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Short Communication

The Phenomenon of Gyroscopic Effects

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The phenomenon of gyroscopic effects attracted people since the time of the ancient civilizations. The unusual and unexplainable motions of the simple spinning top toy, boomerang, and other spinning objects astonished people. With the evolution of science, the intricated behavior of the rotating objects under the action of the unknown forces that named gyroscopic effects, did not leave without the attention of the physicists and mathematicians of the Industrial Revolution. However, the solution of the gyroscopic effects dragged to a couple of centuries and proved to be a solid nut for them. One gyroscopic effect is the side motion of the spinning disc under the action of precession torque was described by the mathematician L. Euler in 1725. His solution as the change in the angular momentum is presented in the contemporary world encyclopedias as the fundamental principle of gyroscope theory. He could describe the second gyroscopic effect based on the action of the centrifugal forces but did not do it for an unknown reason. Analytical solutions of other gyroscopic effects could not be defined in principle because they were based on the discoveries of the following century. The Coriolis acceleration (1835) and the physical laws of energies were formulated in the middle of the nineteenth century (1847). Finally, in 1905, Albert Einstein established the concept of "potential and kinetic energy" that was generalized into the form used today.

At the beginning of the twenty century, physicists and mathematicians had all possibilities to describe the gyroscopic effects and explain their physics but it was done after the pass of one century. The methods developed by physics and mathematics enable formulating and solving more complex problems than properties of the simple in the design of the rotating disc. Described above historical events and years show the link with the so-called "human factor" and its ability to innovate.

For the time of the twenty century, scientists and researchers published probably tons of manuscripts and dozens of theories dedicated to gyroscopic effects, but the practice did not confirm their mathematical models [1-3]. For practical applications of the gyroscopic devices were elaborated many numerical modeling of gyroscopic effects with software. Gyroscopic problems remained without solutions and physical explanation until recent times [4-7].

Today, gyroscopic effects are formulated by mathematical models, and their physics is described. In reality, the analytical solutions of gyroscopic effects are proved to be more sophisticated than in published simplified theories. The reason for such a statement is in several physical approaches to the formulation of the mathematical models of the action of the inertial torques on the spinning object. The first is the scientists did not consider the action of the system of torques generated by the centrifugal and Coriolis forces of the distributed mass of the rotating object and the torque of the change in the angular momentum. The second is the mathematical models did not include the interrelation of all torques by the principle of the mechanical energy conservation law of the rotating object.

The origin of gyroscopic effects is the action of the system of inertial torques generated by the rotating mass of the spinning object under the action of the external torque. The spin of the object expresses its kinetic energy and the action of the external torque expresses its potential energy These energies produce the two sets of the four interrelated inertial torques acting about two axes of the gyroscope motions. The set of the inertial torques contains two torques generated by the centrifugal forces and torques generated by the Coriolis forces and the change in the angular momentum. The equality of the kinetic energies of the gyroscopic motion about axes interrelates the action of the system of inertial torques about two axes of gyroscope motions.

The angular velocities of the gyroscope about axes of rotations and the value of inertial torque are different. The physics of the gyroscopic effects have expressed the principle of the conservation of mechanical energy law for spinning objects. The mathematical models for gyroscopic inertial torques were published and represented in table 1 [8-10]. The action of the external and inertial torques is shown in figure 1.

Inertial torques generated by	Action	Equation
Centrifugal forces	Resistance	$T_{ct.i} = (4\pi^2/9)J\omega\omega_i$
	Precession	
Coriolis forces	Resistance	$T_{cr.i} = (8/9)J\omega\omega_i$
Change in angular momentum	Precession	$T_{am.i} = J\omega\omega_i$
Dependency of angular velocities of the spinning disc about axes of rotation: $\omega_y = (8\pi^2 + 17)\omega_x$		

Table 1: The set of inertial torques about each axis of the spinning disc of horizontal disposition.

Where ω_i is the angular velocity about axis i; ω is the angular velocity about axis oz; J is the moment of inertia of the spinning disc.

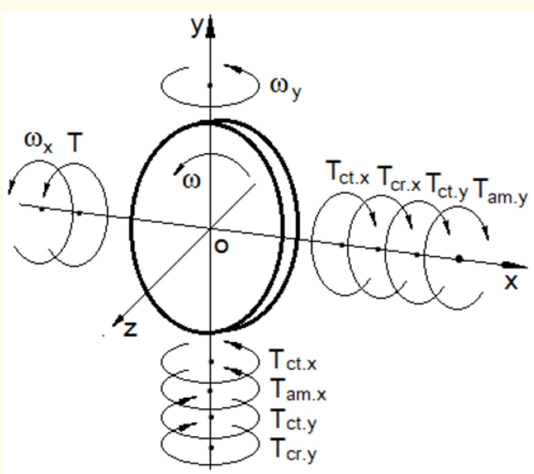

Figure 1: One external and eight inertial torques act on the spinning disc and its motions.

The action of the torques and motions of the spinning disc is presented at the Cartesian 3D coordinate system Σoxyz with coincided axis ox and axle of the disc (Figure 1). The spinning disc rotates with the angular velocity ω in the counter-clockwise direction. The external torque T turns the spinning disc in the counter-clockwise direction about axis ox with the angular velocity ω_x. The external torque T generates the system of the simultaneous action of the inertial torques about two axes. The motions of the spinning disc about axes are implemented due to the interrelations of the inertial torques. The causal investigatory dependencies of actions of inertial torques about two axes are presented by the following steps.

- The external torque T produces the resistance torques ($T_{ct.x}$ and $T_{cr.x}$) that are generated by the centrifugal and Coriolis forces, which are restraint and resistance torques acting about axis ox, and contradict the action of the external torque T.
- The torque T produces the precession torques ($T_{ct.x}$ and $T_{am.x}$) that are generated by the centrifugal forces and the change in the angular momentum acting about axis oy. These precession torques are load torques for the spinning disc originate along with axis ox but act about axis oy in the counter-clockwise direction.
- The spinning disc turns in the counter-clockwise direction about axis oy under the action of the precession torques ($T_{ct.x}$ and $T_{am.x}$). The precession torques ($T_{ct.x}$ and $T_{am.x}$) generate the resistance torques ($T_{ct.y}$ and $T_{cr.y}$) of centrifugal and Coriolis forces which contradict the precession torques.
- The resulting torque about axis oy ($T_{r.y} = T_{ct.x} + T_{am.x} - T_{ct.y} - T_{cr.y}$) is the combination of the precession and resistance torques, generates the precession torques ($T_{ct.y}$ and $T_{am.y}$) of centrifugal forces and the change in the angular momentum acting about axis ox. The sum resistance torques and the precession torques ($T_{r.x} = T_{ct.x} + T_{cr.x} + T_{in.y} + T_{am.y}$) about axis ox constitutes the resulting resistance torque acting opposite to the torque T.
- The total resulting torque acting about axis ox is $T_{t.x} = T - (T_{ct.x} + T_{cr.x} + T_{ct.y} + T_{am.y})$. The total resulting torque acting about axis ox $T_{t.x}$ generates the precession torques acting about axis oy ($T^*_{ct.x}$ and $T^*_{am.x}$) that is not the same as at starting condition (paragraph (a)). The precession torques ($T^*_{ct.x}$ and $T^*_{am.x}$) in turn generate the resistance torque ($T^*_{ct.y}$ and $T^*_{cr.y}$). The equation of the total resulting torque acting about axis oy is presented by the following equation $T_{t.y} = T^*_{ct.x} + T^*_{am.x} - (T^*_{ct.y} + T^*_{cr.y})$.

The inertial torque cannot be separated from the system of inertial torques because all of them are generated by one rotating mass of the spinning objects. The expressions of inertial torques depend on the geometry of the rotating object. Engineering shows many unique rotating designs as propellers, cones, paraboloids, spheres, etc., and all of them manifest gyroscopic effects. The expressions of inertial torques for the complex designs of the rotating objects wait for their own solutions and present the challenge for the engineers and practitioners.

A described peculiarity of the action of inertial torques on the spinning disc expresses the physics of their origination. Inertial torques are proportional to the angular velocity of the spinning disc, to the angular velocity of precession, and its moment of inertia. The action of these torques is presented in the equations of gyroscope motions that depend on the consideration of the gyroscopic problems. The presentation of the action of these torques allows describing the physical processes that result in the gyroscopic effects. All known gyroscopic effects so-called "antigravity effect", "non-inertial", and other artificial terms and anti-scientific statements, are described by the principles of classical mechanics and must be removed from terminology.

The methods of the theory of gyroscopic effects also describe the inversion of the Tippe top nutation of the gyroscope and the cyclic inversions of the rotating objects at the orbital free flight. Any object at the orbital flight is subjected to the action of inertial torques generated by the curvilinear motion. These torques act on the rotating objects that manifest the cyclic inversions that are gyroscopic effects at the free flight.

The physics of gyroscope inertial torques and motions are explained in detail and confirmed by practice. The fundamental principles of gyroscope theory are inertial torques and the dependency of the angular velocities of gyroscope motions about axes of rotation based on the potential and kinetic energy of the spinning disc. Classical mechanics receive a new chapter of the dynamic of rotating objects and new methods for the analysis of the inertial torques and kinetic dependency of rotation of gyroscopes. Today, all gyroscope problems can be solved manually without numerical modeling, and phenomena of gyroscopic effects have been resolved finally and irrevocably.

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