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TECH WATCH

Negative-Stiffness Vibration Isolation Aids Princeton's South Pole Lab

By Jim McMahon

To nullify gyroscopic pick-up of the Earth's rotation while conducting Lorentz symmetry testing, Princeton University's Romalis group set up a field lab at the Amundsen-Scott Station at the South Pole. The lab contains an ultra-precise atomic spin co-magnetometer in a vacuum, equipped with negative-stiffness vibration isolation. With the effects of the Earth's rotation almost completely suppressed, the group's Lorentz symmetry test results improved by two orders of magnitude compared with testing at Princeton's base facility in New Jersey.

Lorentz invariance or symmetry, a set of fundamental frameworks that underpin modern science and physics in particular, lies at the foundation of quantum field theory (QFT) and Einstein's theory of general relativity, the two most successful theories in physics, which together describe the four fundamental forces of nature.

In physics, particularly electromagnetism, the Lorentz force is the combination of electric and magnetic force on a point charge due to electromagnetic fields. While modern Maxwellian equations demonstrate how electrically charged particles and currents, or moving charged particles, give rise to electric and magnetic fields, the Lorentz force law completes that picture by describing the force acting on a moving point charge in the presence of electromagnetic fields.

Lorentz Symmetry Testing

The inability to incorporate gravity, however, as described by general relativity into the QFT standard model of particle physics has led to the development of alternative theories of quantum gravity. Since many of these theories break Lorentz symmetry at some small level, experimental searches for Lorentz-violating effects could help shed light on new physics beyond the standard model, and provide clues as to the nature of quantum gravity.

Some of the most precise tests relating to Lorentz symmetry are being performed by the Romalis group at Princeton University. "Lorentz symmetry underlies all of the known forces of nature, providing one of the few links between gravity and quantum mechanics," says Michael Romalis, Ph.D., professor of physics and head of the Romalis group. "It postulates that laws of physics are invariant under rotation, and remain the same in a moving reference frame. Lorentz symmetry is also closely connected to charge-parity-time (CPT) reversal symmetry that enforces the equivalence of particles and anti-particles."

Romalis uses ultra-high precision techniques involving polarized atomic spin to test Lorentz symmetry. "The presence of Lorentz violation would appear as an effective field felt by the atoms. Presumably, this field acts as a cosmically fixed background which, from the point of view of our Earth bound experiment, fluctuates with a sidereal period as the Earth rotates," he adds.

Effects of the Earth's Rotation

An alkali metal, noble gas co-magnetometer, enclosed within a vacuum chamber, is used in the group's experiment to very sensitively measure fields that couple to atomic spin, while suppressing magnetic field interactions.

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"Polarized atoms in the co-magnetometer are extremely sensitive to rotations," says Romalis. "At Princeton, we pick up a large background signal due to Earth's rotation. At the South Pole, we can almost completely eliminate that signal."

Vibrations in the range of few hertz to a few tens of hertz will influence the testing. These internal and external influences primarily cause lower frequency vibrations which are transmitted through the structure, creating strong disturbances in sensitive equipment.

Vibration within this range can be caused by a multitude of factors. Every structure is transmitting noise. Within a building itself, the heating and ventilation system, fans, pumps and elevators are just some of the mechanical devices that create vibration.

External to the building, the testing can be influenced by vibrations from vehicle movement, nearby construction, noise from aircraft, and even wind and other weather conditions can cause movement of the structure.

Romalis selected a negative-stiffness vibration isolator, customized to be only mildly magnetic, for its Lorentz symmetry testing, both at Princeton University and at the South Pole.

Negative-Stiffness Isolation

Developed and patented by Minus K Technology, negative-stiffness isolators employ a completely mechanical concept in low-frequency vibration isolation, with no air or electricity required.

What is advantageous about negative-stiffness isolators is that they achieve a high level of isolation in multiple directions. Negative-stiffness isolators have the flexibility of custom tailoring resonant frequencies to 0.5 Hz vertically and horizontally, with some versions at 1.5 Hz horizontally).

For an isolation system with a 0.5 Hz natural frequency, isolation begins at 0.7 Hz and improves with increase in the vibration frequency. The natural frequency is more commonly used to describe the system performance.

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. A beam-column behaves as a spring combined with a negative-stiffness mechanism.

Negative-stiffness isolators do not require electricity or compressed air. There are no motors, pumps or chambers, and no maintenance, because there is nothing to wear out. They operate purely in a passive mechanical mode.

If equipment can be isolated from vibrations, without having to deal with compressed air or electricity, then it makes for a system that is simpler to transport, and easier to set up and maintain. For the Romalis group's Lorentz symmetry testing at the South Pole, this has proved advantageous.

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