

The position actuators include a piezoelectric stage for translation control and a motorized stage for coarse rotation control equipped with a piezoelectric actuator for fine rotation control. Together, these actuators enable control of the EC length over a range of about 90  $\mu\text{m}$  with a resolution of 0.9 nm, and control of the grating angle over a coarse-tuning range of  $\pm 6.3^\circ$  and a fine-tuning range of  $\pm 520 \mu\text{rad}$  with a resolution of

10 nrad. A mirror mounted on the platform with the grating assures always the same direction of the output laser beam.

*This work was done by Gerard Wysocki, Frank K. Tittel, and Robert F. Curl of Rice University for Johnson Space Center.*

*In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:*

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## Fiber-Optic Continuous Liquid Sensor for Cryogenic Propellant Gauging

**Either water or liquid nitrogen levels can be measured within 1-mm spatial resolution and 1°C up to a distance of 70 m from the optical interrogation unit.**

*John H. Glenn Research Center, Cleveland, Ohio*

An innovative fiber-optic sensor has been developed for low-thrust-level settled mass gauging with measurement uncertainty <0.5 percent over cryogenic propellant tank fill levels from 2 to 98 percent. The proposed sensor uses a single optical fiber to measure liquid level and liquid distribution of cryogenic propellants. Every point of the sensing fiber is a "point sensor" that not only distinguishes liquid and vapor, but also measures temperature. This sensor is able to determine the physical location of each "point sensor" with 1-mm spatial resolution. Acting as a continuous array of numerous liquid/vapor point sensors, the truly distributed optical sensing fiber can be installed in a propellant tank in the same manner as silicon diode point sensor stripes using only a single feed-through to connect to an optical signal interrogation unit outside the tank.

Either water or liquid nitrogen levels can be measured within 1-mm spatial resolution up to a distance of 70 meters from the optical interrogation unit. This liquid-level sensing technique was also compared to the pressure gauge measurement technique in water and liquid nitrogen contained in a vertical copper pipe with a reasonable degree of accuracy. It has been demonstrated that the sensor can measure liquid levels in multiple containers containing water or liquid nitrogen with one signal interrogation unit. The liquid levels measured by the multiple fiber sensors were consistent with those virtually measured by a ruler.

The sensing performance of various optical fibers has been measured, and has demonstrated that they can survive after immersion at cryogenic temperatures. The fiber strength in liquid nitrogen has also

been measured. Multiple water level tests were also conducted under various actual and theoretical vibration conditions, and demonstrated that the signal-to-noise ratio under these vibration conditions, insofar as it affects measurement accuracy, is manageable and robust enough for a wide variety of spacecraft applications. A simple solution has been developed to absorb optical energy at the termination of the optical sensor, thereby avoiding any feedback to the optical interrogation unit.

*This work was done by Wei Xu of Broadband Photonics for Glenn Research Center. Further information is contained in a TSP (see page 1).*

*Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steve Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-18505-1.*

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## Ionization-Assisted Getter Pumping for Ultra-Stable Trapped Ion Frequency Standards

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A method eliminates (or recovers from) residual methane buildup in getter-pumped atomic frequency standard systems by applying ionizing assistance. Ultra-high stability trapped ion frequency standards for applications requiring very high reliability, and/or low power and mass (both for ground-based and space-based platforms) benefit from using sealed vacuum systems. These sys-

tems require careful material selection and system processing (cleaning and high-temperature bake-out). Even under the most careful preparation, residual hydrogen outgassing from vacuum chamber walls typically limits the base pressure.

Non-evaporable getter pumps (NEGs) provide a convenient pumping option for sealed systems because of

low mass and volume, and no power once activated. However, NEGs do not pump inert gases, methane, and some other hydrocarbon gases. For ultra-high vacuum applications, methane can become the single largest unpumped component. Methane collisions with trapped ions (such as  $^{199}\text{Hg}^+$ ) used for frequency standard applications can produce de-coher-

ence and a very large frequency shift, both significant limitations to high-performance frequency standard operation. Therefore, any methane presence, or buildup in the vacuum system over time, can negate the benefit of getter pumping and degrade frequency standard performance.

It is well known that the presence of a hot surface at or above a particular temperature threshold in a vacuum cham-

ber can “crack” residual methane ( $\text{CH}_4$  or other similar hydrocarbons), dissociating it into C and  $\text{H}_2$ . Each of these can be readily removed by a getter pump. This cracking process can occur when methane molecules interact with the hot tungsten filament of an ion gauge (ionization-assisted gettering). In this case, methane molecules are dissociated either via direct interaction with the hot filament or via electron impact.

Thus an ion gauge in conjunction with a NEG can be used to provide a low-mass, low-power method for avoiding the deleterious effects of methane buildup in high-performance frequency standard vacuum systems.

*This work was done by Robert L. Tjoelker and Eric A. Burt of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-46208*