*Наводяться результати експериментальних і теоретичних досліджень впливу проникаючого акустичного випромінювання високої інтенсивності на прилади інерціальної навігації. Пояснюється природа виникнення додаткових похибок в звукових полях і будуються аналітичні моделі виникаючих в натурних умовах хвильових процесів*

*Ключові слова: гіростабілізатор, хитавиця, акустичний вплив, авто-компенсація впливу перешкод*

*Приводятся результаты экспериментальных и теоретических исследований влияния проникающего акустического излучения высокой интенсивности на приборы инерциальной навигации. Поясняется природа появления дополнительных погрешностей в звуковых полях и строятся аналитические модели возникающих в натурных условиях волновых процессов*

*Ключевые слова: гиростабилизатор, качка, акустическое воздействие, автокомпенсация влияния помех*

*The results of experimental and theoretical researches about the influence of penetrating acoustic emanation of high intensity on the devices of inertial navigation are cited. The nature of appearance of complementary errors in sound waves are explained. Analytical models of wave processes appearing in location conditions are formed*

*Keywords: gyrostabilizer, tossing, acoustic influence, autoindemnification of influence of disturbances*

УДК 629.7.054

# WAVE TASKS OF INERTIAL NAVIGATION

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## 1. Introduction

Researches behave to the area of the applied mechanics. As is generally known, aircrafts of different start conditions – from the Earth surface, from mines, decks, orbiters, mobile stationing – influenced by penetrating acoustic emanation of high intensity (more than 150 dB) which affects inertial devices of flight-navigation equipment and besides leads to the errors in the construction of supporting co-ordinates. All the wave processes appearing in gyroscope suspension and also in correction systems make worse apparatus signatures on the whole [1, 2, 3, 4, 5] and first of all solving tasks of the near space [6].

## 2. Analysis of the state of problem and raising of task of researches

About $10^{-4}$ of jet engine power is transformed into acoustic vibration it reaches 4 kW for one aircraft of deck aviation. The power of acousric vibrations of one-hour flight is measured in 14 mJ. The consumptive energy release of jet engine equal to $6\cdot10^{3}$ Joule is injected into environment by one aircraft (according to INTERNET data www.irak.ru, www.rambler.ru) that corresponds to acoustic vibration power till 5,5 mJ.

As is known, the study of sound generation process by aerodynamic stream was started with M.J. Ligthill's works [7]. The analysis of influence of penetrating acoustic emanation on aircraft apparatus becomes systematical only lately.

Scaled down bench tests prove that under acoustic influence with 160 dB a free attitude gyro has systematical drift of the basic axis and a differentiative gyro has systematical errors.

Having carried out the decomposition of the suspension construction, it turns out well to analyze the nature of elastic surface displace of feat [8, 9, 10, 11] and membranate [12, 13] fragments in full detail.

Experimental researches in land-based testing complexes have allowed not only to reproduce the operational conditions of navigation equipment [14] but to realize some effective methods of passive acoustic insulation [15].

## 3. Preliminaries

In supposition of line material elasticity, the flexural motion of a flat isotropic plate with unlimited extension under the influence of sound wave in the form of

$$P_1 = P_{10}\exp i\left\{\omega t - k_0\left[(z+\delta)\cos\theta + y\sin\theta\right]\right\}, \qquad (1)$$

where $k_0 = \dfrac{\omega}{c}$ - wave number; $\omega$ - frequency; $c$ - sound speed in the air; $P_{10}$ - sound pressure amplitude (fig. 1), can be presented with the ratio –

$$W = \frac{P_{10}}{\rho}\exp i\left(\omega t - k_0 y\sin\theta - \varphi\right)\left[\rho_1\mu_1\exp i\varphi_1 + \rho_2\mu_2\exp i\varphi_2\right]. \qquad (2)$$

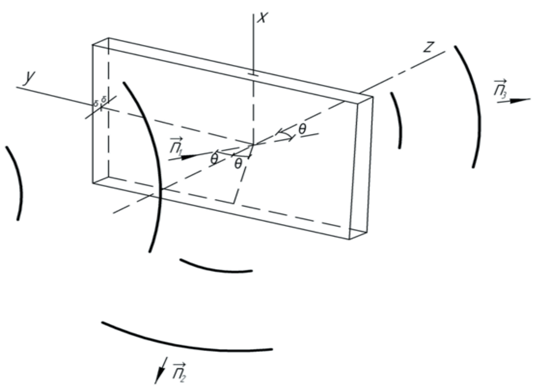


Fig. 1. Scheme of sound wave passing

At the thickness of a plate $\delta = 1\cdot10^{-3}$ m, the length of generated wave changes according to the law represented in fig. 2.

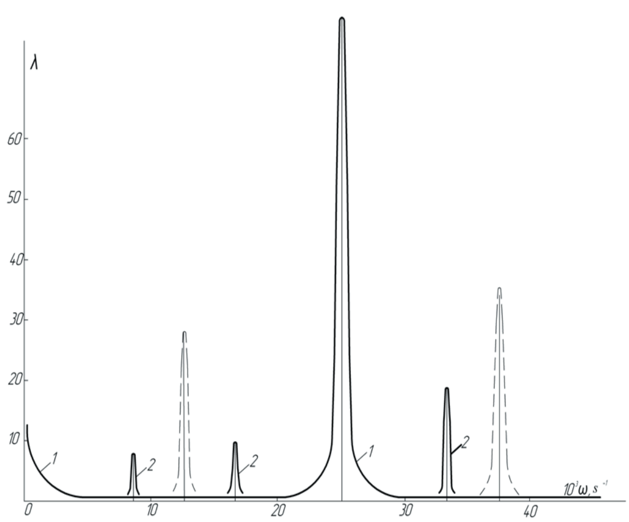



Fig. 2. Length of generated flexural mode in a plate: 1 — basic vibration; 2 — superposition of supplementary vibration form; modulating wave passing resonant area is depicted with a double line

It is obvious that medium power of a process is spread nonuniform throughout frequencies.

In the case of diffusive field the law of flexural motion (after averaging according Peris) can be written as:

$$W_\partial = 2\int_0^{7{,}5\pi/16} W\cos\Theta\sin\Theta d\Theta. \qquad (3)$$

Responsiveness of a plate size leads to another calculation model (fig. 3).

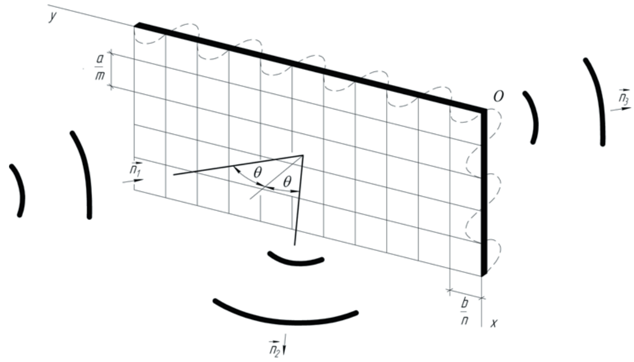


Fig. 3. Distribution of plate flexure

For example, having presented acoustic wave as

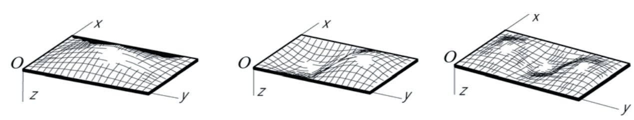
$$P(x,y) = \sum_{m_1=1}^{\infty}\sum_{n_1=1}^{\infty} P_{m_1 n_1}\sin\frac{m_1\pi x}{a}\sin\frac{n_1\pi y}{b}, \qquad (4)$$

where $m_1$, $n_1$ - numbers of half-waves of pressure, flexural motion of a plate (on the analogy) can be treated by dependence:

$$W(x,y) = \sum_{m=1}^{\infty}\sum_{n=1}^{\infty} W_{mn}\sin\frac{m\pi x}{a}\sin\frac{n\pi y}{b}, \qquad (5)$$

where $m$, $n$ - numbers of half-waves of curve.

Vibrational motion for the first forms is illustrated in fig. 4.



a) b) c)

Fig. 4. Flexure of a plate of limited size: a) $m_1 = m = 1$; $n_1 = n = 1$; b) $m_1 = m = 1$; $n_1 = n = 2$; c) $m_1 = m = 1$; $n_1 = n = 3$

The calculation model of sound passing through a round plate can be represented by a scheme (fig. 5). Flexural motion of a plate is described by regularity

$$W_T = c^j u_j, \; j = \overline{1,6}, \qquad (6)$$

where co-ordinate functions are accepted as:

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

$$u_4 = \frac{x^2}{R_i^2}u_1; \; u_5 = \frac{y^2}{R_i^2}u_1; \; u_6 = \frac{xy}{R_i^2}u_1$$

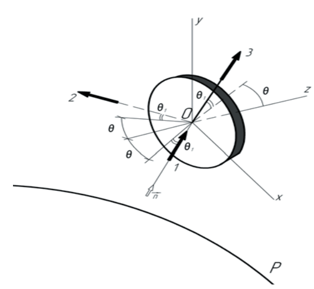


Fig. 5. Scheme of sound wave passing

the column is determined by the expression:

$$C = \left( c^1 \;\; c^2 \;\; \ldots \;\; c^N \right)^T = G^{-1}F =$$

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

$D_i = \frac{E_i h_i}{12(1-\sigma)}$ – cylindrical hardness;

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

A float two-degree gyroscope is being examined concretely. Under the action of penetrating sound wave the surface of a float will produce elastic displacements $U_z$, $U_\varphi$ and W in all three directions – correspondingly along the cylinder generatrix, along the parallel and in the cross direction:

$$U_z(t,z) = \sum_{k=0}^{\infty}\left[z^2(1-z)^2 a_1^{(1)} \exp(i\omega t)\cos z \cos k\varphi + z^2(1-z)^2 a_1^{(2)} \exp(i\omega t)\sin z \sin k\varphi\right]; \quad (7)$$

$$U_\varphi(t,z) = \sum_{k=0}^{\infty}\left[z^2(1-z)^2 b_1^{(1)} \exp(i\omega t)\cos z \cos k\varphi + z^2(1-z)^2 b_1^{(2)} \exp(i\omega t)\sin z \sin k\varphi\right]; \quad (8)$$

$$W(t,z) = \sum_{k=0}^{\infty}\left[z^4(1-z)^2 c_1^{(1)} \exp(i\omega t)\cos z \cos k\varphi + z^4(1-z)^2 c_1^{(2)} \exp(i\omega t)\sin z \sin k\varphi\right]. \quad (9)$$

The biggest in size displacements will be in the level of frame (fig. 6).

Evidently, represented data of elastic surface displacements of flat elements and jacket don't explain the mechanism of appearing gyroscope errors in acoustic fields.

## 4. Phenomenon sense

It's usual to estimate the integral error of inertial navigation devices as superposition from effects of separate disturbing factors and suspension elements are considered to be absolutely solid, properties of which are kept within one notion – a moment of inertia relative to corresponding axis.

At the same time, penetrating acoustic emanation, as it was shown above, transfers suspension into the category of impedance construction whose mechanical resistance to the sound wave influence is determined by the ratio of acoustic pressure to oscillatory speed of active surface, i.e.

$$z = \frac{P}{V} . \quad (10)$$

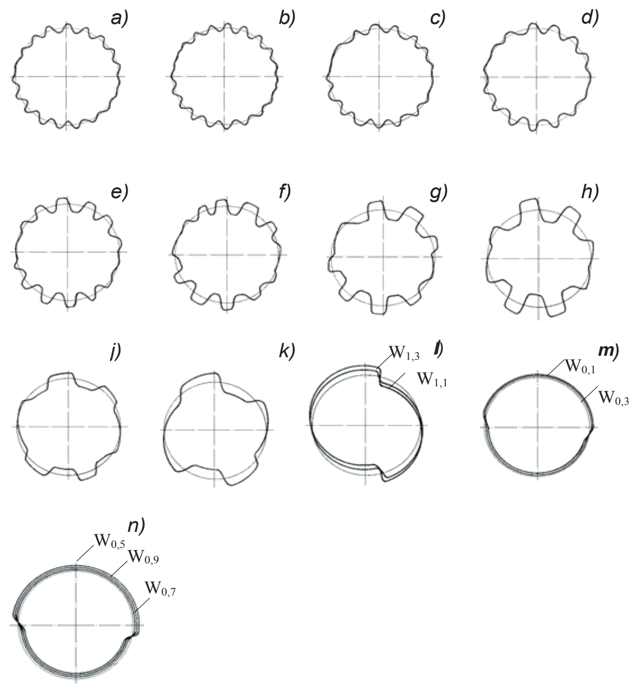



Fig. 6. Flexural vibration of a float in a medium frame at $\omega = 1\cdot 10^3 s^{-1}$: a) m = 10, n = 1; b) m = –10, n = 1; c) m = 9, n = 1; d) m = 8, n = 1; e) m = 7, n = 1; f) m = 6, n = 1; g) m = 5 n = 1; h) m = 4, n = 1; i) m = 3, n = 1; k) m = 2, n = 1; ℓ) m = 1, n = 1; m) m = 0, n = 1,3; n) m = 0, n = 5, 7, 9.

Thus, if the speed V, is equal to zero, the impedance becomes unlimited and the body should be considered as warp-free, absolutely solid. But if the speed is finite quantity elements of gyroscope suspension should be considered as a system with distributed parameters and calculation models should be constructed basing on the ratio of element extension and half-wave of acoustic effect.

Elastic compliance of gyroscope suspension leads to that the device takes the stress state as the input value and the output signal contains "false" component. The most dangerous is the case when the output signal contains systematic component. This is a reason of appearing constant error component in differentiative gyroscope or systematic drift of a basic axis in free gyroscope (gyroscope of direction) or integrant gyroscope.

In this case the peculiarity of construction of calculation models becomes the necessity of taking into account not one but two disturbing factors, for example, aircraft rolling, and penetrating acoustic emanation. Euler inertia power, appeared in this case, causes errors in measuring (fig. 7, 8).

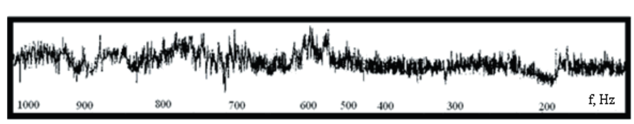



Fig. 7. Output signal of differentiative gyroscope

One could say, that a lot of novelties in technical solutions of gyroscope suspension demands serious reconsideration of their advisability at the work in acoustic fields of the high level – more than 150 dB. It concerns float suspension, string, torsion and many others.

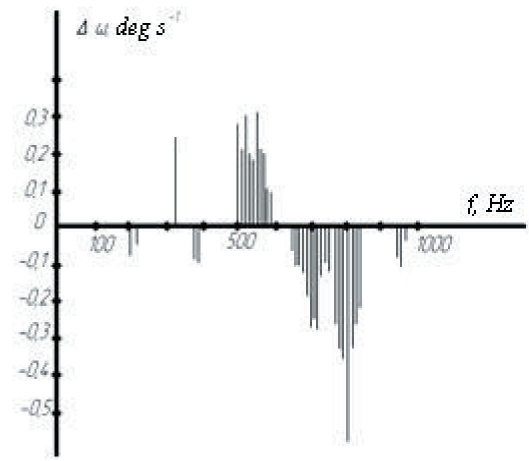


Fig. 8. Systematic error of float differentiative gyroscope in acoustic fields 160 dB

It turned out that penetrating emanation is dangerous not only for noncorrected devices but also for corrected ones, for example, for gyro horizons. The reason is that sound wave gets into the sensor of the correction system and it starts moving in the direction of wave spreading. Thus, the vial of liquid pendular switch works through the gyroscope axis in the direction of the "false" vertical line. When sound wave stops its action the device returns to its working state.

At last, some attention should be paid to the fact that spatial wave can be in the form of penetrating sound wave can be a reason of appearing some peculiarities of the resonance type. The question is about the wave coincidence (spatial resonance) and frequency-spatial resonance when the functioning of inertial navigation devices within the limits of certificate demands becomes problematic.

Special attention should be paid to the complicated gyroscopic system such as a triaxial gyroscope-stabilized platform where a two-degreed gyroscope plays the role of a sensor, for example, in the conditions of two-canal autocompensation of external error effect (fig. 9, 10).

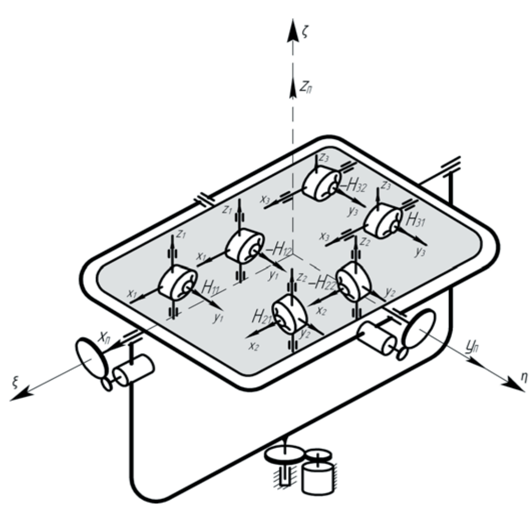


Fig. 9. Kinemaric scheme of a triaxial gyrostabilized platform

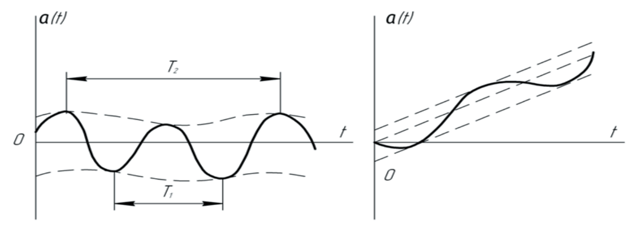


Fig. 10. The changing of stabilization angles of disturbing moments at different frequencies:

a) $\gamma_1 \neq \gamma_2$; $T_1 = \dfrac{2\pi}{\gamma_1+\gamma_2}$; $T_2 = \dfrac{2\pi}{\gamma_1-\gamma_2}$; b) $\gamma_1 = \gamma_2$

For example, the angle speed of the platform drift relative to the axis x is determined by the ratio –

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

$$= -\frac{1}{2}M_x^0 M_y^0 A_1(\gamma)A_4(\gamma)\cos\left[\varphi_1(\gamma)-\varphi_4(\gamma)-\eta_2\right]. \qquad (11)$$

## 5. Conclusion

As bench tests show, inertial navigation devices need in acoustic comfort. The guaranteeing of this condition can be reached by noise reduction at the site of its appearing, during its transmission and at last in the instrument module. The last variant is the most preferred.

In the case when massoverall demands are less strict it's possible to use diagrammatic solutions, in particular, autocompensating methods in decreasing effects of external errors. When these demands are too great it is not unreasonable to realize passive methods of acoustic insulation, for example, with the help of a perforated screen, patented in the Ukraine. Bench tests have confirmed their effectiveness, having permitted to reduce the level of external sound emanation from 161 dB to 115 dB (fig. 11).

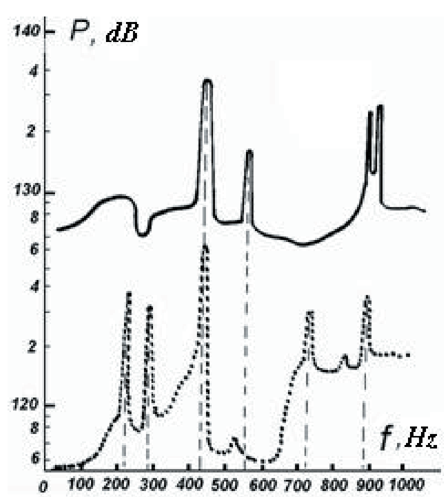


Fig. 11. Acoustic insulation with the help of two coaxial cylinders: compact- continuous line; external with longitudinal slots-dotted line

There are many ways of solving this task. The choice depends on demands presented to the aircraft on the whole.

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