

Heterodyne Interferometer Angle Metrology

This technology can be used in optics, semiconductor, and other industries requiring high-precision angle metrology.

NASA's Jet Propulsion Laboratory, Pasadena, California

A compact, high-resolution angle measurement instrument has been developed that is based on a heterodyne interferometer. The common-path heterodyne interferometer metrology is used to measure displacements of a reflective target surface. In the interferometer setup, an optical mask is used to sample the measurement laser beam reflecting back from a target surface. Angular rotations, around two orthogonal axes in a plane perpendicular to the measurement-beam propagation direction, are determined simultaneously from the relative displacement measurement of the target surface. The device is used in a tracking telescope system where pitch and yaw measurements of a flat mirror were simultaneously performed with a sensitivity of 0.1 nrad, per second, and a measuring range of ± 0.15 mrad at a working distance of an order of a meter. The nonlinearity of the device is also measured less than one percent over the measurement range.

Non-contact angular measurements are essential in numerous applications; for example, to monitor angle of mirror in telescopes used in astrometry, to control stages of x-ray interferometer, to measure Newton's constant using torsion balance, and to test equivalence principle using rotating masses. Two main methods used in angle measurements are traditional autocollimator

technique and modern interferometry. Electronic autocollimators use a beam of collimated light on a flat external mirror reflecting the light back in the objective lens. The position of the spot in the focal plane of the lens is then correlated to the angular displacement of the mirror. Ultimate accuracy of the autocollimator is set by the diffraction limit.

A typical commercial autocollimator provides convenient angle measurement with sensitivity of ≈ 0.1 μ rad with a few-centimeter-beam diameter. Another method is the use of Michelson interferometry, an interferometric method of measuring angle by counting change in interference fringe due to the variations of optical path difference (OPD) between reference plate and measurement plate under rotation. The interferometric technique suffers from nonlinearity in the OPD for the case of relatively large angle measurements. However, in small angle range, there are many variations of interferometer techniques developed based on internal reflection effects, fringe analysis, parallel interference pattern, and prism interferometer to achieve requirements for different applications.

In recent years, laser interferometers have been used widely in high-precision displacement measurements over length scales of nanometers to meters. The Michelson interferometry displacement sensor measures the phase of an optical

wave as a measurement reflector is moved and infers the displacement in terms of λ , wavelength of the optical wave. Resolution of the displacement measurement is determined by noise on the optical signal and the instrument resolution of the phase detection. There are two main categories in the Michelson interferometer metrology. The homodyne interferometer (single frequency) using a quadrature detection is used in many applications where subnanometer resolution is not needed. For more accurate measurements with increasing resolution, heterodyne interferometry (two different laser frequencies) has been a widely used tool. One advantage of the heterodyne interferometer is that the phase information is carried on an AC signal rather than a DC signal. This makes it less sensitive to source laser power fluctuations, ambient light, and other slower noise affecting DC measurements. Also, a single detector is needed to measure both the displacement and the direction. By using acousto-optic modulators for heterodyne generation, many groups have achieved subnanometer level accuracy in the displacement measurements.

This work was done by Inseob Hahn, Mark A. Weilert, Xu Wang, and Renaud Goulioud of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-47179