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The Fundamental Principles of Gyroscope Theory

Ryspek Usubamatov[1]* and Marek Bergander[2]

[1]*Kyrgyz State Technical University, Bishkek, Kyrgyzstan*
[2]*Magnetic Development, Inc. Madison, CT, USA*

Abstract

Beginning from the Industrial Revolution, outstanding and ordinary scientists of the past and present time tried to formulate mathematically the dynamics of rotating objects. However, only the famous mathematician L. Euler expressed one component of the dynamics of a rotating body which is presented by the change in the angular momentum or precession torque. To date, his decision in publications presented as a fundamental principle of the gyroscope theory. Other scientists and researchers presented intuitive interpretations of the gyroscopic effects without mathematical models. All scientists considered the forces and motion acting on the spinning disc, which is the simplest mechanism in classical mechanics that created so many problems for a long time. This is an unusual phenomenon in the physics of mechanics, in which analytical methods enable us to solve more complex problems than inertial forces acting on a simple spinning disc.

Keywords: Euler's angles • Gyroscopic • Precession torque • Coriolis force

Introduction

Practice demonstrates Euler's principle of the change in the angular momentum could not describe and explain multi variations of gyroscopic effects. In reality, the gyroscope theory expressed by a system of five principles based on known concepts of classical mechanics and much time harder than presented in known publications. On the spinning objects are acting the eight inertial torques generated by the centrifugal, common inertial, and Coriolis forces as well as changes in the angular momentum around two axes. The actions of the external and inertial torques are interrelated by the specific ratio of the angular velocities of the spinning object around axes of rotation. The action of these inertial toques manifests the gyroscopic resistance and precession torques. The inertial torques and angular velocities of gyroscope motions around axes express the kinetic energy of the gyroscope. The physical concepts of these terms were developed and published at different times. The concept of the inertial force was developed in 1687 [1], *centrifugal force* in 1659 [2], Euler's precession torque in 1765 [2], Coriolis force in 1835 [3], potential and kinetic energies in 1842 [4]. These chronicle dates of the concepts about the physical properties of the matter are evidenced that scientists and researchers of 17-19 centuries could not solve problems of gyroscopic effects in principle. This statement is founded by the obtained system of the physical principles for gyroscopic effects that validated by the practical tests. Scientists and researchers of the following centuries have published simplified gyroscope theories that do not confirm by practice [5-7]. The mathematical models for the gyroscopic effects at the known theories are based only on the action of the center mass of the spinning disc that do not give correct final solutions. Scientists and researchers did not consider the action of distributed mass-elements of spinning objects which dramatically change the physical and mathematical models for gyroscope motions. Unsolved problems of gyroscopic effects forced to derive their numerical models for practical applications in navigation tasks of aviation, ship, transport, and other industries that do not explain their physics [8]. The recent analysis of gyroscopic effects disclosed causal dependencies of the action of inertial torques based on the principle of the kinetic energy conservation law. The actions of the inertial torques interrelate cinematically by the angular velocities of the spinning objects around axes of precession. The fundamental principles of gyroscope theory are presented as the system of the eight inertial torquesmentioned above and by the ratio of the angular velocities of the gyroscope around two axes [9,10]. The new principles of gyroscope theory constitute the base of all mathematical models for the gyroscopic effects of the spinning objects. Derived mathematical models for the gyroscopic effectsbased on the new principles are simple in expressions and can be computed manually. The physics of the simple mechanisms should be described by the simple analytical models. The obtained mathematical models explain the physics of all gyroscopic effects including their most complexas "antigravity", nutation (galloping), resistance, and others. Physical models for the gyroscope motions derived by the new principles practically validated. Nevertheless, the application of a new analytical approach to mathematical modeling of gyroscopic effects discovered a new phenomenon as the appearance of the deactivation of the inertial torques generated by the spinning object. This new effect manifested in the case of the gyroscope motion around one axis. Suchan effect contradicts the principles of physics. The deactivation of the inertial torques of the running gyroscope presented by the form when the product of a mass and acceleration does not give inertial forces. This phenomenon validated by the practice tests but cannot be explained by the known rules and principles of classical mechanics. Such a new gyroscopic effect presents a challenge for the researchers in physics.

Visual presentation of the physical principles for gyroscopic effects is demonstrated in Figure 1. The action of external torque produces the system of interrelated inertial torques generated by the rotating mass of the spinning disc and expresses its motions around axes of the 3D coordinate system (Σoxyz). The vector of the angular velocity of the spinning disc coincides with the axis of the 3D coordinate system. This method enables dramatically simplify expressions of mathematical models for gyroscope motions around axes of rotation if compare with Lagrange's presentation and Euler's angles in the 3D coordinate system. Where$T$ is the external load torque; $T_{ct.i} T_{cr.i} T_{in.i}$ and $T_{am.i}$ is the inertial torque generated by the centrifugal (*ct*), Coriolis (*cr*), common inertial (*in*) forces, and the change in the angular momentum (*am*) around axis *i* respectively; ω, ω_x, ω_y is the angular velocity of the spinning disc around axis *oz,* and its rotation around axes *ox* and *oy* respectively; γ is the angle of the inclination of the spinning disc axel. The single external torque acting on the spinning disc produces four inertial toques around each axis. The defined system of interrelated inertial torques and the ratio of the angular velocities of the spinning disc around axes of rotation constitute the fundamental principles of the gyroscope theory based on the kinetic energy conservation law. The equations for inertial toques and ratio of the angular velocities of the gyroscope are presented in Table 1. Table 1

***Address for Correspondence:** Ryspek Usubamatov, Kyrgyz State Technical University, Bishkek, Kyrgyzstan, E-mail:ryspek0701@yahoo.com*

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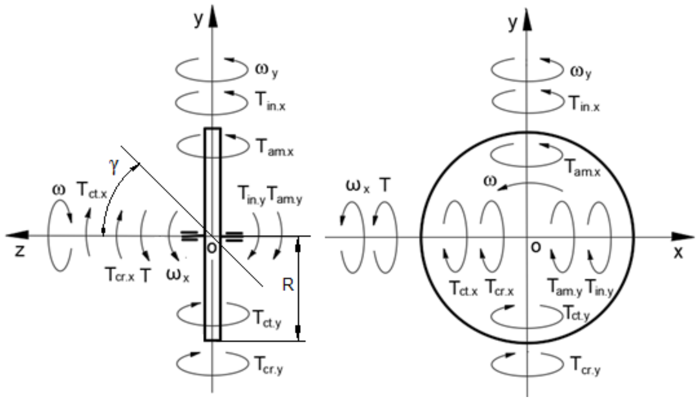

Figure 1. External and inertial torques acting around axes on the spinning disc and its motions around axes.

Types of torques generated by	**Equations around axes of 3D coordinate system**
Torques acting around axis *ox*	
Centrifugal force	$T_{ct.x} = (2/9)\pi^2 J\omega\omega_x$
Coriolis force	$T_{cr.x} = (8/9)J\omega\omega_x$
Common inertial force	$T_{ct.y} = (2/9)\pi^2 J\omega\omega_y$
Change in angular momentum	$T_{am.y} = J\omega\omega_y$
Torques acting around axis *oy*	
Centrifugal force	$T_{ct.y} = (2/9)\pi^2 J\omega\omega_y \cos\gamma$
Coriolis force	$T_{cr.y} = (8/9)J\omega\omega_y \cos\gamma$
Common inertial force	$T_{ct.x} = (2/9)\pi^2 J\omega\omega_x \cos\gamma$
Change in angular momentum	$T_{am.x} = J\omega\omega_x \cos\gamma$
The dependency of angular velocities of a gyroscope rotation around axes	
$\omega_y = \left[\frac{2\pi^2 + 8 + (2\pi^2 + 9)\cos\gamma}{2\pi^2 + 9 - (2\pi^2 + 8)\cos\gamma}\right]\omega_x$	

presents expressions of the eight inertial torques for the thin spinning disc produced by its rotating distributed mass elements and center mass. The mathematical models for the gyroscope motions around every axis should contain expressions of the three inertial toques. The two inertial torques have one expression, namely, the torques of the centrifugal forces and common inertial forces acting around axes *oy* and *ox* respectively that are compensated by the rules of mathematics (Table 1) [10]. This solution is obtained by the principle of equality for kinetic energies of the spinning disc around axes of rotations.

Conclusion

Practically, all rotating objects of different forms and geometries manifest gyroscopic effects. Their distributed mass elements located and rotating along the axis and radii of spinning objects generate inertial torques in which expressions and values are different. In the engineering area, there are numerous mechanisms with rotating components in which geometry can be a ring, sphere, cone, paraboloid, propeller, etc., and combinations of them. Expressions of their inertial torques should be derived and used for the mathematical models of motions of the spinning objects in space. To derive new mathematical models for the inertial torques of rotating objects present the challenge for the researchers. These particularities should be taken into account for engineering calculations of the gyroscopic problems. The new analytical approach for gyroscopic effects enables for deriving the breakthrough gyroscope theory that has expected for a long timeandopens a new chapter in the dynamics of classical mechanics.

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