Scientific Journals
Maritime University of Szczecin

Zeszyty Naukowe
Akademia Morska w Szczecinie

2010, 20(92) pp. 75–81

2010, 20(92) s. 75–81

The method of high accuracy at dynamically tuned gyroscope

Metoda wysokiej dokładności w żyroskopach z regulacją dynamiczną

Evgeniy M. Lushnikov

Maritime University of Szczecin, Faculty of Navigation, Institut of Marine Navigation
Akademia Morska w Szczecinie, Wydział Nawigacyjny, Instytut Nawigacji Morskiej
70-500 Szczecin, ul. Wały Chrobrego 1–2

Key words: accuracy, gyroscope's parameters, characteristics of the resonance

Abstract
The method of high accuracy for dynamically tuned gyroscope is presented. The mathematical description and calculation of the gyroscope's parameters which have coefficient of integrating 6.9 are described. The characteristics of the resonance depending of generalized parameter and influence of balance variation on accuracy were analyzed. The result of experiment is according to theory at condition of experiment in vacuum chamber.

Słowa kluczowe: dokładność, parametry żyroskopu, charakterystyka rezonansu

Abstrakt
W artykule zaprezentowano metodę osiągania wysokiej dokładności w żyroskopach z regulacją dynamiczną. Podano opis matematyczny i obliczono parametry żyroskopu o zwiększonej dokładności do 6,9 raza. Przeanalizawano charakterystyki rezonansu w zależności od przyjętego parametru i wpływ wariacji balansu na dokładność. Wyniki badań eksperymentalnych w komorze próżniowej są zgodne z teoretycznymi.

Introduction

The modern space navigating devices have a big overloads on start of rocket (tens g). The requirement of accuracy to gyroscopes of these systems is exclusively high. Classical heavy gyroscopes in these conditions have exhausted the opportunities.

The most effective type of gyroscope in these conditions is a dynamically tuned gyroscope. The first gyroscopes of such type have appeared in Massachusetts Institute of Technology of USA.

This is often called a Hook's joint or a Cardan joint and allows torsion flexibility. At the other end of the drive shaft is a synchronous motor.

These gyroscopes are used widely in marine gyrocompasses, systems of inertial navigation, in rocket and space complexes. The conceptual scheme [1] of such gyroscope is presented at figure 1.

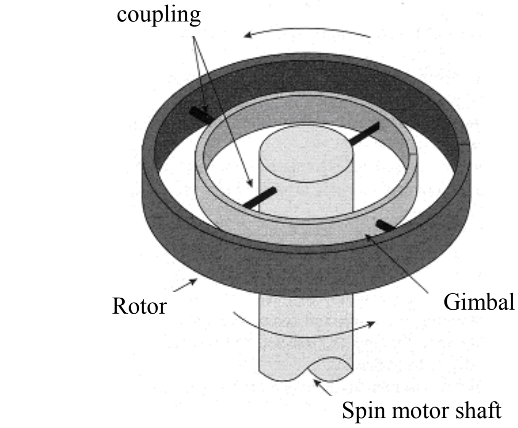

Fig. 1. Dynamically tuned gyroskope rotor and drive shaft assembly [1]
Rys. 1. Rotor i wał napędowy żyroskopu z regulacją dynamiczną [1]

The rotor is connected to the drive shaft by a pair of flexure hinges to an inner gimbals ring. This inner gimbals' ring is also connected to the drive shaft by a pair of flexure hinges, the two axes of freedom being orthogonal. This is an inertial type of gimbals and is far more compact than the external gimbals. At the other end of the drive shaft is a synchronous motor.

Rotation of the gimbals causes a reaction at the rotor that is equivalent to negative torsion spring stiffness. This effect occurs when the angular momentum of the shaft does not coincide with that of the rotor, the angular momentum of the gimbals jumping between that of the shaft and the rotor, at twice the speed of the rotor. Thus careful selection of the torsion stiffness of the gimbals components and rotation speed of the rotor, allows the rotor suspension to have a net zero spring stiffness at a particular rotor speed, known as the tuned speed [1]. Under these conditions, the rotor is decoupled from tie motion of the rest of the sensor and hence is 'free'. In practice, this condition is usually adjusted or trimmed by the use of screws set into the inner gimbals ring that allow minor change in the mass properties of the gimbals.

These gyroscopes are characterized by very stable position of the centre of gravity, high reliability in conditions of the big overloads.

The last modern gyroscope of such type has a three mass and full symmetry of elastic suspension. The same gyroscope is applied today in gyrocompasses [2] with electromagnetic steering.

The suspension of DTG provides stability of gravity center, excludes dry friction and high reliability of construction.

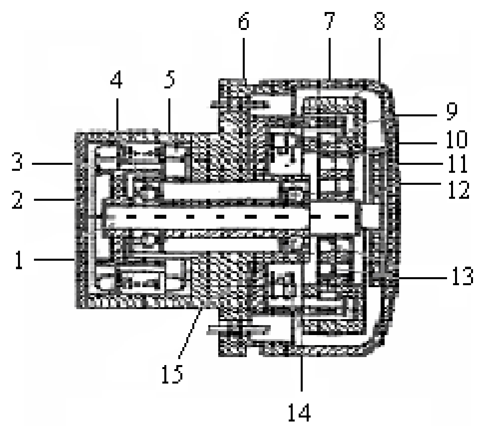

Fig. 2. Construction of dynamical tuned gyroscope (DTG)
Rys. 2. Konstrukcja żyroskopu z regulacją dynamiczną (ŻRD)

At figure 2 it is presented [2] the scheme of DTG of gyrocompass [3] "Yacht". The shaft 1 is situated at bearing 4 and 15. The rotor 8 is fixed at the shaft by means of inner gimbals 10 and elastic elements 10 and 13. The power is transferred by stator 3 and rotor 5.

The system is supplied high stability of rotor's revolving (0.1%). The angle's sensor 14 uses a differential method of measuring. His sensibility is any angles second.

The gyroscope of gyrocompass "Yacht" has diameter 54 mm, length 46 mm and weight 350 gr. The angle speed of gyroscope is $1.256 \cdot 10^3$ s^{-1}. The middle time of reliability is 30 000 hours, speed of keeping up system 200°/s.

The gyrocompasses of such class are Russian gyrocompasses "Giujs", "Yacht", "GKU-5", Russian – South-Koreas gyrocompass "Gyking", a gyrocompass "SKR-82" of Norwegian firm "Robertson", a gyrocompass "Meridian" of British–Russian manufacture.

All these gyrocompasses have high reliability (30 000–50 000 hours of non-failure operation). It is on the order above, than classical gyrocompasses such as "Curs", "Standard" etc. The maximal input rate of system (75 ÷ 200°/s) [3].

Modern gyroscopes of space systems have higher requirements on accuracy and as on overloads during start of rockets; therefore the problem of perfection of gyroscopes is constantly actual. The classical heavy gyroscope has a factor of transmission of entrance influence equal to one unit. It means that a deviation of the main axis of a gyroscope from the basis axis is equal to angle of turn of platform in inertial space. Floating single degree of freedom rate integrating gyroscope has allowed carrying out the factor of transmission in some unit. It was a big success. The same gyroscope in laboratory after Charles Draper had taken accuracy 0.01°/hour [4].

The accuracy of 10^{-4} °/hour [4] is already achieved today in contemporary gyroscopes. The further progress in this part goes with the big problem and by the big expenses. The main obstacles of further increase of accuracy in these gyroscopes were dry friction at axes of suspension and instability of gravity centre of gyroscope.

All these problems are not peculiar for dynamically tuned gyroscope (DTG) with elastic types of suspension. Contemporary type of DTG has a factor of transmission one unit. The possibility of factor transmission increase in DTG is reserve of increase accuracy.

The method of increase of transmission factor for DTG

It is known that in two-mass oscillatory systems can be carry out a mode of dynamic clearing of oscillations by a choice of parameters. It is lawful to raise the question return property, namely about realization of effect of dynamic amplification of oscillations by two rotors DTG. Realization of such task will allow lowering a threshold of sensitivity of a gyroscope and by that to lift his accuracy.

The dynamic model of DTG with two tutors and coaxial elastic element is submitted in figure 3. The gyroscope settles down on a shaft 1. The internal rotor 3 is fastened on a shaft by flexure hinge element 2. The external rotor 5 is fastened on an internal rotor 3 by coaxial flexure hinge element 4.

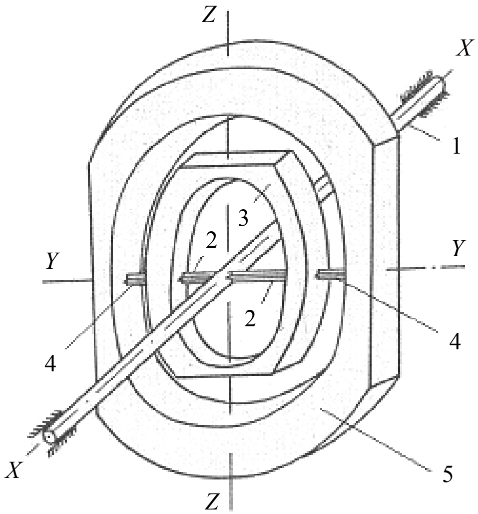

Fig. 3. Generalized dynamic model of two rotors DTG with coaxial flexure hinge element
Rys. 3. Generalizowany model dynamiczny żyroskopu ze współosiowymi sprężystymi elementami

Such model of the gyroscope has oscillation's signal in output.

The differential equations of the gyroscope in rotating system of coordinates, received on the basis of La Grangeau equations have a kind:

$$
\begin{aligned}
& B_1\ddot{\theta}_1 + (A_1 - C_1)\Omega^2\theta_1 + c_{11}\theta_1 + c_{22}(\theta_1 - \theta_2) + \\
& + (k_1 + k_1')\dot{\theta}_1 + k_2(\dot{\theta}_1 - \dot{\theta}_2) - M_1 d_{x_1} j_x \theta_1 + \\
& + M_1 d_{z_1}(j_y \sin\Omega t - j_z \cos\Omega t)\theta_1 = \\
& = \Omega(A_1 + B_1 - C_1)(\omega_y \sin\Omega t - \omega_z \cos\Omega t) - \\
& + M_1 d_{z_1} j_x - M_1 d_{x_1}(j_y \sin\Omega t - j_z \cos\Omega t) \\
& B_2\ddot{\theta}_2 + (A_2 - C_2)\Omega^2\theta_2 - c_{22}(\theta_1 - \theta_2) + \\
& + k_2'\dot{\theta}_2 - k_2(\dot{\theta}_1 - \dot{\theta}_2) + M_2 d_{x_2} j_x \theta_2 + \\
& + M_2 d_{z_2}(j_y \sin\Omega t - j_z \cos\Omega t)\theta_2 = \\
& = \Omega(A_2 + B_2 - C_2)(\omega_y \sin\Omega t - \omega_z \cos\Omega t) - \\
& + M_2 d_{z_2} j_x - M_2 d_{x_2}(j_y \sin\Omega t - j_z \cos\Omega t)
\end{aligned}
\qquad (1)
$$

where:

- A_1, B_1, C_1 – axial and the equatorial moments of inertia of an internal rotor at axis XYZ;
- A_2, B_2, C_2 – axial and the equatorial moments of inertia of an external rotor at axis XYZ;
- Ω – angular frequency of rotation of gyroscope's rotor;
- c_{11} – the module of elasticity moment of the first torsion (from side of shaft);
- c_{22} – the module of elasticity moment of the second torsion (from side of shaft);
- k_1 – the module of the moment of internal friction in the first torsion (from side of shaft);
- k_2 – the module of the moment of internal friction in the second torsion (from side of shaft);
- k'_1 – the module of the moment of external friction in the first torsion;
- k'_2 – the module of the moment of external friction in the second torsin;
- ω_y, ω_z – portable angular speeds of the basis foundation;
- M_1, M_2 – masses of the first and second rotors accordingly;
- d_{x1}, d_{z1} – unbalance of the first rotor on corresponding axes;
- d_{x2}, d_{z2} – unbalance of the second rotor on corresponding axes;
- j_x, j_y, j_z – acceleration of the basis platform along axes X_0, Y_0, Z_0;
- θ_1, θ_2 – the angles coordinates of first and second rotors.

For the aim of simplicity a solving of equations (1) was find at assumptions $k_1 = k'_1 = k_2 = k'_2 = 0$ (system without friction) and at zero entry conditions:

$$
\begin{aligned}
\theta_1(t) = & \frac{1}{2B_1B_2q_1(q_2^2 - q_1^2)}\left[\frac{2q_1R\sin\Omega t}{q_1^2 - \Omega^2} + \right. \\
& \left. + \frac{2q_1S\cos\Omega t}{q_1^2 - \Omega^2} - \frac{2q_1S\cos q_1 t}{q_1^2 - \Omega^2} - \frac{2\Omega R\sin q_1 t}{q_1^2 - \Omega^2}\right] + \\
& + \frac{1}{2B_1B_2q_2(q_2^2 - q_1^2)}\left[\frac{2q_2R\sin\Omega t}{q_2^2 - \Omega^2} + \right. \\
& \left. + \frac{2q_2S\cos\Omega t}{q_2^2 - \Omega^2} - \frac{2q_2S\cos q_2 t}{q_2^2 - \Omega^2} - \frac{2\Omega R\sin q_2 t}{q_2^2 - \Omega^2}\right]
\end{aligned}
\qquad (2)
$$

$$\theta_2(t)=\frac{1}{2B_1B_2q_1\left(q_2^2-q_1^2\right)}\left[\frac{2q_1Q}{q_1^2-\Omega^2}\sin\Omega t+\right.$$
$$\left.+\frac{2q_1T\cos\Omega t}{q_1^2-\Omega^2}-\frac{2q_1T\cos q_1t}{q_1^2-\Omega^2}-\frac{2\Omega Q\sin q_1t}{q_1^2-\Omega^2}\right]+$$
$$+\frac{1}{2B_1B_2q_2\left(q_2^2-q_1^2\right)}\left[\frac{2q_2Q\sin\Omega t}{q_2^2-\Omega^2}+\right. \tag{2}$$
$$\left.+\frac{2q_2T\cos\Omega t}{q_2^2-\Omega^2}-\frac{2q_2T\cos q_2t}{q_2^2-\Omega^2}-\frac{2\Omega Q\sin q_2t}{q_2^2-\Omega^2}\right]$$

where:

$$R=f_1\left(b_2-B_2\Omega^2\right)+f_2c_{22}$$
$$S=-d_1\left(b_2-B_2\Omega^2\right)-d_2c_{22}$$
$$Q=f_2\left(b_1-B_1\Omega^2\right)+f_1c_{22}$$
$$T=-d_2\left(b_1-B_1\Omega^2\right)-d_1c_{22}$$
$$b_1=\left(A_1-C_1\right)\Omega^2+c_{11}+c_{22}$$
$$b_2=\left(A_2-C_2\right)\Omega^2+c_{22}$$
$$d_1=\left(A_1+B_1-C_1\right)\Omega\omega_z-M_1j_zd_{x1}$$
$$d_2=\left(A_2+B_2-C_2\right)\Omega\omega_z-M_2j_zd_{x2}$$
$$f_1=\left(A_1+B_1-C_1\right)\Omega\omega_y-M_1j_yd_{x1}$$
$$f_2=\left(A_2+B_2-C_2\right)\Omega\omega_y-M_2j_yd_{x2}$$
$$q_{1,2}=\mp\sqrt{\frac{c_0}{2a_0}\mp\sqrt{\left(\frac{c_0}{2a_0}\right)^2-\frac{f_0}{a_0}}}$$
$$a_0=B_1B_2$$
$$c_0=B_1b_2$$
$$f_0=b_1b_2-c_{22}^2$$

From solving of equations (2) it is visible, that the gyroscope represents oscillatory system of the fourth order. It is characterized by two own frequencies q_1 and q_2. The condition of dynamical tuned $q_1=\Omega$ or $q_2=\Omega$ allow reaching [3] effect of resonance:

$$\Omega^2=\left(\frac{c_{11}}{2\Delta_1}+\frac{c_{22}}{2\Delta_1}+\frac{c_{22}}{2\Delta_2}\right)\mp$$
$$+\sqrt{\left(\frac{c_{11}}{2\Delta_1}+\frac{c_{22}}{2\Delta_1}+\frac{c_{22}}{2\Delta_2}\right)^2-\frac{c_{11}c_{22}}{\Delta_1\Delta_2}} \tag{3}$$

where:

$$\Delta_1=-\left(A_1-B_1-C_1\right)$$
$$\Delta_2=-\left(A_2-B_2-C_2\right)$$

At condition of resonance ($q_2=\Omega$) the equation (2) is indefinite. The definition of this equation can be exequted by the roole of Lopital:

$$\theta_1(t)=\frac{1}{2B_1B_2q_1\left(\Omega^2-q_1^2\right)}\left[\frac{2q_1R}{q_1^2-\Omega^2}\sin\Omega t+\right.$$
$$\left.+\frac{2q_1S}{q_1^2-\Omega^2}\cos\Omega t-\frac{2q_1S}{q_1^2-\Omega^2}\cos q_1t-\frac{2\Omega R}{q_1^2-\Omega^2}\sin q_1t\right]+$$
$$+\frac{S\cdot t}{2B_1B_2\Omega\left(q_1^2-\Omega^2\right)}\sin\Omega t-\frac{R\cdot t}{2B_1B_2\Omega\left(q_1^2-\Omega^2\right)}\cos\Omega t$$
$$\theta_2(t)=\frac{1}{2B_1B_2q_1\left(\Omega^2-q_1^2\right)}\left[\frac{2q_1Q}{q_1^2-\Omega^2}\sin\Omega t+\right.$$
$$\left.+\frac{2q_1T}{q_1^2-\Omega^2}\cos\Omega t-\frac{2q_1T}{q_1^2-\Omega^2}\cos q_1t-\frac{2\Omega Q}{q_1^2-\Omega^2}\sin q_1t\right]+$$
$$+\frac{T\cdot t}{2B_1B_2\Omega\left(q_1^2-\Omega^2\right)}\sin\Omega t-\frac{Q\cdot t}{2B_1B_2\Omega\left(q_1^2-\Omega^2\right)}\cos\Omega t \tag{4}$$

The most interesting resonant component of the equations solving (4) has the kind:

$$\theta_1=\frac{-1}{2\Omega\left(B_1+B_2\zeta^2\right)}+\left[\left(f_2\zeta+f_1\right)\cos\Omega t+\right.$$
$$\left.+\left(d_2\zeta+d_1\right)\sin\Omega t\right]\cdot t$$
$$\theta_2=\frac{-\zeta}{2\Omega\left(B_1+B_2\zeta^2\right)}\left[\left(f_2\zeta+f_1\right)\cos\Omega t+\right. \tag{5}$$
$$\left.+\left(d_2\zeta+d_1\right)\sin\Omega t\right]\cdot t$$

In expressions (5) designations are entered:

$$\zeta=\frac{1}{2}\left[\left(m+1-n\right)\pm\sqrt{\left(m+1-n\right)^2-4mn}\right]$$
$$m=\frac{c_{11}}{c_{22}} \tag{6}$$
$$n=\frac{\Delta_1}{\Delta_2}$$

The expression (5) in view of the accepted designations and the condition of the resonance (3) can be transformed to the kind:

$$\theta_1=\frac{\left(A_1+B_1-C_1\right)+\left(A_2+B_2-C_2\right)\zeta}{\zeta\cdot 2\left(\dfrac{B_1}{\zeta}+B_2\zeta\right)}\cdot$$
$$\cdot\left(\omega_yt\cdot\cos\Omega t+\omega_zt\cdot\sin\Omega t\right)$$
$$\theta_2=\frac{\left(A_1+B_1-C_1\right)+\left(A_2+B_2-C_2\right)\zeta}{2\left(\dfrac{B_1}{\zeta}+B_2\zeta\right)}\cdot$$
$$\cdot\left(\omega_yt\cdot\cos\Omega t+\omega_zt\cdot\sin\Omega t\right)$$

From these expressions it is visible, that the factors of transmission η for coordinates θ_1 and θ_2 are described by expression:

$$\eta_1 = \frac{1}{\zeta} \cdot \frac{(A_1 + B_1 - C_1) + (A_2 + B_2 - C_2)\zeta}{2\left(\frac{B_1}{\zeta} + B_2\zeta\right)}$$
$$\eta_2 = \frac{(A_1 + B_1 - C_1) + (A_2 + B_2 - C_2)\zeta}{2\left(\frac{B_1}{\zeta} + B_2\zeta\right)} \qquad (7)$$

From formulas (7) it is visible, that factors of transmission of the first and second rotors differ in ζ time. From expression (6) it is visible, that the size of ζ is characterized by two values. This fact view, that increases of transmission factor can be reached in a various ways. Factor $\zeta(m,n)$ is a function of parameters m and n. The parameter n is determined by dependence:

$$n = \frac{A_1 - B_1 - C_1}{A_2 - B_2 - C_2} = \frac{\sum_{i=1}^{k} m_{i1} x_{i1}^2}{\sum_{j=1}^{m} m_{j2} x_{j2}^2} \qquad (8)$$

where:

m_{i1}, m_{j2} – the masses of points of the first and second rotors accordingly;

x_{i1}, x_{j2} – a coordinates of points along axis XX of the first and second rotors accordingly.

From expression (8) it is visible, that change of thickness of a rotor in view of an increment of masses results in increase of number n under the cubic law. The opportunity of essential change of value m a choice of rigidity is obvious. As the parameter ζ is function of easily varied parameters m and n also it will be easily varied.

It is the most expedient to make it by varying of masses characteristics of rotors at set elastic elements or varying flexibility of torsions at the set rotors. It is necessary to remember, that all this satisfies must be exequted at condition of a resonance (2). At the foundation of theoretical analysis it was designed a gyroscope having parameters:

$A_1 = 1{,}0 \cdot 10^4 \ \text{g} \cdot \text{cm}^2$ $\qquad A_2 = 1{,}715 \cdot 10^1 \ \text{g} \cdot \text{cm}^2$

$B_1 = 5{,}21 \cdot 10^3 \ \text{g} \cdot \text{cm}^2$ $\qquad B_2 = 1{,}882 \cdot 10^1 \ \text{g} \cdot \text{cm}^2$

$C_1 = 5{,}21 \cdot 10^3 \ \text{g} \cdot \text{cm}^2$ $\qquad C_2 = 6{,}1 \ \text{g} \cdot \text{cm}^2$

$c_{11} = 528 \ \text{n} \cdot \text{cm}$ $\qquad c_{22} = 11 \ \text{n} \cdot \text{cm}$

The scheme of such gyroscope is presented at the figure 4. Numbers are so as at figure 3. Calculations have shown, that the factor of integration at such gyroscope makes 6.9. It means that his accuracy is higher of a usual gyroscope practically in seven times.

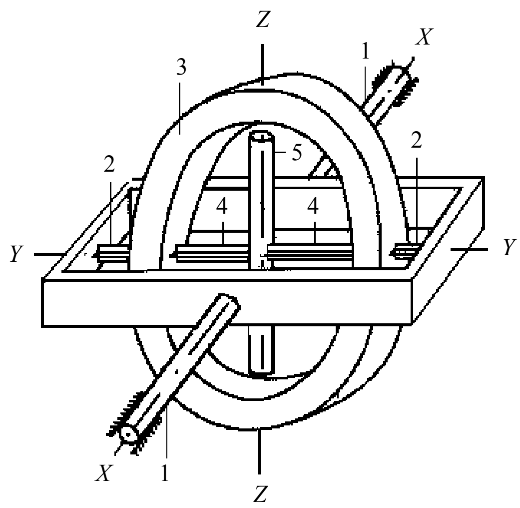

Fig. 4. The scheme of DTG of high sensitiveness
Rys. 4. Schemat ŻRD o wysokiej czujności

Experimental check of such gyroscope in conditions of a pressure chamber at pressure 80 hp has allowed to receive factor of integration 5.4. It is established, that in process of pumping out of air from the chamber the factor of transmission grows to settlement value. In figure 5 dependence of factor of trasmission η on the generalized parameter ζ is shown.

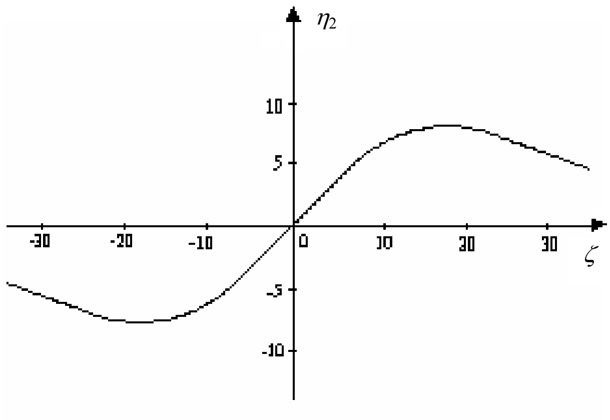

Fig. 5. Dependence of transmission factor η on the generalized parameter ζ
Rys. 5. Zależność współczynnika η od przyjętego parametru ζ

The schedule 3 is designed at the constant moments of inertia A_1, B_1, C_1, A_2, B_2, C_2. Change of the factor ζ, determined in value m and n, within the limits of technological admissions changes very little. The requirement of a maximum of transmission factor is carried out easily enough from this reason.

Dependance of resonance curve from parameters of gyroscope

The magnitude characteristic in dependance of rotations of the gyroscope are presented in figure 6.

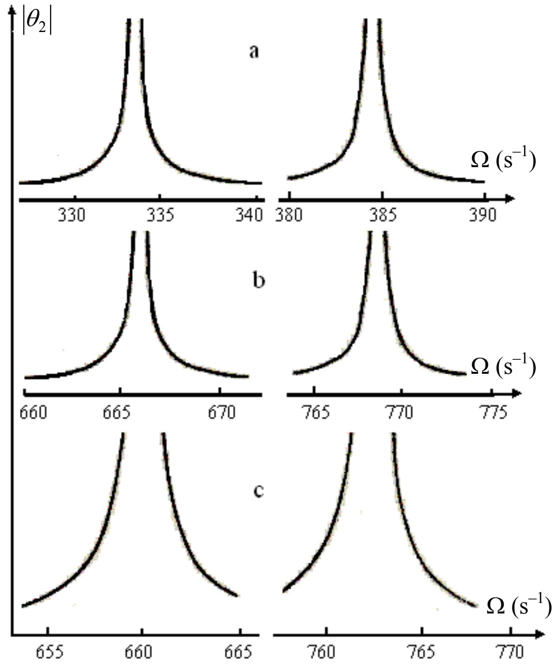

Fig. 6. Resonanse curve at diferent parameter of DTG
Rys. 6. Krzywe resonansu przy różnych parametrach ŻRD

It can see from resonant characteristics, that a primary factor determining width of the resonant zone is a geometry of rotors.

Parameters of DTG for variants a, b, c (Fig. 6) is presented in table 1.

Table 1. The table of comparison DTG
Tabela 1. Tabela porównawcza wariantów DTG

Variant	Ω [s^{-1}]	Rotors parameter [g·cm^2]	c_{11}, c_{22} [n·cm]
A	$\Omega_1 = 325$ $\Omega_2 = 384$	$A_1 = 1\cdot10^4$, $A_2 = 17,5$ $B_1 = 5,21\cdot10^3$, $B_2 = 19,2$ $C_1 = 5,21\cdot10^3$, $C_2 = 6,22$	$c_{11} = 530$ $c_{22} = 10,5$
B	$\Omega_1 = 670$ $\Omega_2 = 768$	$A_1 = 1\cdot10^4$, $A_2 = 17,5$ $B_1 = 5,21\cdot10^3$, $B_2 = 19,2$ $C_1 = 5,21\cdot10^3$, $C_2 = 6,22$	$c_{11} = 2120$ $c_{22} = 42$
C	$\Omega_1 = 670$ $\Omega_2 = 768$	$A_1 = 1\cdot10^4$, $A_2 = 18$ $B_1 = 5,05\cdot10^3$, $B_2 = 18$ $C_1 = 5,21\cdot10^3$, $C_2 = 2$	$c_{11} = 530$ $c_{22} = 10,5$

Calculations and experimental data had shown, that a variation geometry of rotors is more effectively, than a variation of torsion's elastic. In these cases it is possible to receive wider resonant zone that enables to lower requirements to accuracy of stabilization of revolutions of a gyroscope.

Thin rotors are according to widely the resonant zone and it is better quality of the gyroscope. The flexibility of torsions (at performance of the condition of resonance) is invariant parameter regarding resonant characteristics.

Influence of static unbalance on accuracy of DTG

If the angular speeds ω_y and ω_z are equal to zero, from expressions (1) we shall receive target reaction of the gyroscope to acceleration as:

$$\theta_1 = \frac{1}{\zeta}\cdot\frac{M_2 d_{x2}\zeta + M_1 d_{x1}}{2\Omega\left(\frac{B_1}{\zeta} + B_2\zeta\right)}\left(j_y \cos\Omega t + j_z \sin\Omega t\right)\cdot t$$
$$\theta_2 = \frac{M_2 d_{x2}\zeta + M_1 d_{x1}}{2\Omega\left(\frac{B_1}{\zeta} + B_2\zeta\right)}\left(j_y \cos\Omega t + j_z \sin\Omega t\right)\cdot t \qquad (9)$$

From expressions (9) it is visible, that the sensitivity of the device to influence of unbalance also grows. However by virtue of solidity of design DTG this circumstance does not conduct to negative consequences. To reduction the influence of unbalance conducts as a trivial measure – increase of revolving a gyroscope Ω.

Limiting sensitivity of the gyroscope

Limiting sensitivity of the gyroscope is determined by the minimal amplitude of oscillations on frequency Ω which are felt by servo system of the gyroscope. The amplitude of the compelled oscillations for a case of resonant adjustment is found by the account of friction as:

$$|\theta_1| = \frac{\left(A_1 + B_1 - C_1\right) + \left(A_2 + B_2 - C_2\right)\zeta}{\left(k_1 + k_1' + k_2\right) + \left(k_2 + k_2'\right)\zeta^2}\,\omega_{(y,z)}$$
$$|\theta_2| = \zeta\,\frac{\left(A_1 + B_1 + C_1\right) + \left(A_2 + B_2 + C_2\right)\zeta}{\left(k_1 + k_1' + k_2\right) + \left(k_2 + k_2'\right)\zeta^2}\,\omega_{(y,z)} \qquad (10)$$

DTG in an integrating mode works with servo system. The servo system always has the angle of tolerance determined by an angle α_s. The gyroscope will be tolerant to angular speed of a platform at amplitude of the compelled oscillations less than α_s. The angular speed of drift from this reason can be find from condition $|\theta_2| = \alpha_s$. It value is characterized by expression:

$$\omega_{dr} = \frac{\left(k_2 + k_2'\right)\zeta + \left(k_1 + k_1' + k_2\right)\frac{1}{\zeta}}{\left(A_2 + B_2 - C_2\right)\zeta + \left(A_1 + B_1 - C_1\right)}\alpha_c \qquad (11)$$

From this expression it is visible, that the role of internal friction of the second torsions grows, and the first torsions weakens. The drift of the gyroskope is proportional to an angle of insensitivity α_s of servo system. For reduction of drift the sensitivity of servo system should be maximal, and torsions must be produced from high quality steel.

Conclusion

The method of increase of integration factor for DTG offered and checked up experimentally is effective and allows increasing accuracy of the device on the order.

Solidity of a design and as consequence high stability of mass centre provides reliability and high accuracy of the gyroscope.

For reduction requirements to servo system it is necessary to produce a vacuum. for the gyroscope For space conditions it does not represent the big complexities.

The requirements regarding stabilization of revolving of the gyroscope do not fall outside the limits requirements at usual classical gyroscopes.

References

1. TITTERTON D., WESTON J.: Strapdown Inertial Navigation Technology. 2-nd Edition. The Institution of Electronical Engineers, Reston USA 2004.
2. LUSHNIKOV E.M.: Safety of navigation. BGA, Kaliningrad 2007.
3. SMIRNOV E.L. et al.: Sea navigating technics. Elmor, Sankt Petersburg 2002.
4. DZHASHITOV V.E., PANKRATOV V.M.: Gauges, devices and systems of aerospace and sea instrument making. Electropribor, Sankt Petersburg 2005.