SUPPRESSING STRUCTURAL VIBRATION USING MULTIPLE ARRAYS OF LINEAR DYNAMIC VIBRATION ABSORBER (DVA)

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DECLARATION

I declare that this report entitled “Suppressing structrural vibration using multiple arrays of linear dynamic vibration absorbers (DVA)” is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:	....
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APPROVAL

I hereby declare that I have read this thesis 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 Name :……………………………..

Date :……………………………..

ABSTRACT

A fixed-free beam is a structural element supported at one side only and have no any constraint at other side. Exposure to vibration can cause excessive deflections and structure might failed. The aim of this research is to study the application of multi dynamic vibration absorber on a fixed- free beam strucure. For experimentation, two absorbers were fabricated to be installed to the beam and subjected to a force vibration frequency loading using shaker. The resonance frequencies of interest were 14Hz and 99.6Hz. The vibration level of beam is measured for comparing the effect with the presence of application vibration absorbers to see the reduction in its amplitudes. The results shows the reduction of amplitude with single vibration absorber. With application of multiple DVAs, the frequency bandwidth of suppression is increased. Configuration of vibration absorbers on location did not affect its performance in vibration suppression at second natural frequency. From these results, it showd that distributed vibration absorbers is the prefered method of configuration where the range of frequency bandwidth is greatest. The knowledge gained from this research can be used to minimize the vibration amplitdue of sturcutures and increase their life-span. This application can be apply in suppresing the vibration of machine, bridge, and fluttering of airplane wing.

ABSTRAK

Rasuk bebas tetap adalah elemen struktur yang disokong di satu pihak sahaja dan tidak mempunyai sebarang kekangan di sisi satu lagi. Pendedahan kepada getaran boleh menyebabkan pesongan berlebihan dan struktur mengalami kemungkinan gagal. Tujuan penyelidikan ini adalah untuk mengkaji penggunaan penyerap getaran pelbagai dinamik pada strucure rasuk tetap bebas. Untuk eksperimen, dua penyerap telah direka untuk dipasang ke rasuk dan tertakluk kepada frekuensi getaran daya getaran menggunakan penggetar. Frekuensi resonans yang menjadi tumpuan kajian adalah 14Hz dan 99.6Hz. Tahap getaran terhasil pada rasuk diukur untuk membandingkan kesan dengan kehadiran penyerap getaran permohonan untuk melihat pengurangan dalam amplitudnya. Keputusan menunjukkan hasil pengurangan amplitud dengan penyerap getaran tunggal. Dengan menggunakan pelbagai DVA, frekuensi jalur lebar kekerapan penindasan meningkat. Konfigurasi penyerap getaran di lokasi tidak mempengaruhi prestasinya dalam penindihan getaran pada frekuensi resonans kedua. Hasil daripada kajian ini menunjukkan bahawa penyerap getaran teragih adalah kaedah konfigurasi pilihan di mana julat frekuensi jalur lebar adalah lebih besar. Pengetahuan yang diperoleh daripada penyelidikan ini boleh digunakan untuk meminimumkan getaran getaran daripada pelebaran dan meningkatkan jangka hayat mereka. Permohonan ini boleh digunakan pada getaran mesin, jambatan, dan pergerakan sayap pesawat.

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LIST OF ABBEREVATIONS

DVA	Dynamic Vibration Absorber
TVA	Tuned Vibration Absorber
TVD	Tuned Vibration Damper
ATVA	Adaptive Tuned Vibration Absorber
SMA	Shape Memory Alloy
ATMD	Adaptive Tuned Mass Damper
EVA	Electromagnetic Vibration Absorber
PTVA	Passive Tuned Vibration Absorber
VA	Vibration Absorber
ODS	Operating Deflection Shape
HVAC	Heating Ventilation Air Conditioning
ODS	Operating Deflection Shape
FRF	Frequency Response Function
FFT	Fast Fourier Transform

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Structural vibration is basically described as repetitive motion that can be measured and observed in the structure which occurs due to present of external forces and internal forces. External forces are the force that acts from the outside of the structure such as where these external forces can be due to wind induction, seismic activity, rail system or jackhammer. Internal forces are forces that generated from vibrating structure and transmit to another structure such as force generated from rotating imbalance of a pump inside a plant and transmission to the nearby machine. In most cases, this vibration is undesired as it will results in fatigues in structure, reducing the performance and the life span of the structures where these symptoms is not visible. In production plant, vibration can resulted in increase of energy loss, efficiency reduction, and increase of maintenance cost. At this point, vibration can be a source of engineering problem that needed to be solved.

Resonance is a phenomenon that occurs in vibrating machines or structure, when the external excitation frequency coincides with the natural frequency of the vibrating object. In most cases, resonance is detrimental as it will results in large vibrating magnitude and this will lead devastating effects on machines or collapsing of a structure. One of effects of resonance are incident collapsing of Tacoma Narrows Bridge shown in Figure 1.1, a suspended bridge on 7 November 1940 due to wind-induced vibration. There is also case of bridge collapsing due to induction of mechanical resonance such as collapse of Broughton Suspension Bridge due to marching steps by the troops. The Broughton Suspension Bridge is shown in Figure 1.2.

Figure 1.1: Collapse of Tacoma Bridge (Ellison, 2015).

Figure 1.2: Broughton Suspended Bridge after Rebuilt (Dan, 2016).

As Taiwan prone to natural phenomenon such as earthquake wind storm, The Taipei 101, one of the tallest buildings in the world had installed a 728 Ton pendulum suspended from 92th floor to 87^{th} floor that acts as mass damper to cancel the movement of building induced by strong gust of wind. The Figure 1.4 shows that the location of installment of mass damper inside the buildings. For Millennium Bridge shown in Figure 1.5, precautions were taken by engineers to install 37 fluid-viscous dampers and 52 tuned mass dampers to dampen the vibration caused by pedestrians' footsteps when crossing the bridge.

Figure 1.3: Tuned Mass Damper in Taipei 101 (Kaushik, 2014).

Figure 1.4 Millennium Bridge (McManus, 2015).

Stockbridge damper, is a dumbbell-shaped device that consists of two masses at the ends of a short length of cable or flexible rod is also used to suppress the oscillation of transmission line caused by induction of wind. The mass damper is usually clamped at its middle to the main cable due to the large amplitude at the middle of cable as it is clamped at both ends. The figure of application of Stockbridge Damper is shown in Figure 1.5.

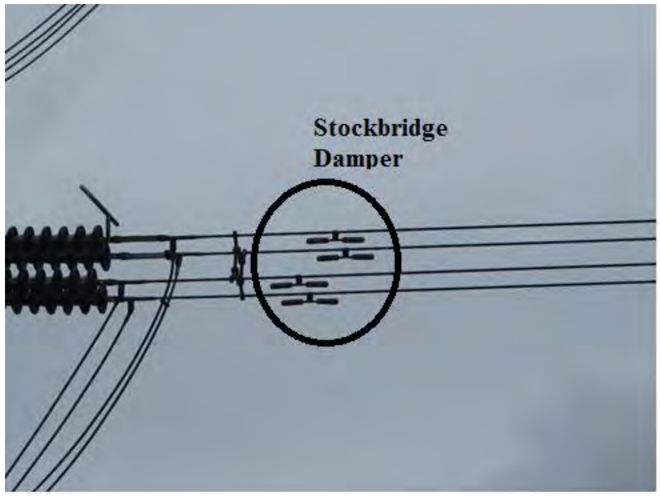

Figure 1.5: Application of Stockbridge Damper on Transmission Cable (Rao, 2015).

1.2 PROBLEM STATEMENT

Dynamic Vibration Absorber (DVA) is a designed mechanical devices that consists of spring-mass system that is able reduce unwanted vibration in machines or structure by exerting a counter force to couple the vibration force. However, DVA can only tuned to a single frequency and it's only effective for that particular resonance that is tuned. Figure 1.6 shows the graph of amplitude against frequency ratio. From Figure 1.6, there is one single point where amplitude is minimum at frequency ratio almost equal to one. The frequency ratio of one means that the DVA's frequency should be equal to the natural frequency of primary system. This indicates that any frequency miss-tuned of the dynamic vibration absorber's frequency result in larger vibration amplitude which will affect the main vibrating system.

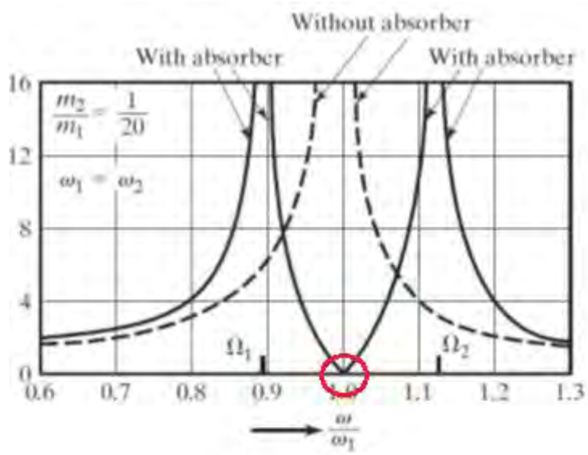

Figure 1.6: Frequency Response (Rao, 2015).

1.3 OBJECTIVE

The objectives of this project are as follows:

1. To characterize the property of a linear DVA.
2. To design and characterize DVA for main structure vibration suppression.
3. To investigate the performance of multiple arrays linear DVA to suppress structural vibration.

1.4 SCOPE OF PROJECT

1. The first and second natural frequency of beam will be considered.
2. Only two DVA will be used to suppress the vibration amplitude of the beam at the first and second natural frequency.

CHAPTER 2

LITERATURE REVIEW

2.1 Vibration

2.1.1 Vibration Terminology

Vibration is a periodic motion of particles of an elastic body or medium in alternately opposite from position of equilibrium where that equilibrium has been disturbed. In other words, vibration is the repetitive motion of after an interval of time, which also referred as oscillation.

2.1.2 Elementary Parts of Vibrating System

In a vibrating system, it consists of mass (inertia) for storing kinetic energy, spring (elasticity) for storing potential energy and damper for dissipating energy. The vibration of system involve the exchange of kinetic energy and potential energy and vice versa, in an alternate manner. Present of damper in vibrating system will dissipate energy for each cycles of vibration and eventually convert the energy of the vibrating system into other forms.

2.1.3 Free Vibration and Forced Vibration

For free vibration, the system is vibrating on its own without the influence of external force. For free vibration, the system is vibrating under external driving force and if the excited frequency coincide with one of the natural frequency of system, resonance will occurs and resulted large vibration amplitude.

2.1.4 Deterministic VS Random Vibration

In deterministic vibration, the magnitude of the force excitation acting on vibrating system is known at any instant. In this case, the excitation is deterministic. Example for deterministic vibration is sinusoidal force produce by shaker where the signal is generated by computer controlled and amplified by amplifier. For random vibration, the value of the excitation at that particular instant not able to be determine. Examples of random vibration are wind induction, seismic activity, or a car moving on a rough surface road.

2.1.5 Discrete VS Continuous

Number of degree of freedoms refer to number of independent coordinates that required to determine completely the position of system at any of time. For discrete or lumped parameter system, the number of degree of freedom are finite. In contrary, continuous or distributed system have infinite number of degrees of freedom and mostly related to deformable structural and machine system with elastic properties.

2.2 Beam Structure as Continuous System

Euler-Bernoulli Theorem, a linear theory of elasticity which relate between beam's deflections and applied load is widely use to study the propagation of flexural waves by considering the boundary condition of the beam. The boundary conditions of beam include pinned-pinned, free-free, fixed-fixed, fixed-free, fixed-pinned and pinned free. The Figure 2.1 shows the boundary conditions of the beam.

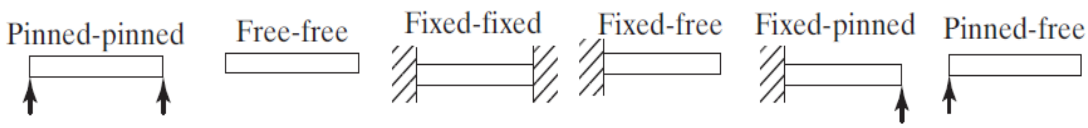

Figure 2.1: Boundary conditions of beam (Rao, 2011).

2.3 Mode Shape

Compared to single mass attached to a single spring, the vibration of complex body vibrate in more different ways. By changing the excitation frequency, the body will exhibit different vibrating pattern, where these patterns are termed as mode shape. Consider a string that is simply supported at both side. By exciting the lowest frequency, also known as the fundamental frequency at the string, the string will oscillates repeatedly as one– with the greatest motion in the center of the string. The Figure 2.2 shows the mode shapes of the string at the different frequency. When the frequency is increase twice the fundamental frequency, two halves of the spring vibrate in opposite manner as shown in Figure 2.3. The solid line is the maximum displacement at one instant and dotted line is the displacement at later instant. If the frequency is further increase to third mode as in Figure 2.4, vibration of string will be divided into three equal length section, each vibrating in opposite to adjacent pieces. Nodal point is point with zero displacement and antinode is point where displacement is maximum.