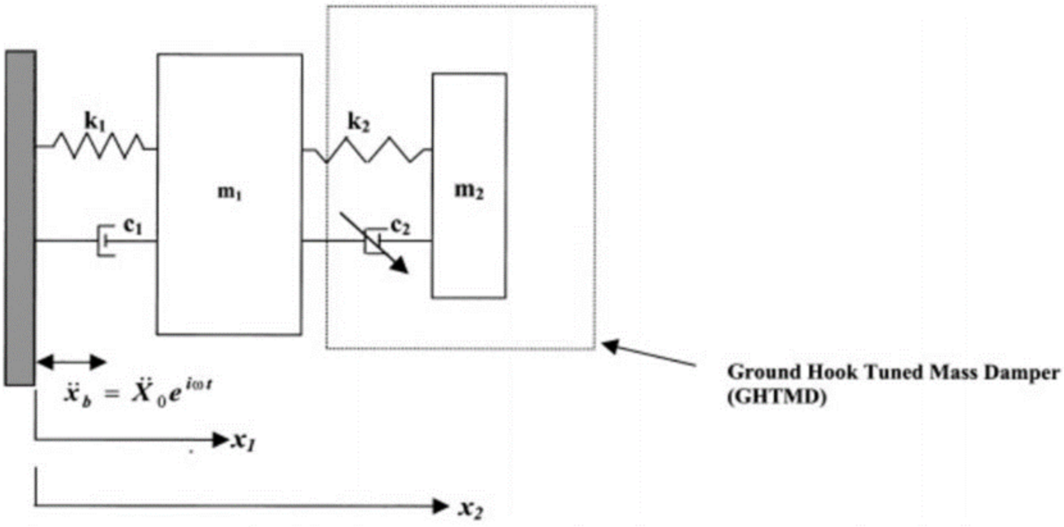

Figure 2. 8 Vibrating system with GHTMD (Setareh, 2001)

2.4.3 Passive Tuned Vibration Absorber

A passive tuned vibration absorber (PTVA) can absorbs the vibrations caused by different types of forces effectively, but the effective tuning area is narrow (Brennan, 2006). Wu & Shao (2007) used a virtual passive approach to widen a narrow frequency range of the DVA. The stiffness, inertia, and damping coefficient of the virtual DVA are easy to adjust by varying the parameters of the virtual element by control algorithms. The virtual element can be a linear actuator or a servomotor. In Wu & Shao's research, the actuator is a