Gyroscopic System: 3/28/2019

Laboratory Report

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Submission Date: 4/6/19

AMME2500

ENGINEERING DYNAMICS

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Gyroscopic Systems Lab

AMME2500 Experiment Report

Introduction

A gyroscope is a device that is freely spinning body rotating about its axis and this system itself is rotating around another axis. This rotating axis is called the precession.

Aim

To study a simple gyroscopic system consisting of a flywheel rotating at a high velocity counter balanced by a weight. To obtain some insight into the two modes of motion of a gyroscope which are precession and nutation. To measure the processing angular velocity and to compare with theoretical prediction.

Theory

The condition of steady precession is defined by:

$$M_x = I_{zz}\omega_s\omega_p$$

where, I_{zz} is the moment of inertia about the z axis of the flywheel, ω_s is the spinning angular velocity and ω_p is the precessing angular velocity.

The turning flywheel has a directional angular momentum about its axis. This can be defined using the right-hand rule. When the pivot point of the flywheel rod is adjusted a net moment is created about this point due to gravity. The change in direction of the angular velocity causes the rotation of the flywheel due to the sum of moments acting perpendicular to the angular velocity.

The moment about the x-axis is defined by:

$$M_x = -WL$$

where, W is the total weight of the system, and L is the distance from the pivotal point to the centre of mass. The negative displays the counter-clockwise moment is positive, along the positive x-axis.

Therefore, the precessing angular velocity is:

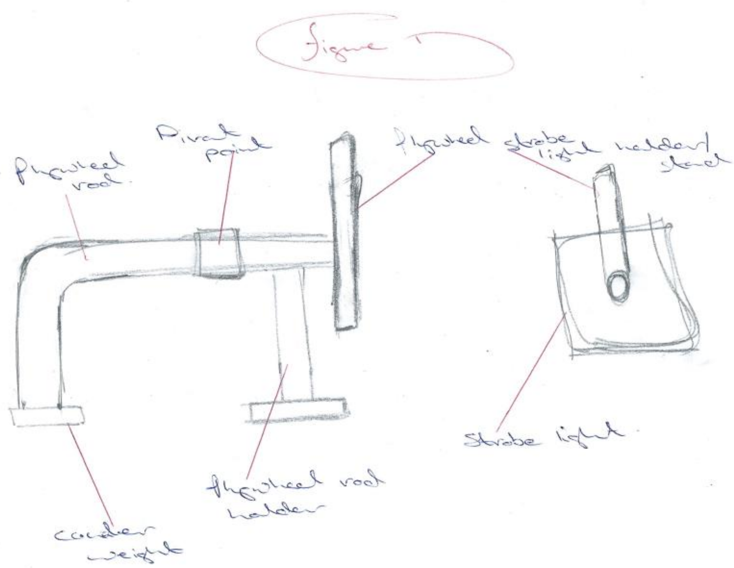
$$\omega_p = -\frac{WL}{I_{zz}\omega_s}$$

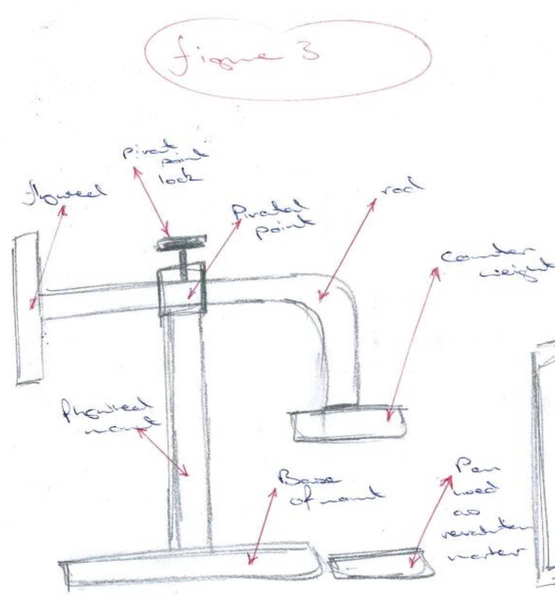
(Meriam & Kraige, 2012)

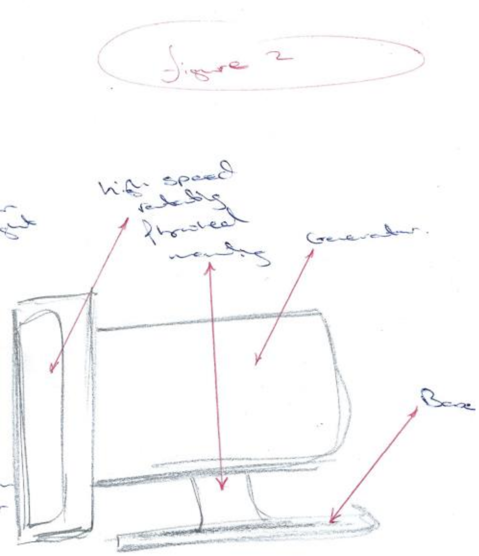
Equipment

- Flywheel attached to a bar balanced by a counter weight with a variable pivot point along the rod.
- Timer.
- Ruler (30cm).
- Strobe light with adjustable frequency.
- High speed rotating wheel.
- Stand or mount for the gyroscope.

Setup







Method

Part 1: Measuring Speed of Decay Rate of Spinning Wheel

1. Setup equipment as displayed in *figure 1.*
2. Turn on the strobe light.
3. Use equipment setup in *figure 2* to spin the flywheel to 3000rpm.
4. Place the flywheel on the mount.
5. Start the timer.
6. Adjust the strobe frequency such that the letter inscribed on the flywheel face appears to be stationary.
7. Record the corresponding RPM using the strobe light measurement.
8. For one and a half minutes adjust the frequency of the strobe light such that the inscribed letter appears to be stationary for five different times.
9. Record the corresponding RPM's for these five times.

Part 2: Measuring the Frequency of the Gyroscope

1. Setup equipment as displayed in *figure 3*.
2. Determine the centre of mass of the rod by adjusting the rod's pivot point until it stands balanced on the stand.
3. Set 10mm markings using a marker and ruler from the centre of mass till 40mm and -40mm (i.e. from either side of the equilibrium point).
4. Use equipment setup in *figure 2* to spin the flywheel to 3000rpm.
5. Place the flywheel on the mount and immediately start the timer and use a marker to set the starting position of the flywheel rod as it sets off such as the one highlighted in *figure 3*.
6. Stop the timer after one revolution of the flywheel is completed.
7. Record the direction of rotation and the time it took for one rotation of the flywheel about the pivot point.
8. Repeat steps 3-6 for the other markings on the rod.

Results

Part 1: RPM Results

Time (s)	RPM
0	2850
10	2700
30	2600
50	2400
70	2100
90	1900

Part 2: Frequency of Gyroscope

Position from centroid (mm)	Time/1 Revolution (s)	Direction of Rotation
10	23.45	Clockwise
20	12.12	Clockwise
30	8.57	Clockwise
40	6.58	Clockwise
-10	22.73	Anti-clockwise
-20	11.50	Anti-clockwise
-30	8.75	Anti-clockwise
-40	6.12	Anti-clockwise

Calculations

The mass of the gyroscope is approximately $2.5kg$, hence let $m = 2.5kg$. The angular velocity of the flywheel, $\omega_s = 3000rpm$. Converting the angular velocity to radians per second for calculations is equal to $\omega_s = \frac{3000\times2\pi}{60} = 100\pi\ rad/sec$. Using the mass, weight can be calculated to be equal to $W = mg = 2.5 \times 9.81 = 24.53N$. The second theoretical moment area is given as $I_{zz} = 0.004kg \cdot m^2$.

Position from centroid (m)	Time/1 Revolution (s)	M_x (kg m^2/s^2)	ω_p (rad/sec)	I_{zz}	Error (%)
0.04	6.58	-0.9812	-0.9549	0.0033	18.23
0.03	8.57	-0.7359	-0.7332	0.0032	20.13
0.02	12.12	-0.4906	-0.5184	0.0030	24.69
0.01	23.45	-0.2453	-0.2679	0.0029	27.15
-0.01	22.73	0.2453	0.2764	0.0028	29.38
-0.02	11.5	0.4906	0.5464	0.0029	28.54
-0.03	8.75	0.7359	0.7181	0.0033	18.45
-0.04	6.12	0.9812	1.0267	0.0030	23.95

Using the above calculations, the average error can be calculated to be $error_{avg} = 23.81\%$.

Discussion

Experimental Uncertainty

Results within this experiment were affected by errors caused by factors such as friction in the flywheel as it spins causing deceleration. Therefore, the rate of decay of the angular velocity from the collected data would be affected resulting in a slower precession revolution and furthermore, increasing the time and decreasing the ω_p. Therefore, the greater position measurements with the longest revolution times have the greatest margins of error. The precision of the timer and the ruler affects the measurements since the measurements are rounded to the nearest millisecond and millimeter respectively as well as the accuracy of the measurements being influenced by human reaction times and estimation of a full revolution of the flywheel rod around the pivotal point. The estimation of the centre of mass causes an inaccuracy of the position from the centroid.

Minimizing Uncertainty

Such uncertainties can be minimized in future investigations through the employment of low friction bearings being employed into the flywheel, using lasers to have a more accurate timing and corresponding computerized systems to record the revolution and time. Furthermore, due to the limited time in the laboratory, the number of tests was limited to only one, therefore, for more accurate measurements with a lower margin of error multiple tests are recommended for future attempts.

Application of Gyroscopic Systems

Gyroscopes are utilized in various machines around the world. An example includes aircraft instrumentation, where the gyroscope is used in the measuring of attitude, compass and turn coordinators. The motion and movements of the plane allows for certain characteristics used in gyroscopic instruments to inform pilots and allow them to rely on such instruments when flying. Gyroscopes are also utilized in the navigation systems of unmanned aerial vehicles where the information can be processed by a computer system. The gyroscope would be used in an aircraft to help in indicating the rate of rotation around the aircraft roll axis. *As an aircraft rolls, the gyroscope will measure non-zero values to indicate* (Goodrich, 2018) a downward direction.

Conclusion

The mass moment of inertia of the flywheel about its axis was calculated experimentally and mathematically through the analysis of the rate of precession and had a margin of error of 23.81% the theoretical value of **0.004kg m^2.**

Bibliography

Goodrich, R. (2018, 5 30). *Accelerometer vs. Gyroscope: What's the Difference?* Retrieved from Live Science: https://www.livescience.com/40103-accelerometer-vs-gyroscope.html

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