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A Survey on Ring Laser Gyroscope Technology

Ayswarya P R
Department of Electronics and Communication Engineering
Sarabhai Institute of Science and Technology
Vellanad, Trivandrum, India

Pournami S S
Department of Electronics and Communication Engineering
Sarabhai Institute of Science and Technology
Vellanad, Trivandrum, India

Ravi Nambiar, Ph.D.
Dean, Department of Electronics and Communication Engineering
Sarabhai Institute of Science and Technology
Vellanad, Trivandrum, India

ABSTRACT
Ring Laser Gyroscope is a single axis laser gyro angle sensor designed and developed for high accuracy launch vehicle navigation systems. They are well suited for high precision strap down Inertial Navigation Systems (INS) due to very high accuracy, high bias, scale factor stability, low scale factor non-linearity and wide dynamic range. A ring laser gyroscope consists of a ring laser having two counter propagating modes over the same path in order to detect rotation. It operates on the principle of Sagnac effect which shifts the nulls of the internal standing wave pattern in response to angular rotation. The interference between the counter propagating beams, observed externally, reflects shifts in that standing wave pattern, and thus rotation. This paper presents a survey of ring laser gyroscope technology, the factors affecting its performance and techniques to overcome the limitations of lock-in effect.

General Terms
RLG, INS, CW, CCW

Keywords
Strap down, Rotation rate, Dither, Lock-in, Beat frequency

1. INTRODUCTION
The term navigation represents the information needed in air, land, space and in ocean regarding the position and direction. The word 'navigation' is originates from the Sanskrit word 'Navgathi' which indicates 'to move or direct'. The techniques for navigation include locating the position, compared to know the locations, the direction and the distance travelled. Development of radio, radar, inertial and satellite navigation systems occurred in the modern phase.

Usually the navigation systems are used for determining position, velocity and direction relative to some reference co-ordinate frame. All navigation systems include requirement of choosing a reference co-ordinate frame as the common aspect. In a three- dimensional system, all these frames are orthogonal and also right handed. Another important orthogonal frame of reference is known as Earth Central Inertial (ECI). The term 'inertial frame' refers to a frame that is non-inertial and non-accelerating in inertial space [11].

An inertial navigation is a navigation aid that uses a computer, motion sensors and rotation sensors to continuously calculate via dead reckoning the position, orientation and velocity of a moving object without the need for external references. It is used on vehicles such as ships, aircrafts, submarines, guided missiles and spacecraft. By processing signals from such devices, tracking of position and orientation of a device is possible.

1.1 Gyroscope
A gyroscope is a device for measuring or maintaining orientation, based on principles of angular momentum. The applications of gyroscopes include inertial navigation systems where magnetic compasses would not work or with low precision. Due to high precision of gyroscopes, they are used in gyro theodolites to maintain direction in tunnel mining [10].

In the past, the basic approach in designing a gyroscope includes a spinning mass mounted on stable element, so that gyroscope was fixed in inertial space and through use of gimbals isolated from the vehicle motion[12]. With advent of lase, a physical mechanism is developed to allow laser to sense rotation. The rotation sensing is possible in the frame of lase, which allows the device to be measured directly to the vehicle and avoiding the need of gimbals. In this type, laser was introduced within a closed contour for the cavity. This is described as a ring laser gyro or simply, RLG. It works on the principle of Sagnac effect.

1.2 Sagnac Effect
In a Sagnac interferometer, two oppositely directed beams, i.e. clockwise (CW) and counter (CCW), arising from same source propagate inside the interferometer along same closed path [6]. At its output, the CW and CCW waves interfere to produce a fringe pattern which shifts if a rotation is applied along an axis perpendicular to the plane of beam path. The two CW and CCW beams undergo a relative phase difference proportional to the rotation rate Ω. With respect to inertial space, the two counter- propagating light waves take different times to complete a trip around a rotating closed path. Thus difference in optical path occurs which is indicated by the fringe pattern due to interference of two beams.

1.3 Ring Laser Gyroscope
Ring Laser Gyroscope is a gyroscope in which Sagnac effect is used to measure the angular rate [6]. During any movement of the aircraft, or on other vehicle it is mounted on, the angular rate is measured by determining the frequency shift in the beams. The RLG became the first optical device for inertial guidance use. Even though currently RLG remains very large and heavy, they are proven to have more accuracy than traditional rotating mechanical gyroscope. Ring laser gyroscopes contain optical elements such as He-Ne laser light, having wavelength 632.8 nm, which was split into two different but identical optical paths set by mirrors and combined to produce an interference pattern.

2. KEY DEFINITIONS
Strap down navigation: It is called so because the sensors are strapped onto the vehicle itself thus reducing the cost and increasing reliability [2].

Dither: It is the intentionally applies form of noise used to randomize quantization error preventing large scale patterns.

Rotation rate: It is rate of rotation sensed by the ring laser gyroscope.

Scale factor: It is the ratio of $4A/L\lambda$, which is directly proportional to beat frequency.

Beat frequency: It is defined as the difference in frequency between the two counter propagating beams of ring laser gyroscope.

Lock-in: It is the region in input-output characteristics of RLG where sensed output is zero for low input rates.

3. WORKING OF RLG

The RLG combines functions of optical frequency generation and rotation sensing into a laser oscillator within a ring shaped cavity [12]. The ring laser gyroscope consists of a solid block, either square or triangular, of glass ceramic material into which a lasing medium is introduced as shown in fig.1. The electrodes provide gain for the lasing medium. The lasing medium is generally a Helium- Neon mixture due to its short coherent length and refractive index nearly 1.0. This generates two independent beams in opposite directions around the cavity. For the optical path to support lasing there must be an integral number of wavelengths, around the path and oscillation will occur at that frequency 'f', which meets this requirement. The cavity size is adjusted to support oscillation at frequencies optimal to the lasing media. This difference in frequency between the two travelling waves is called beat frequency, Δf.

$$\Delta f = 4A\Omega/L\lambda \quad (1)$$

where, A is area of ring cavity, L is path length of laser light, λ is wavelength of light in lasing medium and Ω is angular rate of rotation. The ratio $4A/L\lambda$ is known as scale factor of gyro. Beat frequency is directly proportional to rate of rotation Ω.

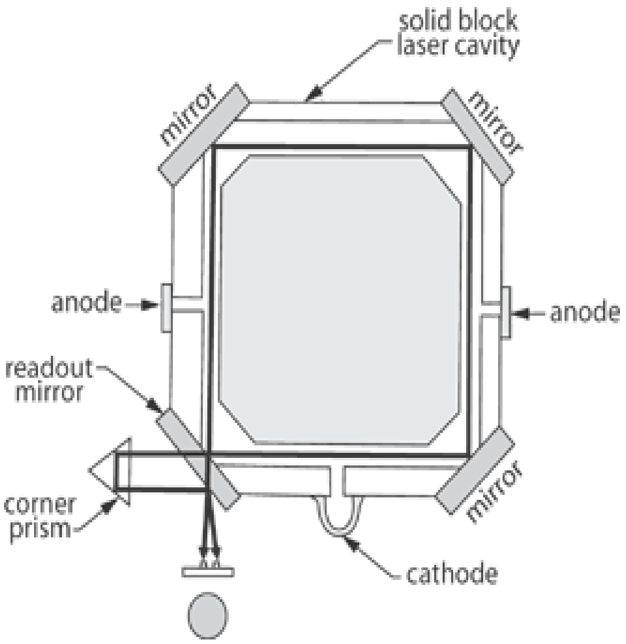

Fig.1: Ring laser gyroscope

The output of ring laser gyroscope is developed by use of a combining prism which produces two nearly collinear beams interfering to create fringe patterns sensed by the photo detectors. The number of beats during a time interval is directly proportional to the rotation rate and the direction of fringe movement indicates the rotational direction.

4. REQUIREMENTS FOR GENERATING TWO BEAMS

In RLG, no external source is required for generating two beams. The CW and CCW laser beams are generated inside the resonator if two conditions are satisfied [7].

1) The number of wavelengths in the cavity must be equal to an integer.
2) The gain of amplifying medium must exceed cavity losses.

5. ADVANTAGES OF RLG

The RLG provides digital output linear with angular rotation. It has high sensitivity and stability. The reaction time to respond to rotation rate is quick. The ring laser gyroscopes are insensitive to acceleration and immune to environmental effects [7].

6. LIMITATIONS

The existing cavity geometries and precision mirrors required for RLG construction and the necessity of assembly under stringent clean room conditions increase its cost. The size and weight of RLG are other limiting factors. The main limitation of RLG rotation sensing is due to its lock-in effect.

7. LOCK-IN EFFECT

At low rotation rates, difference in frequency between the two light beams causes injection locking. Injection locking occurs when two waves with close frequencies become almost identical.

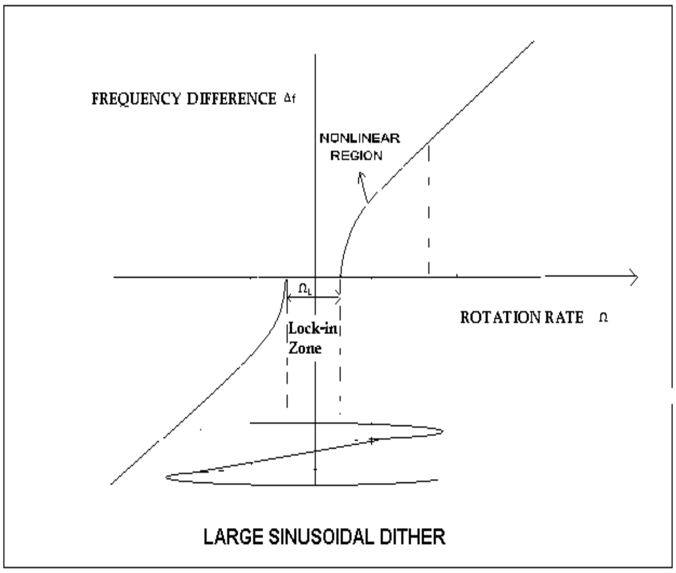

Fig.2: Input- Output characteristics of RLG showing lock-in zone

The region of input-output characteristics of RLG, where sensed output is zero for low input rates is called lock-in zone. The input-output characteristics of ring laser gyroscope is shown in fig.2.

The typical lock-in rate of an RLG can be around or more than 360000 deg/hr. This means that within this value RLG will not be able to detect angular rate. Beyond this lock-in rate and up to lock-in region, the scale factor become highly nonlinear. The possible reason for these lock-in phenomena is due to back scattering of laser beam from mirrors.

8. TECHNIQUES TO AVOID LOCK-IN

The elimination of lock-in can be done by implementing mechanical dithering [1]. Mechanical dither is given by rapidly moving the gyro through the lock-in region. Thus the time constant of the system would keep the gyro from getting locked. The common scheme uses sinusoidal motion about the gyro input axis with amplitude more than lock-in band. This makes the gyro to remain out of lock-in condition. The method of providing sinusoidal dither to overcome lock-in condition is shown in fig.3.

9. CONTROL LOOPS FOR RLG

There are four control loops required for the smooth functioning of Ring laser gyroscope. They are:

a) Dither amplitude control loop

b) Dither frequency control loop

c) High frequency oscillator

d) Path length control

Of these, High frequency oscillator and path length control loop are realized within RLG and Dither control loop outside RLG

The RLG has to be excited with a dither signal at a particular frequency and amplitude to bias the RLG outside the lock-in region. The dither amplitude loop maintains the amplitude of dither wave provided for preventing lock-in of RLG. The frequency loop maintains the frequency of dither.

The two basic requirements for the functioning of ring laser gyro are:

1) A gain mechanism must be there to compensate for the losses in the cavity

2) The frequency of operation so that the number of wavelengths in the cavity must be equal to an integer.

The first requirement is met by the high frequency oscillator and the second by the path length control loop.

The high frequency oscillator loop is used to pump the electrons and ions to the higher energy state by imparting RF energy to them. It maintains the optimum power level required for the excitation of He-Ne medium for maintaining laser beam in the cavity.

The temperature variations due to self-heating of block or external disturbances try to disrupt the path length-wavelength relationship. The path length of the RLG varies with respect to the refractive index of optical components due to temperature change

10. CONCLUSION

This survey deals with the working of ring laser gyroscopes, its advantages and limitations. The various loops for controlling the working of ring laser gyroscope are mentioned. These loops help in making the gyroscope sense in lock-in region. Thus enabling better rotation sensing. The analysis of RLG shows that pure sinusoidal dither results in lock-in zone at zero rates and also near multiples of dither frequencies. This phenomenon is called dynamic lock-in. It can be avoided by adding a random component to dither. This can be done as a futurescope. Thus by using random noise added to dither, the ring laser gyroscope sensing can be highly improved [1].

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