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Vibration Isolation in Sensitive Instruments Equipped with Internal Passive Air Isolators Can Be Significantly Improved When Supported by Piezo-Driven Active Vibration Isolation Platforms

High-resolution instruments equipped with internal passive air isolators may permit the option to add inertial sensors and vibration cancellation motors to convert the passive air isolators to active air isolators. Although this approach cancels the amplification of the air isolators, little isolation is gained over the remaining frequency spectrum. A better approach is to support the entire instrument on a piezo-driven active vibration isolation platform, in which the force actuators are in series with the springs that support the payload, and where the transfer functions of the two stages of isolation are additive. Such a two-stage, passive-over-active approach provides considerably superior vibration isolation when compared to adding active controls to a passive system.

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As the need for nano-precision has become increasingly important in many fields of research and manufacturing – such as microelectronics fabrication, laser/optical system applications, life sciences, materials, and biological research – so has the need to develop better vibration isolation technology to facilitate instrumentation operation under extremely precise requirements. Once the mainstay for stabilizing academia's and industry's most critical micro-engineering instrumentation, passive pneumatic vibration isolation has proved less than adequate in isolating extremely low-frequency vibration that negatively influences instrumentation operating at atomic scale resolutions.

Vibration influencing high-resolution sub-micron instrumentation can be caused by a multitude of factors. Within the building itself, the heating and ventilation system, fans, pumps and elevators are just some of the mechanical devices that create vibration. How far away sensitive instrumentation is from these vibration sources, and where in the structure the equipment is located, will determine how strongly the equipment will be influenced. External to the building, the equipment can be influenced by vibration from adjacent road traffic, nearby construction, aircraft, and even wind and other weather conditions that can cause movement of the structure.

These internal and external influences cause low frequency vibration in the 1.0 Hz to 50 Hz range which is transmitted through the structure, disturbing precision instruments. This low-frequency vibration may be inadequately compensated for in pneumatic vibration isolation systems, and consequently transmitted to the sensitive part of the instrument, compromising resolution, image quality, and the integrity of data.

Pneumatic isolators, particularly at frequencies below 10 Hz, deliver limited isolation vertically and even less isolation horizontally. In fact, such isolators create vibration isolation problems in the region of their resonant frequency. All isolators will amplify at their resonant frequency then start isolating above this frequency. Pneumatic isolators will amplify vibration in a typical range of 1 to 4 Hz. Sensitive instruments, which are typically manufactured with internal air isolation, are, therefore, often subject to problems with vibration.

Further taxing pneumatic isolation functionality is the growing trend of locating highly-sensitive instrumentation – electron microscopes, scanning tunneling microscopes, laser interferometers, and optical profilers – in building locations where vibration levels are high such as upper floors. As vibration-handicapped environments become more prevalent for the placement of sensitive instrumentation, better vibration isolation solutions are required than what have been available with the instruments' internal pneumatic isolation systems, which are designed for less than severe vibration environments.

Converting an Internal Passive Air Isolator to an Active-controlled Air Isolator

At locations with high levels of vibration where the instrument's internal pneumatic isolation is inadequate, the instrument manufacturer may design in an upgrade path, the option to convert the instrument's passive isolation system into an actively controlled system. Such an option may seem attractive given the space efficiencies of locating the active system within the instrument itself instead of necessitating an instrument-supporting, vibration-isolation platform. However, converting internal passive air isolators to actively controlled air isolators provides a relatively minor improvement in vibration isolation performance.

Inertial sensors and cancellation motors are installed to convert the passive air isolators to active air isolators. The sensors are added to the payload which measure X, Y and Z vector vibration, which is fed to a controller that instructs an equal and opposite force to be exerted through actuators to cancel motion of the payload. Such an active-feedback control system continuously monitors the payload that it is controlling, and modifies its output according to the vibration data measured.

This creates a parallel-type active isolation system, since the force actuators are in parallel with the springs that support the payload. The active vibration control of the passive air isolators will effectively suppress the resonant frequency of the air isolator between 1 and 4 Hz. The active cancellation enhances the performance of the air isolator in this frequency range, but little additional isolation is gained over the remaining frequency spectrum from 1 to 50 Hz. Unless the need for enhanced vibration isolation is limited to the 1 – 4 Hz range, the upgrade to this parallel type of active isolation will provide little benefit.

Problematic floor vibration will typically be observed over the frequency range of 1 – 50 Hz. This requires that any improvement to the passive isolators perform over this range. In addition, the instrument has structural resonances which present a problem for an active control system. Since the active control sensors are placed on the isolated payload they are challenged to differentiate between vibration in the environment and structural resonances of the instrument and, therefore, must be "de-tuned" (low gain) to avoid creating feedback loop instability. This inherently limits their performance to a narrow frequency range

Internal Passive Isolator Supported on a Piezo-Driven, Active-Isolation Platform

An alternative and better solution to the relatively ineffective parallel-type active vibration isolation approach for instruments equipped with internal passive air isolators, is to support the entire instrument on a piezo-driven, active vibration isolation platform. In such a platform the force actuators are in series with the springs that support the payload, and the transfer functions of the two stages of isolation are additive. Such a two-stage, passive-over-active approach provides superior vibration isolation compared to adding active controls to a passive system.

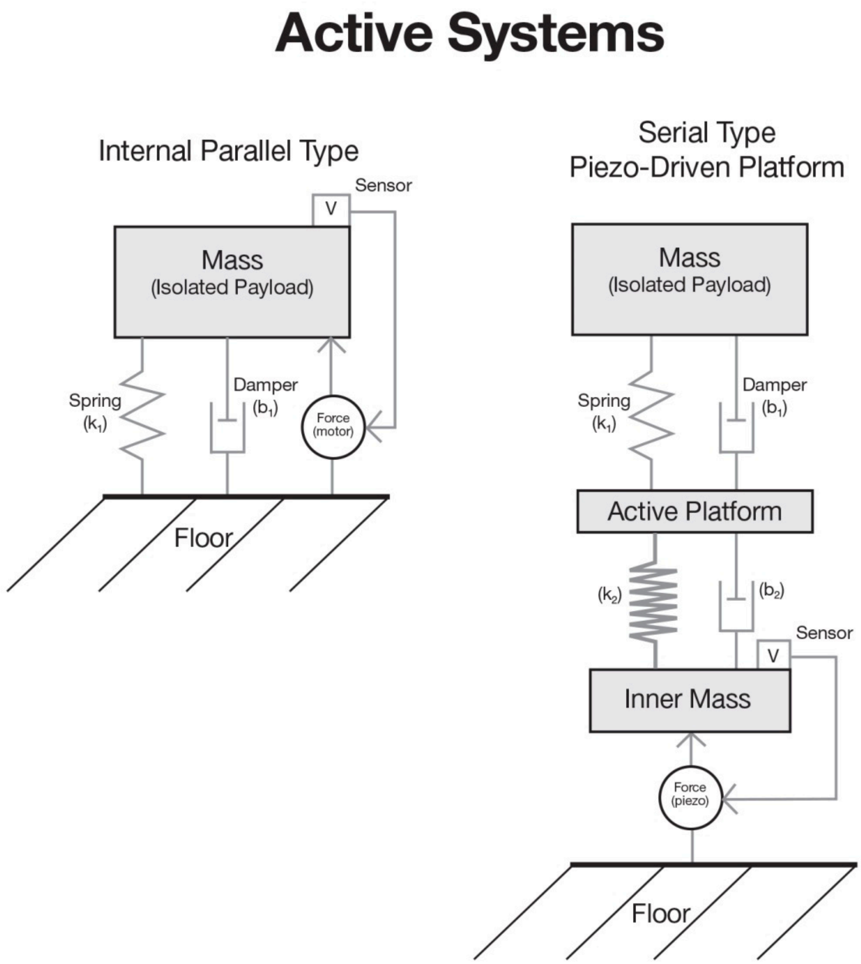

Image 1: Internal parallel-type active system versus serial-type piezo-driven active platform.

The stacking approach will provide 30 decibels more isolation at 10 Hz than upgrading a 2 Hz air isolator to an actively-damped 2 Hz air isolator. The serial approach is stackable, but parallel-type approaches cannot be stacked without technical risk.

The serial configuration, utilizing stiff passive springs and precision piezoelectric actuators, makes the total stiffness of the system very high. Such an active "hard-mount" system is over 100 times stiffer than the typical pneumatic system. The primary advantage of a hard-mount is that softer systems, such as passive pneumatic or even parallel-active pneumatic systems, can be stacked on the hard-mount platform without the two systems coupling, due to the wide separation of their resonant frequencies.

The serial-type control system senses floor motion, not payload motion. Thus, stability and vibration cancellation performance of a serial-type system is not affected by motion and resonances of the payload. It is inherently stable. The sensor is decoupled from the payload by the stiff elastomer mount, and is capable of detecting only floor vibration. The measured vibration is then cancelled via the piezoelectric actuators. Therefore, the floor vibration measurement and subsequent feedback cancellation effort is not corrupted by payload motion or resonances.

The piezoelectric transducers used in serial passive-over-active isolation are uniquely suited to achieve very low frequency performance because of their stiffness and response over a very wide frequency range. This is due to the very high stiffness of the PZT (lead zirconate titanate) stacks, which are composed of layered structures of specialized PZT ceramic interleaved with electrodes. An applied voltage causes a bulk change in the ceramic's length, allowing the actuators to be used for fast, high-force, real-time position control at the nanoscale level. The solid-state nature of PZT materials sets them distinctly apart in precision performance compared to traditional actuators.

Performance

Serial-type passive-over-active systems can maintain active vibration isolation from 0.6 to 150 Hz. Due to the additive performance of the serial active – passive pneumatic combination, they are able to provide cancellation over a broad frequency range, significantly exceeding what passive isolators or active isolators can achieve independently.

Performance with serial-type passive-over-active systems in the 0.6 to 4 Hz band effectively erases the amplification caused by the passive system. It reduces horizontal and vertical vibration by over 50 percent at 1 Hz and over 90 percent at frequencies above 2 Hz.

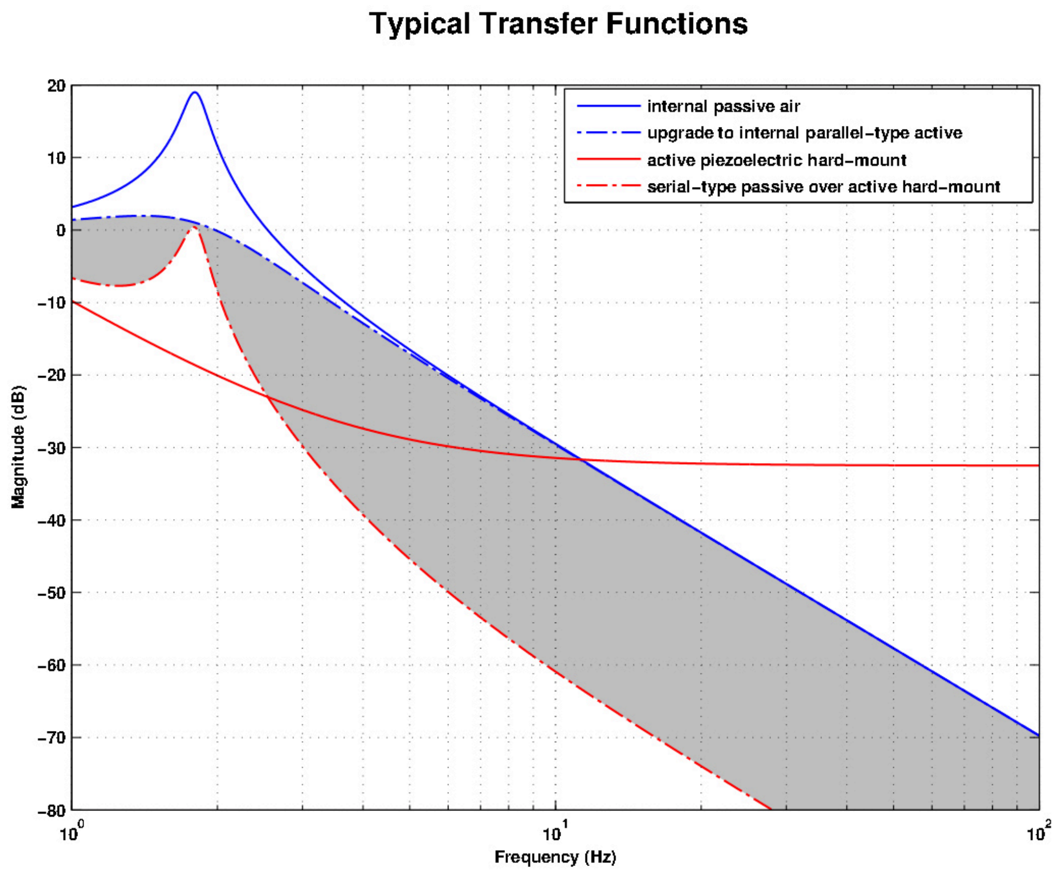

Image 2: Typical transfer functions. The shaded area indicates the improved performance when installing an instrument with internal isolators on a piezo-driven active cancellation platform, compared to installing parallel-type, motor-driven air active cancellation in the payload and installing the instrument on the floor.

Many precision instruments have floor vibration criteria which must be met to achieve their performance specifications. If a site does not meet these requirements, then the instrument must either be moved to a different site, or a suitable vibration isolation solution applied. Serial-type passive-over-active systems provide an extremely effective vibration isolation solution over a wide frequency range that enables instruments with internal passive air isolation to be installed in environments that would otherwise be too noisy for effective operation.

About Technical Manufacturing Corporation (TMC)

TMC designs and manufactures precision vibration isolation systems for sensitive research and manufacturing processes worldwide. TMC is an ISO 9001:2008-certified company. Its products include active and passive vibration isolation systems; optical *tops, optical table systems, and breadboards; laboratory tables and table top platforms; floor platforms; magnetic field cancellation and electric field shielding systems; and acoustic enclosures.*

TMC is a unit of AMETEK Ultra Precision Technologies, a pioneer in the development of ultra-precision measurement instruments and a global leader in ultra-precise machine tools and manufacturing systems for the semiconductor, photovoltaic, nanotechnology, military, defense and ophthalmic lens markets.

AMETEK Ultra Precision Technologies is a division of AMETEK, Inc., a leading global manufacturer of electronic instruments and electromechanical devices with annual sales of $4.0 billion.

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