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ABOUT A REALIZATION OF SERVO-CONSTRAINTS, IMPOSED ON THE CORRECTED GYROCOMPASS

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Abstract - On this paper the realization problem of servo-constraints, which is imposed on a gyrocompass to be corrected, is considered. The equations of motions of a corrected gyrocompass in it nutational motions are received. For realization of servo-constraints, imposed on a corrected gyrocompass, it is offered to construct digital watching system (DWS) and the laws of formation of operating influences are defined out of the full system of equations of DWS. The conditions, at which steady realization of parities of servo-constraints is provided, will be received.

***Key words*: a corrected gyrocompass, gyro chamber, servo-constraints, nutationalal motion, the stability, non-indignant motion, digital watching system (DWS).**

1. Introduction.

The gyroscopic compass, which is a sensitive element, is established on the platform stabilized in the horizon and resulted in a meridian by means of adjusting the rotating moments enclosed to a gyroscope [1] (pages 80), that is possible to name as a corrected gyrocompass.

Let us consider a problem of stabilization in relation to servo-constraints of gyrocompass that is to be corrected [1-4], containing a static gyroscope, an external axis of kardan rings, which is mounted on the stabilized platform on the horizon. Using an auxiliary energy source in the system the certain configuration should work out which is considered in the appointment of the device.

II. Construction of the dynamic equations

For a conclusion of the equations of motions the following systems of coordinates are entered [4]:

$O\zeta\eta\xi$ - the system, the beginning of which coincides with a point of a root of a gyrocompass, the axis $O\xi$ is directed on the radius of the Globe, $O\zeta$ - on the same way to the parallel on the east, $O\eta$ - on the same way to a meridian on the north;

$Ox_1y_1z_1$ - the system connected with an external ring in the way that an axis Oz_1 coincides with axis $O\xi$, and the axis Ox_1 is directed on an axis of rotation of an internal ring of the gyroscope;

Oxyz - the system connected with gyro chamber, so that the axis *Ox* coincides with the axis Ox_1, and the axis *Oz* is directed by the axis of rotation of a rotor.

Relative position of an external ring in the system $O\zeta\eta\xi$ is set by α angle, and the position of gyro chamber concerning the external ring is set by β angle. Angular speed of specific rotation of a gyroscope is designated as $\dot{\gamma}_2$. Absolute angular speeds for an external ring $\overline{\Omega}_1$, an internal ring $\overline{\Omega}_2$

and a rotor $\overline{\Omega}_3$ will be accordingly equal to

$$\overline{\Omega}_1 = \vec{\omega} + \dot{\alpha}_6 \overline{\xi}^o \quad , \quad \overline{\Omega}_2 = \vec{\omega} + \dot{\alpha}_6 \overline{\xi}^o + \dot{\beta}_2 \overline{x}_1^o \quad ,$$
$$\overline{\Omega}_3 = \overline{\omega} + \dot{\alpha}_6 \overline{\xi}^o + \dot{\beta}_2 \overline{x}_1^o + \dot{\gamma}_2 J^o$$

whereas $\vec{\omega}$ - absolute angular speed of rotation of system $O\zeta\eta\xi$;

$\overline{\xi}^o, \overline{x}_1^o, \overline{J}^o$ - unitary vectors of corresponding axes.

By *p, q, r* designating projections $\vec{\omega}$ to axes $O\zeta$, $O\eta$, $O\xi$ the following values will be achieved for projections of angular speed of an external ring to the axes connected with it:

$$\Omega_{1x} = p \cdot \cos\alpha_6 + q \cdot \sin\alpha_6 \quad , \quad \Omega_{1y} = q \cdot \cos\alpha_6 - p \cdot \sin\alpha_6 \quad , \quad \Omega_{1z} = r + \alpha_6$$

Projections of angular speed of the gyro chamber on the axis *Oxyz* will be equal to:

$$\Omega_x = \Omega_{1x} + \dot{\beta}_2 \quad , \quad \Omega_y = \Omega_{1y} \cdot \cos\beta_2 + \Omega_{1z} \cdot \sin\beta_2 \quad , \quad \Omega_z = \Omega_{1z} \cdot \cos\beta_2 - \Omega_{1y} \cdot \sin\beta_2 \ .$$

And for projections of angular speed of a rotor to the same axes will be equal to:

$$\Omega_{3x} = \Omega_x \quad , \quad \Omega_{3y} = \Omega_y + \dot{\gamma}_2 \quad , \quad \Omega_{3z} = \Omega_z ,$$

Kinetic energy of the system will be equal to:

$$T = T_1 + T_2 + T_3, \qquad (1)$$

whereas, T_1, T_2, T_3 -kinetic energy of subsequent external ring, gyro chamber of a rotor.

The following designations will be entered:

A, B, C - the main moments of inertia of a rotor to a point O;

A_1, B_1, C_1 and A_2, B_2, C_2 -the main moments of inertia on the point O of gyro chamber and of an external ring accordingly.

Considering the rotor symmetric to its axis of rotation with the equal equatorial moments (A=B), and the main axes of inertia of gyro chamber is directed to the axes Ox, Oy and Oz, kinetic energy (1) systems we will look like:

$$T = \frac{1}{2}\Big\{A_2\Omega_{1x}^2 + B_2\Omega_{1y}^2 + C_2\Omega_{1z}^2 + (A + A_1)\Omega_x^2 + (A + C_1)\Omega_z^2 + B_1\Omega_y^2 + G_1(\Omega_y + \dot{\gamma}_2)^2\Big\} \qquad (2)$$

where G_1- is the moment of inertia of a rotor concerning an axis *Oy* of own rotation.

According to the purpose of the device (compass) there should be imposed servo-constraints on the system [5]

$$\alpha = 0 \quad , \quad \beta = 0 \qquad (3)$$

expressing the condition of coincidence of the axis of a rotor of the gyroscope with a direction of axis $O\eta$. Considering that the moment of forces of resistance concerning the axis of a rotor of gyroscope Oy is counterbalanced by the active rotating moment, suppose

$$Q_\gamma = 0$$

From (2) it looks like,

$$\frac{\partial T}{\partial \dot{\gamma}} = G_1(\Omega_y + \dot{\gamma}) \quad , \quad \frac{\partial T}{\partial \gamma} = 0 ,$$

It is obtained

$$G_1(\Omega_y + \dot{\gamma}) = H = const$$

Working out the equations of LaGrange on co-ordinates α and β, it is received:

$$(B + C_1)(\ddot{\alpha} + \dot{r}) + (A + C_1 - B_1)\dot{\Omega}_z \cdot \cos\beta +$$

$$(B_1 + B_2 - A_2)\cdot\Omega_{1x}\Omega_{1y} + [H\cdot\cos\beta - (A + A_1)\Omega_{1y} - (A + C_1 - B_1)\cdot\Omega_z](\dot\beta + \Omega_{1x}) = \Phi_\alpha,$$

$$(A + A_1)(\ddot\beta + \dot\Omega_{1x}) + [(A + C_1 - B_1)\Omega_y - H]\Omega_z = \Phi_\beta \quad (4)$$

where Φ_α, Φ_β - the correcting rotating moments enclosed to a gyrocompass concerning axes O_ξ and Ox_1 (reaction of constraints of the second sort).

In references [3;4] being limited to consideration precession motion, i.e. at assumptions the problem of stabilization of a corrected gyrocompass is considered. However, a scope of a corrected gyrocompass, at which correcting moments Φ_α , Φ_β are generated under the laws resulted in [2; 3], it is limited. It cannot be used, for example, in spaceships as it is constructed on the basis of the theory of precession motion of gyroscopes, i.e. at assumptions $\dot\gamma >> \dot\alpha, \dot\beta$.

For the purpose of creation of more exact gyroscopic devices in [6] believing, what the ship moves with constant speed, and the moments of inertia of a gyroscope satisfy to conditions

$A + C_1 - B_1 = 0$, $B_1 + B_2 - A_2 = 0$

the following law of formation of the correcting rotating moments is offered:

$$\Phi_\alpha = D\left[\frac{\upsilon}{R}\cos(x - y)(\dot x - \dot y)\cdot tg\varphi_1 - \kappa_1\dot y - \kappa_1 y\right] + \left[H\cdot\cos\beta_2 - E\left(\omega\cdot\cos\varphi_1\cdot\cos y + \frac{\upsilon}{R}\sin x\right)\right]\dot\beta + H\left(\omega\cdot\cos\varphi_1\cdot\sin y - \frac{\upsilon}{R}\cos x\right)\cdot\cos\beta,$$

$$\Phi_\beta = E\cdot\left[\ddot\beta + \omega\cdot\cos\varphi_1\cdot\dot y + \frac{\upsilon}{R}\cdot\sin x\cdot\dot x\right] + \left[H\left(\omega\cdot\cos\varphi_1\cdot\cos y + \frac{\upsilon}{R}\sin x\right)\sin\beta - \left(\dot y + \omega\cdot\sin\varphi_1 + + \frac{\upsilon}{R}tg\varphi_1\cdot\sin(x - y)\right)\cdot\cos\beta\right] \quad (5)$$

Where

$$x = \varphi_1 + \beta$$

$$y = -\frac{1}{\kappa_5}\left(\ddot\beta + \kappa_3\dot\beta + \kappa_4\beta\right),$$

$D = B_1 + C_1$, $E = A + A_1$,

here φ_1 **- latitude of location ;** $\kappa_3, \kappa_4, \kappa_5$ **- any constants,** which provides asymptotically steady realization of servo-constraints (3) at any initial deviations.

III. The realization of servo-constraints

We will consider a realization problem of servo-constraints (3). From references [4,7] it is known, that watching systems can be, for example, of the systems containing servo-constraints. Therefore for realization of servo-constraints (3) the digital watching system (DWS) which function chart is resulted in work [8] can be constructed. If for executive element DWS to accept the electric machine (EM) a direct current of independent excitation, the full system of equations DWS will consist from:

1) the equations of object of management (OM):

$$(B_1 + C_1)(\ddot\alpha + \dot r) + (A + C_1 - B_1)\cdot\dot\Omega_3\cdot\cos\beta + (B_1 + B_2 - A_3)\cdot\Omega_{1x}\Omega_{1y} + [H\cdot\cos\beta - (A + A_1)\Omega_{1y} - (A + C_1 - B_1)\Omega_z\cdot(\dot\beta + \Omega_{1x}) + J_{я_1}\cdot i_1^2\cdot\ddot\alpha - i_1 K_{m_1}\cdot I_1 = 0$$

$$(A + A_1)(\ddot\beta + \Omega_{1x}) + [(A + C_1 - B_1)\Omega_y - H]\Omega_z + J_{я_2}\cdot i_2^2\cdot\ddot\beta - i_2 K_{m_2}\cdot I_2 = 0, \quad (6)$$

where $J_я$ - the moment of inertia of anchor of electric machine , K_m - factor of the rotary moment; I_1, I_2 – a current strength of a chain of an anchor; i_1,i_2 - factors of transfers.

2) the equations of balance of pressure of a chain of an anchor of electric machines (EM) :

$$L_1\dot{I}_1 + R_1 I_1 + K_{\omega_1} \cdot i_1 \cdot \dot{\alpha} = U_1^{УП},$$

$$L_2\dot{I}_2 + R_2 I_2 + K_{\omega_2} \cdot i_2 \cdot \dot{\beta} = U_2^{УП}, \quad (7)$$

where L_1, R_1 - inductance and active resistance of an anchor chain; $K_{\omega_1}, K_{\omega_2}$ - factor against-EDS and the rotary moment; $U_1^{УП}$ $U_2^{УП}$ - pressure of a chain of an anchor.

3) the equations of the converter of a code in pressure (CCP):

$$T_{\alpha_3}^{ПКН} \cdot \dot{U}_{\alpha_3}^{ПКН} + U_{\alpha_3}^{ПКН} = K_{\alpha_3}^{ПКН} \cdot x_{\alpha_3}^{ЦВМ}, \quad (8)$$

where $U_j^{ПКН}$ - target parameter (pressure) CCP.

4) the amplifier-converter equations:

$$T_j^{УП}\dot{U}_j^{УП} + U_j^{УП} = K_j^{УП} \cdot U_j^{ПКН} \quad (j=1,\dots,n) \quad (9)$$

where: $U_j^{УП}$ - pressure on an amplifier-converter exit; $T_j^{УП}, K_j^{УП}$ - time of delay and strengthening factor.

5) the equations of the digital watching machine (DWM):

$$T_{\alpha_3}^{ЦВМ} \cdot \dot{x}_{\alpha_3}^{ЦВМ} + x_{\alpha_3}^{ЦВМ} = f_{\alpha_3}\left(x, \beta, \dot{\alpha}, \ddot{\alpha}, \dot{\beta}, \ddot{\beta}, \upsilon, \varphi_1, L_1, \dots\right), \quad (\alpha_3 = 1,\ 2) \quad (10)$$

where $x_{\alpha_3}^{ЦВМ}$ - target parameters (codes) DWM; $T_{\alpha_3}^{ЦВМ}$ - time of delay DWM; f_{α_3} - some function of the arguments.

6) the equations of the scheme of the converter :

$$T_{\beta_3}^{СП} \cdot \dot{x}_{\beta_3}^{СП} + x_{\beta_3}^{СП} = K_{\beta_3}^{СП} \cdot U_{\beta_3}^{D}, \quad (\beta_3=0,\dots,8) \quad (11)$$

where $K_{\beta_3}^{СП}$ - factor of transfer of the scheme of the converter ; $x_{\beta_3}^{СП}$ - target codes of the scheme of the converter ; $T_{\beta_3}^{СП}$ - delay time.

7) the equations of gauges measurements (GM):

$$T_{\beta_4}^{D} \cdot \dot{U}_{\beta_4}^{D} + U_{\beta_4}^{D} = K_{\beta_4}^{D} \cdot \beta^{(\beta_4)}, \quad (\beta_4=0,\dots,3;\ \alpha_3=1,\dots,2)$$

$$T_{3+\alpha_3}^{D} \cdot \dot{U}_{3+\alpha_3}^{D} + U_{3+\alpha_3}^{D} = K_{3+\alpha_3}^{D} \cdot \alpha^{(\alpha_3)}, \quad (\alpha_3=1,\dots,2)$$

$$T_6^D \cdot \dot{U}_6^D + U_6^D = K_6^D \cdot x,$$

$$T_7^D \cdot \dot{U}_7^D + U_7^D = K_7^D \cdot \varphi_1$$

$$T_8^D \cdot \dot{U}_8^D + U_8^D = K_8^D \cdot \upsilon \quad (12)$$

where U_j^D - target parameter; K_j^D - transfer factor; T_j^D - delay time.

From system of the equations:

$$D\left[\frac{\upsilon}{R}\cos(x-y)(\dot{x}-\dot{y})\cdot tg\varphi_1 - \kappa_1\dot{y} - \kappa_2 y\right] +$$

$$+\left[H \cdot \cos\beta - E\left(\omega \cdot \cos\varphi_1 \cdot \cos y + \frac{\upsilon}{R}\sin x\right)\right]\dot{\beta}$$

$$+ H\left(\omega \cdot \cos\varphi_1 \cdot \sin y - \frac{\upsilon}{R}\cos x\right)\cos\beta +$$

$$+ J_{я_1} \cdot i_1^2 \cdot \ddot{\alpha} - i_1 \cdot K_{m_1} \cdot I_1 = 0,$$

$$E\left(\ddot{\beta}+\omega\cdot\cos\varphi_1\cdot\dot{y}+\frac{\upsilon}{R}\cdot\sin x\cdot\dot{x}\right)+$$
$$\left[\left(\omega\cdot\cos\varphi_1\cdot\cos y+\frac{\upsilon}{R}\sin x\right)\sin\beta\;-\right.$$
$$\left.-\left(\dot{y}+\omega\cdot\sin\varphi_1\cdot-\frac{\upsilon}{R}\cdot tg\varphi_1\cdot\sin(x-y)\right)\cdot\cos\beta\right]$$
$$+J_{я_2}\cdot i_2^2\cdot\ddot{\beta}\;-i_2\cdot K_{m_2}\cdot I_2=0,$$

$$L_1\dot{I}_1+R_1I_1+K_{m_1}\cdot i_1\cdot\dot{\alpha}=U_1^{УП},$$
$$L_2\dot{I}_2+R_2I_2+K_{m_2}\cdot i_2\cdot\dot{\beta}=U_2^{УП},$$

$$T_{\alpha_3}^{УП}\cdot\dot{U}_{\alpha_3}^{УП}+U_{\alpha_3}^{УП}=K_{\alpha_3}^{УП}\cdot U_{\alpha_3}^{ПКН},$$
$$T_{\alpha_3}^{ПКН}\cdot\dot{U}_{\alpha_3}^{ПКН}+U_{\alpha_3}^{ПКН}=K_{\alpha_3}^{ПКН}\cdot x_{\alpha_3}^{ЦВМ},$$

$$T_{\alpha_3}^{ЦВМ}\cdot\dot{x}_{\alpha_3}^{ЦВМ}+x_{\alpha_3}^{ЦВМ}=$$
$$f_{\alpha_3}\left(x,\dot{\alpha}_6,\ddot{\alpha}_6,\beta_2,\dot{\beta}_2,\ddot{\beta}_2,\upsilon,\dot{\varphi}_1,L_{\alpha_3},...\right)$$

$$T_{\beta_3}^{СП}\cdot\dot{x}_{\beta_3}^{СП}+x_{\beta_3}^{СП}=K_{\beta_3}^{СП}\cdot U_{\beta_3}^{D},$$
(β_3=0,…,8; α_3=1,…,3)

$$T_{\beta_4}^{D}\cdot\dot{U}_{\beta_4}^{D}+U_{\beta_4}^{D}=K_{\beta_4}^{D}\cdot\beta^{(\beta_4)},$$
(β_4=0,…,3)

$$T_{3+\alpha_3}^{D}\cdot\dot{U}_{3+\alpha_3}^{D}+U_{3+\alpha_3}^{D}=K_{3+\alpha_3}^{D}\cdot\alpha^{(\alpha_3)},\quad (\alpha_3=1,\dots,2)$$

$$T_6^D\cdot\dot{U}_6^D+U_6^D=K_6^D\cdot x,$$
$$T_7^D\cdot\dot{U}_7^D+U_7^D=K_7^D\cdot\dot{\varphi}_1$$

$$T_8^D\cdot\dot{U}_8^D+U_8^D=K_8^D\cdot\upsilon$$
(13)

Let's define the law, on which it is necessary to form operating codes on DWM to receive correcting moments (5). For the simplified model of digital watching system, i.e. at assumptions [9,11],

$$T_j^{ЦВМ}=T_j^{ПКН}=T_j^{УП}=T_j=0,\quad (j=1,\dots,n)$$

$$T_{j_2}^{D}=T_{j_2}^{СП}=0,\quad (j_2=1,\dots,(2n)) \qquad (14)$$

having solved system of the equations (13) rather $x_1^{ЦВМ}$ and $x_2^{ЦВМ}$, we will receive:

$$x_1^{ЦВМ}=\frac{R_1}{i_1\cdot K_1^{УП}\cdot K_1^{ПКН}\cdot K_{m_1}}\left\{J_{я_1}\cdot i_1^2\cdot\ddot{\alpha}\;+\right.$$
$$D\left[\frac{\upsilon}{R}\cos(x-y)(\dot{x}-\dot{y})\cdot tg\varphi_1-\kappa_1\dot{y}-\kappa_2 y\right]$$
$$+\left[H\cdot\cos\beta-E\left(\omega\cdot\cos\varphi_1\cdot\cos y+\frac{\upsilon}{R}\sin x\right)\right]\dot{\beta}+$$
$$\left.+H\left(\omega\cdot\cos\varphi_1\cdot\cos y+\frac{\upsilon}{R}\cos x\right)\cdot\cos\beta\right\}+\frac{K_{w_1}\cdot i_1\cdot\dot{\alpha}}{K_1^{УП}\cdot K_1^{ПКН}}$$
$$x_2^{ЦВМ}=\frac{R_2}{i_2\cdot K_2^{УП}\cdot K_2^{ПКН}\cdot K_{m_2}}\left\{J_{я_2}\cdot i_2^2\cdot\ddot{\beta}+\right.$$
$$E\left(\ddot{\beta}+\omega\cdot\cos\varphi_1\cdot\dot{y}+\frac{\upsilon}{R}\cdot\sin x\cdot\dot{x}\right)+$$
$$\left.H\left[\begin{array}{l}\left(\omega\cdot\cos\varphi_1\cdot\cos y+\dfrac{\upsilon}{R}\sin x\right)\sin\beta-\\ \left(\dot{y}+\omega\cdot\sin\varphi_1+\dfrac{\upsilon}{R}tg\varphi_1\cdot\sin(x-y)\cdot\cos\beta\right)\end{array}\right]\right\}$$
$$+\frac{K_{w_2}\cdot i_2\cdot\dot{\beta}}{K_2^{УП}\cdot K_2^{ПКН}} \qquad (15)$$

IV. Stability

Substituting (15) in full system of the equations (12) at assumptions (14) we will receive,

$$\ddot{\alpha}+\kappa_1\dot{\alpha}+\kappa_2\alpha=0,$$

$$\ddot{\beta}+\kappa_3\dot{\beta}+\kappa_4\beta+\kappa_5\alpha=0 \qquad (16)$$

it is easy to see that the system of the equations (16) supposes the private decision (3.

Thus, at any law of movement of the ship and at motors position of balance of an axis of a rotor of a gyroscope is the direction on the north. For satisfactory work of a gyrocompass of its fluctuation concerning position of balance (3) should be fading.

If to believe, α_6 and β_2 as small corners the equations (16) will be the equations in variations. Its characteristic equation will look like

$$\lambda^4+d_1\lambda^3+d_2\lambda^2+d_3\lambda+d_4=0 \qquad (17)$$

where

$d_1=\kappa_1+\kappa_3$

$d_2=\kappa_2-\kappa_4+\kappa_1\kappa_3$

$d_3=\kappa_2\kappa_3+\kappa_1\kappa_4$

$d_4=\kappa_2\kappa_4$

According to Lyapunov's theorem about asymptotically stability on the first approach [10], the system (16) is steady, if roots characteristic the equations (17) have negative material parts. As the equations (16) are the differential equations with constant factors necessary and sufficient conditions of negativity material parts of roots of the characteristic equation (17) can be found under Gurvits's [10] criterion, which for the equation of the fourth order will look like

$d_1>0,$ $d_2>0$

$d_3>0,$ $d_4>0$

$$\Delta_3=\begin{vmatrix} d_1 & d_3 & 0 \\ 1 & d_2 & d_4 \\ 0 & d_1 & d_3 \end{vmatrix}, \qquad (18)$$

where Δ_3 the main diagonal minor of the third order of a matrix

$$\Gamma=\begin{pmatrix} d_1 & d_3 & 0 & 0 \\ 1 & d_2 & d_4 & 0 \\ 0 & d_1 & d_3 & 0 \\ 0 & 1 & d_2 & d_4 \end{pmatrix}$$

Conditions (18) are reduced to inequalities

$\kappa_1>0,$ $\kappa_2>0,$ $\kappa_3>0,$ $\kappa_4>0$

$$\Delta_3=\kappa_1\kappa_2\kappa_3(\kappa_2+\kappa_3)+\kappa_1^2\kappa_3^2(\kappa_2+\kappa_4)+ \kappa_1\kappa_3\kappa_4(\kappa_1^2-2\kappa_2)>0 \qquad (19)$$

steady realization of parities of servo-constraints (3) depends only on a choice of constants κ_1, κ_2, κ_3 и κ_4.

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