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Department of Electronics and Communication Engineering

Course Activity Report on

Construction and Application of Gyroscope in Aviation

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Introduction:

Gyroscopes are used in various applications to either measure the rate of rotation about a defined axis or measure the angle turned. Traditional gimballed gyroscopes use the inertial properties of a spinning wheel and can only measure rate of rotation about one axis. Two or three of these must be employed if rotations about two or three orthogonal axes are to be sensed. Vibrating gyroscopes are another class of gyro, which offer important advantages over the gimballed design. They offer the possibility of sensing rotation about more than one axis, are generally smaller, require less power and the bearings and drive motor required in the gimballed design are removed in the vibrating gyro. With one exception the vibrating gyroscope has not been developed to inertial performance and its use has been limited to rate of turn applications. Forms of vibrating gyroscopes include BAe's Vibrating Structure Gyroscope (VSG) [1] which uses a piezo-ceramic cylinder as the sensing element and Delco's Hemispherical Resonator Gyroscope (HRG) [15], which uses a fused silica hemispherical shell as the sensing element and is electrostatically actuated and sensed. In both of these single axis devices the modes of vibrations used to detect the rate of turn via Coriolis coupling share the same natural frequency thus enabling amplitude multiplication to improve sensitivity. The HRG has achieved inertial navigation performance. The recent development of MEMS technology has enabled the size of the vibrating gyroscope to be very much reduced and a number of designs have been manufactured by this technology. Typical examples include the single axis Micromachined Angular Rate Sensor (MARS-RR) manufactured by HSG-IMIT [14], the vibrating nickel ring gyroscope of General Motors (again a single axis device) [11], and the silicon ring gyroscope of British Aerospace [16]. The first two of these examples use capacitive methods for actuation and sensing while the third uses electromagnetic methods. Other similar designs are referenced in [17] and it is shown that tuning of the modes of the gyroscope, to improve sensitivity, has so far been limited to "ring type" designs. Juneau, et al. [18], has shown that two-axis designs are possible. In this work it is shown that the ring form of gyroscope is capable of being further developed to a rate sensor that can measure rates of turn about three orthogonal axes. The equations of motion of the device are derived using a Lagrangian method and the response to applied rate is calculated. It is shown how maximum sensitivity can be achieved by tuning those natural frequencies of the ring associated with rate measurement. The issues associated with the tuning of the natural frequencies of the ring are discussed.

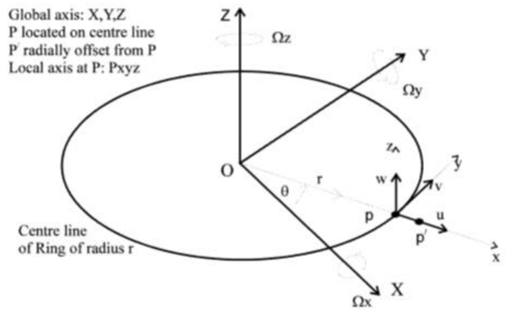


Fig. 2. Coordinate system.

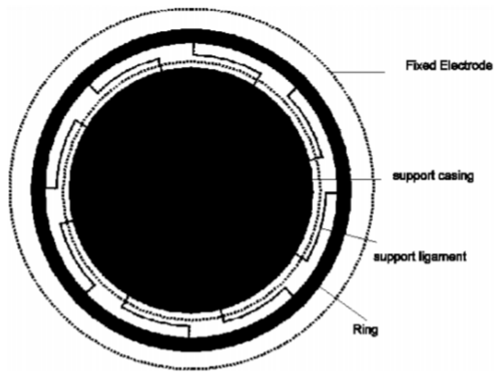


Fig. 1. Basic form of gyroscope.

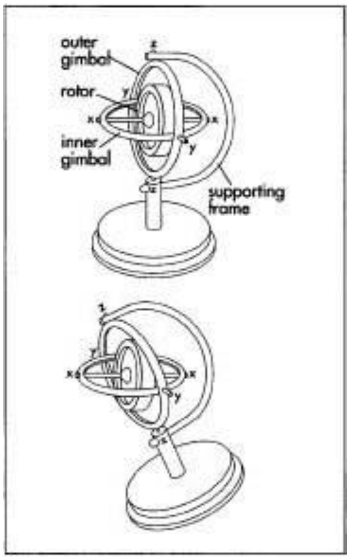
BASIC CONSTRUCTION:

Using the electrical and mechanical aspects of gyroscopic theory as their guides, engineers choose a wheel design for the gimbals and select metal stock appropriate for the design. The designs for many uses of gyroscopes are fairly standard; that is, redesign or design of a new line is a matter of adapting an existing design to a new use rather than creating a new product from the most basic beginning. Design does, however, involve observing the most fundamental engineering practices. Tolerances, clearances, and electronic applications are very precise. For example, design of the gimbal wheels and design of the machining for them has a very small tolerance for error; the cross section of a gimbal must be uniform throughout or the gyroscope will be out of balance.

Process:

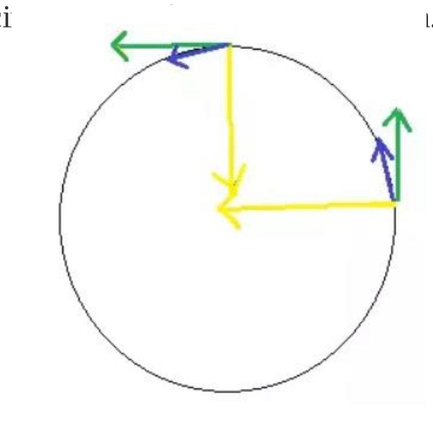
- The gimbals and gimbal frames are machined from aluminum bar stock using tools developed as part of the design process. They are polished and cleaned and stored in bins until assembly. For assembly, the bins are moved to appropriate locations along the assembly line.
- Gyroscopes are manufactured in a straight-forward assembly line process that emphasizes the importance of "touch labor" over automation. Gyroscopes are assembled from the inside out. The motor is the heart of the gyroscope and is installed first. A "typical" gyroscope motor is synchronized to spin at 24,000 revolutions per minute (rpm). It must be perfectly synchronized, and the motor is typically bench-tested before assembly. Electrical connections are added to the motor.
- The gimbals and frames are assembled next, beginning with the inner gimbal and ending with the outer gimbal frame. Bearings are put into place. The "end play" of the bearings (the looseness of fit) typically has a very small tolerance of 0.0002-0.0008 in (0.006-0.024 mm).

- The outermost electrical connections are attached on the assembly line, and circuit cards are added. Finally, the gyroscope is calibrated at the end of the assembly process. The suspension of the bearings and calibration are hand checked; manufacturers have found that, for even calibration, human observation, testing, and correction are more trustworthy than automated methods.



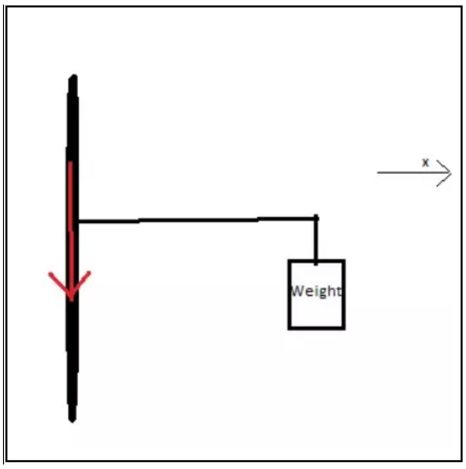
BASIC PRINCIPLE OF A GYROSCOPE:

Gyroscopic principle is just the tendency of angular momentum to go where the torque is. It follows the torque. Sounds easy enough, right? But sometimes it might be a little non-intuitive. So here goes the explanation:
It would help us a great deal to think about the 2 dimensional case first. Let's consider a body going along a ci l.

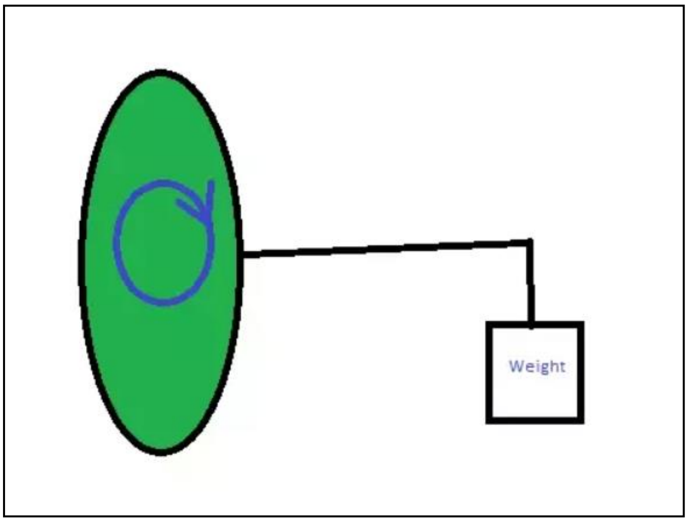


At each point, the velocity is tangential while the centripetal force is along the radius perpendicular to the velocity. At the rightmost point, the body's tangential velocity is along the green line. However the acceleration is along the yellow line. This acceleration wants to increase the body's velocity in its own direction. Since it is perpendicular to the tangential velocity, thus it cannot change it directly. So what does the body do? It takes the middle road. It goes slightly towards the center while continuing to go where the tangential velocity is taking it. It thus follows the resultant blue line. At every point on the circle, the same story repeats and we see the body moving along the circle.

But what does it have to do with a gyroscope? Gyroscope is in some ways the 3 dimensional analog of this. Now consider a rotor rotating in the anti-clockwise direction seen edge on as shown in the figure by a red arrow. We can call the direction of its angular momentum as the **x** direction. Apply some torque on the rotor using the weights as in the picture. The weights will constitute a torque on the rotor in the direction which is into the page which we may call the **z** direction. The torque is perpendicular to the angular momentum.



Now, this angular momentum is just like the tangential velocity while the torque plays the role of centripetal force. Torque wants the angular momentum to increase in its own direction while the initial angular momentum wants to persist as it is. What does the rotor do? It takes the middle road again. It tries to follow the torque while trying to continue to rotate as it is. The rotor now swivels and tries to orient itself towards the torque axis as shown in the figure below. In its new position, the torque is again perpendicular to the angular momentum. The same thing happens again and it keeps swiveling so that its axis of rotation itself rotates. The rotation of the axis as you can see is in the **x-z** plane and can be said to be in the **y** direction.



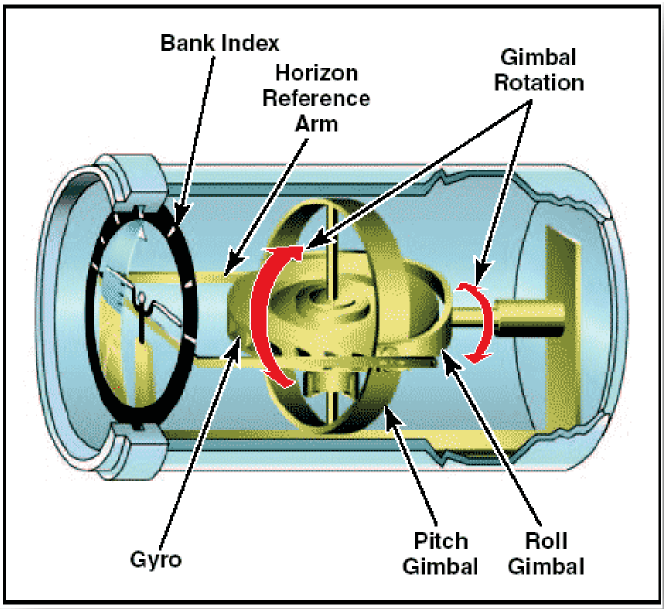
The rotor keeps swiveling. This rotation of the axis is what is known as precession. The angular momentum keeps following the torque and thus its rotational axis precesses. This is the gyroscopic principle.

APPLICATION OF GYROSCOPE IN AVIATION:

Gyros offer two properties that aircraft exploit: **Rigidity in space** (a gyro will resist any attempt to displace it along the axis that it spins), and **precession** (a force applied to a gyro perpendicular to the axis of rotation will manifest itself 90° further along the axis of rotation). Any IFR-capable aircraft has three gyroscopic instruments -- a vacuum gyro, powered by an engine-driven vacuum pump, and two electric gyros.

The vacuum gyro functions whenever the engine is running and generating sufficient power as to create enough suction to spin the gyro. It powers what is considered the most critical gyro instrument, the **altitude indicator**:

The altitude indicator substitutes for the pilot's view of the horizon during poor visibility, and is the primary instrument the pilot references during instrument flight. For that reason, the attitude indicator must be able to continue to function even during an electrical failure.



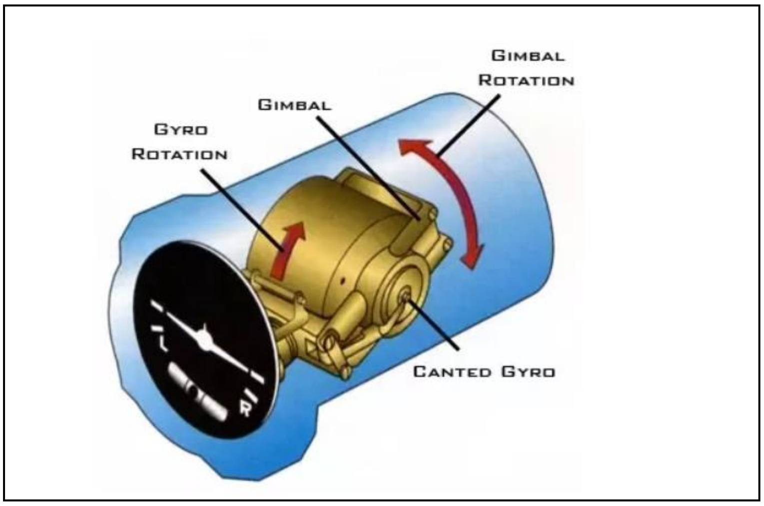
The attitude indicator works by exploiting rigidity in space. The gyro in the attitude indicator remains level with the horizon even as the airplane banks and pitches around it, and is attached to two gimbals that control the height and bank of the index.

The most critical electric-powered gyro instrument is the **turn coordinator**, which gives the pilot rate of turn information.

The icon of the airplane provides bank and rate of turn information. At the onset of the turn, the airplane icon directly indicates bank. Once the turn is established, it indicates rate of turn. There are hatch marks at level and 2-minute turn (3°/second), a so-called "standard rate turn." All turns in instrument flying must be standard rate.
As you can see, the words "D.C. ELEC." on the turn coordinator are a reminder that this is an electrically-powered gyro instrument.

This is the second most critical gyro instrument, because in the event of a vacuum pump failure (and thus attitude indicator failure), this instrument can be used in conjunction with the altitude indicator to maintain straight and level flight.

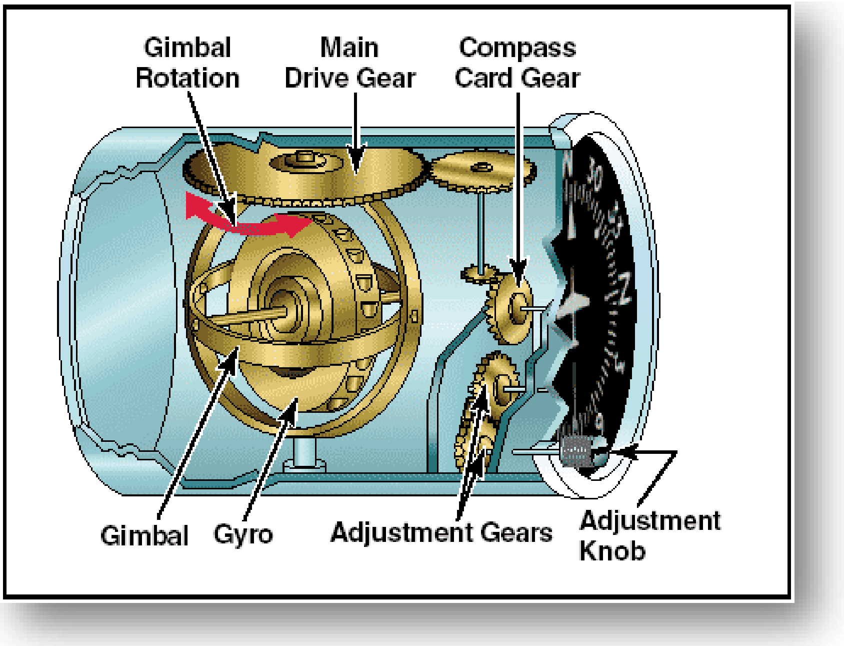
The enclosed ball beneath the airplane icon is the slip indicator. It functions exactly like a leveler, and indicates any side-loading during the turn. The pilot strives to keep the ball centered at all times.



The turn coordinator works by exploiting precession. As the aircraft turns, a force is applied to the gyro, which via precession translates to a perpendicular force applied on the gimbal, causing the airplane icon to bank. If the gyro were flush with the longitudinal axis of the airplane, it would purely indicate rate of turn. By canting the gyro slightly, you allow it to provide bank information at the start of the turn, because now banking the aircraft no longer purely rotates the gyro perpendicular to its axis of rotation.

The final electrical gyro instrument is the **heading indicator**, which displays the aircraft's heading.

This instrument displays the current magnetic heading in degrees. However, because a gyro only offers rigidity, and not any sort of sensitivity to magnetic fields, the heading indicator must be calibrated against the magnetic compass; otherwise it will simply display an arbitrary heading.



The directional gyro exploits the principle of rigidity in space. As the aircraft rotates around the gyro, the gimbal drives a gearing system that turns the compass card. Precession will cause the instrument to become steadily more inaccurate, so pilots must remember to re-calibrate the heading indicator against the magnetic compass every 15 minutes or so. (Some advanced heading indicators can be automatically slaved to the magnetic compass.)

Despite these downsides, heading indicators are still considered the primary source of heading information (rather than the magnetic compass), due to the fact that they remain accurate in banks, during acceleration, and rough maneuvering — all of which cause a magnetic compass to be inaccurate.

Gyroscope in drone- A **gyroscope** measures the rate of rotation and helps keep the **drone** balanced. **Gyroscopes** are devices that consist of a mounted wheel that spins on an axis that is free to move in any direction. They're used to provide stability or maintain a reference direction

Reference

- IEEE Paper- **Principles of a three-axis vibrating gyroscope**
- Quora- Application in Aviation
- www.madehow.com