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AUTOCOMPENSATION OF DIFFRACTION PHENOMENA IN SENSITIVE ELEMENTS

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INTRODUCTION

We will evaluate one of the autocompensation methods, which are used in gyroscopy – namely, the method of autocompensation of the influence of external excitingfactors. The technical basis of the method is the dual-channel principle by B.M. Petrov[1,2].

Let's analyze the possibility of reducing the errors of float gyroscopic instruments in the GSP systems under the action of penetrating acoustic radiation using autocompensation methods. In particular, we will consider two methods – a dual channel scheme and a method of forced rotation of the gimbal around the axis parallel to the vector $\vec{H}$ of the kinetic momentum.

The *dual channel method* is a common method of reversing the kinetic momentum vector. Both use the dependence of the direction of the gyros drift under the influence of noise on the sign of the kinetic momentum. Both methods suggest that there are two differently rotating gyromotors. However, they also have significant differences as to the completeness of compensation of all moments-obstacles. So the *dual-channel method* is only *averaging the manifestation* of internal obstacles in two gyroscopes, but does not compensate them. On the other hand, this method can compensate not only stationary external obstacles, but *non-stationary*. In addition, it provides the compensation for *instantaneous values*, rather than the average for the period of the reverse of the kinetic momentum vector. From the point of view of technical implementation it is also easier.

The *dual-channel autocompensation* of the acoustic radiation influence on the gyroscope is achieved by using the direct principle of dual-channelty of Б.Н. Петрова. It involves the application of two connected electromechanical identical gyroscopes with the opposite direction of the

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[1] Петров Б.Н. О реализуемости условий инвариантности. Всесоюзн. Совещ. По теории инвариантности, Киев, 1958: сб. Науч. Тр. Київ 1958. С. 56–64.

[2] Одинцов А.А. Метод автокомпенсации влияния внешних помех, действующих на гироскопы и маятниковые акселерометры. сб. Научн. Тр. Киев. Полит. Ин-та. Київ 1973. С. 87–94.

kinetic momentum vectors. Achieving this goal is done by identification of the initial alignment of devices relatively to the common basis.

The ability of autocompensation of acoustic pressure impacts on ДУСУ is realized by making two (instead of one) structurally unified channels for receiving two functionally identical manifestations of external obstacles, which differ only in sign. Uniformity of the channels for the acoustic perturbation is provided by the use of gyroscopes with the same kinematic gimbal.

The problem, therefore, is in the choice of technical solutions, when it will be provided a partial invariance of a two-stage gyroscope relatively to the acoustic power load.

1. Differential equations of the triaxial gyrostabilizer motion

Linearized differential equations of the platform can be written as follows [3].

$$A\dot{\omega}_x + A\dot{\omega}_{21}^a - H_1\dot{\beta}_1 - k_1F_1(\beta_1) = M_x;$$

$$I_1\ddot{\beta}_1 + f_1\dot{\beta}_1 + H_1\omega_x + H_1\omega_{21}^a = M_{z1} - H_1\beta_1\omega_y - H_1\beta_1\omega_{22}^a;$$

$$B\dot{\omega}_y + B\dot{\omega}_{22}^a + H_2\dot{\beta}_2 + k_2F_2(\beta_2) = M_y;$$

$$I_2\ddot{\beta}_2 + f_2\dot{\beta}_2 - H_2\omega_y - H_2\omega_{22}^a = M_{z2} - H_2\beta_2\omega_x - H_2\beta_2\omega_{21}^a;$$

$$C\dot{\omega}_z + C\dot{\omega}_{23}^a + H_3\dot{\beta}_1 + k_3F_3(\beta_3) = M_z;$$

$$I_3\ddot{\beta}_3 + f_3\dot{\beta}_3 - H_3\omega_z - H_3\omega_{23}^a = M_{x3} - H_3\beta_3\omega_y - H_3\beta_3\omega_{22}^a, \qquad (1)$$

where A, B, C – moments of inertia *GSP* together with the gimbal relatively to the axes $X_П, Y_П, Z_П$ respectively; f_x, f_y, f_z – coefficients of moments of the viscous friction forces; $\omega_X, \omega_Y, \omega_Z$ – the projections of the angle rate of the platform of the stabilization axis; I_1, I_2, I_3 – moments of inertia of the gyroscope moving parts relatively to the axes of precession; $\beta_1, \beta_2, \beta_3$ –the precession angles of the gyroscope; M_x, M_y, M_z – the projections of the external moments on the stabilization axis; H_1, H_2, H_3 – kinetic momentum of the gyroscope rotors; f_1, f_2, f_3 – coefficients of viscous friction of the gimbal sensitive elements; M_{Z1}, M_{Z2}, M_{X3} – projections of external moments on the precession axis;

[3] Одинцов А.А, Карачун В.В. Об уменьшении погрешностей гиростабилизаторов от перекрестных связей. Прикл. Механика. 1973. Т. IX, Вып. 10. С. 111–118.

$F_1(\beta_1),\ F_2(\beta_2),\ F_3(\beta_3)$ – functions characterizing the dependence between the moments of the stabilizing engines and the corresponding precession angles; $\omega_{2i}^a\ \left(i=1,\ 2,\ 3\right)$ – «*false*» angle rate, on which reacts a float sensor element of GSP, conditioned by the influence of acoustic radiation on the gyroscope gimbal;

$$M_{Z1} = -I_1\dot{\omega}_z - I_1\dot{\omega}_{11}^a - M_{T1} sign\dot{\beta}_1 + M_{\partial б1};$$

$$M_{Z2} = -I_2\dot{\omega}_z - I_2\dot{\omega}_{12}^a - M_{T2} sign\dot{\beta}_2 + M_{\partial б2};$$

$$M_{X3} = -I_3\dot{\omega}_x - I_3\dot{\omega}_{13}^a - M_{T3} sign\dot{\beta}_3 + M_{\partial б3}, \tag{2}$$

where $M_{T1},\ M_{T2},\ M_{T3}$ – moments of friction on the axes of gyroscope precession; $M_{\partial б1},\ M_{\partial б2},\ M_{\partial б3}$ – moments of the gyroscopes unbalance; $\dot{\omega}_{11}^a,\ \dot{\omega}_{12}^a,\ \dot{\omega}_{13}^a$ – additional angle acceleration of a moving part of float sensitive elements caused by diffraction phenomena in the gyroscope gimbal[4]:

$$\omega_{21}^a = \frac{4I_{П1}\omega_z\dot{W}(t)}{H_1R_1};\quad \omega_{22}^a = \frac{4I_{П2}\omega_y\dot{W}(t)}{H_2R_2};\quad \omega_{23}^a = \frac{4I_{П3}\omega_x\dot{W}(t)}{H_3R_3};$$

$$\dot{\omega}_{11}^a = \frac{2I_1}{H_1R_1}\Big\{\Big[\dot{\omega}_y\sin\beta_1 + \dot{\omega}_x\cos\beta_1 + \dot{\beta}_1\left(\omega_y\cos\beta_1 - \omega_x\sin\beta_1\right)\Big]\times$$
$$\times\Big[m_{T1}R_1L_1\dot{W}_{T1}(t) + I_{П1}\left(\dot{V}_1(t) + \pi\dot{W}_1(t)\right)\Big] +$$
$$+\left(\omega_y\sin\beta_1 + \omega_x\cos\beta_1\right)\Big[m_{T1}R_1L_1\ddot{W}_{T1}(t) + I_{П1}\left(\ddot{V}_1(t) + \pi\ddot{W}_1(t)\right)\Big]\Big\};$$

$$\dot{\omega}_{12}^a = \frac{2I_2}{H_2R_2}\Big\{\Big[\dot{\omega}_x\sin\beta_2 + \dot{\omega}_z\cos\beta_2 + \dot{\beta}_2\left(\omega_x\cos\beta_2 - \omega_z\sin\beta_2\right)\Big]\times$$
$$\times\Big[m_{T2}R_2L_2\dot{W}_{T2}(t) + I_{П2}\left(\dot{V}_2(t) + \pi\dot{W}_2(t)\right)\Big] +$$
$$+\left(\omega_x\sin\beta_2 + \omega_z\cos\beta_2\right)\Big[m_{T2}R_2L_2\ddot{W}_{T2}(t) + I_{П2}\left(\ddot{V}_2(t) + \pi\ddot{W}_2(t)\right)\Big]\Big\};$$

$$\dot{\omega}_{13}^a = \frac{2I_3}{H_3R_3}\Big\{\Big[\dot{\omega}_y\sin\beta_3 + \dot{\omega}_z\cos\beta_3 + \dot{\beta}_3\left(\omega_y\cos\beta_3 - \omega_z\sin\beta_3\right)\Big]\times$$
$$\times\Big[m_{T3}R_3L_3\dot{W}_{T3}(t) + I_{П3}\left(\dot{V}_3(t) + \pi\dot{W}_3(t)\right)\Big] +$$

[4]. Многомерные задачи нестационарной упругости подвеса поплавкового гироскопа/ В.В. Карачун, В.Г. Лозовик, Е.Р. Потапова, В.Н. Мельник. Нац. Техн. Ун-т Украины «КПИ». Киев «Корнейчук», 2000. 128 с.

$$+\left(\omega_y \sin\beta_3 + \omega_z \cos\beta_3\right)\left[m_{T3}R_3L_3\ddot{W}_{T3}(t) + I_{\Pi 3}\left(\ddot{V}_3(t) + \pi\ddot{W}_3(t)\right)\right]\Big\}, \qquad (3)$$

where R_i – floats radii of *i-gyroscope; L* – length of floats; $I_{\Pi i}$ – moments of inertia of the moving parts of the floats relatively to the input gyroscope axis; m_{Ti} – masses of the float ends; $W_{Ti}(t)$ – bending of the butt ends under the influence of acoustic radiation; $V_i(t)$, $W_i(t)$ –movement of the elements of the float lateral surface in the former plane (V_i – tangential components, W_i– radial components); $\dot{V}_i = i\omega V_i$; $\ddot{V}_i = -\omega^2 V_i$; $\dot{W}_i = i\omega W_i$; $\ddot{W}_i = -\omega^2 W_i$; $\dot{W}_{Ti} = i\omega W_{Ti}$; $\ddot{W}_{Ti} = -\omega^2 W_{Ti}$;

$$V_i = \sum_{m=-\infty}^{\infty}\sum_{n=1}^{\infty} V_{mni}\exp\left(im\beta_{\Pi i}\right)\sin\frac{n\pi z}{L_i}\ ;V_{mni} = -im\frac{F_{mni}}{\Delta_{mni}}\ ;$$

$$W_i = \sum_{m=-\infty}^{\infty}\sum_{n=1}^{\infty} W_{mni}\exp\left(im\beta_{\Pi i}\right)\sin\frac{n\pi z}{L_i}\ ;\quad W_{mni} = \left[\omega^2\rho - m^2 - \frac{1-\sigma}{2}\left(\frac{n\pi}{Li}\right)^2\right]\frac{F_{mni}}{\Delta_{mni}}\ ;$$

$$\Delta_{mni} = m^2 + \left[\omega^2\rho - m^2 - \frac{1-\sigma}{2}\left(\frac{n\pi}{L}\right)^2\right]\left\{\left(\omega^2\rho + 1\right) + c^2\left[\left(\frac{m}{R_i}\right)^2 + \left(\frac{n\pi}{L_i}\right)^2\right]\right\}; \quad (4)$$

$$m = 0,\ \pm1,\ \pm2,\ ...\ ;\ \ n = 0,\ 1,\ 2,\ 3\ ...;$$

$$F_{mni} = l_{mni}P_0\exp(i\omega t);$$

$$l_{mni} = \frac{2n\pi\left[1-(-1)^n\right]}{(n\pi)^2 - (k_0L_i)^2}\begin{Bmatrix} 1, & if\ \ k_0R_iq = -m; \\ i\dfrac{\exp i\left[-2\pi k_0R_i\left(q + \cos\beta_{\Pi i}\cos\varepsilon_1\right)\right]-1}{2\pi\left[k_0R_i\left(q+\cos\beta_{\Pi i}\cos\varepsilon_1\right)+m\right]}\ , & f\ \ k_0R_iq \neq -m; \\ wgere\quad q = \sin\beta_{\Pi i}\cdot\sin\varepsilon_1\cdot\sin\varepsilon_2\ ,\ \ k_0L_i \neq n\pi & \end{Bmatrix},$$

$\beta_{\Pi i}$ – central angle in the former plane; $k_0 = \dfrac{\omega}{330} = \dfrac{\omega}{c_0}$, $[m^{-1}]$ – wave number;

P_0 – pressure in the falling sound wave, *dB*; $W_{Ti} = W_{T_0 i}\exp(i\omega t)$ (fig. 6.1), where $W_{T0i} = c^j u_j$, $\ j = \overline{1,6}$ [5]

$$u_1 = \left(1 - \frac{x^2}{R_i^2} - \frac{y^2}{R_i^2}\right)^2;\ u_2 = \frac{x}{R_i}u_1;\ u_3 = \frac{y}{R_i}u_1;\ u_4 = \frac{x^2}{R_i^2}u_1;\ u_5 = \frac{y^2}{R_i^2}u_1;\ u_6 = \frac{xy}{R_i^2}u_1\ ;$$

[5] Karachun V.V. Vibration of Porous. Plates under the Action of Acoustic. SOVIET APPLIED MECHANICS. 1987. Vol. 22, №3. P. 236-238.

$$C = \begin{pmatrix} c^1 & c^2 & \dots & c^N \end{pmatrix}^T = G^{-1}F =$$

$$= \frac{R_i^4}{64D_i} P_0 \begin{Vmatrix} 4 & 0 & 0 & 5 & 5 & 0 \\ 0 & 9 & 0 & 0 & 0 & 0 \\ 0 & 0 & 9 & 0 & 0 & 0 \\ 5 & 0 & 0 & 19 & 7 & 0 \\ 5 & 0 & 0 & 7 & 19 & 0 \\ 0 & 0 & 0 & 0 & 0 & 6 \end{Vmatrix}^{-1} \begin{Vmatrix} 4 - 2\left(\frac{\lambda_i}{2}\right)^2 \\ i6 \cdot \frac{\lambda_i}{2} \cos \varepsilon \\ -i6 \cdot \frac{\lambda_i}{2} \sin \varepsilon \\ 5 - 2(2 + \cos 2\varepsilon)\left(\frac{\lambda_i}{2}\right)^2 \\ 5 - 2(2 - \cos 2\varepsilon)\left(\frac{\lambda_i}{2}\right)^2 \\ 2 \cdot \left(\frac{\lambda_i}{2}\right)^2 \sin 2\varepsilon \end{Vmatrix};$$

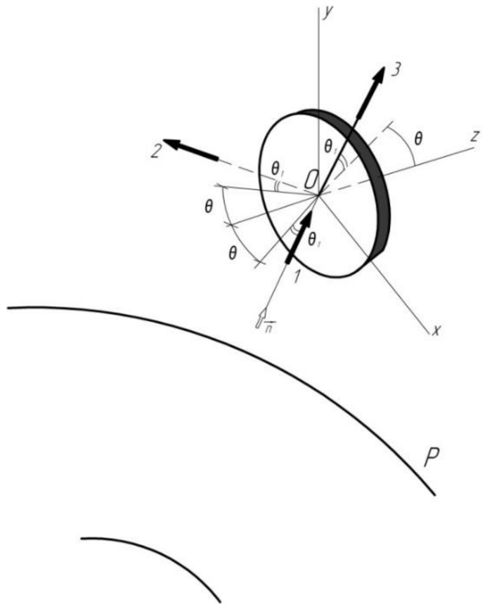

Fig. 1. Chart of the sound waves passing through the butt end of the float gimbal

1 – falling wave; 2 – reflected wave; 3 – passed wave

$D_i = \dfrac{E_i h_i}{12(1-\sigma)}$ – cylindrical stiffness of the butt end;

$$\left(\frac{\lambda_i}{2}\right)^2 = \frac{1}{4}\left(\cos^2\theta_1 \sin^2\theta + \sin^2\theta_1\right)\left(k_0 R_i\right)^2 << 1.$$

Let’s assume that the aircraft fuselage causes determined perturbation, that is periodic with a constant frequency and amplitude and given non-random time functions (fig. 1) –

$$M_x = M_x^* + M_x^0 \sin \gamma_1 t;$$
$$M_y = M_y^* + M_y^0 \sin\left(\gamma_2 t + \eta_2\right);$$
$$M_z = M_z^* + M_z^0 \sin\left(\gamma_3 t + \eta_3\right), \tag{5}$$

where $M_x^0,\ M_y^0,\ M_z^0$ – quantity values of the moments; $M_x^*,\ M_y^*,\ M_z^*$ – constant components.

It is clear that consideration of the constant components of the moments will not bring the significant changes in the final results. Therefore, we assume that $M_x^* = M_y^* = M_z^* = 0$.

The solution of the of equations system (1) we will search by the method of successive approximations.

2. Errors of stabilization

Linear approximation

$$\left(\omega_x + \omega_{21}^a\right) = \omega_x^0 + X_1 + \cdots;$$
$$\left(\omega_y + \omega_{22}^a\right) = \omega_y^0 + Y_1 + \cdots;$$
$$\left(\omega_z + \omega_{23}^a\right) = \omega_z^0 + Z_1 + \cdots;$$
$$\beta_1 = \beta_1^0 + \delta_1 + \cdots;$$
$$\beta_2 = \beta_2^0 + \delta_2 + \cdots;$$
$$\beta_3 = \beta_3^0 + \delta_3 + \cdots. \tag{6}$$

Here $\omega_x^0,\ \omega_y^0,\ \omega_z^0,\ \beta_1^0,\ \beta_2^0,\ \beta_3^0$ – linear approximation solutions which did not take into account the nonlinear members – gyroscopic moments of cross-links; $X_1,\ Y_1,\ Z_1,\ \delta_1,\ \delta_2,\ \delta_3$ – addition to the solutions relatively the first, etc. order infinitesimality.

With the rejection of nonlinear members $H_1\beta_1\omega_y$, $H_2\beta_2\omega_x$, $H_3\beta_3\omega_y$, the equation of the system (6.1) can be regarded as pairs of equation of three independent stabilization systems under the influence of disturbances M_x, M_y and M_z. The reaction of these disturbances is the solution of the linear approximation $\omega_x^0,\ \omega_y^0,\ \omega_z^0,\ \beta_1^0,\ \beta_2^0$ and β_3^0.

After substituting of the expressions (5) into the equation (6.1), we again obtain the linear equations, but relatively to variable X_1, Y_1, Z_1, δ_1, δ_2 and δ_3, structurally similar to the equations of linear approximation, although in the right side will be already present $H_1\left(\beta_1^0+\delta_1\right)\left(\omega_y^0+Y_1\right)$, $H_2\left(\beta_2^0+\delta_2\right)\left(\omega_x^0+X_1\right)$ and $H_3\left(\beta_3^0+\delta_3\right)\left(\omega_y^0+Y_1\right)$.

Assuming that the values X_1, Y_1, Z_1, δ_1, δ_2 and δ_3 much smaller than the corresponding solutions of linear approximation, we can write down –

$$H_1\left(\beta_1^0+\delta_1\right)\left(\omega_y^0+Y_1\right)\approx H_1\beta_1^0\omega_y^0=M_{Z1}^{\Pi};$$

$$H_2\left(\beta_2^0+\delta_2\right)\left(\omega_x^0+X_1\right)\approx H_2\beta_2^0\omega_x^0=M_{Z2}^{\Pi};$$

$$H_3\left(\beta_3^0+\delta_3\right)\left(\omega_y^0+Y_1\right)\approx H_3\beta_3^0\omega_y^0=M_{X3}^{\Pi}. \tag{7}$$

Thus, the task of finding the solutions of the first approximation is reduced again to determination of the reactions of two independent linear systems of perturbation M_{Z1}^{Π} and M_{Z2}^{Π}, caused by the cross impact of the stabilization channels.

Similarly, if necessary, we can find the second, third, etc. the following approximation.

The first four equations of the system (6.1) can be solved independently of the latter two, so we will continue to analyze the system from the first four equations without studying of the GSP dynamics as a closed system. We conditionally assume the circles of stabilization as opened, however, we consider the platform small oscillations relatively to the axes X_{Π}, Y_{Π}, Z_{Π}, which are responsible for stabilization errors.

In the linear approximation equations the two channels of stabilization fall into the following two subsystems which are not connected –

$$\begin{aligned} &A\dot{\omega}_x^0+f_x\omega_x^0-H_1\dot{\beta}_1^0-k_1F_1\left(\beta_1^0\right)=M_x\,;\\ &I_1\ddot{\beta}_1^0+f_1\dot{\beta}_1^0+H_1\omega_x^0+H_1\omega_{21}^a=0\,; \end{aligned} \tag{8}$$

$$\begin{aligned} &B\dot{\omega}_y^0+f_y\omega_y^0+H_2\dot{\beta}_2^0+k_2F_2\left(\beta_2^0\right)=M_y\,;\\ &I_2\ddot{\beta}_2^0+f_2\dot{\beta}_2^0-H_2\omega_y^0-H_2\omega_{22}^a=0\,. \end{aligned} \tag{9}$$

The reaction of GSP on periodic perturbations will contain forced and own oscillations. We assume that the latter ones will quickly die down.

Then the solutions of the systems (8) and (9) at the harmonic perturbations are easily obtained using the frequency characteristics of the system:

$$\omega_x^0 = M_x^0 A_1(\gamma_1)\sin\left[\gamma_1 t + \varphi_1(\gamma_1)\right];$$

$$\beta_1^0 = M_x^0 A_2(\gamma_1)\sin\left[\gamma_1 t + \varphi_2(\gamma_1)\right];$$

$$\omega_y^0 = M_y^0 A_3(\gamma_2)\sin\left[\gamma_2 t + \varphi_3(\gamma_2) + \eta_2\right];$$

$$\beta_2^0 = M_y^0 A_4(\gamma_2)\sin\left[\gamma_2 t + \varphi_4(\gamma_2) + \eta_2\right], \qquad (10)$$

where $A_i(\gamma_1)$, $A_j(\gamma_2)$, $\varphi_i(\gamma_1)$, $\varphi_j(\gamma_2)$ – respectively the amplitude-frequency characteristics and phase-frequent characteristics of the tract between the input influence and the original value; $i = 1,\ 2$; $j = 3,\ 4$.

The structural schemes of the platform in the linear approximation are shown in Fig. 6.2. Their corresponding transfer functions of the platform are outlined by the correlations –

$$\Phi_1(p) = \frac{\left[\omega_x(p) + \omega_{21}^a(p)\right]}{M_x(p)} = \frac{I_1 p^2 + f_1 p}{\Delta_1};$$

$$\Phi_2(p) = \frac{\beta_1(p)}{M_x(p)} = \frac{H_1}{\Delta_1};$$

$$\Phi_3(p) = \frac{\left[\omega_y(p) + \omega_{22}^a(p)\right]}{M_y(p)} = \frac{I_2 p^2 + f_2 p}{\Delta_2};$$

$$\Phi_4(p) = \frac{\beta_2(p)}{M_y(p)} = \frac{H_2}{\Delta_2};$$

$$\Phi_5(p) = \frac{\left[\omega_x(p) + \omega_{21}^a(p)\right]}{P + M_{Z1}(p)} = \frac{-H_1 p - k_1 W_1(p)}{\Delta_1};$$

$$\Phi_6(p) = \frac{\left[\omega_y(p) + \omega_{22}^a(p)\right]}{P + M_{Z2}(p)} = \frac{H_2 p + k_2 W_2(p)}{\Delta_2}, \qquad (11)$$

where

$$\Delta_1 = AI_1 p^3 + \left(I_1 f_x + Af_1\right)p^2 + \left(f_x f_1 + H_1^2\right)p + k_1 H_1 W_1(p);$$

$$\Delta_2 = BI_2 p^3 + \left(I_2 f_y + Bf_2\right)p^2 + \left(f_y f_2 + H_2^2\right)p + k_2 H_2 W_2(p). \qquad (12)$$

From the expression (11) it follows, that the constant components of angle rate $\left(\omega_x + \omega_{21}^a\right)$ and $\left(\omega_y + \omega_{22}^a\right)$ are not shown by linear approximation.

Estimation of the stabilization error in the first approximation. Now we consider the first approximation. Substituting (6) in the system(1), and taking into account (8)

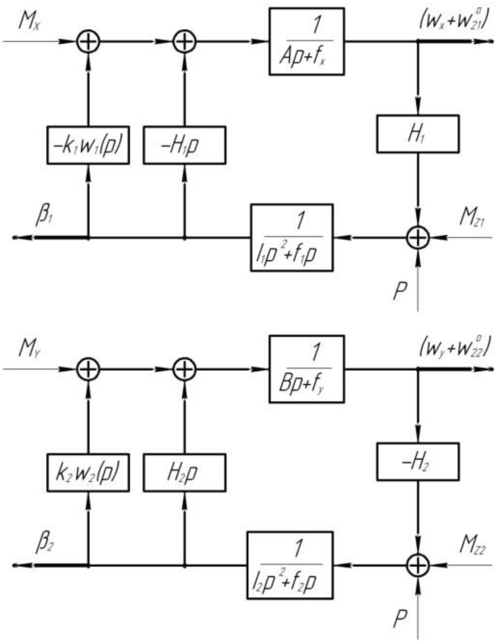

Fig. 2. The structural scheme of the gyrostailized platform in the linear approximation

and (9), we obtain a system of linear equations, where M_{Z1}^{Π} and M_{Z2}^{Π} are determined by the expressions (7):

$$A\dot{X}_1 + f_x X_1 - H_1\dot{\delta}_1 - k_1 F_1(\delta_1) = 0;$$

$$I_1\ddot{\delta}_1 + f_1\dot{\delta}_1 + H_1 X_1 + H_1\omega_{21}^a = M_{Z1}^{\Pi};$$

$$B\dot{Y}_1 + f_y Y_1 + H_2\dot{\delta}_2 - k_2 F_2(\delta_2) = 0;$$

$$I_2\ddot{\delta}_2 + f_2\dot{\delta}_2 - H_2 Y_1 - H_2\omega_{22}^a = M_{Z2}^{\Pi}. \quad (13)$$

Substituting in the expression (6.7) the solution (6.6) we find:

$$M_{Z1}^{\Pi} = -H_1 M_x^0 M_y^0 A_2(\gamma_1) A_3(\gamma_2)\sin(\gamma_1 t + \varphi_2)\sin(\gamma_2 t + \varphi_3 + \eta_2);$$

$$M_{Z2}^{\Pi} = -H_2 M_x^0 M_y^0 A_1(\gamma_1) A_4(\gamma_2)\sin(\gamma_1 t + \varphi_1)\sin(\gamma_2 t + \varphi_4 + \eta_2).$$

Elementary transformations make possible to write these correlation as follows –

$$M_{Z1}^{\Pi} = -\frac{1}{2} H_1 M_x^0 M_y^0 A_2(\gamma_1) A_3(\gamma_2) \Big\{ \cos\big[(\gamma_1-\gamma_2)t + \varphi_2(\gamma_1) - \varphi_3(\gamma_2) - \eta_2\big] -$$

$$-\cos\big[(\gamma_1+\gamma_2)t + \varphi_2(\gamma_1) + \varphi_3(\gamma_2) - \eta_2\big]\Big\};$$

$$M_{Z2}^{\Pi} = -\frac{1}{2} H_2 M_x^0 M_y^0 A_1(\gamma_1) A_4(\gamma_2) \Big\{ \cos\big[(\gamma_1-\gamma_2)t + \varphi_1(\gamma_1) - \varphi_4(\gamma_2) - \eta_2\big] -$$

$$-\cos\big[(\gamma_1+\gamma_2)t + \varphi_1(\gamma_1) + \varphi_4(\gamma_2) - \eta_2\big]\Big\}. \qquad (14)$$

Perturbations of the sensitive GSP elements on the precession axis will be the periodic *moments-obstacles* of different $(\gamma_1 - \gamma_2)$ and total $(\gamma_1 + \gamma_2)$ frequencies. Consequently, the reaction of these perturbations platform will have the same structure (3, *a*).

At the frequencies equality, in other words, when $\gamma_1 = \gamma_2 = \gamma$, the expression (14) changes –

$$M_{Z1}^{\Pi} = -\frac{1}{2} H_1 M_x^0 M_y^0 A_2(\gamma) A_3(\gamma) \Big\{ \cos\big[\varphi_2(\gamma) - \varphi_3(\gamma) - \eta_2\big] -$$

$$-\cos 2\gamma t \cos\big[\varphi_2(\gamma) + \varphi_3(\gamma) - \eta_2\big] + \sin 2\gamma t \sin\big[\varphi_2(\gamma) + \varphi_3(\gamma) - \eta_2\big]\Big\} =$$

$$= -\frac{1}{2} H_1 M_x^0 M_y^0 A_2(\gamma) A_3(\gamma) \Big\{ \cos\big[\varphi_2(\gamma) - \varphi_3(\gamma) - \eta_2\big] - C_1 \cos 2\gamma t + C_2 \sin 2\gamma t \Big\};$$

$$M_{Z2}^{\Pi} = -\frac{1}{2} H_2 M_x^0 M_y^0 A_1(\gamma) A_4(\gamma) \Big\{ \cos\big[\varphi_1(\gamma) - \varphi_4(\gamma) - \eta_2\big] -$$

$$-\cos 2\gamma t \cos\big[\varphi_1(\gamma) - \varphi_4(\gamma) - \eta_2\big] + \sin 2\gamma t \sin\big[\varphi_1(\gamma) - \varphi_4(\gamma) - \eta_2\big]\Big\} =$$

$$= -\frac{1}{2} H_2 M_x^0 M_y^0 A_1(\gamma) A_4(\gamma) \Big\{ \cos\big[\varphi_1(\gamma) - \varphi_4(\gamma) - \eta_2\big] - C_3 \cos 2\gamma t + C_4 \sin 2\gamma t \Big\}.$$

Obviously, there are constant components of exciting moments relatively to the output axis of gyroblocks –

$$M_{(Z1)const}^{\Pi} = -\frac{1}{2} H_1 M_x^0 M_y^0 A_2(\gamma) A_3(\gamma) \cos\big[\varphi_2(\gamma) - \varphi_3(\gamma) - \eta_2\big];$$

$$M_{(Z2)const}^{\Pi} = -\frac{1}{2} H_2 M_x^0 M_y^0 A_1(\gamma) A_4(\gamma) \cos\big[\varphi_1(\gamma) - \varphi_4(\gamma) - \eta_2\big]. \qquad (15)$$

These constant components cause the *systematic drift* of the platform relatively to the axes of stabilization with the angle rate

$$\omega_{(x)const} = X_1^* = M^{\Pi}_{(Z1)const}\Phi_5(0) = \frac{M^{\Pi}_{(Z1)const}}{H_1} =$$

$$= -\frac{1}{2}M_x^0 M_y^0 A_2(\gamma)A_3(\gamma)\cos\left[\varphi_2(\gamma)-\varphi_3(\gamma)-\eta_2\right];$$

$$\omega_{(y)const} = Y_1^* = M^{\Pi}_{(Z2)const}\Phi_6(0) = \frac{M^{\Pi}_{(Z2)const}}{H_2} =$$

$$= -\frac{1}{2}M_x^0 M_y^0 A_1(\gamma)A_4(\gamma)\cos\left[\varphi_1(\gamma)-\varphi_4(\gamma)-\eta_2\right]. \quad (16)$$

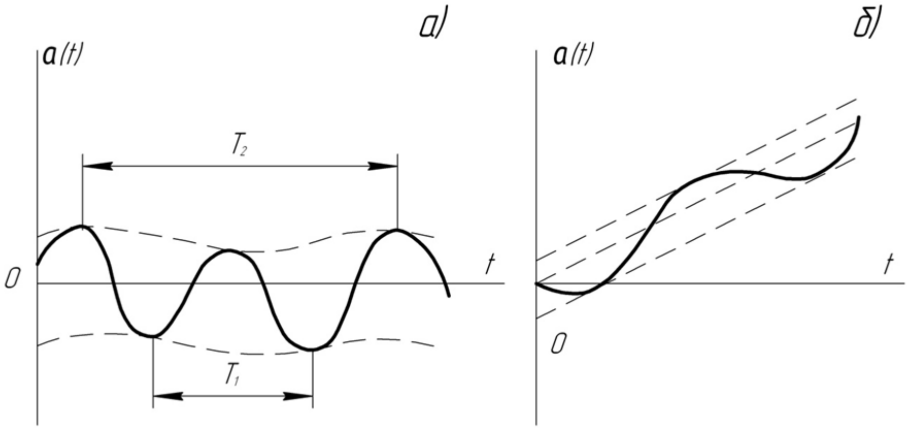

Fig. 3. Changes of inclination angles of the gyrostabilizer platform at different frequencies of exciting:

а) $\gamma_1 \neq \gamma_2$; $T_1 = \dfrac{2\pi}{\gamma_1+\gamma_2}$; $T_2 = \dfrac{2\pi}{\gamma_1-\gamma_2}$; *б)* $\gamma_1 = \gamma_2$

The character of the GSP movement when $\gamma_1 = \gamma_2$ is shown in Fig. 3, *б*. Obviously, the acoustic vibration of the surface float gyroscopic sensitive elements, with a wide frequency range, will contain in the values ω_{21}^a, $\dot{\omega}_{11}^a$, ω_{22}^a, $\dot{\omega}_{12}^a$ the components of the frequencies γ_i of the kinematic perturbation base. Thus, there will be a selectivity of these variables and a *systematic drift* of the platform will also contain the value of pressure of sound radiation P_0. The frequencies, which do not match, will enrich the range of harmonic components.

If the difference between the frequencies γ_1 and γ_2 is large, the GSP errors have the oscillation origin of different oscillation and total frequencies. When they are getting close to each other, except the *long periodic* and *short periodic* components may occur beating.

At *synchronous tossing* the GSP has a systembothatic drift around all three axes of stabilization. Their value depend on the origin of the perturbation and parameters of the platforms which are contained in amplitude-frequent and phase-frequent characteristics, as well as in values of the phase shift.

The estimation of the second approximation generates the confidence to believe that it’s enough to consider only the first approximation.

3. Autocompensation methods of reducing the influence of penetrating sound radiation

The emergence of the compensation theory (invariance theory) in applied gyroscopy usually is associated with the name of Г.В. Щипанова[6,7]. A great importance for the further development of the basic theory of non-perturbation of gyroscopic systems, including a gyrobalance and compass, had a fundamental work by Б.В. Булгакова[8]. In the publications[9,10,11,12,13] it had been also discussed some aspects of compensation of the perturbation factors on gyrodevices from the standpoint of the postulates of the invariance theory.

Undoubtedly, the Б.М. Петрова formulation of criterion by realization of invariance conditions became increasingly important, particularly in the part which stresses the necessity, but not sufficiency, of realization the

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[8] Karachun V.V., Ladogubets N.V., Mel’nyck V.M. THE SPECIFIED DESIGN MODEL. LOW FREQUENCY AND COMBINED RESONANCES// THE ADVANCED SCIENCE JOURNAL. V. 106/ISSUE3. P. 73–78.

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[11] Кухтенко В.И. Проблемы инвариантности в автоматике: монография. Киев. Гостехиздат, 1963. 143 с.

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absolute invariance by presence of at least two channels translation of perturbation between the point of perturbation application and the point, relatively to which invariant (principle of dual channelty) is reached[14].

We will have a closer look at the first mode of autocompensation of influence of external mechanical perturbations – *a dual channel*. It is known that in a single-contour system one cannot be satisfied with the requirements of invariance (compensation) without a breach of the stability conditions. In order to fulfill the conditions of stability relatively to certain perturbations, it is necessary for the information on this factor to come in the controlled point, relatively to which the invariance is achieved, at least on two channels.

In applied gyroscopy, in the works by А.Ю. Ишлинского, Б.В. Булгакова, Н.Д. Кондорского[15] and others, are expanded the suggestions for reducing the influence of some perturbations by applying two gyroscopes, but which are connected by kinematics. However, this method has a significant drawback – the presence of kinematic tie between gyroscopes, which is loaded with the died out obstacles, it causes the growth of moments of dry friction forces, so it is not suitable for float gyros.

The scheme of electromechanical connection between gyroscopes, instead of kinematic was first proposed by N.D. Kondorsky. The ability of removal the influence of angular acceleration of the basis when connecting two integrating gyros at a differential scheme is also noted in the work of V.A Karakashev and in his other publications[16].

A well-known technical realization of the forced rotation of the gyroscope gimbal around its axis, parallel to the kinetic momentum vector is described in[17,18].

A bench seminatural research of autocompensation schemes were carried out at the unit «Sirena» at the Institute for Strength Problems named after G.S. Pysarenko of National Academy of Science of Ukraine.

The dual-channel scheme of autocompensation of the obstacles impact. Two differently rotating angle rate sensors of ДУСУ2-6АС series with the

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[16]. Каракашев В.А. Влияние дрейфа гироскопов на движение гиростабилизированной платформы с *T*=84,4 мин. Изв. ВУЗов СССР, «Приборостроение» 1960. Т. 3, № 5. С. 37–44.

[17]Каргу Л.И., Яблонская В.А. О характере движения астатического гироскопа во вращающемся кардановом подвесе. Изв. ВУЗов СССР «Приборостроение». 1968. Т. 11, № 1. С. 77–81.

[18] Каргу Л.И. О движении свободного гироскопа с принудительным вращением опор. Изв. ВУЗов СССР «Приборостроение». 1962. Т. 5, № 4. С. 54–62.

same orientation of the gimbal relatively to the set basis are installed in a reverberation chamber.

The forced rotation of the gyroscope gimbal around the axis, which is parallel to the angular momentum vector. The gyroscope was set up on a platform of universal turntable table of УПГ-56 series in order to ensure collinearity of the kinetic momentum vector of gyroscope $\vec{H}_i$ and angle rate vector $\vec{\omega}$ of forced rotation of the gimbal.

The tests showed that the ДУСУ errors at the influence of the acoustic level *(~ 163-165 dB*) change the sign at the change of direction of the gyromotor rotation and has the character of instrumental error of the gyroscope. Thus, the dual-channel scheme can only average the size of this error, and the second scheme – reduce to zero, but in the average for the period of rotation.

The experiments prove that the effective means of compensation of intense sound fields is a modulation of constant perturbance moments of a periodic function of time. A known technical realization of this method lies in autocompensation of acoustic error by a forced rotation of the gyroscope gimbal axis, parallel to the vector of the gyroscope kinetic momentum.

Let's expand the task of the analysis and study the gyrostabilizer operation in aircraft operating conditions, in other words, at the simultaneous impact of intense acoustic perturbation, and the carrier vibration caused by the engine operation.

In this case I is suggested an advanced scheme of power (Fig. 4) and the indicator (Fig. 5) of gyrostabilizers.

A biaxial power gyrostabilizer contains the basis 1 on which the dampers are fixed 18, 19, 20 and 21 with fixed bearings of the gyroscope precession axes of swo-stage gyroscopes 22, 23 with the same kinematics of the gimbal, parallel to each other vectors of the angular momentum $\vec{H}_1$ and mutually perpendicular precession axes $\vec{H}_1$ and $\vec{H}_2$. The basis on 1 forcedly rotates with angle rate ω by a special engine 6 around its axis, perpendicular to the plane of the stabilized platform 5 on which it is installed.

The output signal of the gyroscope angle sensors 24 and 25 reaches the converter of coordinates 9, which is mechanically connected with the base 1. The output signal of the converter of coordinates 9 reaches the coordinated device 14 and the input amplifiers 10 and 11 which are controlled by the stabilizing engines 12 and 13. To coordinate the directions of the kinetic momentum vectors $\vec{H}_1$ and $\vec{H}_2$ of gyroscopes with the vector of angle rate $\vec{\omega}$ from 1 base, it is carried out the correction of their position relatively to the basis 5 by giving signals from the angle sensors 24 and 25 to amplifiers 26 and 27, the output signal of which reaches the sensors of moments 28 and 29 which are on the precession axis of gyroscopes. The bearings of the outer frame 15 are set on shock absorbers of the gyrostabilizer 16 and 17, which are rigidly attached to the body of the carrier.

The indicated stabilizer with forced rotation of a gyroscope gimbal (Fig.5) contains basis 1 on which the shock absorbers 2 and 3 is set a tree-stage automatic non-corrected 4 gyroscope in the gimbal. Initially, the vector $\vec{H}$ of the kinetic momentum is perpendicular to the plane of the gyrostabilized platform 5. The basis1 forcedly rotates with angle rate ω by a special engine 6 around the axis, perpendicular to the plane of the stabilized platform 5 on which it is set. On the axes of the gyroscope gimbal there are angle sensors 7 and 8, which receive signals from the converter of coordinates 9 and then reinforce by amplifiers 10 and 11 on the controlled windings of stabilizing engines 12 and 13. The coordinated unit 14 is electrically connected with the converter of coordinates 9 . The bearings of the external frame 15 are set on shock absorbers of the gyrostabilizer 16 and 17, which are rigidly attached to the body of the carrier.

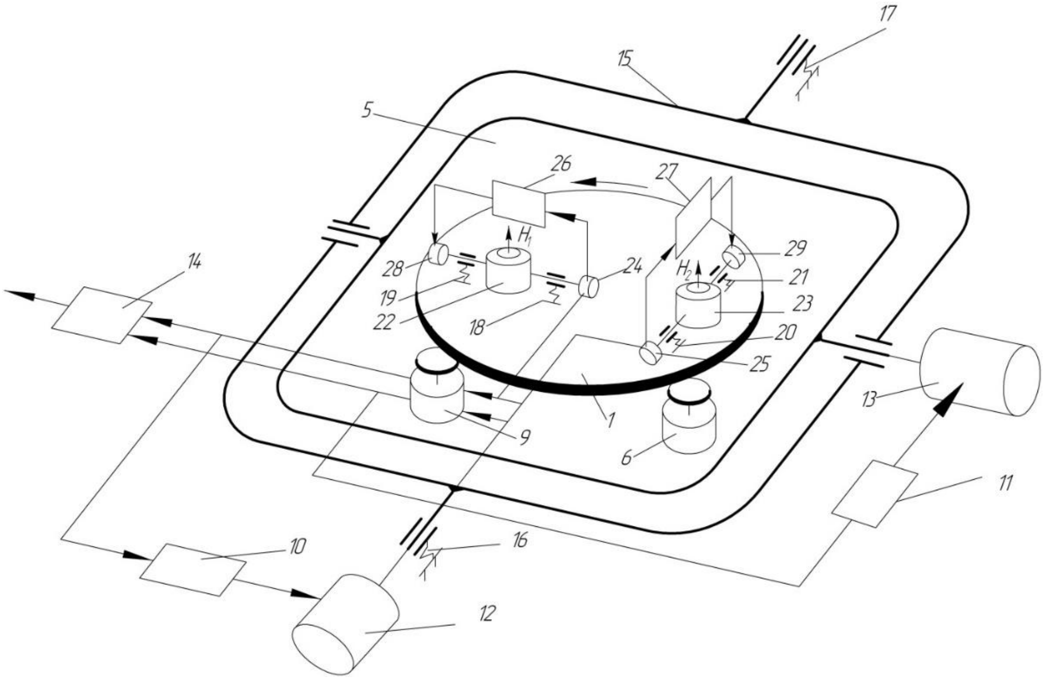

Fig. 4. The kinematic scheme of the power gyrostabilizer

The power of the gyrostabilizer with the simultaneous action of acoustic intense and vibration disturbances of the body carrier works as follows.

Intensive acoustic waves generate oscillations in the gyroscope elements. At certain frequencies these oscillations cause perturbation moments constant in magnitude and direction, which are directed along the axis of precession, and thus cause systematic errors in gyro devices. The forced rotation of the gyroscope gimbal together with the base 1 with angle rate ω by aspecial engine 6 around the axis, perpendicular to the plane of the stabilized platform 5 and parallel to the kinetic momentum vectors $\vec{H}_1$ and $\vec{H}_2$ of gyroscopes, allows to modulate the vector of perturbation moment by a periodic function of time $\sin \omega t$. This will lead to the same modulation of time of a two-stage gyroscope and thus it will minimize its average value at the rotation period.

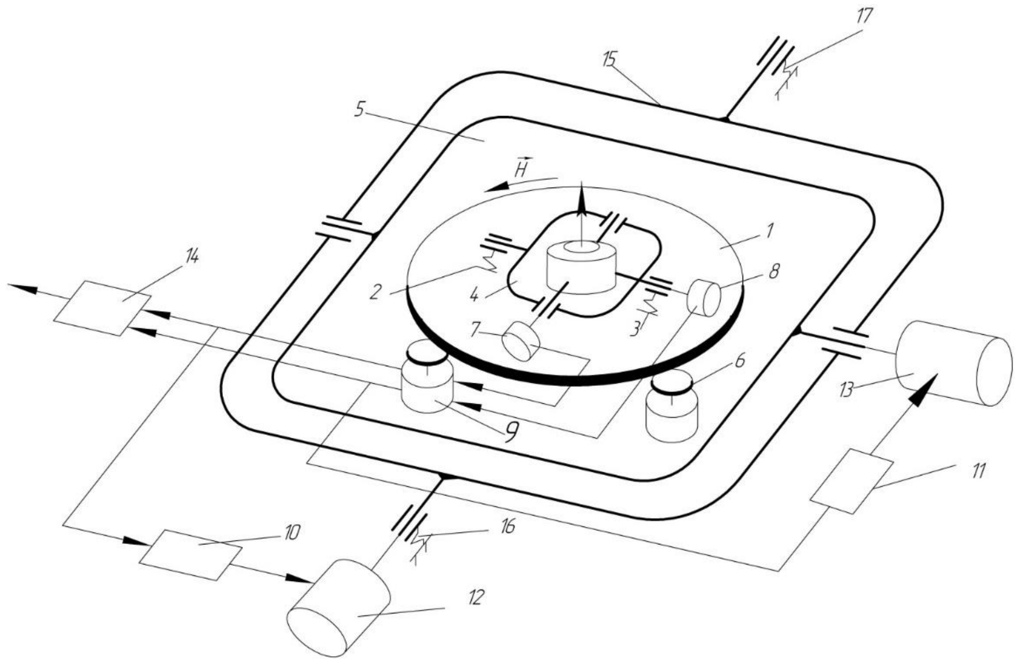

Fig. 5. The kinematic scheme of the indicating gyrostabilizer

Eliminating the influence of the basis vibration 1 generated by the action of intensive acoustic perturbance is carried by installing of bearings of the precession axis on shock absorbers 18,19, 20 and 21.

Considering the fact that forcedly rotation of the gyroscope gimbals leads to their reorientation in space, while the stabilized platform 5 with engines 12 and 13 remains stationary, the signals of angle sensors 24, 25 of gyros reach the amplifiers 10 and 11 of stabilizing motors 12 and 13 from the converter of coordinates 9, mechanically linked with the base 1 of its repeating rotation and electrically connected to the angle sensors 24 and 25. If for solving problems of the flight control a signal of a two-stage gyroscope will be needed, it is available in analog or digital form using coordinative device 14, electrically connected to the converter of coordinates 9. In this case, the entire device can be considered as a two-stage gyroscope, but having less measurement errors at intense acoustic perturbations and the aircraft body oscillation than the conventional gyroscope under the same conditions.

At first, the kinetic momentum vectors $\vec{H}_1$ and $\vec{H}_2$ of gyros parallel to the vector $\vec{\omega}$ of angle rate of basis 1 rotation. When inciting factors appear on the axes of stabilization, a disagreement occur on these vectors, causing additional gyroscopic moments as a result of cross component of the vector $\vec{\omega}$, which is parallel to the gyro sensitive axes 22, 23. An electrical signal of the angle sensors 24, 25, which is proportional to this velocity and previously amplified by the amplifiers 26 and 27, then reaches the sensors of moments 28 and 29, which form the value and the direction of the moment for the initial parallelism of vectors $\vec{H}_1$, $\vec{H}_2$ and $\vec{\omega}$.

To eliminate the effects of oscillations of the aircraft body on the stabilization error, the bearings of the external frame of the power stabilizer are set on the shock absorbers 16 and 17.

At intensive acoustic perturbations and the fuselage vibrations works the indicated gyrostabilizer operates similarly. However, it should be noted that at acoustic loads over *160 dB* the uncorrectable gyroscope doesn't work.

A further improvement of the sceme of the power gyrostabilizer is a gyrostabilizer with forced rotation of the gimbals. These gimbals belong to some gyroscopes electrically connected with oppositely directed kinetic momentum vectors of the same orientation of the gimbal axes (Fig. 7.6). In this case the gyro angle sensors through the summing unit and the amplifier are connected to the angular momentum sensors which are set on the precession axes. By means of the differential amplifier they will be connected to the converter of coordinates. In this case the use of mechanical sparnyka is inappropriate at high level of sound pressure – over *160 dB*. In addition, the mechanical sparnyk practically eliminates the possibility of using float gyroscopes in a gyrostabilizer.

The formation of the output signal of the swo-stage gyroscope as a difference of two output signals of the devices, which are connected electrically, allows compensating the influence of instantaneous values of moments-obstacles, which are caused by side sensitivity of the gyroscopes and angular acceleration of the fuselage at both stationary and non-stationary characters of their change in time. Besides, zeroshift (zero shift in the *integrating gyroscope*) is also compensated. This zero shift which takes place at the kinematic perturbation at the basis even if the angle of rotation of the gyroscope equals the level zero. Hard negative inverse connection by the sum of the gyro sensor signals allows to perform the mutual correction of their position between themselves and with the vector $\vec{\omega}$ of the angle rate of the basis 1 and the signal to sensors of the moments.

In the initial position the kinetic momentum vectors $\vec{H}_i$ of gyros 10, 11, 12 and 13 are parallel to each other and perpendicular to the plane of the stabilized platform 15. Acoustic wave generates bending oscillations in the construction elements of gyros and creates a stringing state of the material, which together cause stable inciting moments and thus to the systematic errors of gyros. The formation of the output signal of the two-stage gyro as a difference of two output signals of two electrically connected differently rotating gyros 10, 11 and 12, 13 allows to compensate the influence of instantaneous values of moments-obstacles due to lateral sensitivity of gyroscopes and the influence of angular acceleration of the aircraft as for their stationary and non-stationary development in time. Finally, the *zero shift* is also compensated and occurs even without the angle of rotation of the gyroscope moving part.

The hard negative inverse connection by the sum of the angle sensor signals 16, 17, 18, 19 of gyroscopes 10, 11, 12, 13 allows to perform the mutual correction of their position between themselves and the vector $\vec{\omega}$ of the angle rate of the basis and the signal to the sensors of the moments 24, 25, 26 and 27.

The forced rotation of the gyroscope gimbal 10, 11, 12 and 13 together with the basis 1 with angle rate ω of the engine 14 around the axis, perpendicular to the plane of the stabilized platform 15 and parallel to the kinetic momentum vectors $\vec{H}_i$ of the gyroscopes, allows to modulate the vectors of inciting moments caused by the influence of acoustic radiation, unbalance of the gyros, dry friction forces and other instrumental errors of periodic function of time, for example $\sin\omega t$, which will cause the same modulation in time of systematic gyroscope errors and thus will allow to minimize its average value over the period of rotation.

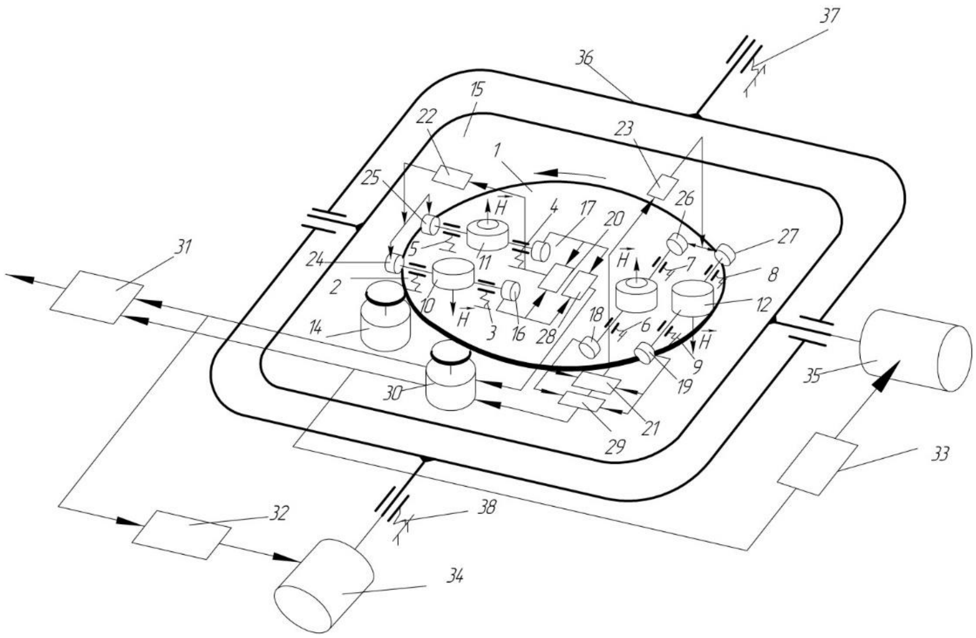

Fig. 6. The kinematic scheme of a power gyrostabilizer with a two-channel autocompensation for reducing the impact of external mechanical perturbations

Eliminating of influence of basis vibration 1 under the action of intensive acoustic perturbations on the gyros construction elements 10, 11 and 12, 13 it is carried out by the installation of bearings of the initial axes on the shock absorbers 2, 3, 4, 5, 6, 7, 8 and 9.

Due to the forced rotations of the gyroscope gimbal leads to the reorientation in space, while the stabilized platform 15 with engines 34 and 35 remains stationary, the signals of differential amplifiers 28 and 29 come to the converter of coordinates 30 mechanically connected with the basis 1 and repeating its rotation, and then through amplifiers 32 and 33 on the control windings of the stabilizing engines 34 and 35.

If for the tasks of air traffic control at intense acoustic perturbations and the fuselage vibration is required a signal of a two-stage gyroscope, it can be received in a digital or analog form using the coordinated device 31 electrically connected to the converter of coordinates 30. In this case, the advised device can be considered as a two-stage gyroscope, but without defects in a common two-stage gyroscope in the intensive acoustic field and vibration.

Experimental studies have proved that the sample of the device for gyroscopic stabilization of devices (GSP) which uses float devices of ДУСУ (the angle rate sensor) class as sensors. These float devices are set on shock absorbers and connected by the differential circuit, or forced rotating around the axis parallel to the angular momentum vector, it normally operates at the acoustic load of *160 dB* intensity in the frequency range up to *1 kHz*.

Bench tests and theoretical research of the influence of intensive sound waves to poly-unit systems of the industrial model of the angle rate sensor of the ДУСУ class allow to make some generalizations for other technical solutions of such systems and to formulate the following conclusions and recommendations:

– poly-unit systems are subjected to the action of intensive acoustic beams. The offered mechanical model of stringing-and-deformative poly-unit system in the form of two coaxial cylindrical shells divided by fluid, allows to make the quantitative and qualitative estimation of the studied phenomena;

– onboard gyro equipment of the poly-unit structure in acoustic fields of the aircraft operating conditions may have methodic and instrumental errors as a result of to Euler inertial forces;

– to overcome the negative impact of acoustic vibration of the component, as one of the variants can be recommended the autocompensation methods that have been tested with a positive result.

Integrated gyroscopes are widely used in GSP as sensors. Therefore, a few words about the peculiarities of their operation.

Let's consider the simpliest case – harmonic oscillations of the platform relatively to three axes, for example:

$$\psi_x = \psi_{xo} \sin\left(\omega_1 t + \phi_1\right);$$

$$\psi_y = \psi_{yo} \sin\left(\omega_2 t + \phi_2\right);$$

$$\psi_z = \psi_{zo} \sin \omega_3 t .$$

For this perturbation the angle of rotation of the movable part of the gimbal is determined by the expression:

$$\beta \simeq \beta(0) - \beta(0) a \sin\omega_3 t + b \sin\left(\omega_1 t + \varphi_1\right) - c\cos\left(\omega_2 t + \varphi_2\right) -$$

$$-\frac{\omega_3 ab}{2}\left\{\frac{\cos\left[\left(\omega_3 - \omega_1\right)t - \phi_1\right]}{\omega_3 - \omega_1} - \frac{\cos\left[\left(\omega_3 + \omega_1\right)t + \phi_1\right]}{\omega_3 + \omega_1}\right\} +$$

$$+\frac{\omega_3 ac}{2}\left\{\frac{\sin\left[\left(\omega_3 - \omega_2\right)t - \phi_2\right]}{\omega_3 - \omega_2} + \frac{\sin\left[\left(\omega_3 + \omega_2\right)t + \phi_2\right]}{\omega_3 + \omega_2}\right\},$$

where $a = k\psi_{zo}$;

$$b = k\psi_{xo};$$

$$c = Tk\psi_{yo}\omega_2 .$$

In integrated gyroscopes the transfer coefficient k is usually close to the unit, and the time constant T equals several milliseconds. Therefore, for certain values ω_2 the inequality is correct

$$T\omega_2 << k \ .$$

If the amplitude of the platform oscillations around x the axes are almost identical, the result of the inequality is the correlation:

$$c << b \ .$$

Then we can simplify the expression for the angle of rotation –

$$\beta \simeq \beta(0) - \beta(0) a \sin \omega_3 t + b \sin\left(\omega_1 t + \varphi_1\right) - c\cos\left(\omega_2 t + \varphi_2\right) -$$

$$- \frac{\omega_3 ab}{2}\left\{\frac{\cos\left[\left(\omega_3 - \omega_1\right)t - \phi_1\right]}{\omega_3 - \omega_1} - \frac{\cos\left[\left(\omega_3 + \omega_1\right)t + \phi_1\right]}{\omega_3 + \omega_1}\right\}.$$

The expression shows that at the tossing around the axes x and z with close frequencies there will be a changeable component of the error in the signal which may reach significant values. The most undesirable is the condition $\omega_1 = \omega_3$.

For this case the angle of rotation is changed by the law –

$$\beta \simeq \beta(0) - \beta(0) a \sin \omega_1 t + b \sin\left(\omega_1 t + \varphi_1\right) - c\cos\left(\omega_2 t + \varphi_2\right) -$$

$$- \frac{ab\omega_1 \sin\phi_1}{2} t + \frac{ab}{4}\cos\left(2\omega_1 t + \phi\right).$$

This is the component that increases proportionally to time, and outlines the large movement of gyroscope under these conditions. For example, let

$$k = 1;\ \psi_{xo} = \psi_{zo} = 5{,}8 \cdot 10^{-4} rad;$$

$$\omega_1 = \omega_3 = 10 s^{-1};$$

$$\phi = \frac{\pi}{2};\ t = 3600 s\ .$$

Then

$$\Delta\beta_t = \frac{ab\omega_1 \sin\varphi_1}{2} t = \frac{1 \cdot 5{,}8^2 \cdot 10^{-8} \cdot 10 \cdot 3{,}6 \cdot 10^3}{2} = 6{,}06 \cdot 10^{-3}\ .$$

This example confirms that even under moderate conditions of tossing, the component of the gyroscope nutation can be significant.

To illustrate this example we will prove how effective is the autocompensation two-channel method of the influence of tossing. The control signal of the stabilizing engine should be formed as a difference of electrical signals of two integrating channels on each axis, i.e.,

$$U_{op} = U_{out1} - U_{out2} = k_{sa1}\beta_1 - k_{sa2}\beta_2,$$

where k_{sa1}, k_{sa2} – coefficients of transfer of the electrical angle sensor of the two devices; β_1, β_2 – angles of the moving parts of the electrically connected gyroscopes.

In order to simplify this effect all parameters of the integrated gyroscopes will be considered as equal, except for the signs of the kinetic momentums. Then, using the above mentioned equality, we write:

$$\beta_1 \simeq \beta_1(0) - \beta_1(0)a\sin\omega_1 t + b\sin(\omega_1 t + \varphi_1) - c\cos(\omega_2 t + \varphi_2) -$$
$$-\frac{ab\omega_1 \sin\phi_1}{2}t + \frac{ab}{4}\cos(2\omega_1 t + \phi);$$
$$\beta_2 \simeq \beta_2(0) + \beta_2(0)a\sin\omega_1 t - b\sin(\omega_1 t + \varphi_1) - c\cos(\omega_2 t + \varphi_2) -$$
$$-\frac{ab\omega_1 \sin\phi_1}{2}t + \frac{ab}{4}\cos(2\omega_1 t + \phi).$$

The angle of rotation of the second integrated gyroscope differs from the first only by the signs of the coefficients a and b, that due to changes in the sign of the angular momentum of the gyroengine of the second device.

It can also be assumed that

$$\beta_2(0) \simeq -\beta_1(0) = -\beta(0).$$

After substitution of the values β_1 and β_2, considering the last expression and the identity of the coefficients k_{sa1} i k_{sa2}, we'll get –

$$U_{op} = k_{sa}\left[2\beta(0) + 2b\sin(\omega_1 t + \varphi_1)\right].$$

A completely different situation occurs when the gyroscopic instruments are in the acoustic fields of a high level – above *150-160 dB*. In particular the following levels occur in the operating conditions in a supersonic motion.

Penetrating acoustic radiation «*swings*» the mechanical systems of devices and accessories. The emerging stringing state of the material of the gimbal causes the Euler inertial forces which create a «*false*» signal and, correspondingly, the error of measurement[19,20]. The cause of the

[19] Karachun V.V., Mel'nick V.N. Influence of Diffraction Effects on the Inertial Sensors of a Gyroscopically Stabilized Platform: Three –Dimensional Problem. International Applied Mechanics. 2012. T.48(4) P. 458–464.

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phenomenon is in the transition the material of the gimbal and the engine unit from the category of a completely solid surface in the category of an impedance construction[21][22]. This idea must necessarily be present in the design of onboard equipment of supersonic technologies[23,24,25].

CONCLUSIONS

Bench and theoretical studies of the effect of intense sound waves on polyaggregate systems of industrial design sensor of angular velocity modification DUSU allow to make some generalizations for other technical solutions of such systems and to formulate the following conclusions and recommendations:

– polyaggregate systems are subject to the action of intense acoustic rays. The proposed mechanical model of the elastically deformable polyaggregate system in the form of two coaxial cylindrical shells separated by a liquid allows to make a quantitative and qualitative assessment of the studied phenomena;

– on-board gyroscopic equipment of polyaggregate structure in the acoustic fields of the operating conditions of the aircraft may have methodological and instrumental errors due to the emerging Euler forces of inertia;

– to combat the negative effects of acoustic vibration of components, as one of the options, autocompensation methods can be recommended, which have passed bench testing with a positive result.

The research has proven the following:

– at the fuselage tossing, the GSP gyroscopic sensitive elements in the acoustic fields of a supersonic flight have the errors of measurement, which

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cause the construction errors of tryorthohonal coordinate system for the aircraft;

– it is clarified the structure of construction errors in the coordinate system using GSP, which enables to estimate the degree of influence of kinematic and acoustic perturbations;

– it is opened the mechanism of diffraction of sound waves in mechanical impedance systems of the gimbal in the inertial devices;

– the results obtained may serve as a theoretical basis of improvement the accuracy of constructing the guide lines for hypersonic vehicles of different classes.

SUMMARY

The paper evaluates one of the methods of autocompensation of diffraction phenomena in sensitive elements, which is used in gyroscopy. The operation of the gyrostabilizer in the operating conditions of the aircraft under the simultaneous influence of external perturbing factors – intense acoustic perturbation, as well as vibrations of the carrier body due to the operation of the engines. The expediency of the method for the use of supersonic aircraft in operational conditions for averaging the instantaneous values of stochastic structure errors is proved. The two-channel method is an effective means of reducing the influence of external perturbing factors due to methodological errors of the kinematics of gyroscopic sensors, in particular is an effective means of reducing the influence of cross-links between the channels of force stabilization of the platform by gyroscopic moment

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