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A Review on Gyroscope Technology

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Abstract: Gyroscopes are used in instruments such as compasses and automatic pilots on board ships and aircraft, in torpedo steering mechanisms, in large-scale anti-rolling equipment and inertial guidance systems. This paper is an overview of current gyroscopes, based on their applications, and their roles. The gyroscopes under consideration include mechanical gyroscopes and macro- and micro-scale optical gyroscopes. In particular, commercially available gyroscope technologies such as Mechanical Gyroscopes, MEMS Silicon Gyroscopes, Ring Laser Gyroscopes (RLGs), and Fiber-Optic Gyroscopes (FOGs) are discussed. The main features of these gyroscopes are related to their performance and their technologies. Some of the more well-known automotive applications like vehicle stability control, navigation assist, and roll over detection are only used in high-end cars, where costs are not a major factor. Examples of consumer applications include 3D input devices, robotics, stable platforms, camcorder stabilization, virtual reality and more.. Most of these applications have not reached any significant volume, due primarily to cost and size. This paper provides a top-level review of different vibrating mass gyroscopes and examines the top commercially available gyroscopes in the technology.

Keywords: MEMS gyroscopes, Mechanical gyroscopes, Optical gyroscopes

INTRODUCTION

The term "gyroscope," conventionally referred to as the mechanical gyroscope class, derives from the ancient Greek language, being the "precession movement" physics, a phenomenon also observed in ancient Greek society.

Gyroscopes[1] are devices mounted on a frame and capable of sensing an angular velocity when the frame rotates. There are many classes of gyroscopes, depending on the physical operating principle and the technology involved. Gyroscopes, such as Gyrocompass, Inertial Measurement Unit, Inertial Navigation System, and Attitude Heading Reference System, can be used alone or included in more complex systems. Mechanical gyroscopes in particular; Optical gyroscopes, including Fiber Optic Gyroscopes (FOGs) and Ring Laser Gyroscopes (RLG); and Micro-electromechanical System (MEMS)[2] gyroscopes were considered with a focus on operating principles and various performance improvements in commercial architectures.

The major problems for all classes of gyroscopes, being angular velocity sensors, are related to the errors in measuring angular velocity. For this reason the stability of the scale-factor is one of the most important figures of merit. Scale factor represents the sensitivity of the optical gyroscope, whereas the accuracy of the gyroscopes is inversely proportional to the sensitivity and takes account of the noise-related measurement errors; Can be expressed by the resolution, R, or, in the RLGs, by the Angle Random Walk (ARW), connecting R to the bandwidth, B, of the measuring system by ARW = R/ [60sqrt(B)]. Minimum stability of the scale-factor results in small sensor errors and requires better instruments and better accuracy, resulting in higher system costs.

Mechanical gyroscopes, classified as displacement gyroscopes and gyroscopes, have been the historical gyroscopes since the 19th century, consisting of a toroid rotor rotating around its axis. Since the 20th century, optical gyroscopes have been operating by sensing the difference in time of propagation between counter-propagating laser beams traveling in opposite directions on a closed or open optical path. IFOG and RLG are the main diffused types of optical gyroscopes which both exploit the Sagnac effect physics. The ring laser gyroscope is currently more diffused and has the larger market share for applications which require very high performance.

Gyroscopes of the micro-electro-mechanical system (MEMS) are motion sensors which detect and measure the angular motion of an object. They measure an object's rate of rotation around a given axis: 1-axis, 2-axis and 3-axis. Using Ring Laser Gyroscopes (RLGs) and mechanical gyroscopes, MEMS and optical gyroscopes, in particular Interferometric[3] Fiber-Optic gyroscopes (IFOG), replace many current systems. However, applications requiring extremely high-scale factor stability only with RLG continue to be achieved among the optical gyroscopes. Stability of the scale factor (i.e., the gyroscope's accuracy in monitoring the sensed angular velocity), expressed in parts per million (ppm), Bias stability function (a parameter inherently dependent on gyroscope technology) is reported. Stability of the scale depends. A wide range of applications are considered for gyroscope technology (i.e., Mechanical, RLG, IFOG, Quartz, Dynamically Tuned Gyroscopes (DTG), Rate and Integrate Gyroscopes, and MEMS) and performance in terms of Scale Factor stability v/s bias stability.

Better performance, such as the highest costs and the smallest volume of production, are related to gyroscope technologies located at the left-bottom corner, whereas the lowest performance, such as the lowest costs and the highest volume of production; Including consumer electronics applications are placed at the top right corner of. In this review, we cover the more diffused and commercial gyroscope technologies (i.e., Mechanical, RLG, IFOG and MEMS) with the relative applications reported in the following figure.

GRYROSCOPES

1. Mechanical Gyroscope:

A mechanical gyroscope consists essentially of a spinning mass which rotates around its axis. Specifically, when the mass rotates on its axis, it tends to stay parallel to itself and oppose any attempt to change its direction. Physicist Léon Foucault invented this mechanism during his studies of Earth's rotation in 1852If a gyroscope is installed on gimbals allowing the mass to navigate freely in the three directions of space, its spinning axis will remain oriented in the same direction, even though it may change direction.

A mechanical gyroscope displays a number of physical phenomena including precession and nutation. The main operating principles of the mechanical gyroscopes, with reference to the inertial navigation systems, are reported in the following sections.

1.1 Principle of Mechanical Gyroscopes: Gyroscopic Effects:

The basic effect on which a gyroscope relies is that an isolated spinning mass tends to maintain its angular position in relation to an inertial reference frame and when a constant external torque (a constant angular velocity, respectively) is applied to the mass, Its axis of rotation undergoes a precession movement at a constant angular velocity (respectively with a constant output torque), in a direction normal to the direction of the torque applied (respectively to the constant angular velocity). The angular position of the rotation axis is not affected by external forces acting on the center of mass of the rotating part. The simplified equations governing the physical phenomenon referred to in Fig.1 are:

$$C_y = -I\Omega W_z$$

$$C_z = -I\Omega W_y$$

Where C_y and C_z, respectively, are the torques acting along y and z axis; I is the polar mass moment of inertia of the spinning mass; W is the angular velocity of the spinning mass along the rotation axis; and W_y and W_z are the precession velocities along y and z axis, respectively. The output torque is proportional to the inertia and the rotational speed of the spinning mass due to an imposed precession motion.

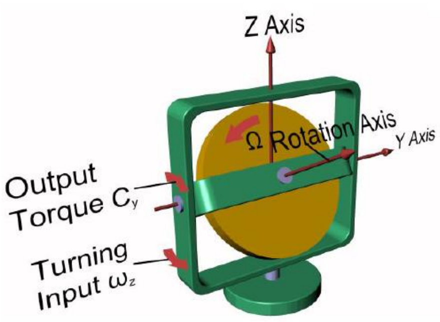

Fig.1:Elements of a Mechanical Gyroscope and Main Parameters

2. Optical Gyroscopes:

By sensing the difference in propagation time between counter-propagating beams traveling in opposite directions in closed or open optical paths, optical gyroscopes operate. A change of the path lengths induced by rotation generates a phase difference between the counter-propagating light beams. Physically this phase difference induced by rotation consists of the Sagnac effect, which is the basic operating principle of all optical gyroscopes.

The optical gyroscopes can be classified based on the Sagnac effect[4] measurement technique. The two principal types of optical gyroscopes[5] are active and passive architectures (see Fig. 2). The closed-loop optical path (i.e., the ring cavity) in the active configurations contains the optical source, forming a ring laser[6]. The active configurations can be built in Bulk Optics or in Integrated Optics technology, although commercial maturity has only been achieved with the Bulk Optics solutions.

There are different categories among the Ring Laser gyros depending on the method used to overcome the lock-in effect (i.e., a condition for which the active gyroscope response results in sensitivity to low rotational rates) that occurs at low rotational rates (tens of degrees / hour). By introducing a mechanical dither, a magneto-optic bias, or using multiple optical frequency configurations, lock-in can be reduced. In contrast, in passive architectures, as in the Interferometric Fiber Optic Gyroscope, the optical source is external to the closed optical loop (i.e. a fiber coil). The more diffused optical gyroscope technology is the ring laser gyroscopes and interferometric fiber optic gyroscopes, whose features differ in size, weight, power requirements, performance and cost.

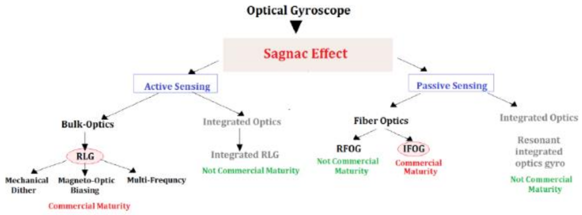

Fig.2: Classes of Optical Gyroscope

3. *MEMS Gryroscope:*

MEMS gyroscopes[7] generally use a mechanical vibrating element as a sensing element for the angular velocity detection. They do not have rotating parts requiring bearings and this allows for easy miniaturization and the use of MEMS-typical fabrication[8] techniques. All MEMS vibrating-element gyroscopes are based on the energy transfer between two vibration modes caused by Coriolis acceleration.

The Coriolis acceleration is an apparent acceleration that is observed in a rotating reference frame, proportional to the angular velocity[9]. We may consider a particle of mass m moving in space with a velocity v (See Fig. 3) to better understand the concept.

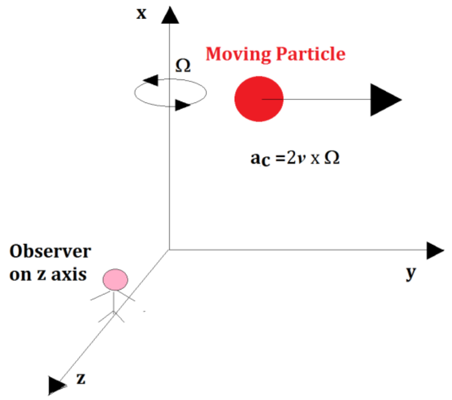

Fig.3: Coriolis Acceleration (a_c) Acting on a Moving Particle

Once fixed to the reference system as shown in Fig.3, if it is rotating with an angular velocity $\Omega = \Omega_x i$(with i the unitary vector along the x axis) around the x axis, an observer, solidly anchored to the z axis, sees the particle moving along the z axis with a Coriolis acceleration equal to $a_c = 2v \times \Omega$, although a real force is not applied along the z axis. This is the key physical principle of the vibrating mass MEMS gyroscope device, described like a mass-spring system[10] (see Fig. 4).

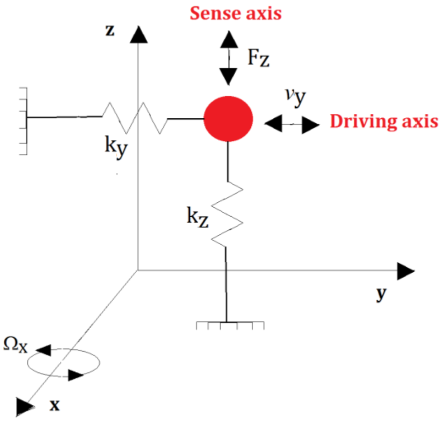

Fig.4: Mass Spring Model of a MEMS Gyroscope

KEY GYRO PERFORMANCE FACTORS

In this section, five critical parameters for consumer grade gyros will be overviewed:

1. Angle Random Walk (ARW):

There is always a wideband white noise element in the output of a gyro. Angle Random Walk describes the error that arises from this noise element and can be assessed using the Allan Variance technique. The gyro's active elements are the major contributors to random noise (laser diode and photo diode for optical gyroscopes and vibrating beam and MEMS electronics detection). Noise is one of the most significant differences between the optical and MEMS gyro performance, resulting in different measurement precision and accuracy.

2. Bias Offset Error:

The gyro output could be nonzero if input rotation is null. The detected rotation of the equivalent input is the Bias Offset Error. For an ideal environment it's typically given at 25 0C. Fixed errors, such as Bias Offset Error, are easy to fix.

3. Bias Instability:

Bias Instability is the bias offset's unstable at any constant temperature and ideal environment. It is measurable using the Allan Variance technique Bias instability introduces errors that might be difficult to calibrate. Its influence on longer measurement periods is greater, thus Bias Instability is one of the most critical factors in the gyro selection process for applications requiring excellent long-term accuracy.

4. Temperature Sensitivity:

The performance of the gyro changes over temperature. To verify that gyro performance meets system targets, a characterization of parameters such as noise, bias offset and scale factor over temperature is necessary.

5. Shock and Vibration Sensitivity:

Noise and bias offset of gyros under vibration and shock input also degrade. In many military and industrial applications vibration performance is critical because of the presence of numerous factors, such as engines or gunfire.

CONCLUSION

They reported on the currently more diffused gyroscope technologies in this review. The gyroscopes under consideration include mechanical gyroscopes and macro- and micro-scale optical gyroscopes. Gyroscope is the next Sensor industry killer application. In the automotive, consumer, industrial, medical, and military markets, there are many mature applications already developed and produced in limited volumes. Many high volume applications, exceeding 100 million per annum, are waiting for a low cost gyroscope to be available Gyroscope products of today are not designed to address the growing demand for costs, creating an opportunity for the new generation of gyroscopes. The new generation designs are designed to take advantage of the gyroscope industry's latest developments.

REFERENCES

[1] K. Liu *et al.*, “The development of micro-gyroscope technology,” *Journal of Micromechanics and Microengineering*. 2009, doi: 10.1088/0960-1317/19/11/113001.

[2] A. C. Fischer *et al.*, “Integrating MEMS and ICs,” *Microsystems and Nanoengineering*. 2015, doi: 10.1038/micronano.2015.5.

[3] B. H. Lee *et al.*, “Interferometric fiber optic sensors,” *Sensors*. 2012, doi: 10.3390/s120302467.

[4] A. Tartaglia and M. L. Ruggiero, “The Sagnac effect and pure geometry,” *Am. J. Phys.*, 2015, doi: 10.1119/1.4904319.

[5] M. N. Armenise, C. Ciminelli, F. Dell’Olio, and V. M. N. Passaro, *Advances in gyroscope technologies*. 2010.

[6] W. Bogaerts *et al.*, “Silicon microring resonators,” *Laser and Photonics Reviews*. 2012, doi: 10.1002/lpor.201100017.

[7] D. Xia, C. Yu, and L. Kong, “The development of micromachined gyroscope structure and circuitry technology,” *Sensors (Switzerland)*. 2014, doi: 10.3390/s140101394.

[8] S. Franssila, *Introduction to Microfabrication*. 2010.

[9] M. Boyle, “The Integration of Angular Velocity,” *Adv. Appl. Clifford Algebr.*, 2017, doi: 10.1007/s00006-017-0793-z.

[10] H. Herrmann and H. Bucksch, “mass-spring system,” in *Dictionary Geotechnical*

Engineering/Wörterbuch GeoTechnik, 2014.

[11] Vishal Jain, Mahesh Kumar Madan, "Information Retrieval through Multi-Agent System with Data Mining in Cloud Computing", International Journal of Computer Technology and Applications (IJCTA) Volume 3 Issue 1, January-February 2012, page no. 62-66, having ISSN 2229-6093 .

[12] Vishal Jain, Mahesh Kumar Madan, "Multi Agent Driven Data Mining for Knowledge Discovery in Cloud Computing", International Journal of Computer Science & Information Technology Research Excellence Vol. 2, Issue 1, Jan-Feb 2012, page no. 65-69, having ISSN 2250-2734.

[13] Kavita Arora, Dr. Kavita, Dr. Vishal Jain. (2020). A Study On Attacks In Mobile Ad-Hoc Networks. International Journal of Advanced Science and Technology, 29(8s), 279 - 289. Retrieved from http://sersc.org/journals/index.php/IJAST/article/view/10502

[14] J Ganeshkumar, N Rajesh, J Elavarasan, M Sarmila, S Balamurugan, "A Survey on Decentralized Access Control Strategies for Data Stored in Clouds", International Journal of Innovative Research in Computer and Communication Engineering, 2015

[15] J Ganeshkumar, N Rajesh, J Elavarasan, M Sarmila, S Balamurugan, "Investigations on Decentralized Access Control Strategies for Anonymous Authentication of Data Stored In Clouds", International Journal of Innovative Research in Computer and Communication Engineering, 2015

[16] VM Prabhakaran, S Balamurugan, S Charanyaa, "Sequence Flow Modelling for Efficient Protection of Personal Health Records (PHRs) in Cloud", International Journal of Innovative Research in Computer and Communication Engineering, 2015