'Negative stiffness' isolates vibrations

By R. Colin Johnson

Minus K Technology Inc. claims that the "negative stiffness" mechanism it has developed isolates objects from vibrations better than traditional solutions. Such techniques provide the stable platform and angstrom-level accuracy needed to test microelectro-mechanical systems, nanoscale metrology and semiconductor fabrication tools, for example.

"Our negative stiffness mechanism exerts an opposing force that cancels out the stiffness in a spring," said David Platus, president and CEO of Minus K (Inglewood, Calif.). "That gives us isolation that is twice as good as other active systems but for half the price of air table-style passive vibration isolation systems."

Even the subsonic background resonance of waves pounding the shores worldwide can be too noisy for some testing environments.

"The U.S. Air Force couldn't find a place quiet enough to test their next-generation accelerometers and gyros," said Platus, "since they wanted isolation even from the .07-Hz background of nano-g-scale vibrations from waves crashing the shores worldwide. That got me thinking about a negative stiffness mechanism to cancel out vibrations."

To isolate atomic-force and scanning-tunneling microscopes from vibrations, researchers have traditionally used passive air tables that support weight on a cushion of air, or they use active electronic feedback to send cancelling forces that damp out oscillations in springs. Now Paltus claims his patented negative-stiffness mechanism outperforms active systems while underpricing passive ones.

Paltus, who founded Minus K, now has a patent portfolio protecting its negative stiffness mechanism. The company offers vibration isolation payload capacities ranging from a 10-pound tabletop to 10,000-pound floor panels. When adjusted to a .5-Hz natural frequency, the Minus K vibration isolators achieve 93 percent isolation efficiency at 2 Hz, 99 percent at 5 Hz and 99.7 percent at 10 Hz.

Blocking the vibrations

The problem is that any platform have a certain positive stiffness coefficient that determines their natural resonant frequency—usually 1 Hz and up. But by subtracting negative stiffness from the positive stiffness of the spring, Minus K's negative stiffness mechanism can block nearly all vibrations higher than .5 Hz.

An example of a commonly known negative stiffness mechanism is the bottom on an oil can, fabricated so that it is puckers out. When the user pushes the bottom, the surface flips into a concave shape, thus sharply forcing out the oil. Since stiffness is the force needed to move something, the bottom of the oil can is said to have negative stiffness. The slightest push makes the bottom jump forward from under the finger to squirt out an oil stream—mathematically exhibiting a negative stiffness coefficient.

"The bottom of the oil can is buckled, but in the center of its travel it is unstable, flipping to one side or the other," said Platus. "If you were to monitor the force deflection behavior at the center of that travel, its stiffness would be negative."

Minus K exploits this passive materials phenomenon by supporting its payload with a spring that is at the center of travel of a negative stiffness flexure. Any positive force pushing on the springs of its vibration isolation platform is opposed by the negative stiffness of the flexure.

"At the top of the negative stiffness mechanism there are horizontally oriented metal flexures coming from the center of the spring out, and they are compressed so that the flexure wants to pop up or down," said Platus. "By carefully tuning the magnitude of this negative stiffness to be a little less than the stiffness of the supporting springs, we can reduce the vibration isolation platform's natural frequency of oscillation to be less than half a hertz, so that higher-frequency vibrations can't get through."

For the vertical direction, the isolation platform loads a beam column in the same way it does for the horizontal flexures. By keeping the beam column near buckling, its horizontal stiffness gets less and less with increased load.

"Theoretically, if you load the vertical beam columns at their critical buckling load, no force will move it back and forth," said Platus.

By balancing a vertical spring against the negative stiffness of the vertical beam columns, the vibration isolation system achieves vertical .5-Hz natural resonance. The combined effect of the negative stiffness of the horizontal flexures and the vertical beam columns isolates all vibrations greater than .5 Hz in both vertically and horizontally.

"Transistors have critical dimensions down around 25 nanometers," said nanotechnology researcher David Ferry, who is an EE professor at Arizona State University. "And the most critical dimension is the oxide thickness, which is 1 nanometer." Consider, he said, that "you have to control 1-nm vertical thickness over 300 millimeters of lateral dimension. That defines modern manufacturing technology's need for effective vibration isolation, which has never been greater than today, and will continue to become more demanding as the nanoindustry progresses."

Arizona State University isolates its atomic-force and scanning-tunneling microscopes with Minus-K vibration isolation platforms. ■

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