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Using Negative-Stiffness Mechanical Vibration Isolators

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For almost 40 years pneumatic vibration isolators have been the mainstay for stabilizing industrial and academia's most critical micro-engineering instrumentation. There has been an increasing need for more precise vibration isolation in microelectronics fabrication, industrial laser/optical systems and biological research. These so called "passive system" air tables are now being seriously challenged by the newer negative-stiffness vibration isolators.

Negative-stiffness isolation is rapidly gaining popularity in industrial and laboratory environments, and to no small degree because of its ability to effectively isolate vibration in diverse and challenging environments.

An isolator is used to solve a problem, and how bad the problem is determines the solution that is needed. Since the 1960s air tables have been used for isolation. Basically cans of air, they are still the most popular isolators used. But, air tables with resonant frequencies at 2 to 2-1/2Hz can typically only handle vibrations down to about 8 to 10Hz, not quite low enough for optimum performance with today's nano-equipment. Also, greater isolation efficiencies are needed in the frequency ranges that air isolators can handle.

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Better Isolation Needed

While the air systems have been adequate up until a few years ago, better isolation is now needed. For purposes of clarity in scanning probe microscopes and interferometers, air tables are an inefficient isolation solution.

Because of their very high isolation efficiencies, negative-stiffness vibration isolation systems enable vibration-sensitive instruments such as scanning probe microscopes, micro-hardness testers, profilers and scanning electron microscopes to operate in harsh conditions and severe vibration environments that would not be practical with top-performance air tables and other pneumatic isolation systems.

Fully Mechanical System

Negative-stiffness isolators use a completely mechanical concept in low-frequency vibration isolation. Vertical-motion isolation is provided by a stiff spring that supports a weight load, combined with a negative-stiffness mechanism. The net vertical stiffness is made very low without affecting the static load-supporting capability of the spring. Beam-columns connected in series with the vertical-motion isolator provide horizontal-motion isolation. The horizontal stiffness of the beam-columns is reduced by the "beam-column" effect. (A beam-column behaves as a spring combined with a negative-stiffness mechanism.)

The result is a compact passive isolator capable of very low vertical and horizontal natural frequencies and very high internal structural frequencies. The isolators (adjusted to 1/2Hz) achieve 93 percent isolation efficiency at 2Hz; 99 percent at 5Hz; and 99.7 percent at 10Hz. Ten key points demonstrate the benefits:

Low Hertz Perturbations. An air table will amplify vibrations in a typical range of 2 to 7Hz, because of the natural frequencies where air tables resonate. All isolators will amplify at their resonant frequencies and then they will start isolating. So, with an air table, any vibration in that range could not only fail to be mitigated, it could be amplified. The low cycle perturbations would just come straight through to the instrument.

Negative-stiffness isolators resonate at 0.5Hz. At this frequency there is almost no energy present. It would be very unusual to find a significant vibration at 0.5Hz.

Image Clarity. Negative-stiffness vibration isolation can reduce vibration noise levels in Atomic Force Microscopes, for example, by a factor of 2 to 3 when compared with top-performance air tables. This is particularly significant for noise levels in the sub-Angstrom range. This results in clearer images and features not discernible with pneumatic isolation systems.

Severe Vibration Environments. As nano-equipment use becomes more prevalent, lab sites are being set up in much more severe vibration-prone environments, such as upper floors of buildings and clean rooms. Such severe vibration locations are too extreme for pneumatic isolators to effectively do their job.

But negative-stiffness isolators perform well in such environments, producing much better images and data than can be obtained with even the best high-performance air tables.

Harsh Environments — High/ Low Temperature Extremes, Vacuums, Radiation. Air tables are not particularly compatible when it comes to operating in vacuums, extreme high and low temperatures, and radiation. Yet these harsh operating environments are often necessary when conducting research and testing, such as with cryogenic chambers in semiconductor research.

All metal negative-stiffness systems can be configured which are compatible with high vacuums and other adverse environments, such as extreme high and low temperatures, and radiation. With vacuums, for example, negative-stiffness isolators can be used right inside the vacuum chambers. This offers other advantages such as much lower payload weights, more compact systems, and eliminates problems associated with vacuum chamber feed-through.

Compressed Air. Air tables require constant supply of compressed air. This requires either a dedicated compressed air line to be plumbed in to your lab, a tank of pressurized gas or a small compressor. Tanks of compressed gas have to be mounted very securely to minimize danger. Changing the tanks can be quite difficult and inconvenient as well. Compressors are sources of both mechanical and acoustic noise, and vibration.

Location Selection for Vibration-Sensitive Equipment. Air tables are big, bulky structures, and take up a lot of lab space. High-performance air tables are even bigger. This can become a limiting factor when laying out the equipment in your lab. Negative-stiffness isolators are available in high-performance benchtop configurations, considerably more compact than air tables and easy to move around. They are also available as workstations, tables, and floor platforms where these configurations are required.

Load Adjustment. Low-frequency passive vibration isolators are somewhat sensitive to small changes in weight loads, as well as to large displacements. Pneumatic systems utilize leveling valves to mitigate the problem.

Negative-stiffness isolators provide a very simple manual adjustment to accommodate variations in weight loads. Auto-adjust systems are available.

Scanning Probe Microscopes. Scanning Probe Microscopes (SPMs) have vibration isolation requirements that are unparalleled in the metrology world. The vertical axis is the most sensitive for most SPMs. They can also be quite sensitive to vibrations in the horizontal axes. In order to achieve the lowest possible noise floor, on the order of an Angstrom, isolation is always used. Benchtop air systems provide limited isolation vertically and very little isolation horizontally. Negative-stiffness isolators provide increased isolation performance for SPMs over air tables, while offering better ease-of-use and no facility requirements. Negative-stiffness isolators can be custom tailored for vertical and horizontal resonant frequencies .

Laser/Optical Equipment. Laser-based interferometers are extremely sensitive devices that are capable of resolving nanometer scale motions and features. They often have very long mechanical paths which makes them even more sensitive to vibrations. The sophisticated modern ellipsometry techniques that allow this high performance rely on low noise to be able to detect fringe movement. Properly isolating an interferometer will allow it to provide highest possible resolution.

Optical profilers have similar sensitivity to vibrations. Optical component systems are often quite complex. The long optical paths can lead to angular magnification of vibrations. Optical air tables can make the problems worse since they have a resonant frequency that often matches that of floor vibrations. Negative-stiffness 0.5Hz isolators provide isolation in these environments when air tables simply cannot.

Maintenance. Because negative-stiffness isolators utilize simple elastic structures and viscoelastic materials that deform, their isolation performance does not degrade with micromotions typical of laboratory floors and fabrication rooms, as do conventional pneumatic isolators.

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