Continuous Tuning and Calibration of Vibratory Gyroscopes

Vibrational excitation is periodically switched between orthogonal axes to derive calibration data.

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A method of control and operation of an inertial reference unit (IRU) based on vibratory gyroscopes provides for continuously repeated cycles of tuning and calibration. The method is intended especially for application to an IRU containing vibratory gyroscopes that are integral parts of microelectromechanical systems (MEMS) and that have cloverleaf designs, as described in several previous *NASA Tech Briefs* articles. The method provides for minimization of several measures of spurious gyroscope output, including zero-rate offset (ZRO), angle random walk (ARW), and rate drift. These benefits are afforded both at startup and thereafter during continuing operation, in the presence of unknown rotation rates and changes in temperature.

A vibratory gyroscope contains a precision mechanically resonant structure containing two normal modes of vibration nominally degenerate in frequency and strongly coupled via a Coriolis term. In the case of the cloverleaf design MEMS gyro, these normal modes of vibration are plate rocking modes. The rocking motion of the plate is described by giving two angles, θ_1 and θ_2. A proof mass consisting of a post orthogonal to the plate ensures a high degree of Coriolis coupling of vibratory energy from one mode into the other under inertial rotation. The plate is driven and sensed capacitively across a few-microns-wide gap, and the normal mode frequencies can be tuned electrostatically by DC voltages applied across this gap. In order to sense rotation, the resonator plate is caused to rock in the θ_1 direction, then any small motions in the θ_2 direction are sensed, rebalanced, and interpreted as inertial rotation. In this scenario, the "drive" has been assigned to the θ_1 direction, and the "sense" has been assigned to the θ_2 direction.

The accuracy with which the rate of rotation can be determined depends crucially on the properties of the resonant structure. To minimize ARW error, the normal modes must be very close in frequency. To minimize ZRO, the dampening of the resonator must be very low [high resonance quality factor (high *Q*)] and the dampening axes well matched. To minimize rate drift, the frequencies and *Q*'s must be very stable over time and temperature. It is expensive to attempt to achieve these desired characteristics in the fabrication process, especially in the case of small MEMS structures, and thus one has limited overall sensor performance.

The method herein described, stems from the observation that all of these physical parameters can be distinguished from inertial rate, and thus their errors compensated for, if the assignment of the "drive" and "sense" direction are periodically reversed during operation. First, the "drive" mode is assigned to the θ_1 direction and the frequency of this mode is measured during its rocking. A record of the sensed rate is kept during this time period as well. Second, the "drive" mode is assigned to the θ_2 direction and the frequency in this direction is measured and rate signal collected. The difference between these two frequency values, as well as another signal called the "quadrature," are then fed into two control loops which adjust electrostatic voltages to bring the modal frequencies together. Because the drive direction has been switched by 90°, the dampening induced ZRO in the θ_1 drive case is opposite in sign from the θ_2 drive case. If the gyro is not undergoing changing rotation during these intervals, a simple subtraction is enough to cancel this ZRO error. Under the added assumption of changing inertial rotation during operation, a redundant gyro operating during the time interval between drive direction switching provides enough additional information to cancel the ZRO.

The method is intended to be used in a tetrahedral four-gyroscope IRU. In round-robin fashion, one gyro at a time is chosen to switch its drive direction while the other three are used to keep track of rate changes during this gyro's "down time." In this way, error sources can be continually compensated for even if they include temperature hysteresis or time-dependent ware.

This work was done by Ken Hayworth of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*

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