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Opto-Mechanical Inertial Sensors (OMIS) for High Temporal Resolution Gravimetry

Lee Kumanchik, Felipe Guzman, and Claus Braxmaier

Gravity field measurement by free-falling atoms has the potential for very high stability over time as the measurement exposes a direct, fundamental relationship between mass and acceleration. However, the measurement rate of the current state-of-the-art limits the performance at short timescales (greater than 1 Hz). Classical inertial sensors operate at much faster response times and are thus natural companions for free-falling atom sensors. Such a hybrid device would gain the ultra-high stability of the free-falling atom sensor while greatly extending the bandwidth to higher frequency using the classical sensor. This requires the stable bandwidth of both devices to overlap sufficiently. We have developed opto-mechanical inertial sensors (OMIS) with good long term stability for just this purpose. The sensors are made of highly stable fused silica material, feature a monolithic optical cavity for displacement readout, and utilize a laser diode stabilized to a molecular reference. With no temperature control and only the thermal shielding provided by the vacuum chamber, this device is stable down to 0.1 Hz which overlaps with the bandwidth of free-falling atom sensors. The OMIS are self-calibrating by converting the fundamental resonances of a molecular gas into length using the free-spectral range of the optical cavity, $FSR = c/2nL$, and then sampling the OMIS mechanical damping rate and resonance frequency using a nearby piezo. This acceleration calibration is potentially transferable to a companion free-falling atom sensor. Readout is performed by modulating the cavity length of the OMIS with one cavity mirror being the OMIS itself and the other being a high frequency resonator. The high frequency resonator is driven by a nearby piezo well above the response rate of the OMIS and acts like an ultrastable quartz clock. The resulting highly stable tone is demodulated by the readout electronics. For the low finesse optical cavity used here, this yields a displacement resolution of $2x10^{-13}$ m/√Hz and a high frequency acceleration resolution of 400 n*g* /√Hz. At 0.1 Hz the acceleration resolution is 1.5 μ*g* /√Hz limited by the stability of our vibration isolation stage. The OMIS dimensions are about 30 mm x 30 mm x 5 mm and can be fiber coupled to enable co-location with other sensors or as standalone devices for future gravimetry both on Earth and in space