American Journal of Physics and Applications
2020; 8(1): 1-7
http://www.sciencepublishinggroup.com/j/ajpa
doi: 10.11648/j.ajpa.20200801.11
ISSN: 2330-4286 (Print); ISSN: 2330-4308 (Online)

Research/Technical Note

Interpretation of Gyro Stability and Precession Mechanism by Law of Rotational Inertia

Shaoshu Huang[1, 2]

[1]Academic Center, No. 23 Middle School of Liupanshui, Liupanshui, China

[2]School of Mathematics and Physics, Anshun University, Anshun, China

Email address:
597015954@qq.com

To cite this article:
Shaoshu Huang. Interpretation of Gyro Stability and Precession Mechanism by Law of Rotational Inertia. *American Journal of Physics and Applications*. Vol. 8, No. 1, 2020, pp. 1-7. doi: 10.11648/j.ajpa.20200801.11

Received: January 31, 2020; **Accepted**: February 13, 2020; **Published**: February 19, 2020

Abstract: The precession mechanism and stability of gyroscope is an outstanding problem. It has been widely believed for a long time that the precession of gyroscope is the result of the action of heavy moment. But this is not completely consistent with the experimental facts. This paper introduces the experimental phenomena of gyroscopic precession on the horizontal plane, presents the laws of rotational inertia and micro deformation action, gives the empirical expression of micro deformation action. The experimental phenomena of gyro precession are analyzed based on the principle of virtual fixed axis rotation balance and the law of conservation of momentum moment. The condition of whether the gyro can recover stable rotation state in certain condition is given, the determinants of precession angular velocity and rotation angular velocity of gyroscope and their relations are also given. The stability and precession mechanism of the gyroscope on the horizontal plane are explained comprehensively.

Keywords: Law of Rotational Inertia, Gyroscopic Precession, Law of Micro Deformation Action, Principle of Virtual Fixed Axis Rotation Balance, Maximum Chapter Angle

1. Introduction

It has been widely believed for a long time that the precession of gyroscope is the result of the action of heavy moment. In fact, this conclusion is far fetched, which is not consistent with the experimental facts. Only the gravity effect is considered [1, 2] which can not explain why the gyro precession experiment shows that the gyro does not topple during precession, and can not fully explain the precession mechanism of the gyro in the dynamic analysis of gyro precession.

The problem of gyro stability has always been controversial. It seems that there is no consensus on whether the gyro rotateed at high speed can return to the original pure rotation state and what conditions are needed to restore the pure rotation state.

In addition, there are some differences on the direction of gyro precession and rotation. Most of viewpoints think that the direction of precession angular velocity is the same as that of rotation angular velocity, but there are still a few opinions that the direction of precession angular velocity is opposite to that of rotation angular velocity.

2. Three Lemmas

In addition to the well-known law of conservation of momentum moment, the laws of rotational inertia and the law of micro deformation action which have not been found or proposed in the past, as well as the principle of virtual fixed axis rotational balance which has been found but not yet extended, must also be used in this paper. Three rules in the form of lemma are given firstly in order to explain and express the problem clearly.

2.1. Lemma 1: Law of Rotational Inertia

The longer it takes to maintain rotation of gyroscope rotating at high speed in vertical direction on horizontal plane when the smoother of horizontal surface is. The greater the moment of inertia, the less likely it is for the gyro to change its rotational state. If the power is cut off and the top cover is pulled up at the same time, the dewatering bucket will stop soon. If the power supply is cut off but the top cover is not pulled up, the dewatering bucket will take a long time to stop. It takes longer for the loaded dewatering bucket to stop rotating than the unloaded dewatering bucket in the same condition.

The practice shows that any rotating object always keeps its original state of uniform rotation until it is forced to change this state by external torque.

The law is called the law of rotational inertia in this paper. At the same time, the property of keeping the original rotational state of the object is called rotational inertia. The moment of inertia of an object is determined by its moment of inertia. The greater the moment of inertia, the greater the moment of inertia.

To explain: The rotation here includes pure rotation and the coexistence of rotation and precession, Uniform rotation refers to the rotation with constant angular velocity in the process of rotation.

2.2. Lemma 2: Law of Micro Deformation Action

The deformation on the contact surface of two objects (quasi rigid body) with high hardness contacting and squeezing each other is very small, which is called micro deformation. Due to the existence of micro deformation, the real contact surface between two objects will shift to zero pressure state in the case of extrusion.

The interaction force produced in the process of micro deformation is called micro deformation force in this paper. It is stipulated here that the micro deformation force includes the elastic force and friction force produced in the process of micro deformation, and the law it follows is relatively complex.

According to the practical experience, the micro deformation force will increase with the increase of micro deformation variable and rotation speed, and decrease with the increase of precession angle. Here, in order to simplify reasoning, approximate expression is made: The monotone increasing function F of micro deformation force x and micro variable $f_{(x)}$, monotone increasing function $\omega_{(\theta)}$ monotone increasing with rotation velocity $\chi_{(\omega_{(\theta)})}$, monotone decreasing function $\psi_{(\theta)}$ monotone increasing of chapter angle θ following precession. where

$$F = k(f_{(x)} + \chi_{(\omega_{(\theta)})} + \psi_{(\theta)}) \text{ , } (k \geq 1) \tag{1}$$

The law is called the law of micro deformation action in this paper, where $f_{(x)}$, $\chi_{(\omega_{(\theta)})}$ and $\psi_{(\theta)}$ have dimensions of all forces. k is a dimensionless constant related to the rigidity of the object and the smoothness of the contact surface, which is called the micro deformation factor. k equals 1 if the contact surface between two objects is absolutely smooth and rigid.

2.3. Lemma 3: Principle of Virtual Fixed Axis Rotation Balance

Here, the principle of virtual fixed axis rotation balance given by reference [3]: When a rigid body rotates around a virtual fixed axis, the sum of the moment vectors of the non-tangential forces on the rotating vertices is zero under the condition of stable rotation.

$$\vec{M}_1 + \vec{M}_2 + \cdots + \vec{M}_n = 0, \sum \vec{M} = 0 \tag{2}$$

According to the literature [3], the fixed axis rotation of rigid body can be divided into two types: real fixed axis rotation and virtual fixed axis rotation. The real fixed axis rotation refers to the type of force exerted by the fixed axis on the rotating rigid body, such as: the door rotates around the door axis, the eccentric wheel rotates, etc. The virtual fixed axis rotation refers to the type where the fixed axis has no force on the rotating rigid body. For example, it belongs to the type of coaster, gyro rotation, bicycle stability, etc [4, 5].

The rigid body rotating around the virtual fixed axis follows the principle of virtual fixed axis rotation balance, the surface swept by the rigid body is often a conical surface, and the vertex of the conical surface is called the rotational vertex in the course of rotation. In fact, the vertex of rotation must be on the virtual fixed axis around which the rigid body rotates.

3. The Gyro Precession Experiment

First of all, this paper only studies the gyro rotation on the horizontal plane, and the horizontal plane is considered to be smooth if not specially specified in the deduction.

3.1. The Description of Several Concepts

When the gyro is driven by a certain initial external torque, it will rotate around its axis of symmetry at high speed, which is often called rotation. If the resultant external torque of the high-speed rotating gyroscope is zero, the rotating state will not be changed. If the combined external torque is not zero due to some disturbance, the rotation axis will deviate from the original rotation state and rotate around the rotation axis passing a certain point (such as the tip of gyroscope) for virtual fixed axis, which is the precession of gyroscope in the high-speed rotation process of gyroscope. In the precession process of gyroscope, the original rotation state can be restored under certain conditions, which is the stability of gyroscope.

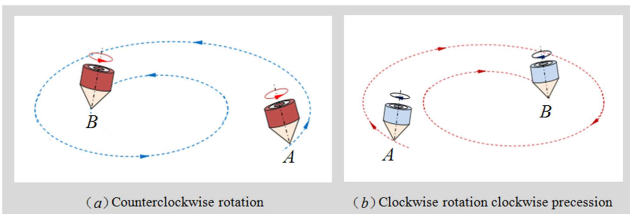

Figure 1. *The angular velocity direction of gyro precession and rotation is ths same.*

3.2. The Experiment

As shown in Figure 1, the gyro state and precession track of rotation and precession on the horizontal plane are drawn according to the experimental phenomena. At point A, a rope whip is used to give the gyro a instantaneous external moment. When the gyro rotates around its axis of symmetry, it moves from point B along the arc to point A, and then moves at point B. It can be seen that the angular velocity direction of gyro precession is always the same as that of its rotation from the figure.

A large number of experiments show that:

(1) Gyro precession includes two stages: arc or quasi arc precession and fixed-point precession, while fixed-point precession usually includes two processes: recovery of stable rotation and re precession.

(2) The angular velocity direction of gyro precession is always the same as that of its self angular velocity direction. That is to say, the precession angular velocity and the rotation angular velocity are always counter clockwise or clockwise.

(3) In the precession process of gyro, the angle of seal (the angle between the symmetry axis and the vertical direction) or the angle of inclination (the angle between the symmetry axis and the horizontal plane) will change. The maximum angle of seal is related to the smoothness, flatness and rigidity of the support surface. That is, if the smoothness and flatness are better and the rigidity is stronger, the maximum chapter angle will be smaller.

(4) Under the constraint of given initial energy, the angular velocity of gyro precession is less than and equal to that of non-precession.

4. The Precession Mechanism of Gyro

In the ideal case without friction, during the stable precession of the gyro, its symmetry axis (i.e. rotation axis) will sweep over the conical surface, as shown in Figure 2. Generally, in the initial stage when the gyro is whipped by the whip, its rotation speed is very large, and its chapter angle is also relatively large. At this time, the tip of the gyroscope will roll the micro deformation to make an arc (ideal condition) or quasi arc movement, and the rotation axis OZ will advance around the vertical axis O_1Z_1, as shown in Figure 2(a). Because there is always friction, the rotation speed will gradually decrease, and the chapter angle will also decrease. When the chapter angle is reduced to a certain extent and the gyro tip is not enough to roll over the obstruction of micro deformation, the gyro tip will be fixed at the O_2 point (the O_2 point coincides with the o point, the same below). At this time, the rotation axis OZ moves around the vertical axis O_2Z_2, as shown in Figure 2(b).

According to lemma 1, it is not difficult to understand that the precession process of the gyroscope is essentially the process of the obstruction caused by the micro deformation of the tip rolling and the process of the micro deformation preventing the tip rolling. This process is driven by the rotation inertia of the gyroscope. When the gyro rotates counter clockwise, if it is disturbed and the rotation axis deviates from the vertical direction, the gyro must move counter clockwise because of the rotation inertia. In the same way, if the clockwise rotating gyroscope is disturbed, it must move clockwise. In other words, the rotating inertia is the root cause of gyro precession. At the same time, the precession of the gyroscope follows lemma 2 and Lemma 3, and is regulated by the law of conservation of momentum [6] and the law of conservation of mechanical energy.

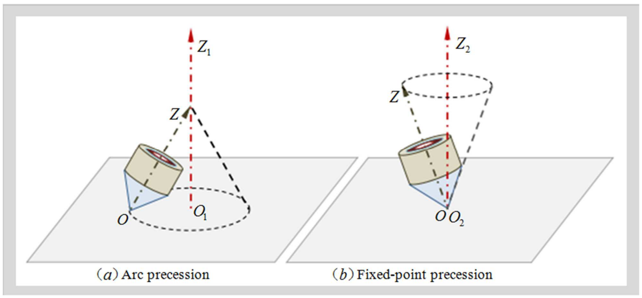

Figure 2. *Symmetry axis sweeps over conical surface during gyro precession.*

This section mainly studies the constraint relationship between precession angular velocity and self-angular velocity during precession.

As shown in Figure 3, let the angular velocity of the gyro rotating counterclockwise around the vertical axis OZ be ω, and the moment of inertia of the gyro relative to the rotation axis be $J_{(0)}$. Then, according to the right-hand spiral rule, the direction of the moment of momentum of the gyro relative to the rotation axis is vertically upward along the OZ axis, the size is $L_{(\omega)}$.

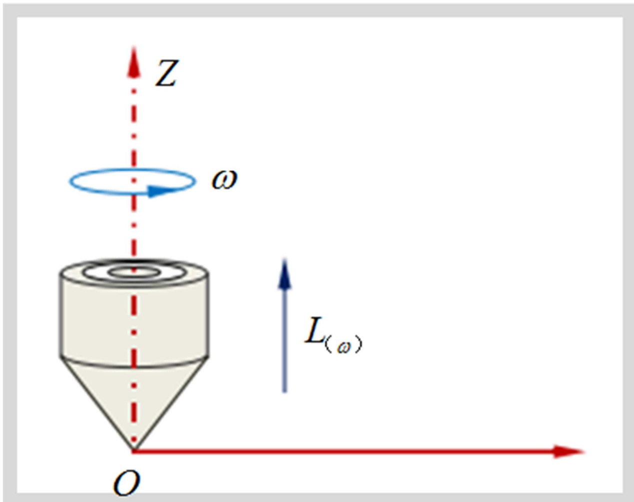

Figure 3. *Gyro rotaing around vertical axis OZ.*

So, the total moment of momentum L in the vertical direction is

$$L = L_{(\omega)} = J_{(0)}\omega \tag{3}$$

When the gyro is disturbed and its rotation axis deviates from the vertical direction, precession will occur due to the rotation inertia. In fact, in the precession process of gyroscope, the rotation speed is often a function of precession angle. Under the constraint of given initial energy, the angular velocity of gyro precession decreases with the increase of chapter angle, and is less than or equal to the angular velocity of non-precession. This is due to the regulation of conservation of mechanical energy, whether the mechanical energy increases during rotation. This is due to the regulation of conservation of mechanical energy, whether the mechanical energy increases during rotation. Its specific energy constraint relationship is relatively complex and limited to space, so it is not suitable to discuss it here.

4.1. Arc Precession

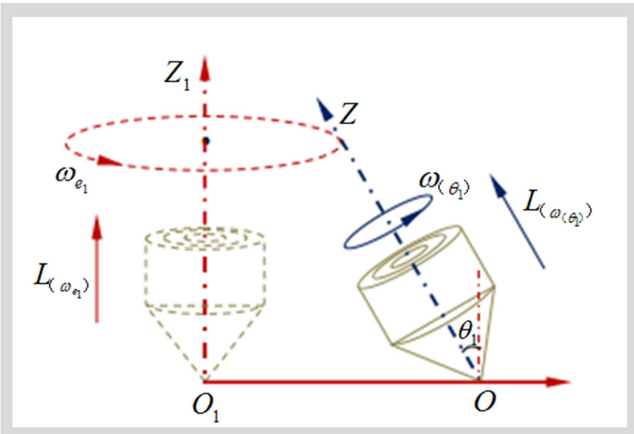

Figure 4. *Gyroscope moving counterclockwise around vertical axis* O_1Z_1.

When the self-rotating axis OZ moves around the vertical axis O_1Z_1 at the precession angular speed ω_{e_1} anticlockwise, set the chapter angle as θ_1 (the same below), as shown in Figure 4. According to the right-hand spiral rule, the moment of gravity action is horizontal. Therefore, according to the conservation law of momentum moment, the momentum moment of gyroscope in the vertical direction remains unchanged. Therefore, the top must move in a counter clockwise direction. Then, the direction of the gyro's rotation momentum moment relative to the rotation axis inclines upward along the OZ axis, and the magnitude can be expressed as

$$L_{(\omega_{(\theta_1)})} = J_{(0)}\omega_{(\theta_1)} \tag{4}$$

Let the moment of inertia of the gyro precession with respect to the O_1Z_1 axis be $J_{(\theta_1)}$ (the same below), then the precession momentum moment direction of the gyro relative to the O_1Z_1 axis is vertically upward along the O_1Z_1 axis, and the magnitude is

$$L_{(\omega_{e1})} = J_{(\theta_1)}\omega_{e_1} \tag{5}$$

Since the total moment of momentum l of the gyro in the vertical direction remains unchanged, based on eq.(4) (5) there are

$$L = J_{(0)}\omega_{(\theta_1)}\cos\theta_1 + J_{(\theta_1)}\omega_{e_1} \tag{6}$$

According to formula (6), the precession angular velocity W can be expressed as

$$\omega_{e_1} = \frac{L - J_{(0)}\omega_{(\theta_1)}\cos\theta_1}{J_{(\theta_1)}} \tag{7}$$

It can be seen from formula (7) that since the moment of momentum L is a fixed value, the larger the rotation speed $\omega_{(\theta_1)}$ of the gyro, the smaller the precession speed ω_{e_1}. In fact, in the precession process of gyroscope, the angular velocity $\omega_{(\theta_1)}$ will gradually decrease and the angular velocity ω_{e_1} will gradually increase due to friction in a certain range. By formula (3) (7), ω_{e_1} can be expressed as

$$\omega_{e_1} = \frac{J_{(0)}\omega - J_{(0)}\omega_{(\theta_1)}\cos\theta_1}{J_{(\theta_1)}} \approx \frac{J_{(0)}\omega(1\text{-}\cos\theta_1)}{J_{(\theta_1)}} \tag{8}$$

Obviously, when $\theta = 0^\circ$, $\omega_{(\theta_1)} = \omega$, $\omega_{(\theta_1)} = 0\,rad/s$. Under normal conditions, $J_{(\theta_1)}$ is much larger than $J_{(0)}$. It can be seen from formula (8) that the precession angular velocity ω_{e_1} is much smaller than the self-angular velocity ω.

Explain: In the above formulas, $J_{(\theta_1)}$ is the monotone increasing function of the chapter angle θ_1, and is related to the shape and mass distribution of the gyro.

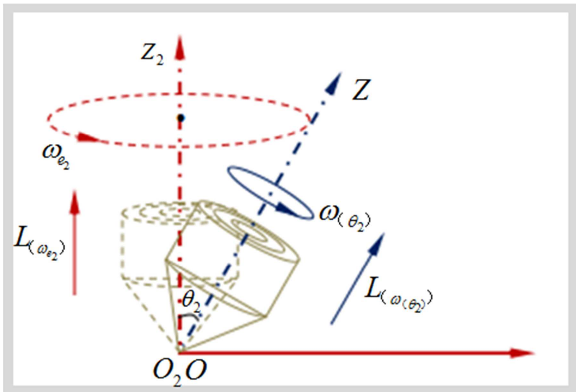

Figure 5. *Gyroscope moving counterclockwise around vertical axis* O_2Z_2.

4.2. Fixed Point Precession

When the self-rotating axis OZ moves counterclockwise around the vertical axis O_2Z_2 at the precession angular speed ω_{e_2}, set the chapter angle as θ_2 (the same b- elow), as shown in Figure 5. Then, the direction of the gyro's rotation momentum moment relative to the rotation axis inclines upward along the OZ axis, and the magnitude can still be expressed as

$$L_{(\omega_{(\theta_2)})} = J_{(0)}\omega_{(\theta_2)} \tag{9}$$

Let the moment of inertia of the precession of the gyro relative to the O_2Z_2 axis be $J_{(\theta_2)}$, then the precession momentum of the gyro relative to the O_2Z_2 axis is vertically upward along the O_2Z_2 axis, and the magnitude is

$$L_{(\omega_{e_2})} = J_{(\theta_2)}\omega_{e_2} \tag{10}$$

Similarly, since the moment of momentum L of the gyro in the vertical direction remains unchanged, there are

$$L = J_{(0)}\omega_{(\theta_2)}\cos\theta_2 + J_{(\theta_2)}\omega_{e_2} \tag{11}$$

By formula (11), the precession angular velocity ω_{e_2} can be expressed as

$$\omega_{e_2} = \frac{L - J_{(0)}\omega_{(\theta_2)}\cos\theta_2}{J_{(\theta_2)}} \tag{12}$$

Similarly, from formula (12), it can be seen that since the moment of momentum L is a constant value, therefore, the larger the rotation velocity $\omega_{(\theta_2)}$ is, the smaller the precession velocity ω_{e_2} is.

According to formula (3) and (12), we can also obtain

$$\omega_{e_2} = \frac{J_{(0)}\omega - J_{(0)}\omega_{(\theta_2)}\cos\theta_2}{J_{(\theta_2)}} \approx \frac{J_{(0)}\omega(1-\cos\theta_2)}{J_{(\theta_2)}} \tag{13}$$

As mentioned before, when $\theta = 0^\circ$, $\omega_{(\theta_2)} = \omega$, $\omega_{e_2} = 0\,\text{rad/s}$. In general, $J_{(\theta_2)}$ is much larger than $J_{(0)}$, it can be seen from formula (13). The precession angular velocity ω_{e_2} is much smaller than the self-angular velocity ω.

Explain: In the above formulas, $J_{(\theta_2)}$ is the monotone increasing function of the chapter angle θ_2, and is related to the shape and mass distribution of the gyro.

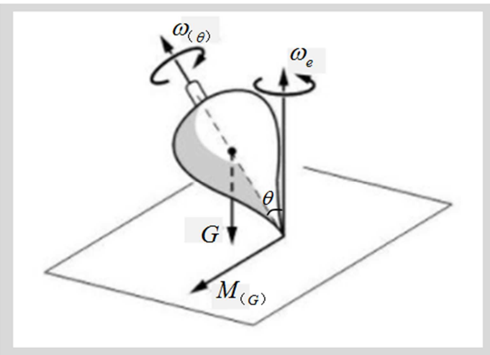

Figure 6. *Effect of heavy moment.*

4.3. Historical False Truth

It has been widely believed for a long time that the precession of gyroscope is the result of the action of heavy moment. Some references [1, 7] analyze the causes of gyro precession, which are based on the co counter clockwise rotation and counter clockwise precession as the model, and attached with [8] as shown in Figure 6 or similar diagram for auxiliary explanation.

Historical analysis: when the gyro rotates counterclockwise at the angular velocity $\omega_{(\theta)}$, the gravitational moment $M_{(G)}$ in it has the effect of driving the gyro to advance counterclockwise. Therefore, the gyro will advance counterclockwise at the angular velocity ω_e.

Simulation Reasoning: when the gyro rotates clockwise at the angular speed $\omega_{(\theta)}$, the magnitude and direction of the gravity moment $M_{(G)}$ are exactly the same as that of the counter clockwise rotation, and there is still the effect of driving the gyro to move anticlockwise. Therefore, the gyro still moves counterclockwise at the angular velocity ω_e.

Conclusion: the top that rotates counter clockwise and the top that rotates clockwise all move counter clockwise.

Obviously, this is not consistent with the actual experimental facts and belongs to the false truth.

5. Analysis of the Stability of Gyro

In this section, we mainly analyze the conditions of whether the gyro can keep not toppling and whether it can restore the pure rotation state in the precession process, as well as the decisive factors of precession angular velocity.

5.1. Conditions for Stable Precession

As shown in Figure 7, the gyro rotates anticlockwise and advances anticlockwise. Let the gyro mass be m, the distance between the differential mass concentration point P of the gyro and the tip O point be l, and the gravity G and the micro deformation force F_1 or F_2 during the precession of the gyro have been indicated in the figure.

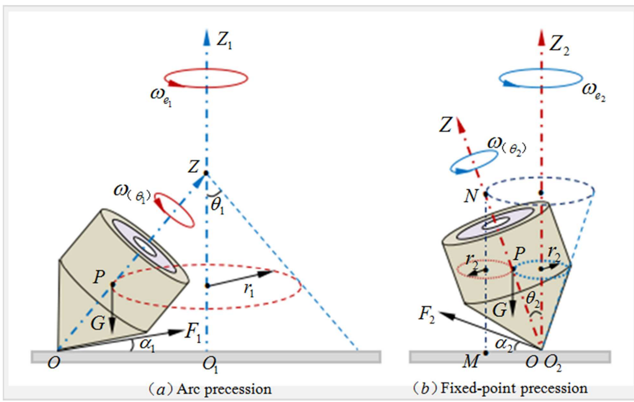

Figure 7. *The rotation axis sweeps through the conical surface in the precession process of gyro.*

5.1.1. Arc Precession

At a certain moment when the gyro makes arc precession, the apex of the conical surface swept by the rotation axis is Z point. Let its chapter angle be θ_1, its rotation radius (the distance from differential mass concentration point P to O_1Z_1 axis) be r_1, and its precession angle speed be ω_{e_1}, as shown in Figure 7. According to the force situation in Figure. 7 and the relevant physical quantities indicated, combined with formula (1) (2), it can be seen that during the precession process of gyro around O_1Z_1, the torque magnitude of micro deformation force F_1 and gravity G to Z point are respectively.

$$\mathrm{M}_G = Gr_1 = mgr_1 \tag{14}$$

$$\begin{aligned} &\mathrm{M}_{F_1} = \\ &F_1 \cos\alpha_1 \cdot \overline{OZ} \cos\theta_1 = \\ &k(f_{(x_1)} + \chi_{(\omega_{(\theta_1)})} + \psi_{(\theta_1)})\overline{OZ}\cos\alpha_1 \cos\theta_1 = \\ &k(f_{(x_1)} + \chi_{(\omega_{(\theta_1)})} + \psi_{(\theta_1)}) \quad (l\cos\theta_1 + r_1\cot\theta_1)\cos\alpha_1 \end{aligned} \tag{15}$$

When the gyro is in a steady precession state, according to formula (2), the sum of each moment vector is equal to zero, that is

$$\mathrm{M}_G - \mathrm{M}_{\mathrm{F}_1} = 0 \tag{16}$$

Or

$$F_1 = k\ (f_{(x_1)} + \chi_{(\omega_{(\theta_1)})} + \psi_{(\theta_1)}) = \frac{mgr_1}{(l\cos\theta_1 + r_1\cot\theta_1)\cos\alpha_1} \tag{17}$$

At the same time

$$\begin{cases} k\ (f_{(x_1)} + \chi_{(\omega_{(\theta_1)})} + \psi_{(\theta_1)})\sin\alpha_1 - mg = 0 \\ k\ (f_{(x_1)} + \chi_{(\omega_{(\theta_1)})} + \psi_{(\theta_1)})\cos\alpha_1 - \sqrt{mJ_{(\theta_1)}} \cdot \omega_{e_1}^2 = 0 \end{cases} \tag{18}$$

From formula (18), the precession angular velocity can be expressed as

$$\omega_{e_1} = \sqrt{\frac{k\ (f_{(x_1)} + \chi_{(\omega_{(\theta_1)})} + \psi_{(\theta_1)})\cos\alpha_1}{\sqrt{mJ_{(\theta_1)}}}} \tag{19}$$

5.1.2. Fixed Point Precession

At a certain time when the gyro makes fixed-point precession, set its chapter angle as θ_2, its rotation radius (distance from differential mass concentration point P to O_2Z_2 axis) as R, and its precession angle speed as $\omega_{(\theta_2)}$, as shown in Figure 7(b). According to the force situation in Figure 7(b) and the relevant physical quantities indicated and combined with formula (1) (2), it can be seen that during the precession process of the gyro, the torque magnitude of the micro deformation force F_2 and the gravity point G (the conjugate point of the point O_2, O_2Z_2 is the conjugate axis) are respectively.

$$\mathrm{M}_G = Gr_2 = mgr_2 \tag{20}$$

$$\begin{aligned} &\mathrm{M}_{F_2} = \\ &F_2 \cos\alpha_2 \cdot \overline{ON} \cos\theta_2 = \\ &k(f_{(x_2)} + \chi_{(\omega_{(\theta_2)})} + \psi_{(\theta_2)})\overline{ON}\cos\alpha_2 \cos\theta_2 = \\ &k(f_{(x_2)} + \chi_{(\omega_{(\theta_2)})} + \psi_{(\theta_2)}) \quad (l\cos\theta_2 + r_2\cot\theta_2)\cos\alpha_2 \end{aligned} \tag{21}$$

As mentioned above, when the gyro is in a stable precession state, according to formula (2), the sum of each moment vector is equal to zero, that is

$$\mathrm{M}_G - \mathrm{M}_{\mathrm{F}_2} = 0 \tag{22}$$

Or

$$F_2 = k(f_{(x_2)} + \chi_{(\omega_{(\theta_2)})} + \psi_{(\theta_2)}) = \frac{mgr_2}{(l\cos\theta_2 + r_2\cot\theta_2)\cos\alpha_2} \tag{23}$$

Similarly,

$$\begin{cases} k(f_{(x_2)} + \chi_{(\omega_{(\theta_2)})} + \psi_{(\theta_2)})\sin\alpha_2 - mg = 0 \\ k(f_{(x_2)} + \chi_{(\omega_{(\theta_2)})} + \psi_{(\theta_2)})\cos\alpha_2 - \sqrt{mJ_{(\theta_2)}} \cdot \omega_{e_2}^2 = 0 \end{cases} \tag{24}$$

Based on formula (24), the precession angular velocity can also be expressed as

$$\omega_{e_2} = \sqrt{\frac{k(f_{(x_2)} + \chi_{(\omega_{(\theta_2)})} + \psi_{(\theta_2)})\cos\alpha_2}{\sqrt{mJ_{(\theta_2)}}}} \tag{25}$$

5.2. Failure of Steady Precession

In general, the micro deformation force in the precession process of gyroscope has transient deformation. Therefore, the moment of micro deformation force on the apex of precession cone will change at any time, which will affect the stable precession of gyro.

5.2.1. Gyro Effect

According to formula (14) and (15), when $\mathrm{M}_{F_1} < \mathrm{M}_G$,

$$F_1 = k(f_{(x_1)} + \chi_{(\omega_{(\theta_1)})} + \psi_{(\theta_1)}) > \frac{mgr_1}{(l\cos\theta_1 + r_1\cot\theta_1)\cos\alpha_1} \tag{26}$$

Or according to (20) and (21), when $\mathrm{M}_{F_2} > \mathrm{M}_\mathrm{G}$

$$F_2 = k(f_{(x_2)} + \chi_{(\omega_{(\theta_2)})} + \psi_{(\theta_2)}) > \frac{mgr_2}{(l\cos\theta_2 + r_2\cot\theta_2)\cos\alpha_2} \tag{27}$$

The chapter angle will gradually decrease, the precession will gradually disappear, and the gyro will gradually return to a stable rotation state. This is known as the gyroscopic effect. Gyro effect is widely used in many fields [9-15].

5.2.2. Causes of Dumping

It's not hard to understand, when $\mathrm{M}_{F_1} < \mathrm{M}_\mathrm{G}$

$$F_1 = k(f_{(x_1)} + \chi_{(\omega_{(\theta_1)})} + \psi_{(\theta_1)}) < \frac{mgr_1}{(l\cos\theta_1 + r_1\cot\theta_1)\cos\alpha_1} \tag{28}$$

Or when $\mathrm{M}_{F_2} < \mathrm{M}_\mathrm{G}$

$$F_2 = k(f_{(x_2)} + \chi_{(\omega_{(\theta_2)})} + \psi_{(\theta_2)}) < \frac{mgr_2}{(l\cos\theta_2 + r_2\cot\theta_2)\cos\alpha_2} \tag{29}$$

chapter angle will gradually increase. When the chapter angle increases to a certain limit value θ_m, the gyro will topple.

6. Conclusion

(1) The high-speed rotation (rotation and precession) gyroscope can restore stable rotation state (i.e. gyroscope stability or gyroscopic effect) or topple due to the combined effect of micro deformation force and gravity.

(2) The precession mechanism of gyroscope is the rotation inertia of gyroscope, not the action of heavy moment. Rotation inertia is the reason why gyro can keep stable pure rotation state and can keep stable precession state.

(3) The angular velocity of gyros is determined by (3), and the angular velocity of gyros precession is determined by (19) or (25). However, the constraint relationship between precession angular velocity and self angular velocity is (7) and (12) or (8) and (13), respectively.

(4) According to the viewpoint of micromorphology, if the horizontal support surface is absolutely smooth and rigid, the gyro will not have precession and can only do stable rotation or toppling.

Explain

As for the analysis of the precession mechanism of gyro stability, the precession of clockwise rotation is exactly the same as that of counter clockwise rotation. This paper is limited to the space and will not elaborate.

References

[1] Department of theoretical mechanics, Harbin University of technology. Theoretical mechanics (II) [M]. Beijing: Higher Education Press 2009 (7), 110-134.

[2] Deng Jingyuan. Research on precession mechanism and stability analysis of gyroscope [J], Equipment Engineering of China, 2016 (8): 62, 63.

[3] Huang Shaoshu, Wu Cinan. The principle and example analysis of virtual fixed axis rotating balance [J], Asia Pacific Journal of Physics, 2019 (1), 1: 1-5.

[4] Huang Shaoshu, Jiang Jintuan. Research and Interpretation on Bicycle Stability Issue [J]. Physics Bulletin, 2017, 11: 67-70.

[5] Huang Shaoshu, Jiang Jintuan. A study on the problem of bicycle's "no turning" [J]. PHYSICS TEACHER, 2017, 38 (8): 57-58.

[6] Department of theoretical mechanics, Harbin University of technology. Theoretical mechanics (I) [M]. Beijing: Higher Education Press. 2009 (7), 260-264.

[7] Qiu Jiuzi. Analysis of a singular phenomenon in precession of gyroscope [J], Knowledge of modern physics, 1998 (10), 3: 36-37.

[8] Written by R. P. Feynman, R. B. Leighton, M. Sands; Translated by Zheng Yongling, Hua Hongming and Wu Ziyi. Feynman's lecture notes on Physics (Volume 1) [M]. Shanghai: Shanghao science and Technology Press. 2013 (1), 210.

[9] Zhang Qingchun, Wu Dongjiang, Zhuang Juan, et al. A method of measuring precession angular velocity of gyroscope [J], physical experiment, 1997 (17), 2: 53-54.

[10] Peng Yi, Liang Zhibin. The effect of gyroscopic precession in sen spacetime [J], Acta Physica Sinica, 49 (9): 1670-1678, 2000.

[11] Lei Hao, Yang Hairong, Zhu Mu, et al. Errors Analysis of Dynamical Servo Gyro in IR Guided Weapons [J], Aerospace Shanghai, 34 (1): 86-91, 2017.

[12] Hong Zixin, Shai Kai, Ai Qing, Research on torsion gyroscope [J], Physics experimentation, 38 (6): 35-39, 2018.

[13] Fu Xianluo. Analysis of nutation resistance of free precession gyroscope [J], Chinese Journal of mechanics, 1985 (17), 2: 177-181.

[14] Zhang Han, Zhang Yu, Zhao Hui, Dynamics Analysis of GyroWheel for its Micro-spacecraft Attitude Control Application [J], Journal of System Simulation, 27 (1): 112-117, 2015.

[15] Li Zhihong, Chen Run'en, Cheng Xiaodong, et al. Research on Single-wheel Self-balancing Robot Based on Horizontal Gyro Structure [J], China Mechanical Engineering, 27 (6): 726-731, 2016.

Biography

Shaoshu Huang born in 1967, bachelor's degree, Professor, senior teacher. The research direction is mainly the connection of physics education and teaching and general physics, good at practical and experimental research.