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Ring Laser Angle Encoder

A new angle encoder concept is presented, which would provide continuous digital readout with great precision. It has characteristics particularly applicable to space navigation, space- and ground-based surveying, inertial attitude determination and alignment, antenna or telescope attitude determination, and rotary table precision-angle determination, with improvements of at least an order of magnitude over present techniques. A unique feature is that this encoder measures the angular difference in inertial attitudes of target two at time t_2 relative to target one at time t_1. "Target" means any phenomena which generate or reflect a detectable light beam.

The encoder combines a ring laser, a scanning photometer autocollimator, and an isolation axis with a rate-servo drive. The ring laser is rotated at an approximately constant inertial rate above an inertially fixed axis. The photometer is rigidly fixed to the ring laser body and its optical axis scans in the plane of rotation.

An operational cycle consists of rotating the assembly through 360°. Initially, the plane of the ring laser is oriented to coincide with the angle measurement plane formed by the lines of sight to the two targets. When the first target center is detected, two counts of the ring laser beat are initiated. The first count terminates at detection of the center of the second target. The second count terminates after redetection of the first target after 360° rotation. The ratio of these two counts constitutes a measurement of the angle between the two targets. This operational cycle provides an intrinsic calibration when the first target is inertially stationary or moves in a sufficiently defined manner, eliminating the effect of principle error sources.

A single-mode ring laser establishes a standing optical reference wave around a closed path. Typical node-angular spacing for the equivalent circular ring laser would be of the order of an arc second. Since electromagnetic radiation in empty inertial space is described entirely by Maxwell's equations and boundary conditions, if loss at the boundaries is sufficiently small, the reference wave remains practically stationary in inertial space when the ring is rotated about its axis. Each antinode of the ring laser reference wave is detected by a photosensor and level-detection circuitry and is labelled a beat. Beat count including time interpolation gives rotation-angle digital resolution from 0.1 to 0.001 second.

In practice, nonreciprocal effects result in motion of the reference wave around the optical path. When this motion is proportional to optical cavity rotation rate, the beat counting technique remains accurate. This motion is intrinsic to noncircular geometries. Also, Doppler shifts of the laser optical dispersion with cavity rotation produce this type of reference motion. Dispersion drifts occur with changes in environment temperature and electronic components. The time constants are long compared to the operational cycle, contributing negligible angle measurement errors.

There are nonreciprocal effects independent of rotation rate, e.g., Langmuir flow of the laser gas. Then, the beat counting technique must be supplemented by subtraction of the bias motion. Accuracy is not affected, since the nonreciprocal properties also remain sufficiently constant during the operational cycle.

Even without nonreciprocity the scale factor relating beat count to rotation angle depends on rotation rate. The standing wave, considered resolved into two oppositely-directed traveling waves, experiences backscatter with Doppler shift at mirror imperfections. This mechanism couples the traveling wave modes,

(continued overleaf)

resulting in a hyperbolic functional relation between the beat rate and the rotation rate, with a dead zone below a certain rotation rate. Therefore, beat-count technique accuracy deteriorates with increasing variation of rotation rate about the average rate. Proper use of a ring laser with this nonlinearity dictates minimizing variations about the calibrated rotation rate by sensing ring laser beat-count rate deviation and correcting the rotation rate. Contributions to the measurement error can be made as low as 0.01 arc second. Beat counting and time interpolation logic define the attitude of the photometer relative to the laser reference wave at the coincidences of the optical axis with the two target beams.

Each target beam is transformed by the photometer optics to an image at the photometer focal plane. The optical axis is defined by a slit aperture at the focal plane. The target image position at the aperture is determined by combination of the photodetector and the scanner estimation logic. This photometer optical axis is related to the ring laser plane by the optics mechanical assembly.

The optics mechanical assembly, which transforms the target beams to images at the aperture and relates the image to the laser reference wave, is a critical part of the design. Limitations due to the optical transformation and slit precision and the mechanical rigidity and drift characteristics are analyzed and discussed.

Note:

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Title to this invention has been waived under the provisions of the National Aeronautics and Space Act [42 U.S.C. 2457 (f)], to the Massachusetts Institute of Technology, Cambridge, Massachusetts.

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