Gyroscope

Parts List:

- Base Bearing
- Cradle
- Handle
- Instructions
- Pull String
- Rocker
- Rotor Assembly
- Weight Set

Introduction:

The gyroscope demonstrates the principles of precession, gyroscope compass operation, inertial guidance and gyroscopic stabilization. It is good for demonstrating the phenomenon of an even angular velocity in which a massive rim minimizes the acceleration produced by various torques because the moment of inertia has been raised to a maximum. The distribution of mass rather than the mass itself is significant.

A gyroscope consists of a rotor, spinning at several thousand revolutions per minute, mounted in a "gimbal ring" sup-ported in turn by various "gimbal cradles" appropriate for its function. The spinning rotor has two interrelated properties:

High Inertia:

It is difficult to rotate the spinning rotor about any axis other than its spin axis..

Perpendicular Axes:

To cause rotation about one axis requires a torque about a different axis perpendicular to both rotation and spin axes.

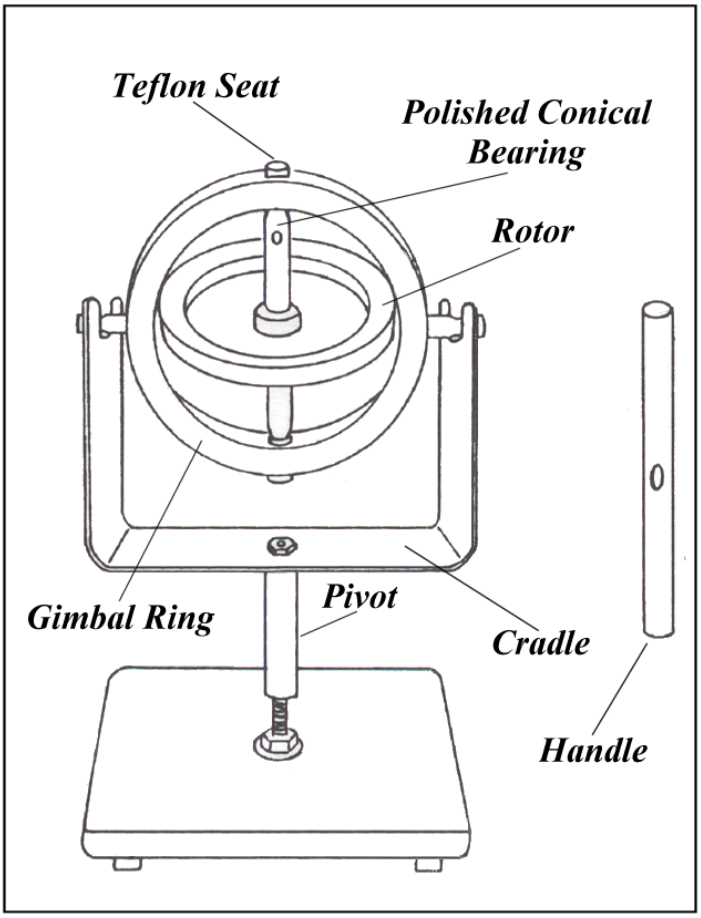
Care of the Gyroscope:

The Gyroscope is a precision instrument, so please insure to follow these instructions.

1. Do not drop gyroscope. Bearing surfaces have been polished to reduce friction. Damage to these surfaces causes imbalance and vibration. This results in rapid wear and short running time.

2. Do not attempt to balance on a pivot or string. The gyroscope may fall, resulting in permanent damage.

3. Keep bearings lubricated with a few drops of light machine oil at least once a year.



How To Spin Gyroscope:

1. Pass about one inch of the pull string through the hole in the rotor-shaft. Turn the rotor so the string winds smoothly onto the shaft, keeping the string away from the bearings.

2. In like fashion, wind the free end of the string a few turns onto the handle. A void knots which weaken the string.

3. Grasp gimbal ring firmly in one hand and pull handle with other. Practice pulling steadily and straight so that the string does not chafe on the rotor. You get best results by positioning the gyro-scope so that the side with the hole points upward. Pull string slightly upward from the horizontal. Your rotor will spin up to five min-utes if the shaft remains horizontal. How-ever, friction increases with the torque required to turn the spin axis or if the shaft is vertical. This results in shorter times during demonstrations. The reduced running time is not due to "energy extracted from the spinning rotor to power the gyroscope" as may be thought. Ideally, the torque and rotation axes are perpendicular to each other with no energy transfer with the rotor.

How To Teach with Gyroscope

Concepts:

Principle of function of gyroscope. Pivot, gimbal ring, rotor, gimbal cradles, axes of rotation and spin. Rotational Inertia (Moment of Inertia) of bodies; relation to their mass distribution. Angular velocity; angular acceleration; Torque.

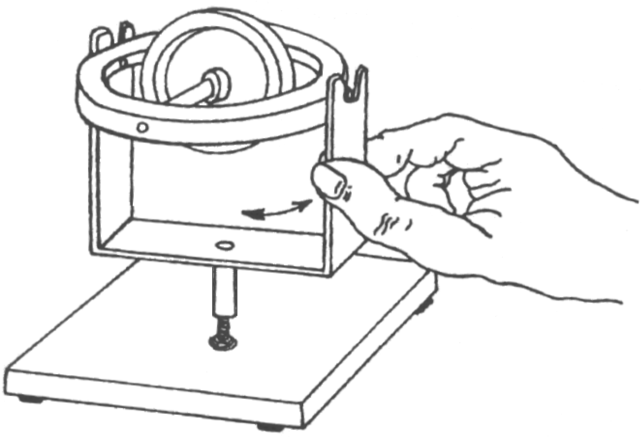
Curriculum Fit:

Motion and Force. Equilibrium, simple machines and stability. Causes of Motion - Newton's First and Second Laws.

Demonstrations:

High Inertia:

Place gyroscope (not spinning) in the pivoted cradle as shown in the next Figure. Make sure rotor shaft is horizontal. By hand, gently turn pivoted cradle about its vertical axis. Observe how easily it responds Now spin rotor and repeat your motion. This time you will find the cradle much more difficult to rotate even. though there is no external interference. Why? Because the inertia has been increased. **Try it with your eyes shut!**



Perpendicular torque and rotation axes:

Follow the procedure described above. Note that, although your hand is applying a torque about a vertical axis, the resultant rotation of the rotor and gimbal cradle is about the horizontal axis. Once the rotor shaft reaches the vertical direction, however, the spin axis and torque axis are the same. There is no longer a discrepancy between direction of torque and rotation.

Variations:

These demonstrations are good for an individual "hands-on" experience. **To demonstrate to a group**, hang a weight on the gimbal ring near a rotor bearing. Gravity acts on the weight so that the stationary gyroscope rotates easily about the horizontal axis.

Now spin the gyroscope and observe the effect. The gyroscope no longer rotates easily because inertia has increased.

As the spinning gyroscope rotates (or **precesses**) about the vertical axis, it demonstrates the phenomenon of **perpendicular axes**. Observe rate and direction of precession for different weights and spin. Have your group record and graph.

Another variation is to **place a loose weight on the rim** to cause precession. Stop the precession by placing an obstacle in the cradle's path. The gyroscope instantly rotates about the horizontal axis and tips the weight off!

At first this seems to contradict both principles of inertia and perpendicular axes. The answer is that the obstacle is applying a large torque to the cradle about a vertical axis. This causes the resulting rotation about the horizontal.

Applications

Passive Direction Indicator:

If a spinning rotor is mounted freely by means of the gimbal cradle (in an *airplane*, for instance), the high inertia will keep the **spin axis pointing on one direction** even though the airplane turns. The gyroscope thereby acts as a compass. If the spin axis is initially set to point North, the compass action can be demonstrated by holding the base horizontal while you walk carrying the gyroscope. Note that even with the rotor stopped, some compass action occurs over small angles. If you continue to turn in one direction, the initial direction is lost.

The gyroscope does not find North automatically as does a magnetic compass. Even the gyroscopic (directional) gyroscope in a small aircraft must be set to North by referring to a magnetic compass. Periodic resetting is needed because these compasses tend to drift. Such drifting is due to imperfections in their bearings and drive mechanisms, as well as the fact that the compass' horizontal plane rotates in space, reacting to the Earth's spin on its own axis.

The "ultimate compass" - high quality gyroscopes - take advantage of this fact to find the Earth's rotational axis.

Two mechanisms keep practical gyroscopes, such as those in planes, spinning: **electric motors** or the **force of air** rushing in to replace air which has been pumped out as, for instance, in an aircraft engine. Aircraft usually have a second gyroscope as well one with its spin axis initially set to vertical. This second gyro-scope acts as an altitude indicator. It tells if the airplane is pitching (pointing its nose up or down) or rolling (pointing the right wing up or down.)

To demonstrate this, hold the normally horizontal base of the gyroscope at the vertical.
Make slight pitching and rolling movements.

Two rotors with their axes perpendicular to each other in the same gimbal show all possible forms of rotation. They even demonstrate part of an inertial guidance system where the spin axis of one rotor is perpendicular to the other.

Computerized guidance systems use a more sophisticated approach than allowing the spin axis to stay fixed in space. They apply sufficient torque about the appropriate axes to align the spin axis to align with the vehicle which carries it. In this case the vehicle is most likely an aircraft or missile. As the vehicle turns, the spin axis of the gyroscope no longer matches up. The computer measures the torque required to turn the spin axis to align once again with the direction of the vehicle.

In this way the computer "knows" the rate of turn and can compute changes indirection - all with the advantage of needing no external references. A computerized inertial guidance system is therefore completely self-contained yet can measure minute changes in direction. The gyroscope used to detect the rate of turn is known as a "rate gyroscope."

Passive Stabilizers:

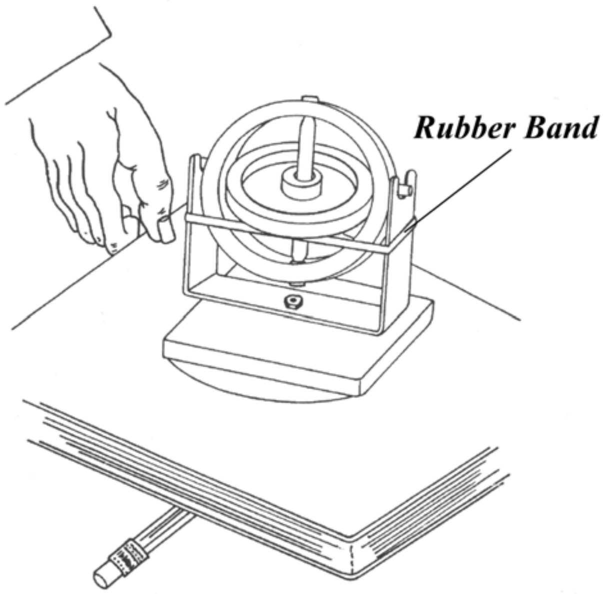
Passive stabilizers, in the form of large rotors, mounted in a ship or pace satellite, help prevent rolling. They are in direct opposition to a fly wheel, for instance, that is used to store energy from regenerative braking in a bus. Here, the axis should be vertical or the buss cannot steer!

Demonstrate roll stability by placing the gyroscope on the rocker cradle (as shown in Figure (top right) Omit the rubber band.) The rocker cradles function as the cross-section of a boat, while the book beneath simulates the waves. Rock the book and observe the behaviour of the "boat", first with gyroscope spinning, then with it still.

When the rotor spins, the "boat" remains level even though the book is at an incline. Under these conditions, gravity exerts a torque on the "boat" - and therefore on the gyroscope itself. This results in a **precession of the gyroscope**, with precession defined as ***a rotation, about the mounting axis of the gimbal***. Obviously, the gyroscope cannot hold the "boat" at a level position indefinitely. The precession will eventually bring the spin axis to a horizontal plane, at which point stability is lost.

Stability can be maintained, however, if the book ("waves") rocks back and forth in less time than it takes to precess to the horizontal position. In the real world, ocean waves may be too long to satisfy this requirement, in which case stability will be lost.

Position a **strong elastic band** in such a way that precession is prevented. (This is similar to preventing the precession by attaching an obstacle in the form of a weight to the gimbal ring.) The elastic band exerts a torque on the gyroscope causing it and the "boat" to rock in relation to the "waves" - just as the weight tips off the gimbal ring earlier.



The elastic band prevents the precession to the horizontal at the expense of the roll stability. It also consolidates pitch and roll movements with the result that the boat rocks in the forward direction with unfortunate effects on the passengers! You can demonstrate this by turning the pencil (shown in Figure 3) to lie across (perpendicular to) the "boat's" course (its direction.)

Tip the boat forward the observe the roll which results.

These effects can be compromised by using a very weak elastic band which serves to stabilize the system under severe wave conditions. At the same time it prevents the excessive precession which could result under conditions of high amplitude "waves" of long duration.

Similarly, a second gyroscope set at right angles to the first gyroscope can be used to stabilize pitch movements.

Active Devices:

Active devices are those that take advantage of axes of the gyroscope. An example is the monorail, which is stable in pitch (end pointed up or down) but not in roll (motion side to side.)

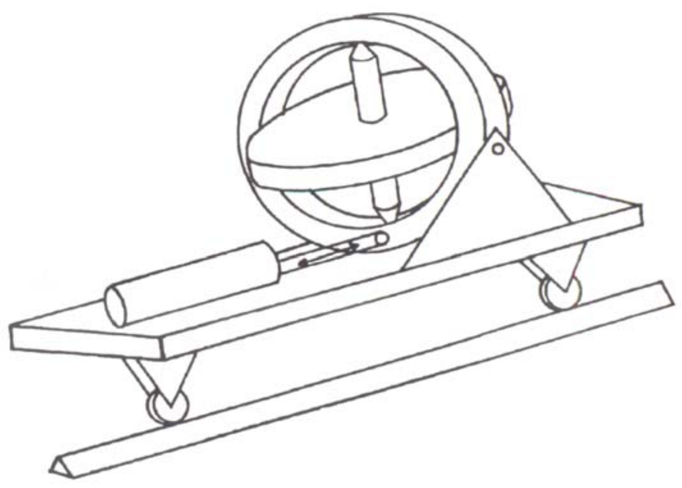
Next figure illustrates another application in the form of a vehicle driven by a hydraulic piston.

A large gyroscope is mounted with its spin axis in the vertical position.

The hydraulic piston acts along the direction of the vehicle without affecting the pitch due to the stability provided by the rail. As the piston turns the gyro-scope, the gyroscope exerts a torque on the vehicle, which rolls to either side.

This rolling motion can be used to balance the vehicle or bank it in either direction where cutting comers, for in-stance, is desired.

Similar devices are used in icebreaker ships to cause the rocking motion that cuts the ice.



Theory

Newton's Law of Motion explains howa gyroscope works. Newton's Law states that the *force required to change the motion of a body is determined by the rate of change of the body's momentum,* where **momentum** is defined as *the mass (m) multiplied by the velocity (v).* For a body of fixed mass, therefore, the force is given by mass multiplied the **rate of change of velocity**.

Ideally you can analyse a gyroscope by imagining a rotor made up of a large number of small pieces ("bodies ") to each of which Newton's Laws should be applied. To simplify, however, it's easier to study qualitatively four representative pieces. These pieces, labelled **A, B, C** and **D**, are equally spaced around the rim of the rotor. Figure 5 depicts the rotor with pieces **A, B, C**, and **D** located at positions so labelled.

Imagine that a fraction of a second following the time at which the rotor attains the position depicted in Figure 5, the spinning rotor tilts about the X horizontal axis in such a way that the pieces are again located at positions **A, B C, D** etc... What forces were applied to bring this about?

According to Newton's Laws, **velocity** has both magnitude (i.e. speed) and direction. It takes a large force to change the direction of a fast-moving object. This is so even though its speed may be constant. In the case of the spinning gyroscope, the speeds are constant but some directions are changing.

Velocities are indicated by arrows (to show direction of motion) in the next Figure. The velocities of **B** and **D** are essentially unchanged, since both are merely displaced on going from 1 to 2. According to Newton's Law, no force was required.

Piece C, in contrast, underwent a downward (negative Z) change in velocity, consequently requiring a downward force at that point on the rim.

These two forces - upward at **A** and downward at **C** - constitute a torque around the Y (vertical) axis. Thus a torque about Y is necessary for a rotor with spin axis Z to rotate about an axis X. (Previously demonstrated under **Perpendicular Axes**.) The directions involved may be checked in group demonstrations. The faster the spin of the rotor, the higher the torque that is required to change its direction.

Conversely, where the amount of torque is fixed - as in the case of a weight applied to the rim - the slower the spin of the rotor becomes, the faster the precession that results.

A quantitative analysis of all parts of the rotor verify these conclusions, giving rise to mathematical expressions including vector calculus and the relation of torque to spin rate, rotation rate and rotor shape.

The velocities of each piece of rotor change in direction only. These forces do not work in the rotor since they are perpendicular to the direction of motion. As a result the spin rotational energy does not change during rotation.