Eguide

Minimizing the Effects of Ground Vibration on Sensitive Equipment

There are three primary sources of vibration (noise) which can disturb a payload: ground vibration, acoustic noise, and "direct force" disturbances. Ground or seismic vibration exists in all environments throughout the world.
This noise has various sources, from waves crashing on coastal shorelines, the constant grind of tectonic plates, wind blowing trees and buildings, to man made sources like machinery, HVAC systems, street traffic, and even people walking.
Vibration isolation systems are designed to minimize the influence of these vibration sources.
It is impossible to completely eliminate noise, but it's possible to mitigate it. Many techniques have been used to mitigate ground vibration and its effect on sensitive instrumentation. In this guide we discuss the options available and the advantages and disadvantages of each technique.

HOMEMADE ASSEMBLIES

Homemade isolation systems – often a steel or granite slab placed on rubber pads, tennis balls, or air bladders - will work only if the disturbing vibrations are high frequency and minimal isolation is required. While all isolators use the principle of placing a mass on a damped spring, their performance is differentiated primarily by spring stiffness: the stiffer the spring, the higher the resonant frequency. Thus, homemade solutions are limited by their high resonant frequency.

A tennis ball under a steel plate with a 7 Hz resonant frequency begins to isolate above 10 Hz and reduces vibrations by 90% at 30 Hz. But most building floors exhibit their highest vibrational displacements between 5 and 30 Hz, so that a tennis ball or rubber pad makes the problem worse by amplifying ambient frequencies between 5 and 10 Hz.

Use cases: Typically used in cases where cost is more important than performance.

ADVANTAGES

- Easy to implement
- Inexpensive

DISADVANTAGES

- Does not provide isolation at lower frequencies
- Makes vibration worse between 5 and 30 Hz

Thick-Wall Rubber Diaphragms

Commercial isolators typically employ an inexpensive, thick-walled rubber diaphragm in the piston to achieve vertical isolation. Because of the relative inflexibility of these elements, low amplitude vibration isolation performance is compromised.
Though such a system feels "soft" to gross hand pressure, typical low-level floor vibration causes the rubber to act more like a rigid coupling than a flexible isolator.

Use cases: Typically used in cases where cost is more important than performance.

Figure 1. Thick-walled rubber diaphragm

Pneumatic Isolators (Passive)

Sealed Pneumatic Isolators

Figure 2 shows a simplified pneumatic isolator. The isolator works by the pressure in the volume (V) acting on the area of a piston (A) to support the load against the force of gravity.

A reinforced rolling rubber diaphragm forms a seal between the air tank and the piston. The pressure in the isolator is controlled by a height control valve which senses the height of the payload and inflates the isolator until the payload is "floating." There are many advantages to pneumatic isolators.

Unlike steel coil springs, this resonant frequency is nearly independent of the mass of the payload, and the height control valve always brings the payload back to the same operating height.

Gas springs are also extremely lightweight, eliminating any internal spring resonances which can degrade the isolator's performance. The load capacity of an isolator is set by the area of the piston and the maximum pressure the diaphragm can tolerate and is simply the product of these two numbers. It is common to rate the capacity at 80 psi of pressure. This allows a 4 in. piston to support a 1,000lb load (for example). Though the simple isolator in Figure 2 will work, it has very little horizontal isolation and has very little damping.

Sealed air isolators do not automatically adjust to load changes. The primary limitation of such systems is that they must be made too stiff to be effective isolators. For example, a passive isolator with a true 1.5 Hz resonant frequency would drift several inches vertically in response to small changes in load, temperature, or pressure and require constant manual adjustment. Thus, no practical sealed isolators are designed with such low resonant frequencies.

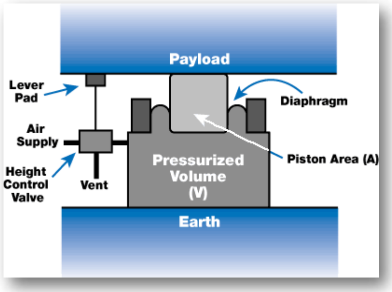

Figure 2. Simplified pneumatic isolator

Use cases: Typically used where cost is more important than performance.
Figure 1. Thick-walled rubber diaphragm

ADVANTAGES

- Inexpensive
- Easy to implement

DISADVANTAGES

- Poor performance at low frequency
- Can amplify vibration at lower frequencies

Practical Pneumatic Isolators

Figure 3 shows a cutaway view of TMC's Gimbal Piston Isolator. It uses two air chambers instead of one. These are connected by a small orifice. As the piston moves up and down, air is forced to move through this orifice, producing a damping force on the payload. This type of damping is very strong for large displacements of the piston and less for small displacements. This allows for fast settling of the payload, without compromising small amplitude vibration isolation performance. Damping of this type usually produces a Q ≈ 3 for displacements on the order of a few millimeters.

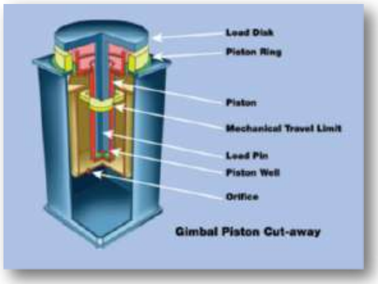

Figure 3. Cutaway of Gimbal Piston isolator

If more damping is needed in a pneumatic isolator system it's possible to replace the air with oil or another more viscous fluid to increase the damping. TMC's MaxDamp® isolators use a different method: Multi-axis viscous fluid damping (Patent No. 5,918,862). These isolators can extend the damping to near critical levels for those applications which require it. For example, semiconductor inspection equipment often uses very fast moving stages to transport wafers. MaxDamp isolators allow the payload to settle very quickly after a stage motion, while still providing significant levels of vibration isolation. The isolator uses a very low outgassing, high viscosity synthetic oil which is hermetically sealed within the isolator's single air chamber. A special geometry ensures that the isolator damps both vertical and horizontal motions (in both X and Y directions) with equal efficiency.

Use cases: Typically used in cases where very good vibration isolation is needed at a reasonable cost. Optical Microscopes, Optical Benches, Lasers, Semiconductor Inspection Equipment, Metrology Equipment

ADVANTAGES

- Inexpensive
- Easy to implement
- Reliable
- Thousands of systems in the field

DISADVANTAGES

- Marginal performance at low frequency
- Can amplify vibration at lower frequencies

Active Vibration Isolation Systems

Active vibration systems use sensors such as voice coils to detect vibration and cause the active system to produce an equal and opposite reaction to cancel out the vibration.

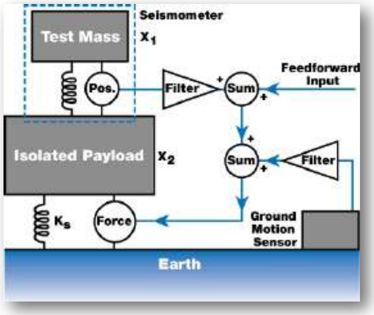

Figure 4. Parallel type active vibration isolation system

Parallel Type Systems

The first embodiments of inertial feedback active systems were parallel-type configurations in which the inertial sensor is mounted to the isolated surface, and the cancellation actuator is mounted in parallel with springs (air isolator supports) that support the isolated surface. This approach can effectively suppress the resonant amplification of the support air isolators in the 1-4 Hz range.

Use cases: Typically used where cost is more important than performance.

However, attempts to isolate over wide bandwidths with this approach meet with difficulty, as the sensors cannot differentiate between rigid body motion of the top and resonances of structures on the isolated payload. The control system will attempt to cancel both, leading to system instability. While the compromise has been to limit the bandwidth of such systems to <8 Hz, effectively suppressing resonant amplification of the air isolators and improving stability, it does little to improve vibration isolation over the broad 0.5-30 Hz range.

Serial Systems

An alternative approach has been developed using a serial-type configuration. Here, the support spring is placed in series with the cancellation actuator. The sensor is mounted to an ultra stiff inner mass that supports the payload through a stiff, 15-20 Hz spring. The actuator supports the inner mass to ground.

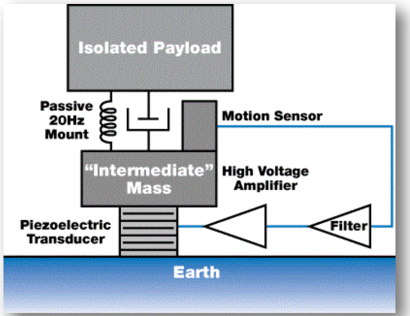

Figure 5. Serial type active vibration isolation system

With this approach, linear motors and other conventional actuators are not feasible because the actuator in a serial-type configuration must support the static weight of the top. But, developments in piezoelectric actuator technology make piezos the ideal choice for serial-type configurations, as they can now be designed to support a large static mass and have excellent response characteristics to very low displacements.

In this embodiment, floor vibration is sensed at the inner mass as it is transmitted through the stiff actuator. The feedback loop is closed at the inner mass as the actuators "filter" floor noise from reaching the inner mass. That is, as the floor moves upward, the actuators contract; as the floor moves downward, they expand.

A three-axis design expands this control behavior to all six DOFs. Such systems are inherently robust, as the payload resonances are filtered from reaching the inner mass by the stiff spring and the sensor is mounted to an inner mass that can be designed to achieve the very high stiffness required — >1000 Hz. Therefore, gain settings can be aggressive with bandwidths of up to 150 Hz frequently achieved, leading to very high levels of vibration attenuation with little risk of instability.

This approach is particularly effective at low frequencies, achieving up to two orders-of-magnitude improvement over passive air isolators in the 1-3 Hz range. In addition, the hardmount support offers the fringe benefit of maintaining the payload's positional stability with respect to off-board beam sources, which is impractical with a soft-air support.

ADVANTAGES

- Widest bandwidth, best low frequency performance
- Settling time is low compared to parallel
- Minimal tuning required
- Best for "point of use" applications like charged beam tools (TEM, SEM, e-beam lithography)

DISADVANTAGES

- More costly than less advanced solutions
- Limited stroke of piezo stacks – 25 microns
- Cannot directly cancel stage

Use cases: Typically used in cases where performance is paramount – Transmission Electron Microscopes, Atomic Force Microscopes, Scanning Electron Microscopes

Combined Passive and Active Solutions

For the ultimate in vibration isolation, it's possible to combine passive and active vibration isolation systems to provide attenuation at very low frequencies and at high frequencies. This is typically accomplished by putting a passive isolation system on top of an active system. The two stage of isolation are cumulative across the frequency range.

For example, with 30 dB of attenuation at 10 Hz actively and 30 dB of attenuation at 10 Hz passively, 60 dB of total attenuation at 10 Hz is achieved. And since the serial-type architecture is an active hard mount, it can be stacked with no risk of instability or crosstalk between the isolation system. The 15-20 Hz hard-mount spring is sufficiently stiffer than the 2 Hz passive air spring to achieve adequate impedance mismatch, ensuring stability.

Such systems (as shown in Figure 7) are commercially available with six DOF performance and provide the best of both worlds: aggressive low-frequency vibration cancellation from an inherently stable architecture with two stages of vibration isolation since the attenuation of the air isolators and piezo isolators are additive.

Passive-over-active systems are being adopted for some of the most sensitive applications, including single-molecule biophysics, multiphoton imaging, atomic force microscopy, confocal microscopy, and interferometric studies of large samples where sub-nanometer and even sub-angstrom resolution is desired. As resolution is sought at ever-smaller scales, rapid advances in vibration isolation technology ensure that floor vibration need not be the critical limiting factor.

Typical uses cases: Highly sensitive instruments with moving stages such as semiconductor inspection equipment, semiconductor lithography equipment, nano-optical microscopy and spectroscopy

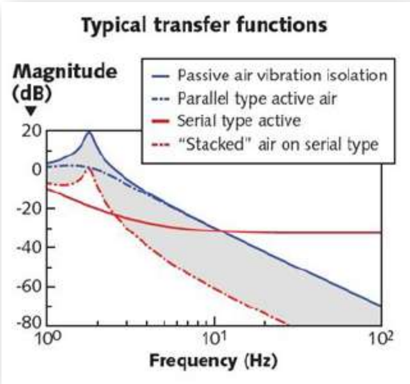

Figure 6. Transfer function for typi-cal combined solution

Figure 7. Example of a combined system - active isolation on the bottom and passive on the top

ADVANTAGES

- Cumulative isolation performance across the entire frequency range
- Works well with systems with moving stages
- Commercial designs are available

DISADVANTAGES

- More costly than less advanced solutions

Summary

There is no vibration solution that is ideal for every situation. Each method has advantages and disadvantages in any situation. If you suspect you have vibration issues with your critical equipment, contact us and we can recommend the best solution for your situation.