Missile Laser Gyro Rate Sensor

R. F. Morrison*
Sperry Gyroscope, Great Neck, N.Y.

and

C. B. Strang†
Martin Marietta Aerospace, Orlando, Fla.

I. Introduction

THE laser gyro is becoming widely recognized as the key inertial sensor candidate for many future strapdown guidance and navigation systems. The primary reasons for this posture include: 1) insensitivity to many error sources which are critical to conventional gyros; 2) dynamic range capability estimated to be on the order of 10^7, which is unequaled by any other rate sensor; 3) rapid maturity of high-capacity, small-size digital computer and microprocessor techniques applicable to laser gyro strapdown systems; and 4) low cost of ownership including life, periodic maintenance, and calibration.

II. Missile System Rate Sensor Requirements

The laser gyro is used in the interceptor missile system as a body rotation rate sensor that must function over a wide dynamic range. The missile dynamics establish an angular rate environment requiring gyro operation over a ±1000-deg/sec range. The gyro must be able to survive and operate satisfactorily after application of instantaneous input rates up to 5000 deg/sec.

A three-axis laser gyro sensor now under contract calls for the development of a 7.5-in. perimeter, 1.5-μ three-axis laser gyro and support electronics. The three-axis ring laser gyro (RLG) assembly is comprised of three ring laser gyros whose cavity bores are machined in a common Cer-Vit glass block to achieve maximum alignment stability. The three laser paths are interwoven to minimize configuration volume and to provide a rugged structural design capable of withstanding the very high dynamic environments of acceleration, vibration, and shock.

Current efforts now are being concentrated on technology investigations and the suitability of the laser gyro techniques for application to these rigorous dynamic and nuclear environments. Identification of critical technologies, such as the laser gyro for ballistic missile defense systems, begins with definition of the performance requirements which are given in terms of mission-oriented performance specifications. The system block diagram of the Advanced Interceptor Missile Subsystem (AIMS) guidance system is shown in Fig. 1. The inertial sensors measure missile attitude rate and acceleration changes, the guidance set receives and stores *S*-band radar steering commands, the digital data processor combines the radar and inertial signals to form missile steering control actuator commands. In addition, discrete commands are generated to control the missile functions in time and sequence. The laser gyro specifications developed to meet the systems design goals are shown in Table 1.

Presented at the AIAA Guidance and Control Conference, San Diego, Calif., Aug. 16-18, 1976 (no preprint); submitted Sept. 13, 1976; revision received Dec. 20, 1976.

Index categories: LV/M Guidance; LVM Command and Information Systems.

*Senior Research Section Head.

†Senior Group Engineer.

Table 1 Laser gyro specifications

Input limits	±1000 deg/sec
Overload limits	±5000 deg/sec
Scale factor	
Nominal	193,363 counts/rev
Stability	±0.05%
Linearity	
Low rates	±0.02 deg/sec
High rates	±0.5%
Null offset	0.02 deg/sec
Null offset stability	0.01 deg/sec
Threshold	
Dynamic	0.01 deg/sec
Static	5 deg/sec
Random output error	±10% at 50 deg/sec
Cross coupling	0.2% of input rate
Ready time	1 sec
Acceleration	400 g
Shock	3000g
Vibration	65.5g rms

III. Laser Gyro Rate Sensor Description

The sensor assembly contains three laser gyros machined into a single block of Cer-Vit. The basic gyro features a modular design approach in which the gyro elements are separable assemblies. The gyro triad consists of three identical 7.5-in. perimeter units mounted on a common block, such that the three sensitive axes are mutually orthogonal. This structural approach significantly reduces laser gyro size and makes a more rugged assembly. Volume is reduced as well as cost, since many single-axis assembly parts are eliminated, and assembly operations performed once suffice for three gyros. Improved axis alignment and stability are achieved because a single rigid structure, precisely machined, orients the sensitive axes and guarantees alignment stability. Shock and vibration resistance are enhanced.

Figure 2 is a photograph of the sensor assembly without its case. The basic dimensions of the unit, 4-in. diam by 4½-in. long, translate into a weight of approximately 5 lb. Factory calibration determines a sensitive axis alignment matrix, relative to the reference surfaces, for computer software compensation.

The optical cavity of each gyro is a triangle with mirrors mounted on each corner. Through-holes are bored into the block to form these triangles such that one leg of each gyro is inside one of the other gyros. This "nesting" of the gyro optical paths provides the compactness of this sensor assembly. One leg of each triangle is notched out to facilitate mounting the separable gas discharge tube. Each of three laser gyros is identical as depicted in the optical schematic of Fig. 3.

When the gas discharge tubes are energized, two counterrotating beams traverse the optical cavity. When the op-

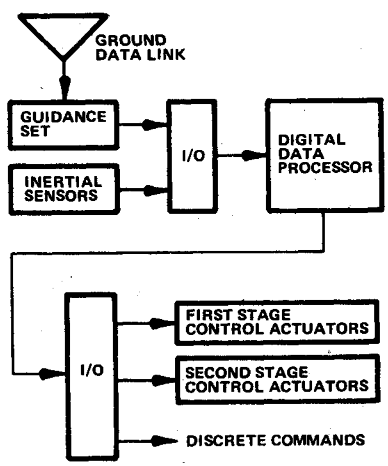

Fig. 1 Digital missile controller set.

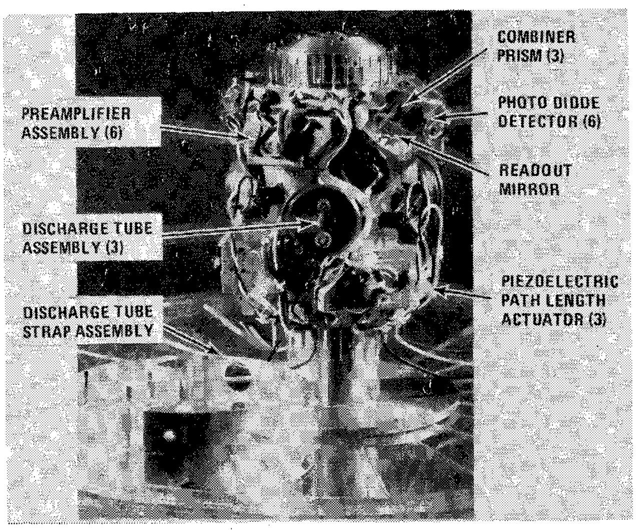

Fig. 2 Laser gyro optical cavity assembly.

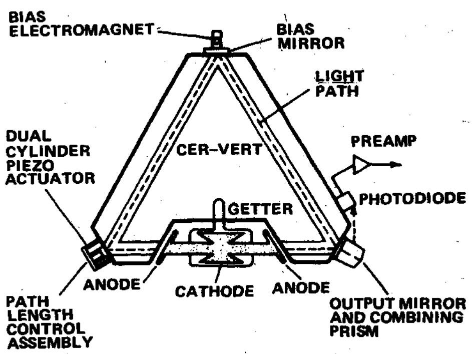

Fig. 3 Laser gyro optical schematic diagram.

tical cavity is not rotating, the clockwise and counterclockwise waves have the same frequency. When the cavity is rotated, one path length is increased and the other decreased, which changes the optical frequencies with the resulting difference between the CW and CCW optical frequencies being proportional to input angular rate. The count resulting from summing this difference frequency is therefore proportional to the total angle through which the gyro has been rotated. Approximately 6.6 arcsec of input angle result in one cycle of output.

Each mirror defining the optical cavity has additional functions. The output mirror is used to extract optical information from the gyro. Its optical coating is designed specifically to transmit approximately 0.5% of the incident light of both the CW and the CCW beams. The beams are internally reflected by the combining prism assembly and are superimposed on an optical coating (beam splitter) which is located on one of the prisms at the interface between the prisms. This coating reflects half and transmits half the incident light, which results in a combined beam consisting of a mixture of the CW and CCW beams.

The combined beam is intercepted by an optical detector that is alternately exposed to the sum of the CW and CCW optical amplitudes when the beams are in phase, and is exposed to approximately zero input when the beams are out of phase. As the beams alternately come into phase at their optical difference frequency, the detector generates an electrical signal having a frequency proportional to input rate. The signal is amplified by a preamplifier.

The perimeter control mirror is used to servo the cavity perimeter, to make it an integral number of the particular wavelengths for which the neon lasing medium has gain. The mirror is mounted on a piezoelectric actuator which alters its length in response to applied voltage. Length control is achieved by oscillating the mirror a small farction of a wavelength and applying a direct voltage to the actuator to eliminate variations in signal level at that alternating frequency. This insures operation at the peak of the gain of the lasing medium.

The third mirror, the bias mirror, is used to introduce an apparent rotation in the gyro to bias the CW and CCW frequencies away from each other. This avoids the output nonlinearity caused by energy coupling between the waves that results in a laser gyro rate threshold.

Vehicle input rotation rate is extracted by processing the gyro output to remove the intentionally applied optical bias. The optical bias polarity is controlled logically to provide the required dynamic range without operating within the lock-in-induced rate threshold nonlinearity band.

The source of gyro gain, the plasma tube, is a glass structure sealed by using glass-to-metal joints and contains a low-pressure mixture of helium and neon gases. The gas mixture is excited by passing an electrical discharge through it, from two anodes to an aluminum cold cathode. At each end of the tube is a metal anode assembly containing an optical window. The glass-metal seal design has exhibited long stable life and is designed structurally to insure compliance with the 3000-g shock load requirements. The laser gyro electronics assembly contains circuitry to provide a signal processor, laser gyro control, and power supply.

IV. Preliminary Test Results

The previously described laser gyro triad has been designed and fabricated for advanced interceptor missile application. The first breadboard laser gyro rate sensor was built and delivered March 16, 1976 for preliminary test and evaluation. Initial tests were performed after which the electronics configuration was modified to provide operation with closed-loop path length control with the optical bias continuously operating. The basic design has an open-loop path length control that allowed the optical perimeter to vary, thereby influencing gyro performance. To extract the maximum performance capability of the gyro, a closed-loop control system was implemented, and the optical bias mechanism was incorporated in the basic design primarily for self-test. That is, a laser gyro configured with an optical bias mechanism functionally can be checked statically by logically controlling the excitation to the bias mechanism. In the interceptor missile application, where the vehicle dynamics have angular rates always in excess of the laser gyro static threshold, an antilock or bias mechanism is not required. However, the existence of the rate threshold caused by the lock-in creates a gyro output nonlinearity that changes scale factor as a function of input rate. To linearize the gyro response, the antilock mechanism forces gyro operation away from the nonlinear region created by the static threshold.

Operation of closed-loop path length control and continuous optical bias was implemented on the first breadboard unit. Tests performed showed significant improvement over operation with the open-loop path length control.

V. Conclusion

Because of its inherent ruggedness, reliability, and low cost, the laser gyro is attractive for many inertial system applications. Improvements in both the sensor and its electronics have been identified and currently are being incorporated in the second breadboard gyro. Continued success in the test of the laser gyro, where performance potential appears to exceed its predicted performance by a considerable margin, will broaden its missile system applicability.