MECHANICAL AND OPTICAL LASER GYROS

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COMPARISON OF MECHANICAL AND OPTICAL LASER GYROS

This subsection briefly discusses the gyroscope, or gyro, the rotational-motion inertial sensor. There are two main branches of gyroscope design: mechanical gyros that operate using the inertial properties of matter, and optical gyros that operate using the inertial properties of light. Mechanical gyros, at present, are more commonly available for the types of applications discussed in this paper. Optical gyros are typically more expensive than mechanical gyros and are currently developed primarily for navigational applications.

Original gyro designs, called gimballed systems, were based on the preservation of rotational momentum and consisted of a spinning disk or rotor connected to the moving body of interest by low-friction gimbals. When the body underwent rotation, the spinning rotor maintained its original orientation (preserving its angular momentum). Today's mechanical gyroscope designs are more commonly of the vibrating type. Instead of using angular momentum to sense when they rotate. This is accomplished by establishing an oscillatory motion orthogonal to the input axis in a sensing element within the gyro. When the sensor is rotated about its input axis, the vibrating element experiences Coriolis forces in a direction tangential to the rotation (orthogonal to the vibratory and rotating axes).

The double tuning fork gyro (Figure 1.) is a popular vibrating gyro design. This sensor two pairs of tines, with each pair having the same orientation. The double tines are made to oscillate antiphase, which yields no net motion but provides a varying radius about the input axis. When a tuning fork gyro is made to rotate about its input axis, its tines undergo sinusoidally varying Coriolis forces in the direction normal to the driven motion of the tines. When the tines are subjected to these Coriolis forces, they oscillate in the same direction as the forces. These oscillations are detected by the sensing elements of the gyro. Tuning fork gyros may use piezoelectric, piezo resistive, magnetic, or other types of sensing elements.

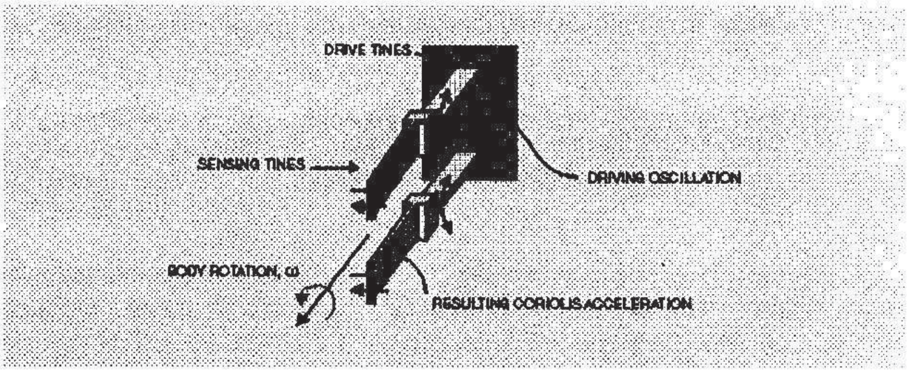


Figure 1.
A tuning fork gyro

A gyro design using principles similar to the tuning fork design is a vibrating gyro whose cross section is an equilateral triangle. Murata Electronics Corporation's vibrating gyroscope, the Gyrostar[1], employs this design.

Figure 2. shows cross-sectional views of the gyro while at rest and while rotating. This design uses three piezoelectric ceramic elements, one attached to each outer wall. One driving element, C, is made to oscillate and the two other, A and B, act as sensors. The output signal of this device is the difference between A's signal and B's signal.

$$output(t) = a(t) - b(t)$$

[1] Trademark or registered trademark of Murata Electronics Corporation

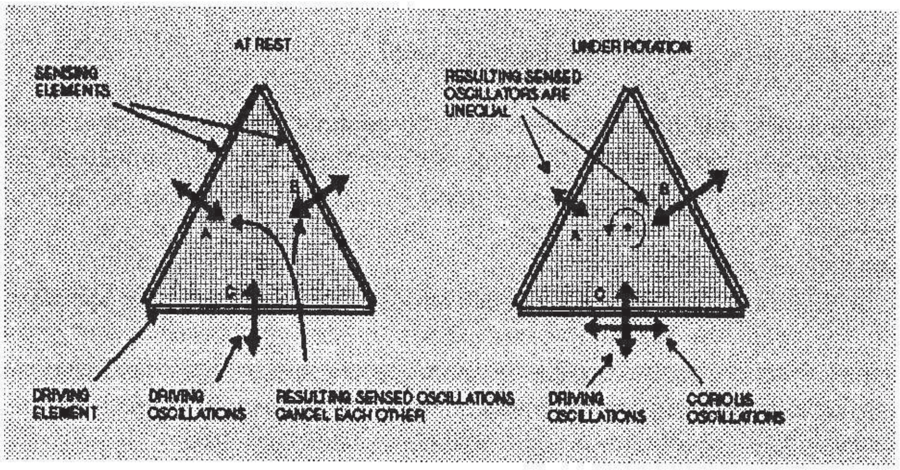


Figure 2.
Murata's Gyrostar

When the gyro is at rest, the signals at A and B are equal, and therefore there is zero output, but under rotation, C experiences Coriolis forces, and there is a sinusoidally varying difference between A and B whose amplitude is proportional to the rotation rate.[7]

In addition to vibrational gyros, the main gyroscopes operate based on "The Sagnac Effect". These sensors use two light waves, travelling in opposite directions around a fixed path. When the device is rotated, the light wave travelling against the direction of rotation will complete a revolution faster than the light wave travelling with the rotation. This effect is detected by means of the phase difference in the two light waves. The ring laser gyro (RLG), zero lock-ring laser gyro (ZLG), and the interferometric fiber optical gyro (IFOG) are the main types of optical gyros currently being developed.

A BRIEF HISTORY OF RING LASER GYROS.

In the early days of lasers, it was predicted that when two laser beams are made to oscillate in the same optical cavity that encloses an area (a triangle, a square), such that they propagate in opposite directions around the periphery, their frequencies would differ slightly if such a cavity would rotate around an axis normal to the cavity plane. Such a cavity is called a ring laser. (In a linear laser with a cavity made of two opposing mirrors, any effect of the rotation would not be visible.)

What is the physics behind the ring laser gyro?

The Sagnac effect in a ring laser is the frequency difference that aries between counterrotating modes when the whole system is rotating. The co-rotating mode shifts to the red, the counterrotating mode to the blue. Measuring the frequency difference gives the rotation rate. The frequency difference is also the beat frequency.[1, 4, 5, 10]

Or said in another way, a ring laser senses any nonreciprocity in the effective path length of the couter-rotating beams, induced for example by absolute rotation. The two modes consist of one clockwise and counter-clockwise mode wich form a standing wave pattern, with (in the Canterbury ring Figure 3) approximately 11 million nodes and antinodes, inside the cavity.

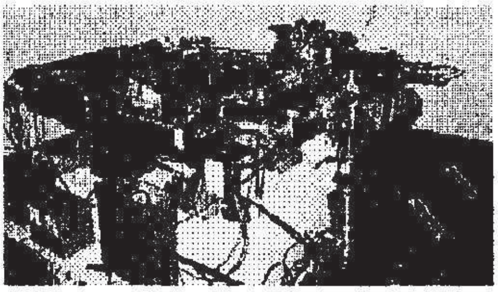
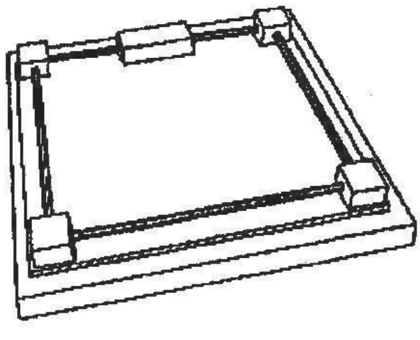


Figure 3.
The Canterbury I ring laser (C I).

Its area is 0.7547 square meter, the perimeter is 3.477 meter, the mounting base of Zerodur is 1 meter x 1 meter x 0.025 meter, the granite slab underneath is about 300 kg. [6, 10]



The idea of a ring laser was put to the test by W. Macek of Sperry-Rand in 1963. Their square ring demonstrated the Sagnac frequency splitting, but only after additional rotation beyond what is called the lock-in frequency. The two beams that were supposed to show a frequency difference of some tens of Hertz due to the earth's rotation, synchronised instead. The lock-in frequency is the rotational frequency at which you start to see the Sagnac effect.

The potential of such ring lasers to measure rotation was seized, and the (ring) laser gyro industry soon produced viable inertial navigation instruments. Typically, they have perimeters of the order of one-half to three decimetres. All work with the Helium-Neon gas mixture as an amplifying medium at the vacuum wavelength of 633.0 nanometer, and the amplifying plasma is dc-excited [3, 5].

The Ring Laser Gyro (RLG) can be used as the stable elements (for one degree of freedom each) in an inertial guidance system. The advantage of using a RLG is that there are no moving parts. Compared to the conventional spinning gyro, this means there is no friction, which in turn means there will be no inherent drift terms. Additionally, the entire unit is compact, lightweight and virtually indestructible, meaning it can be used in aircraft.[2, 9]

Some examples of commercially available optical gyros are Hitachi's IFOG models HGA-V and HGA-D. Compared with the vibrational gyros mentioned above, these IFOGs are fairly large and expensive, but they exhibit superior bias stabilities (see Table 1.)[7, 8].

Make/ Model	**Type**	**Input Range (deg/s)**	**3dB Bandwidth (Hz)**	**Output Noise 12Hz (deg/s)**	**Bias Stability**	**Price Range ($U.S.)**	**Size (in)**
Murata Gyrostar	vibrating piezoelectric	0 to ±90	0 to 7	0.45	0.9deg/10min	80-300	0.8x0.3x0.3
Systron Donner GyroChip II.	double tuning fork	0 to ±100	0 to 50	0.17	0.05deg/sec	1000	2.7x1x0.75
Watson Industrial ARS-C132-1A	tuning fork	0 to ±100	0 to 50	0.05	10deg/sec	700-800	2x3x1
Hitachi HGA-V	IFOG	0 to ±60	not available	not available	5.0deg/$\sqrt{hr}$	1500	3x3x1
Hitachi HGA-D	IFOG	0 to ±60	not available	not available	1.3deg/$\sqrt{hr}$	1250	6.7x4.7x2

Table 1.
Summary of selected gyroscopes

CONCLUSIONS

What is the promise behind optical gyros as opposed to mechanical gyros?

They promised to be less expensive and more accurate than mechanical gyros, as the basic limitation to laser gyro sensitivity is the quantum noise of the beams. They also did not show a variety of drawbacks of mechanical gyros, mainly due to the fact that no mechanical rotating parts are involved in ring lasers.

They have a very high resolution. We can measure to within milliseconds in the length of the day. This is beyond the capability of mechanical gyros.

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