Optical Testing of Retroreflectors for Cryogenic Applications

Commercial uses include cryogenic metrology on aerospace structures and optical metrology instrumentation.

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A laser tracker (LT) is an important coordinate metrology tool that uses laser interferometry to determine precise distances to objects, points, or surfaces defined by an optical reference, such as a retroreflector. A retroreflector is a precision optic consisting of three orthogonal faces that returns an incident laser beam nearly exactly parallel to the incident beam. Commercial retroreflectors are designed for operation at room temperature and are specified by the divergence, or beam deviation, of the returning laser beam, usually a few arcseconds or less. When a retroreflector goes to extreme cold (≈35 K), however, it could be anticipated that the precision alignment between the three faces and the surface figure of each face would be compromised, resulting in wavefront errors and beam divergence, degrading the accuracy of the LT position determination.

Controlled tests must be done beforehand to determine survivability and these LT coordinate errors. Since conventional interferometer systems and laser trackers do not operate in vacuum or at cold temperatures, measurements must be done through a vacuum window, and care must be taken to ensure window-induced errors are negligible, or can be subtracted out. Retroreflector holders must be carefully designed to minimize thermally induced stresses. Changes in the path length and refractive index of the retroreflector have to be considered.

Cryogenic vacuum testing was done on commercial solid glass retroreflectors for use on cryogenic metrology tasks. The capabilities to measure wavefront errors, measure beam deviations, and acquire laser tracker coordinate data were demonstrated. Measurable but relatively small increases in beam deviation were shown, and further tests are planned to make an accurate determination of coordinate errors.

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Measuring Cyclic Error in Laser Heterodyne Interferometers

Amplitude modulation, instead of phase modulation, associated with displacement oscillations is measured.

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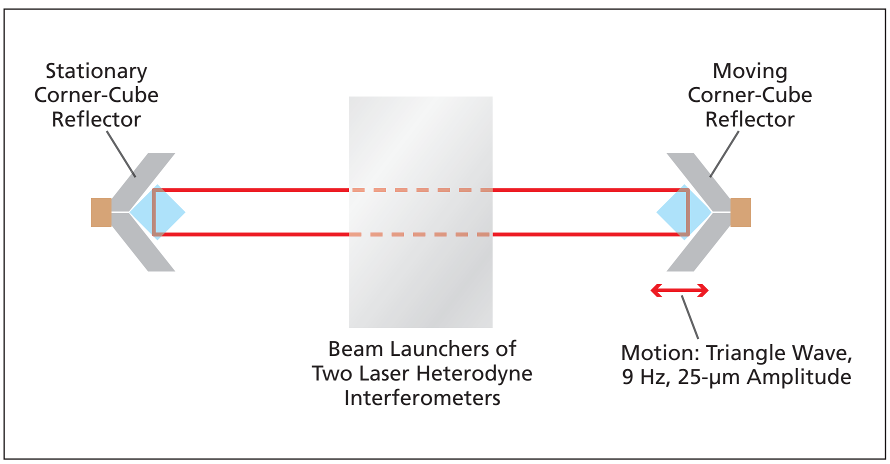
An improved method and apparatus have been devised for measuring cyclic errors in the readouts of laser heterodyne interferometers that are configured and operated as displacement gauges. The cyclic errors arise as a consequence of mixing of spurious optical and electrical signals in beam launchers that are subsystems of such interferometers. The conventional approach to measurement of cyclic error involves phase measurements and yields values precise to within about 10 pm over air optical paths at laser wavelengths in the visible and near infrared. The present approach, which involves amplitude measurements instead of phase measurements, yields values precise to about ≈0.1 pm — about 100 times the precision of the conventional approach.

In a displacement gauge of the type of interest here, the laser heterodyne interferometer is used to measure any change in distance along an optical axis between two corner-cube retroreflectors. One of the corner-cube retroreflectors is mounted on a piezoelectric transducer (see figure), which is used to introduce a low-frequency periodic displacement that can be measured by the gauges. The transducer is excited at a frequency of 9 Hz by a triangular waveform to generate a 9-Hz triangular-wave displacement having an amplitude of 25 μm.

The displacement gives rise to both amplitude and phase modulation of the heterodyne signals in the gauges. The modulation includes cyclic error components, and the magnitude of the cyclic-error component of the phase modulation is what one needs to measure in order to determine the magnitude of the cyclic displacement error. The precision attainable in the conventional (phase measurement) approach to measuring cyclic error is limited because the phase measurements are af-



Displacement Oscillations are introduced between two corner-cube retroreflectors that are common to two displacement gauges. The magnitude of an amplitude modulation in the outputs of the gauges is measured.