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Isolating negative-stiffness vibration in laser and optical systems

David Platus

A passive mechanical approach to minimizing motion [[OK up to here?]] makes it possible for sophisticated instruments such as scanning probe microscopes to operate in environments that would otherwise not be practical.

As technology steadily migrates from micro to nano, so has the need for more precise vibration isolation in lasers and optical systems used in applications such as industrial testing, microelectronics fabrication, and biological research. Laser and optical systems, whether used in academic labs or industrial and manufacturing facilities, are very susceptible to vibrations from the environment. These instruments almost always need vibration isolation. When measuring a very few angstroms or nanometers of displacement, an absolutely stable surface must be maintained upon which to rest the instrument. Any vibration, coupled into the mechanical structure of the instrument, will cause vertical noise and fundamentally an inability to measure these kinds of high-resolution features.[1]

Traditionally, large air tables have been the isolators used for laser and optical equipment. The ubiquitous passive-system air tables, adequate up until a few years ago, are now being seriously challenged by the need for more refined imaging requirements. Bench-top air systems, however, provide limited isolation vertically and very little isolation horizontally. Yet scanning probe microscopes (SPMs), for example, have vibration isolation requirements that are unparalleled in the laser and optical world. For most SPMs, the vertical axis is the most sensitive. These machines can also be quite sensitive to vibrations in the horizontal axis. To meet this challenge, so-called negative-stiffness mechanism isolators are able to custom-tailor resonant frequencies both vertically and horizontally,[2] providing increased isolation performance for SPMs over air tables.

Laser-based interferometers represent another kind of extremely sensitive device that is capable of resolving nanometer-scale motions and features. 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 the highest possible resolution. But interferometers and other optical component systems [[OK?]] are often quite complex. They have long optical paths that can lead to angular magnification of vibrations. Air tables can make the problems worse since they have a resonant frequency that often matches that of floor vibrations, typically 2–3Hz. And their isolation efficiency is quite limited below about 8Hz. Negative-stiffness mechanism isolators provide isolation in these environments where air tables simply cannot.

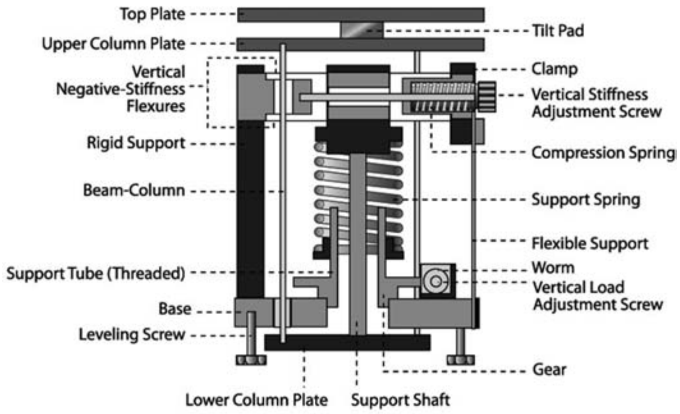

Figure 1. *The transmissibility of a passive negative-stiffness vibration isolator—that is, the vibration that transmits through the isolator measured as a function of floor vibrations—can be 100 times better at low frequencies of around 2.5Hz than a higher-cost air table.*

What negative-stiffness isolators provide is genuinely unique to the field of laser and optical systems. In particular, the trans-

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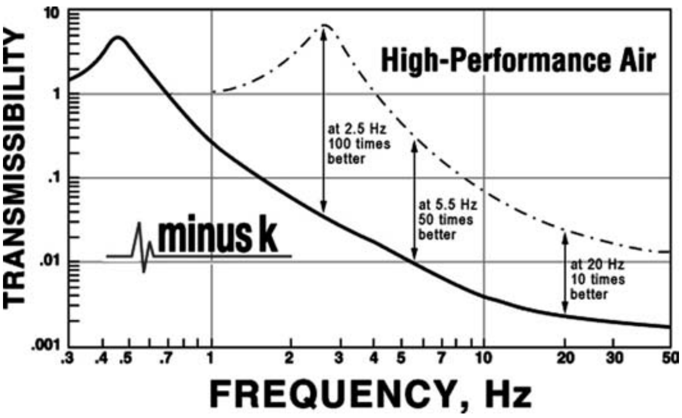

Figure 2. Schematic of a negative-stiffness mechanism vibration isolator.

missibility of a negative-stiffness isolator: that is, the vibrations that transmit through the isolator relative to the input floor vibrations (see Figure 1). Transmissibility with negative-stiffness is substantially improved over air systems, and even over active isolation systems. Also known as electronic force cancellation, active isolation uses electronics to sense motion, and then adds equal amounts of motion electronically to compensate, effectively canceling out the movement. Their efficiency is adequate for application with the latest lasers and optics, as they can start isolating as low as 0.7Hz. But because they run on electricity, they can be negatively influenced by problems of electronic dysfunction and power modulation, which can interrupt scanning.

Negative-stiffness isolators employ 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 (see Figure 2). 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% isolation efficiency at 2Hz, 99% at 5Hz, and 99.7% at 10Hz.[3]

As industry and universities continue to broaden their laser and optical research, and to devise applications necessitating more sensitive equipment and expanded lab facilities, vibration-handicapped environments will become more prevalent.[4] A better vibration isolation solution will be required than what has been available.

Negative-stiffness mechanism vibration isolation is a highly workable vibration solution and costs significantly less than conventional alternatives—up to one-third the price—making it an economical solution to cost-conscious administrators. [[Here we just need a few words about how the negative-stiffness mechanism vibration isolators could be improved. What do you intend as next steps?]] [[Finally, do you want to add a technical reference?]]

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