CHAPTER 1: INTRODUCTION

It is an imperative requirement of any engineering design to manage vibration within acceptable levels, to ensure good performance. Applications of vibration management could be seen in our day to day life, from cars to buildings and from spacecrafts to submarines. Improper vibration management would lead to performance degradation and poor quality.

1.1. NEED FOR VIBRATION CONTROL

Mechanical vibrations are present in varying magnitude in all locations wherever machine/equipment works. The effect of vibrations can range from negligible to catastrophic depending on the severity of the disturbance and the sensitivity of the equipment (ElMadany and El-Tamimi, 1990).

Few examples where vibration control is required:

- Car suspension can be regarded as the most famous ground application of vibration management. Many researchers focused their attention on vibration control in car suspension to improve the passenger comfort and to reduce the jerk effect on the body and components of car.

- Automotive industry has been in forefront to incorporate vibration suppression, even the mirrors of cars have to undergo vibration test to ensure visual clarity at high speed.

- Machine tools need to function with high accuracy to achieve high precision in machining operations. Only if vibrations are suppressed, dimensional accuracy, surface texture and productivity can be achieved.
- In case of hand-held machines, the continuous use of vibrating machines can cause injuries such as the hand-arm vibration syndrome (HAVS) or dead fingers.

- In sensitive optical payload applications, vibration causes appreciable performance degradation.

- Advanced measurement and production systems such as high-precision measuring and semiconductor manufacturing are sensitive to vibrations.

- The tall buildings of this modern day require that they are isolated from ground vibrations. The isolation of buildings from potentially destructive earthquakes is a formidable task.

- Vibration transmission to the hull from working machine in marine vessels is of serious concern. Vibration propagating from propulsion affects passenger comfort. The noise from the hull creates a problem for civil vessels and detection hazard in naval vessels.

There are two ways of controlling the effect of vibration: damping and isolation. Damping is the absorption of vibration energy entering the system, by dissipating it using springs and dampers. Isolation is the prevention of vibrations from entering the system.
In vibration isolation the equipment of concern is isolated from the harmful vibration thus achieving good vibration control. There are two cases of vibration isolation:

- The operating equipment can generate an oscillating disturbance (force) propagating into the supporting structure.

- The disturbance can be propagated by the supporting structure into the sensitive equipment.

A classic approach to the vibration isolation problem is by passive isolation i.e., by providing rubber pads, mechanical springs and dampers to suppress the amplitude of vibration. Although passive isolation offers a simple and reliable solution of protecting precision equipment from a vibration environment, it has its own performance limitations. Passive isolation lacks in versatility & effectiveness and also results in large size & weight when used for low-frequency vibration control. This necessitates active vibration isolation (AVI) system.

1.2. BASICS OF ISOLATOR

Consider a single-axis isolator model as shown in Fig. 1.1, where $M$ is the mass of sensitive equipment mounted on a vibrating structure using passive isolator.

![Fig. 1.1. Sensitive equipment mounted on a vibrating structure via passive isolator](image-url)
The isolation mount consists of a linear spring of stiffness $k$ in parallel with a passive damping coefficient $c$. The natural frequency of the system, $\omega_n$, is given by $\sqrt{k/M}$ and the damping ratio is denoted by $\xi$. The transfer function between the disturbance displacement $x_d$ and the sensitive payload displacement $x_c$ is given by

$$\frac{x_c(s)}{x_d(s)} = \frac{1 + 2\xi s / \omega_n}{1 + 2\xi s / \omega_n + s^2 / \omega_n^2}$$

(1.1)

Fig. 1.2 shows a plot of transmissibility in decibels (dB) versus the frequency ratio for various values of damping ratio ($\xi$). When $\xi$ is on the higher side, the overshoot at the resonance decreases but, regrettably, the sharpness of the roll-off at high frequency decreases too.

Fig. 1.2. Transmissibility for various values of damping ratio, $\xi$

Also, when $\xi = 0$, the high frequency roll-off is $1/s^2$ (-40 dB/decade) is obtained, while very large amplitude is seen at resonance. In contrast, when the damping ratio $\xi$ is increased the overshoot is reduced at the resonance but the roll-off also is reduced to $1/s$ (-20 dB/decade) at higher frequency (Tzou, 1991; Izumi, 1991). As a result, the design of a passive damper involves a trade-off stuck between the resonance
amplification and the high frequency attenuation. To maintain the sharp roll-off at high frequency while decreasing the overshoot at resonance, active vibration control is needed.

1.3. OBJECTIVE OF AVI

The objective in designing an active isolation system is to achieve a transmissibility which provides good attenuation (-40 dB/decade) at high frequency and at the same time has no amplification in the vicinity of the resonance frequency as depicted by the dotted line in Fig. 1.2.

1.4. WORKING PRINCIPLE OF AVI SYSTEM

An active vibration isolation system, along with the traditional spring and damper, consists of a feedback circuit, a controller, and an active transducer as shown in Fig. 1.3. The vibration signal is processed by the control circuit which directs the active transducer to actuate in opposite direction to that of vibration. As a result of such a feedback system and active transducer, the sensitive mass will remain in equilibrium position compared to the vibrating base. Thus AVI isolation system will have considerably stronger suppression of vibrations as compared to ordinary passive isolation.

![Fig. 1.3. AVI system, isolating the mass M from ground vibration](image-url)
1.5. STEWART PLATFORM

Stewart platform is a typical parallel manipulator, which consists of two platforms connected by six extensible limbs (actuators) with joints at either ends. The fixed platform is called the “base frame” and the movable platform is called the “top platform”, which has six degree of freedom (DOF) relative to the base frame. Fig. 1.4 shows a general Stewart platform in which six identical limbs connect the moving platform to the fixed base by spherical joints. Such a configuration provides the top platform with six degrees of freedom in space.

![Stewart Platform Diagram](image)

Fig. 1.4. A general Stewart platform

This mechanism is first suggested as universal tire-testing machine by Gough in 1949, shown in Fig. 1.5, which was re-discovered and presented to academia in 1965 by Stewart as a flight simulator, shown in Fig. 1.6. Even though Stewart never actually built a flight simulator, all types of parallel mechanisms are commonly referred as Stewart platforms.
1.5.1. Applications of Stewart platform

When high load carrying capacity, precise positioning capability and good dynamic performance, are of paramount importance Stewart platform finds its place in industry. Some of the major industrial applications of Stewart platform are:

- Flight simulators: As Stewart platform possesses 6 DOF and which is the requirement of full flight simulator replicating the cockpit for aircraft crew training, Stewart platform is used as a flight as illustrated in Fig. 1.7.

Fig. 1.5. Gough's tyre testing machine
Source: http://mikrolar.com/images/gough_tyre_now.jpg

Fig. 1.6. Stewart's flight simulator
Source: http://mikrolar.com/images/StewartPlatform.gif

Fig. 1.7. A Stewart Platform in use by Lufthansa
Source: http://wikipedia/Simulator-flight-compartment.jpg
• Pick and place robot: Fig. 1.8 shows a commercial pick and place robot based on Stewart platform. A Delta robot used in a chocolate factory for packaging is shown in Fig. 1.9.

Fig. 1.8. TSOY commercial pick and place robot, Source: http://tossy.com

Fig. 1.9. Delta robot used in chocolate factory, http://protoneer.co.nz/

• Parallel Kinematic Machine tools (PKM): It has been a dream of many machine tool developers to incorporate flexibility, accuracy and stiffness, which resulted in development of PKM. Fig. 1.10 shows a multi-functional PKM, which can perform friction-stir welding, laser beam welding, deep rolling and milling operations. Fig. 1.11 shows another PKM which can perform drilling, milling, routing, touch probing, optical inspection, fastener/rivet installations, friction stir welding, deburring and finishing.

Fig. 1.10. Pentapod multifunctional system, Source: http://www.iws.fraunhofer.de

Fig. 1.11. Tricept T9000 PKM, Source: http://www.pkmtricept.com/
- Stewart platform for space applications: Hexapods are ideal for positioning optical and radio telescope antennas. Active damping of space structures is a future application of Stewart platform.

- Stewart platform in medical field: Because of high precision and high accuracy, Stewart platform is used in medical field to carry out precise surgical operations (Fig. 1.12).

Fig. 1.12. Hexapod Surgical Robot with Endoscope and Phantom

1.6. AVI USING STEWART PLATFORM

Researchers are on the lookout for utilizing the potential advantages of Stewart platform for AVI. The main advantage of using the Stewart platform for AVI is that it can be directly kept in the path of disturbance. Fig. 1.13 illustrates the use of Stewart platform for AVI; the sensitive equipment is isolated from harmful vibration from floor by means of Stewart platform.
1.7. PRESENT WORK

Stewart platform has several features which make them particularly attractive for six DOF active vibration control. They use the minimum number of linear actuators to provide six DOF motions. Considerable efforts are on, for utilizing the concept of Stewart platform for six DOF AVI (Doug et al., 1998; Preumont et al., 2002; Ren et al., 2004; Hauge and Campbell, 2004; Yun and Li, 2011). Present work is aimed at optimizing the configuration of Stewart platform based AVI, for better isolation.