Gyroscope Tests and New Effects

Ryspek Usubamatov

***Abstract*--**The main property of the gyroscope device is maintaining its axis, which mathematical model is formulated on the law of kinetic energy conservation. The nature of gyroscope effects is more complex and known mathematical models do not match the actual motions in the gyroscope devices. Recent investigations demonstrate that in the gyroscope are acting four components: the centrifugal, inertial and Coriolis forces and the change in the angular momentum. The applied torque to the spinning rotor generates the resistance torque based on centrifugal and Coriolis forces. The torque generated by the inertial forces and by the change in the angular momentum of the spinning rotor resulting in the precession torque of a gyroscope. Tests demonstrate that the resistance torques do not generate the reactive forces on the support. The blocking of the gyroscope motion about one axis deactivates the resistance torque. The new mathematical principles for the gyroscope effects are tested and the results practically validated.

***Keywords* -** Gyroscope tyheory, test, property

I. Introduction

GYROSCOPIC effects are relayed in many engineering ılations of rotating parts and gyroscope properties enable function the numerous gyroscope devices in aviation, space and other industries [1, 2]. There are many publications regarding the gyroscope theory as well as many approaches and mathematical solutions that describe the gyroscope properties [3, 4]. There are many valuable publications dedicated to the gyroscope effects and applications in engineering [5, 6]. All publications in the area of gyroscope theory describe gyroscope effects in terms of conservation of kinetic energy and the change in the angular momentum [7]. However, the nature of gyroscope effects is more complex and known theory and mathematical models do not match practice of gyroscope devices [8. 9]. This unaccountable situation with gyroscope effects spawned terms like gyroscope resistance, gyroscope couple and fantastic properties like non inertial, non gravitational, etc. [10, 11]. This is the reason that the gyroscope theory still attracts many researchers who continue to discover new properties among gyroscope devices.

The recent investigations of physical principles of gyroscope motions manifested that four classical forces acting in the spinning rotor generate gyroscope effects. Conducted analyses demonstrate that centrifugal, inertial and Coriolis forces and the rate change in the angular momentum of the spinning rotor are basis of the all gyroscope effects [12]. The external torque applied to the gyroscope generates the torques that based on mentioned forces and motions. In turn, the centrifugal and Coriolis forces generate the resistance torque that counteract on inclination of the rotor's location. The inertial forces and the rate change in the angular momentum of the spinning rotor generate the precession torques. All these torques are interrelated and acted simultaneously. The action of the resistance and precession torques is combined and represented the gyroscope effects. A new mathematical model based on these four physical components describe accurately the gyroscope motions and validated by tests. This new fundamental principles in the gyroscope theory enable to solve gyroscope problems and close the term gyroscope mystery. However, new forces acting in the gyroscope demonstrate new properties that should be taken into account for engineering calculations.

Ryspek Usubamatov is with the School of Manufacturing Engineering, University Malaysia Perlis, 02600 Arau, Perlis, Malaysia. Phone: 6049885131, Fax: 6049885034, ryspek@unimap.edu.my.

II. Methodology

Investigations in the area of the gyroscope effects are represented new mathematical models of gyroscope forces and torques. Resistance torques are generated by action of the centrifugal and Coriolis forces of the gyroscope. Precession torques are generated by action of the inertial forces of the gyroscope and by the change in the angular momentum of the spinning rotor, which value is less than first one. The change of the angular momentum is counter acted to action of the torque generated by the inertial forces. The mathematical model of the resistance torque that generated by the centrifugal and Coriolis forces of a spinning rotor is represented by the following equation [12].

$$T_r = \left[2\left(\frac{\pi}{3}\right)^2 + \frac{8}{9}\right] J\omega\omega_p \qquad (1)$$

where T_r is a resistance torque generated by the centrifugal and Coriolis forces, $J = (mR^2/2)$ is the rotor's mass moment of inertia about the rotor's axis, m is the rotor's mass, R is the external radius of the rotor, ω_p is an angular velocity of resistance precession of a spinning rotor.

The mathematical model of the precession torque generated by the inertial forces and the change in the angular momentum is is contrary and represented by the following equation [12]:

$$T_p = \left[2\left(\frac{\pi}{3}\right)^2 - 1\right] J\omega\omega_p \qquad (2)$$

where T_p is a precession torque and other parameters are as specified above.

The analysis of Eqs. (1) and (2) demonstrates the first component of equations that are the resistance and precession torque, which generated by the centrifugal and inertial forces is the same. These torques are generated by the same rotating masses, which accelerations are directed perpendicular to each other. The action of the inertial forces is perpendicular to the rotor's axis and perpendicular to the axis of the resistance torque.

Analysis of the acting forces in the gyroscope enables to state that actual gyroscope effects have more complex nature than represented by known publications. Table I represents the four different torques generated by the internal forces of the spinning rotor under the action of the external torque applied to the gyroscope. The percentage of action of these torques are different. The change in the angular momentum of the spinning rotor is one component among others and plays not first role at gyroscope physics. Action of this torques should be considered at new mathematical models of gyroscope motions.

The formulated new equations for the resistance and precession torques at defined proportion depend on the mass moment of inertia and the angular velocity of the spinning rotor, as well as on the angular velocity of its precession.

TABLE I
INTERNAL TORQUES ACTING IN GYROSCOPE

Torque generated by	Equation	Percentage of action, (%)
Centrifugal forces	$T_{ct} = T_{in} = 2\left(\frac{\pi}{3}\right)^2 J\omega\omega_x$	34.95
Inertial forces		34.95
Coriolis forces	$T_{cr} = (8/9)J\omega\omega_x$	14.16
Change in an angular momentum	$T_{am} = J\omega\omega_x$	15.94
Total		100
Resistance torque $T_r = T_{ct} + T_{cr}$	$T_r = \left[2\left(\frac{\pi}{3}\right)^2 + \frac{8}{9}\right] J\omega\omega_x$	72.1
Precession torque $T_p = T_{in} - T_{am}$	$T_p = \left[2\left(\frac{\pi}{3}\right)^2 - 1\right] J\omega\omega_x$	27.9
Total		100

The change of the angular momentum of the spinning rotor, which resulting in the precession torque is one component and plays not first role in gyroscope's physics. The gyroscope theory should consider the simultaneous action of the centrifugal, inertial and Coriolis forces and the change in the angular momentum of the spinning rotor, which actually represent fundamental principles of the gyroscope theory.

At constant values of the torques the angular velocity of precessions is constant that contradicts to the principle of classical mechanics which states that under action of external load torque a body rotates with even acceleration. At first sight, on a basis of represented conclusion some publications declare that a gyroscope is non inertial system. However, this statement is not correct by the following reasons:

- Equations (Table 1) represent the internal torques of the spinning rotor. This torques is generated by the external or load torque.
- The angular velocity of precessions is generated by the internal torques of the spinning rotor.
- Internal torques, angular velocities of precessions and angular velocities of rotor's spinning represent the internal energy of the gyroscope which is constant.
- The constant load torque generates the constant angular velocities of precession.

For the gyroscope that act at real condition all torques involved in process of motions about axes interrelated and constant for the given gyroscope parameters. This property of the gyroscope does not contradict to principles of classical mechanics. Hence, gyroscope is inertial system.

New mathematical models lead to new properties and will be useful for modelling the behaviour of the gyroscopic devices. The new analytical approach represents not only new properties with respect to a gyroscope, but also new challenges for future studies of the gyroscopic problems. The gyroscope new properties enable to formulate true gyroscope theory in science.

III. GYROSCOPE TESTS

The action of the internal torques is validated by practical tests of the gyroscope with one side support. The action of internal forces is displayed on the motion of the gyroscope about the axis *ox*. The test on the angular velocities of gyroscope precessions was conducted on the base of the Supper Precision Gyroscope "Brightfusion LTD" (Fig. 1), which technical data are represented in Table II. The velocity of the spinning rotor measured by the Optical Multimeter Tachoprobe Model 2108/LSR Compact Instrument Ltd. with range of measurement 0 – 60,000.00 rpm. The drop of the revolution velocity for the spinning rotor is 67.0 rev/s. For simplicity of calculations, the tests of the gyroscope motions are conducted for the location of the gyroscope axis that close horizontal with deviations ± 10^0. The angular measurements of the location for the gyroscope axis conducted optically and used the angular template with accuracy ± 1.0^0.

The Supper Precision Gyroscope "Brightfusion LTD" designed with spinning rotor of the complex form with components that mounted in the spherical ribbed frame (Fig. 1). The technical parameters of the gyroscope components were calculated and used for the equations of the gyroscope torques that represented in Table I.

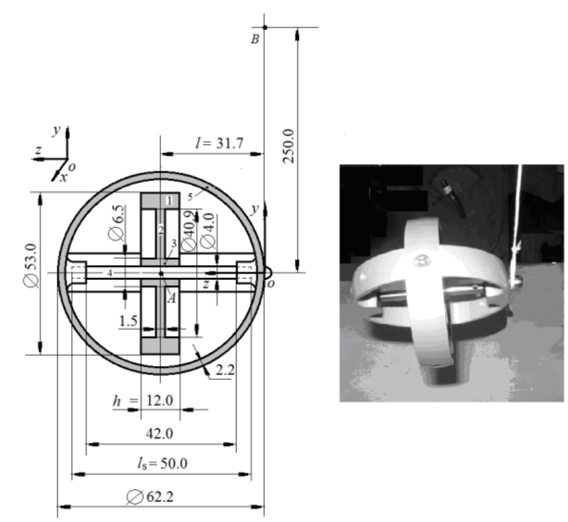


Fig. 1. Geometrical parameters of the Supper Precision Gyroscope "Brightfusion LTD"

TABLE II
DATA OF GYROSCOPE "BRIGHTFUSION LTD"

	Parameters and components		Numerical data
Weight, W	Total gyroscope		0.146 kg
Mass moment of inertia, J kgm^2	Spinning parts about axis *oz*		0.5543873×10^{-4}
	About axis *ox*	Spinning components	1.3981904×10^{-4}
		Total	2.1069097×10^{-4}

The gyroscope with one side free support is suspended on the cord and its weight generates the external torque T that results the gyroscope precessions about the point o of the support, which is the centre of coordinate system $\Sigma oxyz$ (Fig. 2). This type of the tests for the gyroscope with one side free support enables to rotate the gyroscope about two axes *ox* and *oy*. The defined gyroscope parameters (Table II) enable to calculate the values of the internal torques.

TABLE III
TEST RESULTS OF FORCES ACTING IN GYROSCOPE

Gyroscope parameters	Tests, gr	Theoretical, gr
Reaction of the weight	146.0	146.0
Reaction of resistance torque		10.8
Reaction of precession torque		135.2
Total reaction in free support	146.0	292.00

The resistance and precession torques that generated by the centrifugal and inertial forces is represented by the following result:

$$T_{cti} = T_{inri} = 2\left(\frac{\pi}{3}\right)^2 J\omega\omega_{p.i} =$$

$$2\left(\frac{\pi}{3}\right)^2 \times 0.5543873\times10^{-4}\,\omega\omega_{p.i} =$$

$$1.2159074\times10^{-4}\,\omega\omega_{p.i}$$

The resistance torque that generated by the Coriolis forces is represented the following result:

$$T_{cri} = \frac{8}{9}J\omega\omega_{p.i} = \frac{8}{9}\times5.543873\times10^{-5}\,\omega\omega_{p.i} =$$

$$0.4927887*10^{-4}\,\omega\omega_{p.i}$$

where all parameters are as specified above.

The tests of the gyroscope with one side free support on motions are conducted at the horizontal location of the gyroscope axis. The weight of the gyroscope and torques generated by centrifugal, inertial and Coriolis forces and generated by the rate change in the angular momentum of the spinning rotor should react on the free support of the gyroscope. The reactions all these forces are represented by vectors in Fig. 2 according to the rules of classical mechanics.

The formulas of reactive forces acting at the free support by axis *oy* based on action of the gyroscope weight, resistance and precession torques ($F_i = T_i/l$) of the gyroscope are represented by the following equations:

$$F_W = Wg$$
$$F_{rx} = \left[2\left(\frac{\pi}{3}\right)^2 + \frac{8}{9}\right]\frac{J\omega\omega_x}{l} \qquad (3)$$
$$F_{py} = \left[2\left(\frac{\pi}{3}\right)^2 - 1\right]\frac{J\omega\omega_y}{l}$$

where T_i is the torque, l is the overhang of the centre mass of the gyroscope, other parameters are as specified and calculated above.

The tests of the gyroscope with one side free support demonstrate the gyroscope precession velocities about axis *ox*, ω_x = 0.0125386 rad/s and about axis *oy*, ω_y = 0.741588 rad/s. Substituting defined parameters that calculated and represented in Table 2 into Eqs. (3) and transforming yield the following results:

$$F_W = Wg = 0.146\times9.81 = 1.43226N$$

$$F_{rx} = \left[2\left(\frac{\pi}{3}\right)^2 + \frac{8}{9}\right]\frac{J\omega\omega_x}{l} = \left[2\left(\frac{\pi}{3}\right)^2 + \frac{8}{9}\right]\times\frac{0.5543873\times10^{-4}}{0.0317}\times$$

$$\frac{10000\times2\pi}{60}\times0.018826 = 0.106210N = 0.0108kg$$

$$F_{py} = \frac{J\omega\omega_y}{l} = \frac{0.5543873\times10^{-4}}{0.0317}\times\frac{10000\times2\pi}{60}\times0.724428 =$$

$$1.326043N = 0.1352kg$$

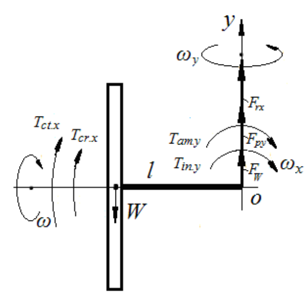


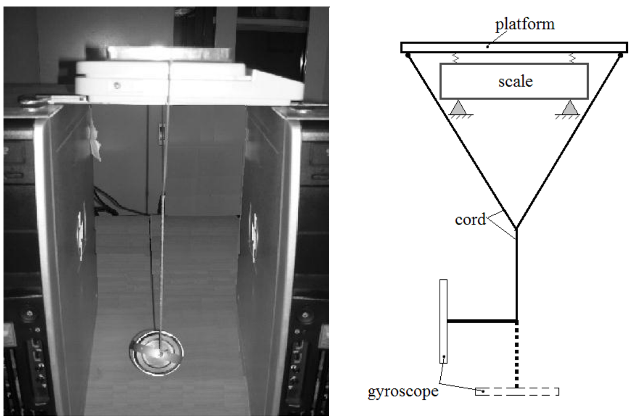
Fig. 2 Reactions of the one side free support of the gyroscope

Total reaction of the free support by axis *oy* on action of the active forces of the gyroscope is as follows:
$F_o = F_W + F_{rx} + F_{py}$ = 1.43226 + 0.106210 + 1.326043 = 2.864513 N = 0.292 kg

The theoretical reaction of the forces acting on the cord does not correspond definitely to the actual magnitude. This disparity leads to practical investigation and validation of the real magnitude of reaction on the cord. Practical test of the gyroscope with one side free support and measurement of the forces action on the cord was conducted by the stand that represented in Fig. 3. The forces were measured by the Compact Digital Scale of the model Taylor TE10FT 5.0 kg with increments 1.0 gr. Figure 3 (a) and (b) represents the photography and the sketch of the stand with the digital scale and the gyroscope with one side support. The gyroscope with one side support is suspended on the flexible cord that connected with the platform of the scale. The tests conducted with the spinning rotor of the gyroscope, which axis of the spinning rotor was at horizontal location.

The results of theoretical calculations by Eq. (3) and measurements of practical tests of the acting forces are represented in Table 3. Results of practical tests of the forces acting on the cord of the support demonstrate that the force generated by the gyroscope weight is equal to the reactive force of the support. The reactive forces that generated by the centrifugal, inertial, Coriolis forces and by the rate change in the angular momentum do not act on the support of the cord or along the axis *oy*. At the first sight this phenomenon contradicts to the rules of the classical mechanics. However, this gyroscope property can be explained by the following reasons:

- The internal resistance torques generated by the centrifugal, inertial, Coriolis forces and by the rate change in the angular momentum are the reaction on action of the load torque.
- The value of the internal resistance torques are acting about axis *ox* does not exceed the value of the load torque. It means this resistance torques is restraint torques only and do not generate the reactive force on the support.



(a) (b)

Fig. 3 Measurement of the acting forces on the gyroscope with one side free support

Described property of the action the gyroscope internal resistance torques is new and should be taken into account for the calculations of the gyroscope forces and motions at different mechanisms and devices. Gyroscope resistance torques that generated by internal forcers do not cause the reaction on the support along the axis *oy*. This statement is contradicted to the rules of the classical mechanics that deal with real forces and moments. However, in the gyroscope are acting the internal forces that are appearing only in process of motions and disappearing in case of absent one. The nature of these proprty of the action the internal forces in mechanical systems did not describe in science and need detailed investigation and mathematical modeling of their physics.

The obtained results, which ate representing new property, can be spread on the action of the torques are acting about axis *oy* that have load torques and resistance torques. In this case, the resistance torques is restraint torques also that do not act on the support. The action of these torques are measured for the gyroscope with fixed supports about axis *ox* when the gyroscope rotation about axis *oy* is blocked or inhibiting demonstrates new properties. These properties are represented as the high angular velocity of the gyroscope rotation about the axis *ox*, which larger then the free gyroscope rotation about two axes. Analysis of acting torques in the gyroscope enables to explain this property by the following reason. In case of the blocking the gyroscope rotation about axis *oy* the following torques are involved in process:

- The torque generated by the inertial forces and the rate change in the angular momentum of the spinning rotor with the precession about axis *ox*, activates the reactive counter torque from the support.
- Reactive counter torque about axis *oy* leads to deactivation of the resistance torque generated by the centrifugal and Coriolis forces about axis *ox* and to deactivation of the resistance torque generated by the inertial and the change in the angular momentum of the spinning rotor about axis *oy*.
- Deactivation of all resistance torques about axis *ox* leads to increasing the angular velocity of the gyroscope precession about the axis *ox*.
- Inhibiting the gyroscope rotation about axis *oy* leads to proportional decreasing the action of the resistance torques that are involved in processes and to proportional increasing the angular velocity of gyroscope precession about axis *ox*.

IV. Results And Discussion

The load torque applied to the gyroscope activates an angular velocity of precessions and generates the resistance and precession torques. The torques based on action of the centrifugal, inertial and Coriolis forces, and the change in the angular momentum of the spinning rotor. This torques act simultaneously and interdependently. Experimental tests of the internal torques for the gyroscope suspended on one side support demonstrate that resistance torque does not generate the reactive force of the support. The values of the resistance torque do not exceed the magnitude of the load torque and inertial torque. Blocking motions of the gyroscope about one axis deactivate the resistance torques.

The known gyroscope theory and mathematical models for gyroscope effects do not consider the action of the internal centrifugal, inertial and Coriolis forces of the rotating mass of spinning rotor, which play a critical role. New mathematical models for the gyroscope effects manifested the new properties and will thus be useful for modelling the behaviour of the gyroscopic devices. The new analytical approach to the gyroscopic effects describes the gyroscope properties at new light.

Acknowledgment

The author would like to thank the University Malaysia Perlis for granting this research and express respect to governing body for their excellent strategic policy in scientific research.

References

[1] G. Greenhill, Report on Gyroscopic Theory, General Books LLC, London, 2010.
[2] R. F. Deimel, Mechanics of the Gyroscope, Dover Publications Inc. New York, 2003.
[3] Gregory D. R., Classical Mechanics, Cambridge University Press, New York, 2006.

[4] R. C. Hibbeler, Engineering Mechanics - Statics and Dynamics, 12th ed. Prentice Hall, Pearson, Singapore, 2010.
[5] M. D. Ardema, Analytical Dynamics. Theory and Application. Academic/Plenum Publishers, New York, 2005.
[6] M. N. Armenise, et al, Advances in Gyroscope technologies, 1st ed., Springer- Verlag New York, LLC, 2010.
[7] H. Weinberg, Gyro Mechanical Performance: the most important parameter, Technical Article MS-2158, *Analog Devices*, Norwood, MA, 2011, pp. 1-5.
[8] T. J. Quinn and A. Picard, The mass of spinning rotors: no dependence on speed or sense of rotation, *Nature 343*, France, 1990, pp. 732 –735
[9] L. Zyga, Gyroscope's unexplained acceleration may be due to modified inertia, *PhysOrg.com***,** July 26, 2011.
[10] J.E. Faller et al., Gyroscope-weighing experiment with a null result. *Physical Review Letters 64, APS Journal*, Vol. 64. No. 8, 1990, pp. 825–826**.**
[11] C. Ciminelli, et al., Advances in Gyroscope Technologies, Springer-Verlag Berlin and Heidelberg GmbH & Co. KG, Berlin, 2010.
[12] R. Usubamatov, Mathematical Model for Gyroscope Effects, *Proceedings of International Conference on Mathematics*, *Engineering and Industrial Applications*, (ICoMEIA 2014), 28~30 May Penang, Malaysia, 2014, Paper 71.

Ryspek Usubamatov graduated from Bauman Moscow State Technical University (MSTU). He is Professional Engineer in Mechanical and Manufacturing Engineering, PhD in Automation of Manufacturing Processes 1972 and Doctor of Technical Sciences, Habil, 1993.
He worked as professional engineer-designer of machine tools in several factories and was lecturing and researching in a number of universities in Central Asia and Malaysia. He is currently with University Malaysia Perlis as a Professor in the School of Manufacturing Engineering.

His current research focus is the areas of the productivity theory for industrial engineering and gyroscope theory. He works in the field of machine tools, metal cutting technology processes, and automated production lines. He has received more then 60 patents of inventions in engineering, published 7 books, 30 brochures and more then 350 papers.