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FOREIGN TECHNOLOGY DIVISION

GYRO SYSTEMS

(Selected Pages)

by

D.S. Pel'por

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GYRO SYSTEMS (Selected Pages)

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U. S. BOARD ON GEOGRAPHIC NAMES TRANSLITERATION SYSTEM

Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

GRAPHICS DISCLAIMER

All figures, graphics, tables, equations, etc. merged into this translation were extracted from the best quality copy available.

GYRO SYSTEMS.

D. S. Pel'por.

Translator's Note: "Free gyroscope"should read "Gyroscopes with two degrees of freedom".

Translator's Note: "balancing moustache" should read "balancing whisker"

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Introduction.

The development of contemporary aviation and rocket engineering is characterized by a considerable increase in the velocity, flight altitude and maneuverability of flight vehicles.

The enormous technical successes in the field of the creation of contemporary aircraft, rockets and spacecraft became possible in connection with the use of achievements of aerodynamics, engine construction and automation of control processes of flight vehicles.

The basic tasks of control of flight vehicle, orientation, autonomous navigation and stabilization are solved with the aid of the gyroscopes and the systems the accuracy of work of which determines the effectiveness of the action of aircraft, rockets and spacecraft.

In addition to this, on gyro systems are laid the complex problems on the stabilization to control of a whole series of special onboard systems (antenna of airborne radar, sensing elements of the self-homing heads of rocket projectiles, aviation sights, aerial cameras, etc.).

The onboard systems, which are subject to stabilization in the assigned direction in the space, possess large weight and with the moments of inertia; in this case under the conditions for the intense fluctuations of flight vehicle the gyro stabilization tests/experiences considerable dynamic loads. The requirements of the high accuracy of the stabilization of onboard systems in the assigned direction in the space and the severe conditions for their operation led to the creation of gyro stabilizers.

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Gyro systems are applied in different areas of technology: in the aviation and on the marine vessels - for purposes of navigation and automatic steering of ship; in the artillery and on the tanks - for determining of course and stabilization of sights and instruments in the assigned direction in the space; in the mining and petroleum industry - with the packing of mines/shafts and tunnels, during drilling of the oil wells, etc.

With the aid of gyro systems determine the direction of meridian and true vertical, measure the angular velocities and the accelerations, and also linear velocity and the coordinates of moving objects.

Contemporary gyroscopes and systems are the complicated electromechanical devices/equipment, in constructions/designs of which are utilized high-speed synchronous and induction motors, zero moment inductive sensing elements, electronic, transistor and magnetic transducers and amplifiers, precision selsyn and potentiometric teletransmissions, reduction and ungeared servodrives, electromagnetic moment sensors, precision special ball bearings and other forms of precision suspensions (float, air, electrostatic, electromagnetic, etc.) and i.e.

Instruments and the systems whose action is based on the use of properties of gyroscope, they are called gyroscopic.

Gyroscopes and systems according to the designation/purpose are divided into the following basic groups: the differentiating and integrating gyroscopes, gyrostabilizers, course gyro systems, gyroscopic sensors of the direction of the true vertical and inertial systems.

The action of the integrating and differentiating gyroscopes is based on the principle of the measurement of the gyroscopic moment/torque, developed with gyroscope during the forced rotations of the axis of its rotor in the absolute space.

In the gyro stabilizers is utilized the property of gyroscope to keep constant the direction of the stabilized axis in the absolute space.

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Course gyro systems and gyroscopic sensors of the direction of the true vertical are the gyro stabilizer, corrected with the aid of the inductive or magnetic detector, the physical pendulum, the local infrared vertical and other devices/equipment, which possess the properties of selectivity with respect to the direction of the true vertical or to the direction of meridian.

Inertial systems are the most complicated gyroscopic devices, basic element/cell of which is precision gyro stabilizer with the accelerometers or accelerometer-integrators, are corrected with the aid of sensing elements, which possess properties selectivities with respect to the direction of the true vertical and to the direction of meridian. With the aid of the precision accelerometric caps/knobs and the integrators are determined the accelerations of the motion of ship, rocket or aircraft, is conducted the integration of accelerations and is located speed and place of the position of ship, rocket or aircraft relative to the earth/ground or in outer space.

Basic part of any gyroscope or system is gyrostabilizer, in essence being determining accuracy and operating characteristics of gyroscopes and systems.

The wide application of gyroscopes for orienting the moving objects is explained by the fact that the gyroscope possesses the increased resistivity with respect to the acting on it moments of external forces and in the larger measure, the usual "nongyroscopic" solid body, it is allotted by the ability to keep the direction of the axis of its rotor constant in the absolute space.

Are known the remarkable properties of the fast-turning gyroscope which under its own weight falls sideways in line of force of weight, and quietly it balances on the tip of its axis. The surprising stability, communicated to gyroscope by high-spin motion, has already long ago attracted attention. Even in the XVIII century were done the attempts to utilize this property of gyroscope for determining the direction of the true vertical aboard the ship; however, at that time this instrument did not obtain practical use/application.

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The first serious use of remarkable properties of gyroscope was experiment, set up by physicist Foucaults in 1852. Foucaults demonstrated the constructed with it instrument the gyroscope (Fig. V.1), basic part of which was the fast-turning rotor (handwheel).

Foucaults's instrument is the gyroscope with three degrees of freedom, the center of gravity of which coincides with the center of the gimbal suspension. The gimbal suspension provides to handwheel the freedom of rotation around the fixed point (three degrees of freedom). It consists of external 4 and internal 3 rings. Handwheel 2 rotates on the bearings relative to internal ring 3, which is achieved by its untwisting with the aid of the cord around the axis, perpendicular to the plane of drawing. Handwheel 2 together with internal ring 3 pivots relative to outer ring 4 around the horizontal axis x-x, and outer ring 4, suspended/hung from filament 1, together with the internal ring and by handwheel is turned around the vertical axis y-y.

Foucaults's instrument for the first time allowed to reveal/detect the fact of the daily rotation of the Earth the direct laboratory ones of experiments. Term gyroscope is obtained from the Greek words: gyros - rotation, and scopeo - I observe. At present term gyroscope is applied in a broader sense for the designation of the instruments in which is used the peculiar property of the fast-turning body to develop inertia gyroscopic moment/torque.

The theory of gyroscopes and systems is based on the general theory of gyroscopes and gyrostabilizers. The theory of gyroscopes is the development of the section of theoretical mechanics about the motion of solid body about the fixed point.

To the study of the motion of solid body about the fixed point are dedicated the work of such outstanding scientists as L. Euler, Zh. Lagrange, L. Poinsot and S. Kovalevskiy et al.

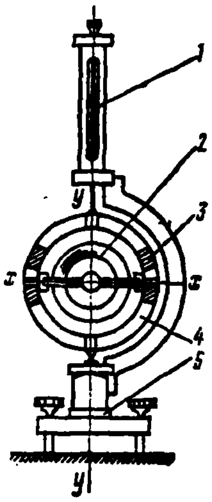

Fig. V.1. Foucaults's gyroscope: 1 - filament; 2 - handwheel; 3 - internal ring; 4 - outer ring; 5 - basis/base.

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These remarkable investigations arose during the study of the laws of planetary motion.

From the time of L. Euler (1765) and Zh. Lagrange (1788) passed about 200 years; however, the fundamental results, obtained in these works, are basic and at present.

During the investigation of complicated mechanical systems which include the gyrostabilizers, it is convenient to use D'Alembert's principle, which makes it possible to isolate the so-called effective and lost moments/torques.

Is very interesting and demonstrative the treatment of the theorem about the moment of momentum, given by Resal. Resal theorem is utilized with the explanations of physics of the phenomena, which appear during the motion of gyroscope.

With the development of gyroinstrument manufacture the classical problems of the dynamics of the motion of solid body about the fixed point fell back to the second plan/layout, after yielding the place for the problems, advanced gyroinstrument manufacture technique, whose development in essence relates at the beginning of the XX century.

The important representatives of this direction are M. Schuler, A. I. Krylov, B. V. Bulgakov, Ye. L. Nikolai, R. Grammel', B. I. Kudrevich, S. S. Tikhmenev et al.

From the contemporary important scientists in the region the theory of gyroscopes and systems and in particular the theory of gyrostabilizers should be named/called A. Yu. Ishlinskiy, Ya. N. Roytenberg, S. S. Rivkin.

Gyrostabilizer together with relief mechanism or servomechanism is automatic control system and during the selection of its parameters are utilized not only the principles of theoretical mechanics, but also the methods of the theory of automatic control.

Theory encompasses the study of the constrained motion of the gyrostabilizers of those representing by itself the system, which consists of the series/row of solid bodies. The constrained motion of gyrostabilizer determines its errors under operating conditions. The theory of gyrostabilizers also studies questions of stability and quality of the transient processes, which appear during the motion of the platform of gyrostabilizer, which is controlled system.

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The accuracy of gyrostabilizer in essence is determined by the average/mean deflection velocity of the stabilized axis of platform from the assigned direction in the space, and also by the amplitude of the periodic oscillations of the stabilized axis.

The average/mean deflection velocity of the stabilized axis of the platform of gyrostabilizer, called subsequently the actual speed of the precession of the platform of gyrostabilizer, is its main characteristic.

The actual speed of the precession of the platform of gyrostabilizer appears as a result of the action on the platform and the gyroscopes of the gyrostabilizer of the perturbing moments/torques. The quality of gyrostabilizer is also determined by the ratio of the amplitude of periodic forced oscillations of platform in the space to the amplitude of the angular oscillations of that object on which is established/installed the gyrostabilizer.

The value of the actual speed of precession and the amplitude of the angular oscillations of the platform of gyrostabilizer depend on the parameters of gyroscopes and relief mechanism, and also on value and character of the perturbing moments/torques.

Value and character of the perturbing moments/torques, which act on the platform and the gyroscopes of gyrostabilizer, are determined by operating conditions: by amplitude and frequency of angular oscillations, by value and by character of the overloads, which appear during the motion of that object on which is established/installed the gyrostabilizer, by the intensity of the vibrations of the attachment point of the housing of gyrostabilizer, etc.

It was before accepted to divide gyrostabilizers into direct and indirect action. Gyrostabilizers whose gyroscopic moment/torque directly counter-balance moments of external forces, its acting around axes stabilization, were called direct. In the gyrostabilizers of indirect action the gyroscope is utilized only for measuring the angle of deflection of the stabilized object from the assigned direction in the space, and the stabilization of object in the assigned direction in the space is realized with the aid of the servo systems.

Direct gyrostabilizers divide into the power and indicator-power.

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In the power gyrostabilizers the motion of gyroscopes relative to the axes of their precession is not squeezed by any connections/communications, and the moments of external forces, the acting around the axes stabilization, in essence they are balanced by gyroscopic moments/torques and only partially by the moments/torques, developed with the engines of relief mechanisms. In indicator-power gyro stabilizers around the axes of precession of gyroscopes act the moments/torques, created by the damping devices (floating gyroscopes) or elastic elements/cells and damping devices (sensors of angular velocity), adjusted on the axes of precession of gyroscopes.

Damping devices and elastic elements/cells decrease the speed of gyro precession around the axis of its precession and, consequently, also the value of the gyroscopic moment/torque, which acts on the platform. In this case the moments of external forces in indicator-power gyrostabilizers in essence by the counter-balance moments, developed with the engines of relief mechanism; whereas gyroscopes are converted into the indicator instruments; only measuring the deviation or the angular deflection velocity of the platform of gyrostabilizer from the assigned direction.

Power and indicator-power gyrostabilizers divide into one-, two- and triaxial ones, or three-dimensional/space ones, gyrostabilizers. Uniaxial gyrostabilizers in turn, divide into one- and two-rotor, and biaxial - on two - and four-rotor.

To the power ones uniaxial to gyrostabilizers also can be attributed gyroscopes in the gimbal suspension.

The selection of diagram and constructing/designing the gyrostabilizer is determined by the problems, laid on it, and by the requirements, which escape/ensue from use conditions.

The simplest gyrostabilizer, successfully which decides series of problems in the orientation of flight vehicles, is astatic gyroscope in the gimbal suspension.

However, the inadequacy of diagram and elements of the construction/design of gyroscopes in the gimbal suspension leads to the emergence of the moments/torques, which act on the gyroscope in the process of its operation and which considerably deflect the axis of its rotor from the assigned direction in the space.

Gyroscope in the gimbal suspension under the effect on it of the moments of external forces develops the gyroscopic moment/torque, counter-balance moment of external forces.

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In the power gyrostabilizers the moment of external forces is balanced not only by gyroscopic moments/torques, but also by moment/torque, developed with the engine of relief mechanism or with the engine of servo system, which raises the stability of platform in the space and, therefore, which lowers the actual speed of its precession.

In this case power or indicator-power gyrostabilizers are more complicated systems than astatic gyroscope in the gimbal suspension.

At the same time relief mechanisms in a number of cases during the operation become the sources of errors in the stabilization of the platform of gyrostabilizer in the assigned direction in the space.

The investigation of such errors is the important section of course "Theory of gyro stabilizers".

The determination of errors in the stabilization of the platform of gyrostabilizer in the space for the arbitrary motion of aircraft or rocket on which is established/installed the gyrostabilizer, does not lead to the demonstrative physical forseeable results, which is especially important with the presentation of complicated theoretical course to engineers. In this case are determined errors in the stabilization of platform or axis of gyrorotor for the bases, the important ones from the point of view of the operation of the motions of aircraft or rocket. By such motions are the straight flight of aircraft - forward motion, turn, periodic oscillations of aircraft around its center of gravity, veering, acrobatic maneuvers (loop, barrel/buoy, Immelman turn, etc.).

In accordance with the basic forms of the motion of aircraft and in connection with by the tests of gyroscopes and systems in the laboratory, that imitates operating conditions, in the present course is examined the motion of gyro systems on the motionless and vibrating bases/bases, on the rotating and swaying bases/bases and during the unlimited rotations of the aircraft when the motion of gyroscope occurs near the coincidence of the axis of its rotor with the axis of the external framework of the gimbal suspension.

As a result of theoretical studies of the motion of gyroscopes and gyrostabilizers under the varied conditions for their operation in the textbook are given the simple analytical dependences, convenient for the use at the determination of accuracy and selection of the necessary diagram and parameters of gyroscopes and gyrostabilizers.

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PART II.

Free gyroscopes.

There are gyroscopes whose action is based on the use/application of horoscopes, which possess two degrees of freedom. Such instruments include the differentiating and integrating gyroscopes, and also gyrocompass - the declinometric gyroscope also of gyro-ranges - inclinometric gyroscope.

If we turn to the definition of term gyroscope, given in Chapter 1, then it is easy to see that the free gyroscope is not actually gyroscope. In this case, naturally, and the basic properties of the gyroscope, which has three degrees of freedom, and free gyroscope are completely different.

Let us visualize the free gyroscope (Fig. RP.1), established/installed on the basis, which rotates around the fixed point.

The rotor of 1 gyroscopes rotates with high angular velocity $\dot{\varphi}$ around z axis which together with framework 2 pivots around x axis relative to basis/base 3.

Y axis it is directed perpendicularly to plane xz so that the trihedron xyz would be right.

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Basis/base 3 rotates with the movable angular velocity ω, the sense of the vector of which does not coincide with z axis of gyroscope. Angular velocity ω let us decompose on two components: component ω_x, directed along the axis x, and component ω_{yz}, located in plane P, carried out through y and z axes.

Thus, component ω_{yz} is the projection of vector ω on plane P.

If one assumes that bearing friction of the framework of 2 gyroscopes is absent, then during the rotation of basis/base around x axis the latter does not transfer any moment/torque to the framework of gyroscope, and therefore it will not show/render effect on its motion.

Component ω_{yz} let us decompose on the directions of y and z axes, namely:

$$\left.\begin{aligned} \omega_y &= \Omega_y^e = \omega_{yz}\sin(\widehat{H, \omega_{yz}}),\\ \omega_z &= \omega_{yz}\cos(\widehat{H, \omega_{yz}}). \end{aligned}\right\} \quad (1)$$

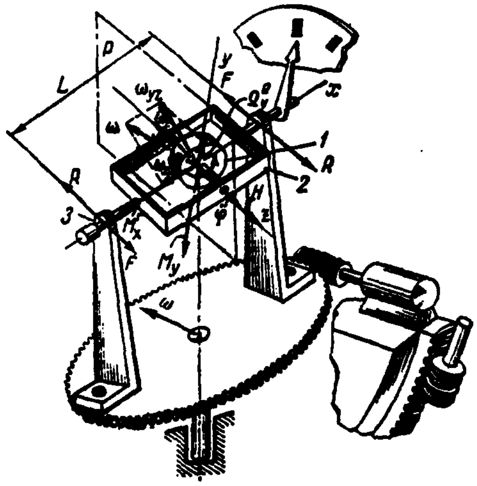

Fig. RP.1. Free gyroscope: 1 - rotor; 2 - framework; 3 - basis/base.

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Storing/adding up component ω_z with the relative angular velocity $\dot{\varphi}$, we obtain the absolute angular rate of rotation of the rotor

$$\Omega_z = \dot{\varphi} - \omega_{yz}\cos(\widehat{H, \omega_{yz}}).$$

In the practical applications/appendices angular velocity $\omega_{yz}\cos(\widehat{H, \omega_{yz}})$ is small in comparison with $\dot{\varphi}$ and in the first approximation, we consider that $\Omega_z \simeq \dot{\varphi}$, and also $H = C\Omega_z \simeq C\dot{\varphi}$.

Component Ω_y^e of movable angular velocity ω is the instantaneous angular velocity of the rotation of the axis of gyrorotor in space ($\omega_y = \Omega_y^e$).

In this case appears the gyroscopic moment/torque

$$M_x^г = H\Omega_y^e = H\Omega_{yz}\sin(\widehat{H,\ \omega_{yz}}). \qquad (2)$$

As a result of the ideality of supports 3 basis/base cannot report to gyroscope the moment of external forces, acting around axis x. In this case the gyroscope is turned around x axis under the action of gyroscopic moment/torque $M_x^г$ so, as is turned any solid body under the action of the moment of external forces.

The motion of gyroscope around x axis is determined by the differential equation, which contains only inertial moments

$$-A_0\dot{\Omega}_x + M_x^г = 0.$$

These inertial moments act on the framework of gyroscope, and the framework is turned with the angular acceleration

$$\dot{\Omega}_x = \frac{M_x^г}{A_0} = -\frac{H\Omega_y^e}{A_0}.$$

where $\dot{\Omega}_x$ - the angular acceleration, which appears during the rotation of z axis of gyroscope; A_0 - moment of the inertia of gyroscope relative to x axis encompassing the sum of the moments of inertia $A+A_1$ (A_1 - moment of the inertia of the framework relative to x axis).

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Appearing during the rotation of z axis with an angular velocity of Ω_x gyroscopic moment/torque $M_y^{г} = -H\Omega_x$ counter-balance moment FL, communicated by basis/base to the framework of the gyroscope where F - forces, which appear in the supports of framework 2, acting on it from the side of basis/base and directed in parallel to axis z, and L - distance between the supports of framework 2. However, gyroscopic moment/torque $M_x^{г}$ creates the reactive/jet pair RL, counter-balance moment FL.

Force R is determined from the expression

$$R = \frac{H}{L}\Omega_x = -\frac{H}{LA_0^{\circ}}\int M_x^{г}\,dt + S_1 = \frac{H^2}{LA_0}\int \Omega_y^{e}\,dt + S_1,$$

where S_1 - integration constant.

The value of gyroscopic moment/torque $M_x^{г}$, acting around x axis of gyro precession, is proportional to the component Ω_y^{e} movable angular velocity ω of the rotation of basis/base to y axis, perpendicular to the plane, which consists the axes of rotor and framework of gyroscope.

The operating principle of the sensors of angular velocity and integrating gyroscopes is based on value measurement of gyroscopic moment/torque $H\Omega_y^{e}$.

In this case such instruments measure precisely component

$\omega_y = \Omega_y^*$ of the movable angular velocity ω of the basis/base of instrument to y axis, which is called the measuring axis of free gyroscope.

From expression (2) it is evident that gyroscopic moment/torque M_x^Γ becomes zero, when vector H is combined with vector ω_{yz} and $(\widehat{H, \omega_{yz}})$ is equal to zero.

If z axis of gyrorotor differs from the direction of projection ω_{yz} of vector $\bar{\omega}$ on plane P to that or other side, then appears gyroscopic moment/torque $(H\Omega_y^*)$ (since $[\sin(\widehat{H, \omega_{yz}}) \neq 0]$), returning z axis of gyrorotor to the direction of the projection ω_{yz} indicated.

With the aid of the free gyroscope it is possible to determine the direction of projection ω_{yz} of the vector $\bar{\omega}$ of the movable angular velocity of the rotation of its basis/base to the plane, which consists z axis of gyrorotor and measuring y axis.

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Chapter IV.

Sensors of angular velocity and the integrating gyroscopes.

This chapter does not have as a goal the presentation of the theory of the sensors of angular velocity and integrating gyroscopes, since this theory is given in the course 'Gyroscopes". Is here communicated only the information, necessary for the following presentation of the course of the theory of gyrostabilizers. For the stabilization of the platform of gyrostabilizer and automatic flight control frequently is necessary to measure not only the deviation of platform from the assigned direction, but also the angular deflection velocity.

In the measurement of the angle of rotation of the platform of gyrostabilizer around any axis are applied the integrating gyroscopes.

The simplest sensor of angular velocity is free gyroscope (Fig. IV.1).

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The rotor of 1 gyroscopes with high angular velocity rotates around z axis which together with framework 3 is turned around x axis. Bearings 2 are attached on the platform whose angular velocity is subject to measurement. On the axis the framework of 3 gyroscopes are established/installed lever 9, connected with damper 8, by connecting rod 7 by guard 6, and also the brush of 5 potentiometric pickups. Brush slips on potentiometer 4, and signal U, removed from the potentiometric pickup, enters the amplifier (amplifier Fig. IV.1 does not show).

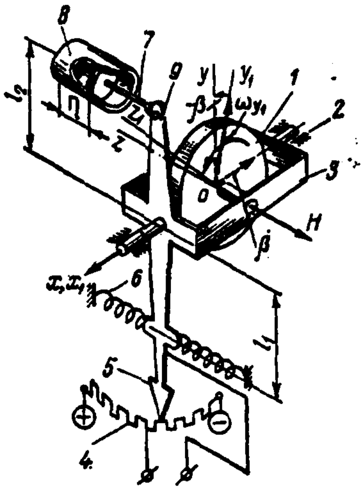

Fig. IV.1. Schematic of the sensor of angular velocity.

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If for example, it is necessary to measure angular velocity ω_{y_1} of the rotation of the platform of gyrostabilizer, then velocity transducer is established/installed in such a way that the y axis of device, perpendicular to the plane, which consists z axis of rotor and x of the framework of gyroscope, would coincide with axis y_1.

The forced rotation of framework 3 together with the platform of gyrostabilizer and, consequently, also z axis of gyrorotor around axis y_1 causes the appearance of the gyroscopic moment/torque whose vector is directed along the axis x.

Gyroscopic moment/torque M_x^{Γ} is equal to vector product of moment of momentum H and angular velocity ω_{y_1}, and its modulus/module is determined from the formula

$$M_x^{\Gamma} = H\omega_{y_1} \sin(H, \omega_{y_1}) = H\omega_y = H\Omega_y^e = \\ = H(\omega_{y_1} \cos\beta + \omega_{z_1} \sin\beta).$$

Gyroscopic moment/torque M_x^{Γ} by balancing spring 6, the angle of deflection of framework 3 and, consequently, also the brushes 5 depending on value and sense of the vector angular velocity ω_{y_1}.

The motion of the framework of the meter of angular velocity is determined by momental equation, which act on the framework of gyroscope; namely

$$\sum M_x = A_1(\ddot{\beta} + \dot{\omega}_{x_1}) + Dl_2^2\dot{\beta} + k_1 l_1^2 \beta + \\ + H\omega_{y_1} \sin(H, \omega_{y_1}) + M_{x_1}^{\text{в. с}} = 0,$$

or

$$\ddot{\beta} + \frac{Dl_2^2}{A_1}\dot{\beta} + \frac{k_1 l_1^2}{A_1}\beta = \\ = -\dot{\omega}_{x_1} - \frac{H}{A_1}\omega_{y_1}\cos\beta + \frac{H}{A_1}\omega_{z_1}\sin\beta - \frac{M_{x_1}^{\text{в. с}}}{A_1}, \quad \text{(IV.1)}$$

where β - angle of rotation of framework 3 relative to the housing of gyroscope; A_1 - moment of the inertia of rotor 1 and framework 3 relative to x axis; D - force gradient of attenuation, developed with damper 8; k_1 - spring constant 6; $\omega_{x_1}, \omega_{y_1}, \omega_{z_1}$ - components of the angular rate of rotation of platform in axis x_1, y_1 and z_1.

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Damper 8 effectively extinguishes the natural oscillations of the framework of 3 sensors of the angular velocity, the frequency of sustained oscillations of which

$$n=\frac{l_1}{2\pi}\sqrt{\frac{k_1}{A_1}} \qquad \text{(IV.2)}$$

and usually is selected in the limits from 2 to 100 Hz. In this case the angle β and, consequently, also the systematic error in the measurement of angular velocity ω_{y_1} is relatively small; inertia error $\frac{A_1}{k_1 l_1^2}\dot{\omega}_{x_1}$ also is usually small.

Considering angle β small and assuming/setting $\omega_{z_1}=0$ and $M_x^{\text{в.с}}=0$, we will obtain the approximate equation

$$A_1\ddot{\beta}+Dl_2^2\dot{\beta}+k_1 l_1^2\beta=-H\omega_{y_1}. \qquad \text{(IV.3)}$$

If from the framework of 3 gyroscopes (see Fig. IV.1) to disconnect spring 6, then it is converted into the so-called integrating gyroscope.

Assuming that for the integrating (floating) gyroscope moment/torque $Dl_2^2\dot{\beta}$, they are given rise to; by damper, it is great in comparison with inertial moment $A_1\ddot{\beta}$, approximately we will obtain

$$\dot{\beta} = -\frac{H}{k_1 l_1^2}\omega_{y_1}. \qquad \text{(IV.4)}$$

As a result of integration (IV.4) will take the form

$$\beta = -\frac{H}{k_1 l_1^2}\int \omega_{y_1}\,dt + S_1.$$

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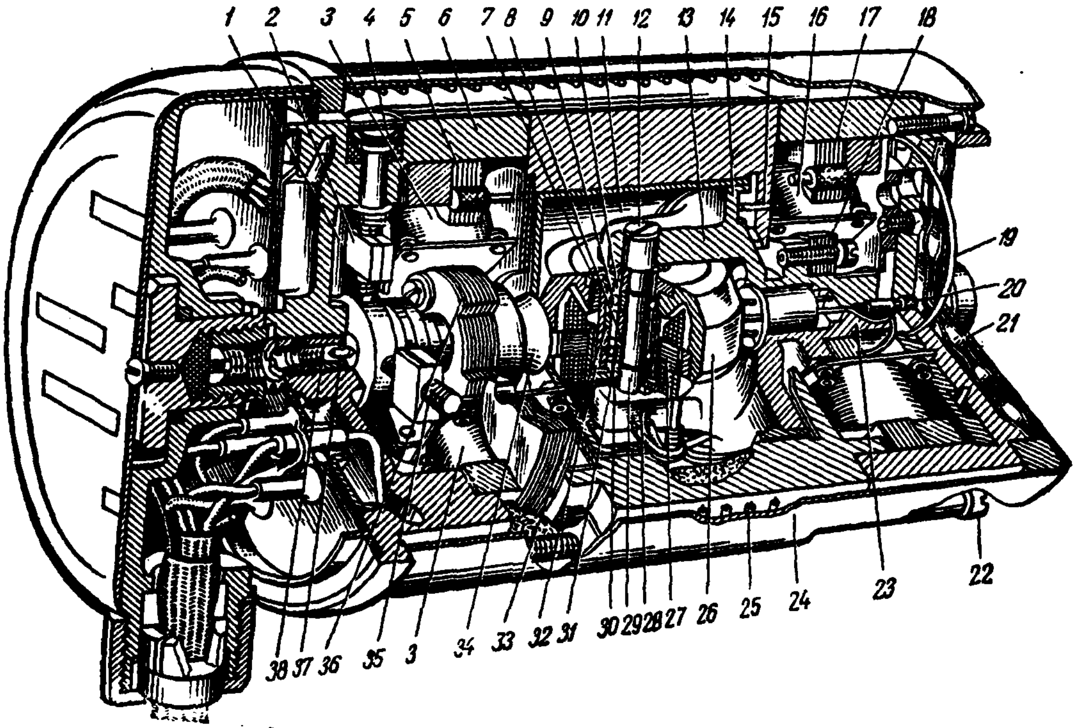

Fig. IV.2. The floating gyroscope: 1 - fork; 2 - balancing nuts; 3 - winding of the stator of the microsyn of sensor; 4 - cap/knob of balancing fork; 5 - package of the stator of the microsyn of sensor; 6 - housing; 7 - screw/propeller; 8 - the spacer; 9 - cover/cap; 10 - spin bearing; 11 - cylindrical part of the jacket/case/housing of float gyro-element; 12 - axis of rotor; 13 - arm; 14 - cover/cap of jacket/case/housing with arms 13 and 28; 15 - detent; 16 - winding of the stator of the microsyn of sensor; 17 - package of the stator of the microsyn of sensor; 18 - rotor of the microsyn of sensor; 19 - current inputs; 20 - hollow cylinder of the bellows; 21 - the bellows; 22 - coupling screw; 23 - shank of part 14; 24 - jacket/case/housing of the housing of instrument; 25 - heating element/cell; 26 - gyrorotor; 27 - stator of gyromotor; 28 - arm; 29 - spin bearing; 30 - washer; 31 - bushing; 32 - rotor hub; 33 - the spacer; 34 - shank of part 11; 35 - balancing moustache; 36 - rotor of the microsyn of sensor; 37 - support; 38 - bushing.

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Assuming that $\int \omega_{y_1} dt = \theta$ (where θ - angle of rotation of platform around axis y_1), and considering that with t=0, θ=0, we will obtain

$$\beta = -\frac{H}{k_1 l_1^2}\theta.$$

Thus, the angle of rotation of the framework of 3 gyroscopes and, consequently, also brushes 5 proves to be proportional to the angle θ of the rotation of platform around axis y_1. At the same time angle of rotation β is proportional to integral of the measured parameter - angular velocity ω_{y_1} - the rotation of platform.

As an example of the gyroscope, which integrates the angular rate of rotation of platform relative to any body axis, can serve floating gyroscope (Fig. IV.2).

Gyromotor 26, 27 is installed into float chamber 11, which floats in the heavy liquid. The axis of float rests on stone supports 37. On the axis of float are established/installed sensitive inductance pickup 36 for measuring the angles and moment sensor 16, 17. The clearance between the float chamber and the housing of instrument is approximately/exemplarily 0.25 mm, and the coefficient of the viscosity of liquid are approximately 600-700 cP.

Viscous liquid resistance to rotation of float in this case is proportional to the speed of its rotation and, therefore, fluid friction replaces the action of the air damper (see Fig. IV.1). This instrument can be used as the meter of the angle of rotation of the platform of gyrostabilizer in the absolute space.

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Second Section.

THEORY OF GYRO STABILIZERS.

Part IV.

UNIAXIAL GYRO STABILIZERS.

Gyroscope in the gimbal suspension the axis of rotor of which with the aid of relief mechanism is held in the direction of perpendicular to the plane of the external framework of the gimbal suspension, it is called uniaxial gyrostabilizer. In the process of operation under the effect of the moments of the external forces, which act around the axis of the external framework of the gimbal suspension, the axis of gyrorotor differs from the direction of perpendicular to the plane of the external framework of the gimbal suspension, and angle β grows/rises.

With an increase in the angle β effective component $H\cos\beta$ of the moment of momentum of gyroscope decreases and the actual speed of its precession grows/rises, and with the coincidence of Z-axis of gyrorotor with axis y_1 of the external framework of gimbal suspension (β=90°) is lost the ability of gyroscope to retain the direction of Z-axis of rotor by constant/invariable in the absolute space.

For the coincidence of Z-axis of gyrorotor with the direction of axis z_0, perpendicular to the plane of the external framework of the gimbal suspension (plane xy_1), is applied relief mechanism. The moments/torques, developed with the engine of relief mechanism, together with the gyroscopic moment/torque participate in the balancing of the moments of the external forces, which act around axis y_1 of gyroscope in the process of its operation. Relief mechanism is the system, which tracks after value and sense of the vector of the moments of forces. Uniaxial gyrostabilizer is the locked automatic control system.

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During the identification of the parameters of the channel of relief mechanism use methods the theories of automatic control. Relief mechanism gives rise to the actual speed of the precession of gyrostabilizer, especially with the tossing, the veerings and other evolutions of aircraft, rocket or any other unit on which is established/installed the gyrostabilizer, i.e., it is the source of its errors.

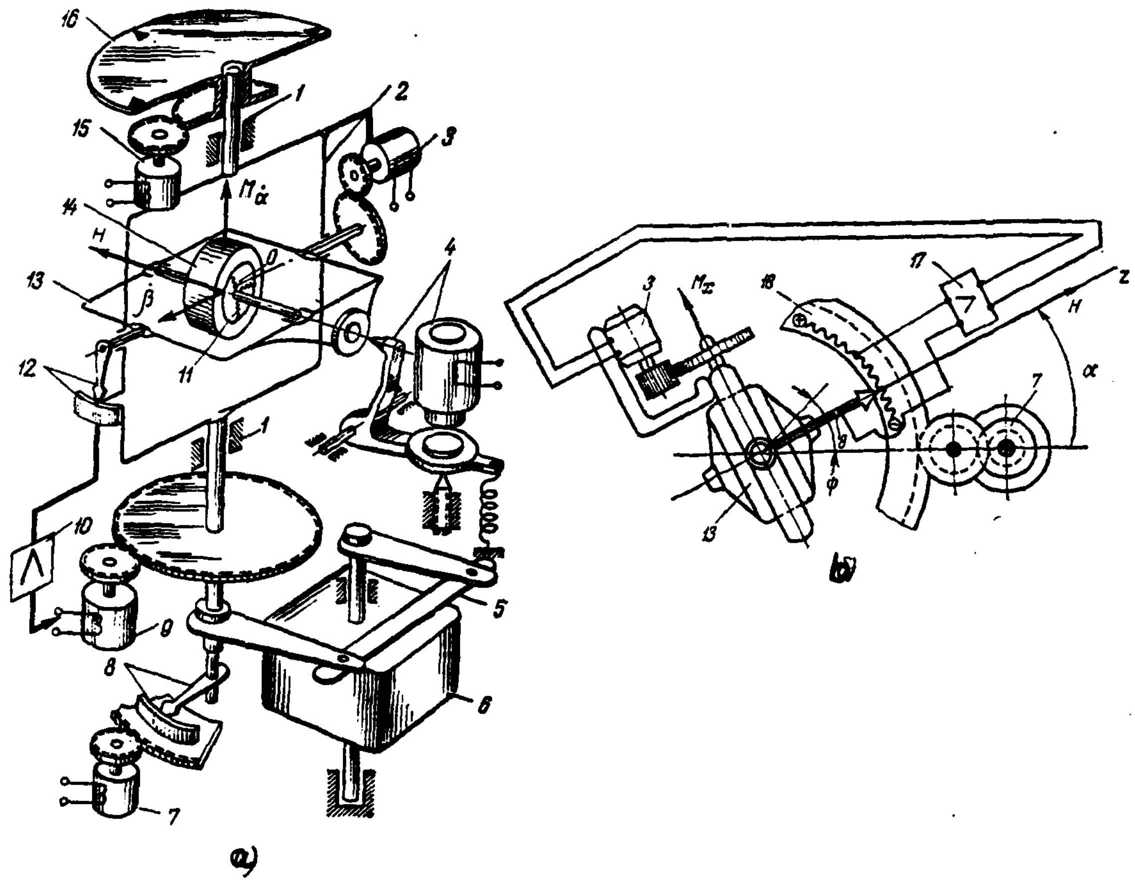

Fig. RV.1. Diagram of uniaxial power gyrostabilizer

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The reason for the emergence of such errors in the power uniaxial gyrostabilizer consists in the fact that Z-axis of gyrorotor actually has one degree of freedom relative to the object on which is established/installed the gyrostabilizer,-rotation around axis y_1 of the external framework of the gimbal suspension. During the rotations of aircraft around any axis, perpendicular to axis y_1 of the external framework of the gimbal suspension, the engine of relief mechanism is switched on and develops moment/torque, and Z-axis of rotor is turned in the space, giving rise to the actual speed of gyro precession.

In the second section are examined questions of the formation of the channel of relief mechanism and are determined the errors in the uniaxial gyrostabilizer, given rise to by relief mechanism in the process of its operation.

The standard diagram of uniaxial single-rotor gyrostabilizer is represented in Fig. RV.1. The rotor of 14 gyromotors, established/installed in the bearings of internal framework 13 of Cardan suspension is rotated by engine 11. Internal framework 13 together with the gyrorotor is turned around the axis of external framework 2, which pivots in the bearings, attached in the housing 1 of instrument. Engines 3 and 9 develop around the axes of the gimbal suspension the moments/torques, which correct the direction of the axis of gyrorotor in the space.

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The deviation of the external framework of the gimbal suspension relative to aircraft is fixed/recorded with the aid of the sensor of angle 8 or scale 16, and external framework 2 relative to internal 13 - by sensor 12 of relief mechanism.

The axis of the external framework of the gyrostabilizer, represented in Fig. RV.1, is directed in parallel to the normal axis of aircraft. The initial direction of the axis of gyrorotor relative to aircraft is established/installed with the aid of arresting device/equipment 4.

For the realization of the assigned law of a change in the course angle of aircraft either rocket on the gyrostabilizer is established/installed base, or programmed, the mechanism with engine 7. Stabilized object 6, for example optical sight, is connected with the gyrostabilizer with four-link chain 5.

For the adjustment of the readings and initial installation of scale 16 in certain cases it is turned relative to the external framework 2 of gimbal suspension with the angular velocity, given by engine 15.

In the uniaxial gyro stabilizer is accepted relief mechanism (12, 10, 9), which in principle differs it from the astatic gyroscope in the gimbal suspension.

As an example Fig. RV.2 presents the construction/design of the uniaxial power gyrostabilizer of sight, utilized in the system of autopilot.

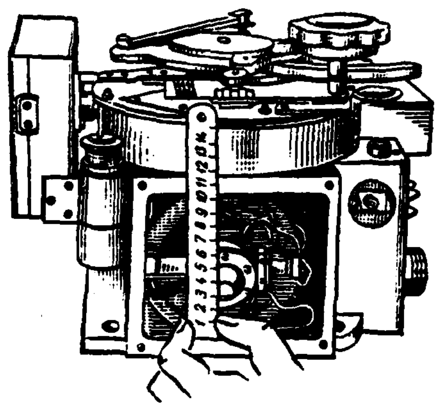

Fig. RV.2. The appearance of the uniaxial power gyrostabilizer of sight AP-5.

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In the process of flight on the gyroscope constantly act the moments of the external forces: the inertial moments, which appear during the unsteady flight; the moments/torques, developed with discharging engine; elastic moments/torques from current inputs, etc.

In this case in the process of build-up/growth and decrease of the moments of the external forces, which act around the axes of the gimbal suspension, appear the nutational oscillations of gyroscope. Especially effective nutational oscillations appear in the gyrostabilizers, intended for the stabilization of heavy devices/equipment, somehow: sights, antennas, aerial cameras, etc.

The operating principle of power uniaxial gyrostabilizer consists of the following.

Let the aircraft be turned/run up around normal axis y_1, and Z-axis of gyrorotor retains constant/invariable direction. In this case the internal rings of the bearings of the axis of the external framework of the gimbal suspension and stabilized object are turned relative to outer rings and in the bearings of gyroscope and stabilized object (Fig. RV.3) appears the moment of friction $M_{\dot{\alpha}}$. In accordance with the law of precession (if we are distracted from the nutational motions) under the action of moment/torque $M_{\dot{\alpha}}$ the axis of rotor z of gyroscope is turned around x axis of the internal framework of the gimbal suspension with an angular velocity of $\dot{\beta}=\frac{M_{\dot{\alpha}}}{H}$. X axis is called axis of precession of gyrostabilizer. During the motion of Z-axis of gyrorotor with the angular velocity $\dot{\beta}$ around axis y_1 of the external framework acts the inertia gyroscopic moment/torque, equal to $\frac{M_{\dot{\alpha}}}{H}$. H and directed to the side, opposite to the direction of external moment/torque $M_{\dot{\alpha}}$, and, therefore, in the dynamics balances external moment/torque. In this case Z-axis of gyrorotor is not turned around axis y_1 of the external framework, if we disregard/neglect the friction moment, which appears in the axle mountings x of the internal framework of the gimbal suspension.

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The motion of Z-axis of gyrorotor around x axis of the internal framework of the gimbal suspension causes the displacement of the brush of sensor 4, which sends control signal to discharging engine 2, and the latter develops moment/torque M_p, acting around axis y_1 of the external framework and to the countermoment of friction M_{α}.

Let us assume that the value of discharging moment/torque M_p grows/rises with the misalignment z of gyrorotor from the perpendicular to the plane of external framework ($\beta \neq 0$) and becomes zero with their coincidence. It is assumed that $|M_{p.max}| > |M_{\alpha}|$.

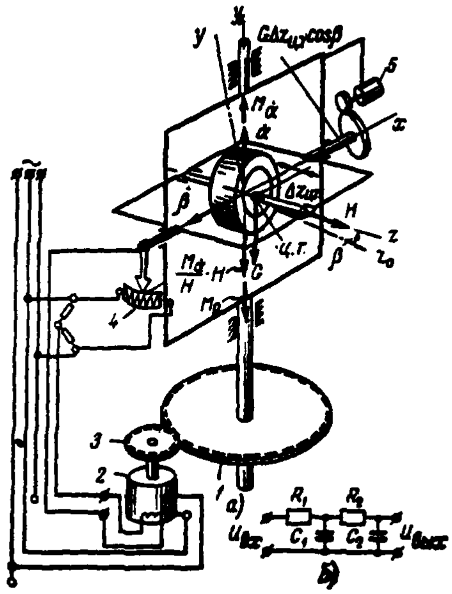

Fig. RV.3. The diagram of uniaxial power gyrostabilizer by the proportional characteristic of relief mechanism: 1, 3 - reducers of relief mechanism; 2 - engine of discharging; 4 - sensor of relief mechanism; 5 - engine.

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The moment of the external forces, which act around axis y_1, is equal to a difference in moments/torques $M_{\dot\alpha} - M_p$, and the speed of the precession of the axis of gyrorotor around the x-axis of the internal framework, equal to $\frac{M_{\dot\alpha} - M_p}{H}$, in this case decreases. If moment/torque M_p, developed with discharging engine, becomes equal to moment of friction $M_{\dot{\alpha}}$, the motion of Z-axis of gyrorotor around x axis of the internal framework of the gimbal suspension ceases.

As a result the misalignment z of the gyrorotor of uniaxial gyrostabilizer around axis y_1 of the external framework of the gimbal suspension does not occur (independent of value and direction of moment $M_{\dot{\alpha}}$, of the external forces, which act around axis y_1 of the external framework of suspension). Axis y_1 is called axis of the stabilization of gyrostabilizer.

However, the motion of Z-axis of gyrorotor around axis y_1 of the external framework of the gimbal suspension without difficulty appears, if the moment of external forces acts around the input axis.

Let the center of gravity of gyroscope be displaced with respect to x axis of the internal framework of the gimbal suspension along Z-axis of gyrorotor to the value, equal to $\Delta z_{\text{ц.т}}$, and the moment/torque, created by gravitational force, is equal to $G\Delta z_{\text{ц.т}}$, where G - weight of the rotor and internal framework. This moment/torque causes gyro precession around axis y_1 with an angular velocity of $\dot{\alpha} = \frac{G\Delta z_{\text{ц.т}}}{H}$ and in the bearings of the axis of the external framework of the gimbal suspension appears moment/torque $M_{\dot{\alpha}}$, which as before causes the precession of Z-axis of gyrorotor around x axis of the internal framework of the gimbal suspension and firing discharging engine. Discharging engine in the steady motion of gyroscope develops the moment/torque, the counter-balance moment of friction M_{a}, whereas moment/torque $G\Delta s_{\text{н.т}}$ remains unbalanced, and the misalignment z of gyrorotor around axis y_1 of the external framework of the gimbal suspension continues.

The moments/torques, which act around x axis of the internal framework of the gimbal suspension, somehow: moments/torques from the imbalance, the moments/torques of bearing friction of the input axis of the gimbal suspension, the elastic moments/torques, created, by current inputs and, etc., they give rise to gyro precession around axis y_1 of the external framework of the gimbal suspension and is caused the misalignment z of gyrorotor from the assigned direction in the space.

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The simplest uniaxial gyrostabilizers are the course instrument-gyrocompasses widespread in aviation and the sensors of the direction of arc of great circle, which are the astatic gyroscope, the axis of rotor of which is held with the aid of relief mechanism in the plane of the horizon/level. The same uniaxial gyrostabilizers are applied as the elements of gyromagnetic, astroinertial and other systems.

Power uniaxial gyrostabilizer also is utilized for the stabilization in the assigned direction and for the control of the optical sight of aircraft, entering the assembly of autopilot.

Uniaxial indicator-power gyro stabilizers with the floating gyroscopes or the sensors of angular velocity do not find independent use/application in the aviation, rocket engineering or marine fleet. Such instruments, just as power uniaxial gyrostabilizers, are the composite/compound component part two- or triaxial three-dimensional/space gyrostabilizers, and also extensively are used during the tests and the investigations, for example, of the integrating gyroscopes under laboratory conditions.

Let us examine the operating principle of indicator-power gyrostabilizer with the floating integrating gyroscope (Fig. RV.4). Connections/communications of the elements of the network of relief mechanism of uniaxial gyrostabilizer with the floating gyroscope do not differ from connections/communications of the elements/cells of relief mechanism of the power gyrostabilizer, represented in Fig. RV.. and RV.3.

A basic difference in the operating principle of indicator-power gyrostabilizer with the floating gyroscope from the power gyrostabilizer is in the fact that the freedom of the motion of float 6 of integrating gyroscope around axis x (internal framework of the gimbal suspension) is limited as a result of the emergence of damping moment $D_\beta\dot{\beta}$, of that developed with the viscous fluid, which fills the clearance between float 6 and housing 7 (by external framework of the gimbal suspension of gyrostabilizer) the integrating gyroscope.

Let us visualize uniaxial indicator-power gyrostabilizer with the extended channel of relief mechanism, i.e., let us assume that relief mechanism of gyrostabilizer is switched off. Let us assume that around axis y_1 of the stabilization of gyroscope acts fixed time $M^0_{y_1}$ of external forces.

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The equations of motion of gyroscope accordingly (II.21) will be:

$$\left.\begin{aligned} A_0\ddot{\beta} - H\dot{\alpha}\cos\beta_0 + D_\beta\dot{\beta} = 0, \\ J_0\ddot{\alpha} + H\dot{\beta}\cos\beta_0 = M^0_{y_1}, \end{aligned}\right\} \qquad \text{(PB.1)}$$

where D_β - specific torque of attenuating the float.

Eliminating from differential equations (RV.1) of the motion of gyroscope coordinate β, we will obtain

$$\dddot{\alpha} + \frac{D_\beta}{A_0}\ddot{\alpha} + \frac{H^2\cos^2\beta_0}{A_0J_0}\dot{\alpha} = -\frac{D_\beta M^0_{y_1}}{A_0J_0}. \qquad \text{(PB.2)}$$

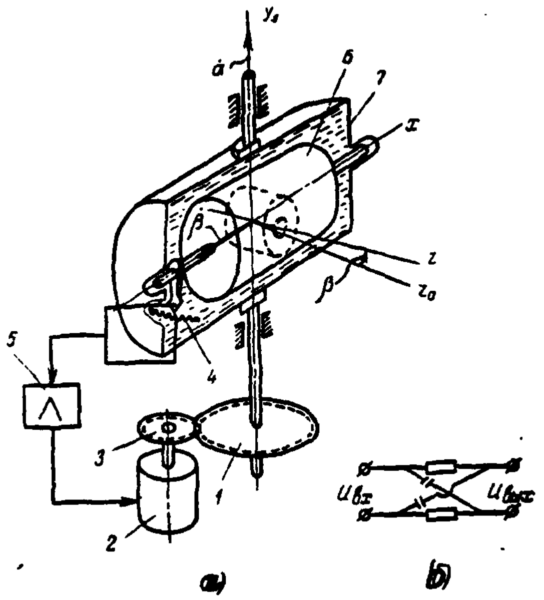

Fig. RV.4. The schematic of the uniaxial indicator-power gyro stabilizer: 1, 3 - reducers of discharging engine; 2 - engine of discharging; 4 - sensor of angle; 5 - amplifier; 6 - float; 7 - housing of gyroscope.

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The general solution of differential equation (RV.2) of the motion of gyroscope when $\frac{H^2\cos^2\beta_0}{A_0J_0} > \left(\frac{D_\beta}{2A_0}\right)^2$, will be:

$$\dot{\alpha} = -\frac{D_\beta M^0_{y_1}}{H^2\cos^2\beta_0} + e^{-\frac{D_\beta t}{2A_0}}\left[S_1 \sin \sqrt{\frac{H^2\cos^2\beta_0}{A_0J_0} - \left(\frac{D_\beta}{2A_0}\right)^2}\, t + S_2 \cos \sqrt{\frac{H^2\cos^2\beta_0}{A_0J_0} - \left(\frac{D_\beta}{2A_0}\right)^2}\, t\right], \quad \text{(PB.3)}$$

where S_1 and S_2 - integration constant, which depend on initial conditions.

Last two terms (RV.3) are the rapidly damped nutational vibrations of gyroscope, whereas the first term - the constant component of the actual speed of gyro precession, given rise to moment $M^0_{y_1}$ of external forces, which acts around axis y_1 of the stabilization of gyroscope.

If specific damping moment D_β of float is great and is satisfied condition $\frac{H^2\cos^2\beta_0}{A_0J_0}<\left(\frac{D_\beta}{2A_0}\right)^2$, the motion of gyroscope takes the form

$$\dot{\alpha}\cong-\frac{D_\beta M^0_{y_1}}{H^2\cos^2\beta_0}+S_1'e^{-\left[\frac{D_\beta}{2A_0}-\sqrt{\left(\frac{D_\beta}{2A_0}\right)^2-\frac{H^2\cos^2\beta_0}{A_0J_0}}\right]t}$$

(PB.4a)

and the second term of solution (RV.4a) is exponential motion.

In the steady motion of gyroscope as before

$$\dot{\alpha}_0=-\frac{D_\beta M^0_{y_1}}{H^2\cos^2\beta_0}=-\frac{M^0_{y_1}}{iH\cos^2\beta_0}, \qquad \text{(PB.4)}$$

where $i=\frac{H}{D_\beta}$.

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According to (RV.1) for the coordinate $\dot{\beta}$ in the steady-state

state of motion of the gyroscope

$$\dot{\beta}=\frac{H\cos\beta_0}{D_\beta}\dot{\alpha}=-\frac{H\cos\beta_0}{D_\beta}\cdot\frac{D_\beta M_{y_1}^{0}}{H^2\cos^2\beta_0}=-\frac{M_{y_1}^0}{H\cos\beta_0}$$

and coordinate β continuously increases, since

$$\beta=\frac{M_{y_1}^0}{H\cos\beta_0}t,$$

and, therefore, if with t=0 α=0, then

$$\alpha=-\frac{M_{y_1}^0}{iH\cos^2\beta_0}t \qquad \text{(PB.5)}$$

and coordinate α in the course of time increases. For example, for the parameters of gyroscope i=5, H=4000 g·cm·s, $\beta_0=0$, $M_{y_1}^0=1000$ g·cm, t=1 s we will obtain

$$\alpha=\frac{1000\cdot 1\cdot 57,3}{5\cdot 4000\cdot 1}=2,8^\circ.$$

The axis of the rotor of the dry gyroscope, which has the same parameters, as the floating gyroscope (see § VI.4), is deflected/diverted in the direction of the action of the moment of external forces $M_{y_1}^0$ independent of the time of its action on value

$$\Delta\alpha=\frac{A_0M_{y_1}^0}{H^2\cos^2\beta_0}=\frac{3\cdot 1000}{4000^2\cdot 1}=\frac{3\cdot 1}{16\cdot 10^3}=\frac{3}{16}\cdot\frac{3340}{10^3}\cong 0,6'. \qquad \text{(PB.5a)}$$

Z-axis of the rotor of indicator-power gyrostabilizer with the integrating floating gyroscope without relief mechanism, in contrast to the dry gyroscope, is turned in the direction of the action of moment $M_{y_1}^0$ of external forces with high angular velocity $\dot{\alpha}_0$, not admitted during its practical use/application.

For decreasing the actual speed of the precession of indicator-power gyrostabilizer, loaded even with relatively small moment $M_{y_1}^0$ of external forces, is necessary relief mechanism.

Let us examine the motion of indicator-power gyrostabilizer with simplest relief mechanism, which has proportional characteristic.

$$M_{y_1}^p = -E\beta.$$

According to (RV.1) we will obtain:

$$\left.\begin{aligned} A_0\ddot{\beta} - H\dot{\alpha}\cos\beta_0 + D_\beta\dot{\beta} = 0, \\ J_0\ddot{\alpha} + H\cos\beta_0\cdot\dot{\beta} = -E\beta + M_{y_1}^0, \end{aligned}\right\} \qquad \text{(PB.56)}$$

where E - mutual conductance of relief mechanism.

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We will be restricted to the examination only of the precessional motion of the gyrostabilizer:

$$\left.\begin{aligned} H\dot{\beta}\cos\beta_0 + E\beta = M_{y_1}^0, \\ \dot{\alpha} = \frac{D_\beta}{H\cos\beta_0}\dot{\beta}. \end{aligned}\right\} \qquad \text{(PB.6)}$$

The general solution of first differential equation (RV.6) will be

$$\beta = \frac{M_{y_1}^0}{E} + S_1 e^{-\frac{E}{H\cos\beta_0}t}, \qquad \text{(PB.7)}$$

where S_1 - integration constant, which depends on initial conditions.

The motion of gyrostabilizer, which corresponds to the second member of formula (RV.7), attenuates also in the steady-state state of motion of the gyroscope

$$\beta^* = \frac{M^0_{y_1}}{E},$$

and also

$$\alpha^* = \frac{D_\beta}{H\cos\beta_0}\beta^* + S_2. \qquad \text{(PB.8)}$$

If with t=0 $\alpha=\beta=0$, then $S_2=0$ and

$$\alpha^* = \frac{D_\beta}{H\cos\beta_0}\cdot\frac{M^0_{y_1}}{E} = \frac{1}{\cos\beta_0}\cdot\frac{M^0_{y_1}}{iE}.$$

In the process of the work of gyrostabilizer the angle β_0 remains small $(\cos\beta_0 \simeq 1)$ and, therefore,

$$\alpha^* = \frac{1}{iE}M^0_{y_1}. \qquad \text{(PB.9)}$$

Static error (RV.4) in indicator-power gyrostabilizer without relief mechanism and error (RV.9) in the gyrostabilizer with relief mechanism are in principle characterized by the fact, in the first case this error depends on time, but in the second case on time it does not depend. An error in indicator-power gyrostabilizer without relief mechanism is so/such great, that its practical use without relief mechanism is not possible.

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From the comparison of an error in the power and indicator-power (RV.9) gyrostabilizers it is evident that with equal mutual conductances of the static errors

$$E=\frac{H^2}{iA_0}.$$

For example, with A_0=3 g·cm·s², H=4000 g·cm·s, i=5 the static errors in the gyrostabilizers will be identical, when

$$E=\frac{H^2}{iA_0}=\frac{4000^2}{5\cdot 3}\cong 1,1\cdot 10^6.$$

The static errors in indicator-power gyrostabilizer are determined in essence by mutual conductance of relief mechanism. For increasing the accuracy of gyrostabilizer slope/transconductance E of the characteristic of relief mechanism of gyrostabilizer it follows as far as possible to increase. An increase in slope/transconductance E of the characteristic of relief mechanism is limited by the stability condition of indicator-power gyrostabilizer as automatic control systems.

For the stabilization of system with the formation of relief mechanism are applied different corrective cells.

The effect of the corrective cells on the stability of indicator-power gyrostabilizer as automatic control systems, is examined in chapter XI.

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Part V.

BIAXIAL GYRO STABILIZERS.

The bearings of the axis of the external framework of the gimbal suspension of uniaxial gyrostabilizer are established/installed on the object and, therefore, during the rotations of object around the center of its gravity the axis of the external framework of gyrostabilizer is turned in the space. In this case as a result of the effect of the noncommutativity of final rotations appears the actual speed of gyro precession.

More advanced is the biaxial gyrostabilizer which is intended for the stabilization of platform in the assigned plane. In the biaxial gyrostabilizer two uniaxial gyrostabilizers are connected into the single system, the operating principle of each of them does not differ from the operating principle of uniaxial gyrostabilizer or gyroframe (see Chapter XI and XV). The platform of biaxial gyrostabilizer has two degrees of freedom relative to aircraft, whereas the rotation of platform around the axis, perpendicular to the plane, which consists the axes of stabilization, occurs together with the aircraft.

The rotations of aircraft around the axis, perpendicular to the plane, which consists the axes of the stabilization of gyrostabilizer, exert the perturbing action on the platform of gyrostabilizer, which gives rise to the actual speed of the precession of platform and the deviation of platform from the assigned stabilization plane.

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Two- and triaxial gyrostabilizers are applied for the stabilization and the control of radar antennas, by sights, by aerial cameras, and also as sensing elements of autopilots and inertial systems.

The advantage two- and triaxial gyrostabilizers consists in the fact that the gyroscopes, established/installed on the platform of gyrostabilizer, with any evolutions of aircraft are turned around the axes of precession only to small angles.

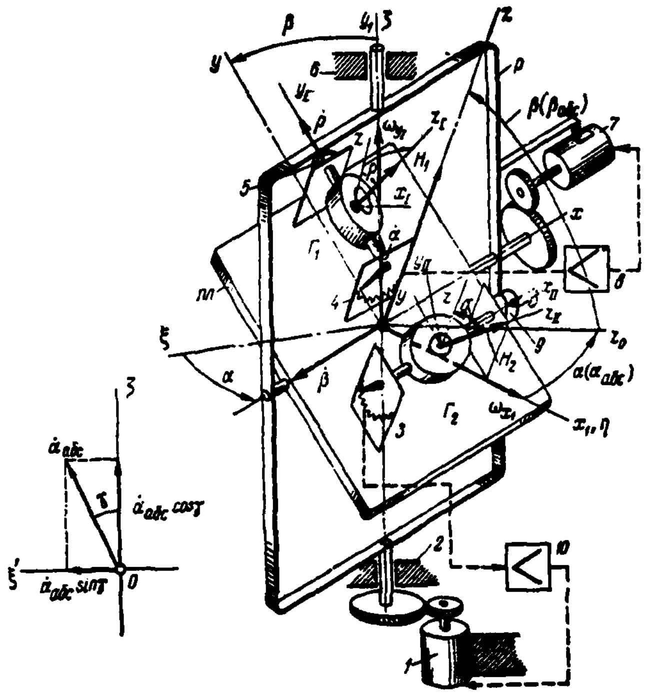

Fig. XVII.1. The diagram of biaxial two-rotor gyrostabilizer the axes of the gyrorotors of which are parallel to the stabilized Z-axis of platform.

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In this case is facilitated balancing/trimming gyroscopes around the axes of precession, are expanded the possibilities of accepting the structural/design measures for reducing the moments/torques of bearing friction and elastic moments/torques from the current inputs, which act around the axes of precession and which wait the actual speed of the precession of the platform of gyrostabilizer.

The selection of diagram, parameters of gyrostabilizer and its structural/design formulation are determined by the tasks, laid on it, by the required accuracy of gyrostabilizer and by the conditions for its operation.

In this case of the operating conditions especially great effect on the accuracy of gyrostabilizer have the overloads, which appear in the process of flight, the angular oscillations of aircraft and place of the attachment of the housing of gyrostabilizer.

Diagram of one of the biaxial gyrostabilizers is represented in Fig. XVII.1. The gimbal suspension of gyrostabilizer consists of platform Pl, by the being internal framework of the gimbal suspension, and the external framework P, suspended/hung in the housing in bearings 2 and 6. On the platform Pl are established/installed two gyroscopes G_1 and G_2 each of which has two degrees of freedom relative to it (rotation of the rotor of gyromotor and the rotation of its jacket). The angles of rotation of the jackets of gyromotors G_1 and G_2 relative to platform are determined with the aid of sensors 3 and 4 precession angles.

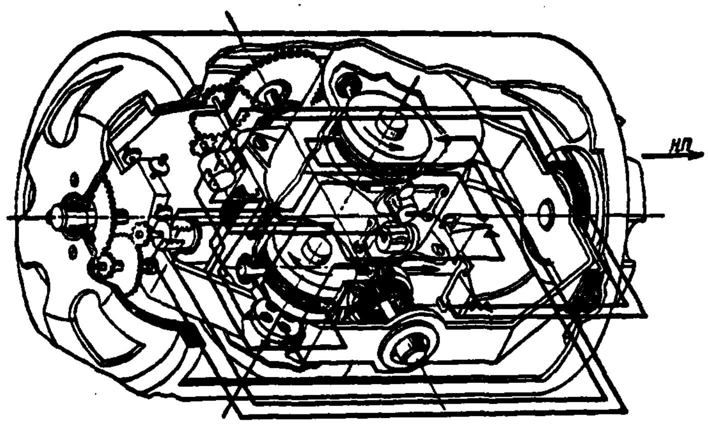

Fig. XVII.2. Design concept of central gyro horizon (biaxial two-rotor power gyrostabilizer).

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The signals, taken from sensors 3 and 4, through amplifiers 8 and 10 enter appropriate engines 1 and 7 discharging. For the correction of the position of platform Pl serve moment sensors 5 and 9, of the creating moments with respect to the axes of precession of gyroscopes.

The design concept of the biaxial two-rotor gyrostabilizer, which is central gyro horizon, is given in Fig. XVII.2.

Are applied gyrostabilizers with four gyromotors (Fig. XVII.3). The jackets of gyromotors G_1 and G'_1, G_2 and G'_2 established/installed on the platform Pl, are in pairs connected with gear quadrants or by anti-parallelogram lever systems just as in the uniaxial gyroframes.

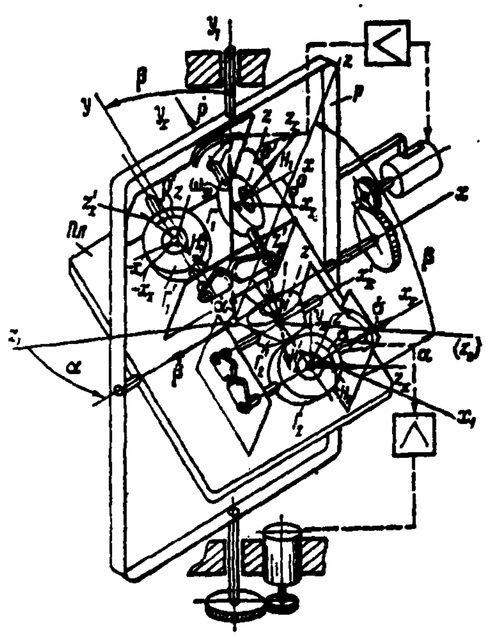

Fig. XVII.3. The schematic of the biaxial four-rotor gyrostabilizer, axis of the gyrorotors of which are parallel to the stabilized Z-axis platforms.

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Besides the arrangement/position of gyroscopes on the platform of the gyrostabilizer, given in Fig. XVII.1 and XVII.3, their another possible location, during which, for example, axes of precession of the corresponding gyroscopes are directed in parallel to Z-axis, stabilized in the space (Fig. XVII.4 and XVII.5).

The designation/purpose of biaxial gyrostabilizer lies in the fact that with the evolutions of the aircraft on which it is established/installed, to hold by constant/invariable in the absolute space the direction of Z-axis, perpendicular to the plane of platform Pl.

The motion of platform around Z-axis not stabilized and platform is turned around this axis together with the aircraft. In this case the rotations of aircraft cause the deviation of the framework of the gimbal suspension of gyrostabilizer in the absolute space, which leads to the emergence of the inertial moments (see Chapter, IV), which are together with the moments/torques of bearing friction of the axes of the framework of the gimbal suspension the moments of external forces with respect to the gyroscopes, established/installed on the platform.

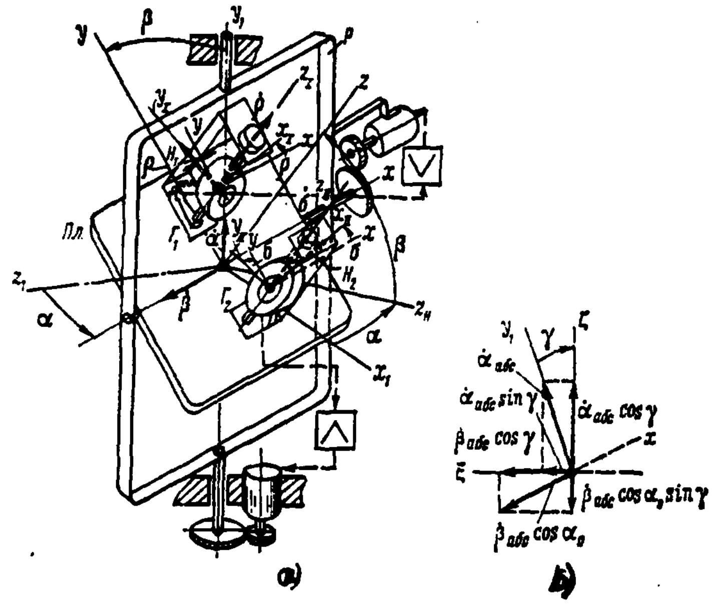

Fig. XVII.4. The schematic of the biaxial two-rotor gyrostabilizer, axis of precession of gyroscopes of which are parallel to the stabilized Z-axis platforms.

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The misalignments of gyrorotors relative to platform Pl and the movable rotation of platform around its Z-axis together with the aircraft in conjunction with the action of relief mechanism give rise to the deviation of the stabilized Z-axis of platform in the absolute space.

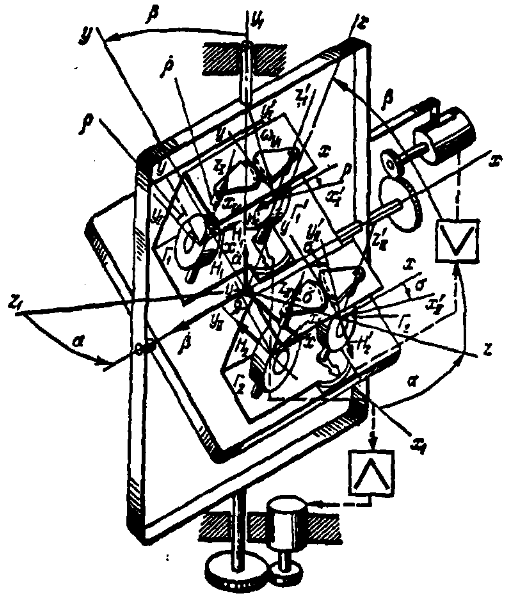

Fig. XVII.5. The schematic of the biaxial four-rotor gyrostabilizer, axis of precession of gyroscopes of which are parallel to the stabilized Z-axis platforms.

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PART VI.

Triaxial, or three-dimensional[redacted], gyro stabilizers.

Triaxial, or three-dimensional/space, gyrostabilizers serve for the stabilization and the control of the platform of gyrostabilizer with the different devices/equipment established/installed on it around three axes of stabilization (Fig. XX.1) x_0, y_0, z'_0, connected with the platform. The platform of triaxial gyrostabilizer has three degrees of freedom of rotation relative to airplane fuselage and, therefore, in contrast to the biaxial gyrostabilizers and the gyroscopes in the gimbal suspension, which stabilize any object in the assigned plane, are realized the stabilization and steering of platform in the space; triaxial gyrostabilizers are three-dimensional/space gyrostabilizers. Are applied the gyrostabilizers, based on the principle of power and indicator-power gyro stabilization. With the use of triaxial gyrostabilizers are constructed the central piloting course selectors and direction of vertical line, self-homing head of rockets, the inertial systems of navigation, etc. In the latter case as gyroscopic sensing elements of platform usually serve the floating gyroscopes, weighed in the liquid.

Triaxial gyrostabilizer - central course selector and vertical line of the autopilot, axis of gimbal suspension of which they are arranged/located on the aircraft in the manner that this is shown in Fig. XX.1, are measured the course angles, bank and pitch without the cardan errors (in accordance with Resal's angles, accepted as the standard angles for determining the position of aircraft relative to the Earth).

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The aircraft axes x_1, y_1, z_1 are shown in Fig. XX.1.

Triaxial gyrostabilizer possesses the structural/design advantages (see Part V), inherent and in biaxial gyrostabilizers. Triaxial gyrostabilizer possesses relatively smaller errors, than two- or uniaxial gyrostabilizer, since its platform has three degrees of freedom relative to airplane fuselage and during the angular oscillations of aircraft around its center of gravity it does not create inertia disturbances/perturbations in the system of gyrostabilizer.

The rotation of platform around its axis z, and axis y, of the external framework of the gimbal suspension in principle is not limited, whereas the angle of the rotation of platform around axis x, of the internal framework of the gimbal suspension is allowed/assumed less than 90°.

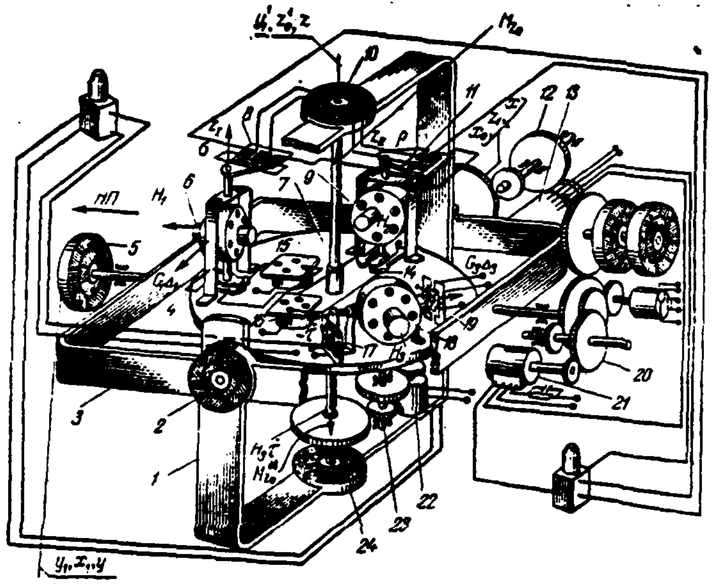

Fig. XX.1. Kinematic diagram of the sensor of the course angles, bank and pitch of autopilot AP-15 (three-dimensional/space gyrostabilizer).

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Chapter XX.

Power gyrostabilizers.

As an example let us examine the design concept of the central course selector, bank and pitch of the autopilot, basic part of which is power triaxial gyrostabilizer with the external gimbal suspension (see Fig. XX.1). Platform 7 serves as basis/base for three gyroscopes 6, 9, 18, which have relative to platform two degrees of freedom. The gimbal suspension of platform consists of two framework of the gimbal suspension: internal 3 and external 1. Established/installed on the platform gyroscopes 6 and 9 serve for its stabilization around axes x_0 and y_0 (in the plane of the horizon/level), gyroscope 18 is intended for the stabilization of platform around axis z_0 (in the azimuth). On platform 7 are also arranged/located liquid pendulums-switches 15 and 16. On the precessional axis of each gyroscope are established/installed corrective moment sensors 4, 14 and 19 and inductance pickups 8, 11 and 17 angles of rotation of the jackets/cases/housings of gyroscopes relative to platform. On the axes of the framework of the gimbal suspension and platform are installed discharging engines 13, 21 and 22 with reducers 12, 20 and 23, synchrotransmitters 2, 5 and 24 angles of rotation of platform relative to airplane fuselage and coordinate converter 10.

Axis y_1 of the external framework of 1 gimbal suspension of gyrostabilizer is parallel to longitudinal axis x_1 of aircraft. Axis z'_0 of the platform of 7 gyrostabilizers is held in the direction of the true vertical with the aid of pendulum liquid switches 15 and 16, which control corrective moment sensors 4 and 14. The position of platform in the azimuth is corrected by the induction compass (in the figure induction compass is not shown), which controls moment sensor 19 on the error signal between readings/indications of induction compass and synchrotransmitter 24.

Each of the channels of gyrostabilizer - the channel of course, bank and pitch - in the first approximation, is separate uniaxial power gyrostabilizer.

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If around axis z_0 of platform acts moment/torque $M_{\text{в}}$, then under the action of this moment/torque gyroscope 18 precesses around its axis of precession with the angular velocity - $\dot{\tau}$ and develops gyroscopic moment/torque - $H_3\dot{\tau}$, into the first instant counter-balance moment $M_{\text{в}}$. Gyroscope 18, and together with them the armature of inductance pickup 17 they are turned to the angle τ, and the sensor through the appropriate channel of amplification sends signal to engine 22. The latter develops moment/torque - $M^{дв}_{z_0}$, counter-balance moment M_{z_0} of external forces. The action of the channels of bank and pitch of gyrostabilizer is more complicated, since the mutual location of gyroscopes 6 and 9 and discharging engines 13 and 21 with the rotations of platform around its axis z', and x axis of the internal framework of the gimbal suspension changes. For example, Fig. XX.2a and b show two positions of the platform of gyrostabilizer, which differ from each other in terms of the rotation of platform by angle of 90°.

In Fig. XX.2a under the effect of moment M_x of external forces around x axis of the internal framework of the gimbal suspension engine 13 must control gyroscope 6, and in the case of b engine 13 must control gyroscope 9.

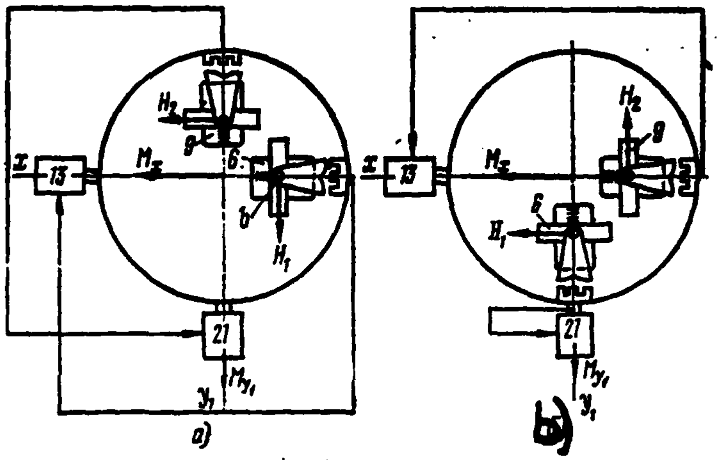

Fig. XX.2. To the explanation of the action of coordinate converter (see positions in Fig. XX.1).

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In the case of a under the effect of moment M_{y_1} of external forces around axis y_1 of the external framework of the gimbal suspension engine 21 must control gyroscope 9, and case 6 engine 21 must control gyroscope 6. In accordance with the example examined the engine control 13 and 21 relief mechanisms must be realized first from gyroscope 6, then from gyroscope 9 depending on the position of the platform of gyrostabilizer relative to axes x and y_1 framework of the gimbal suspension. The necessary distribution of the signals, sent by gyroscopes 6 and 9 for the engine control 13 and 21, is realized with the aid of special coordinate converter 10 (see Fig. XX.1) whose armature is established/installed on z axis of the platform of gyrostabilizer and is turned together with the platform relative to the stator, established/installed on the internal framework of 3 gimbal suspensions.

Coordinate converter 10 is the rotary transformer, which sends on the windings of inductance pickups 8 and 11 angles of rotation of gyroscopes 6 and 9 voltages, proportional to sine and to the cosine of the angle of rotation of platform around z axis relative to the internal framework of 3 gimbal suspensions. As a result relief mechanisms of the channels of engine control 13 and 21 with the aid of the sine-cosine rotating transformer-converter of coordinates 10 are formed/shaped in such a way that the moments/torques, developed with engines 13 and 21, correspond to functional dependences (XX.8), indicated in S XX.1.

The conditions of the independence of action of the channels of the stabilization of platform, controlled by gyroscopes 6 and 9, with the formation of the channels of discharging in accordance with formulas (XX.8) are given in S XX.1.

The diagram of the layout of gyroscopes on the platform of triaxial gyrostabilizer, represented in Fig. XX.1, is not the only one. Are possible other versions of the location of gyroscopes on the platform of gyrostabilizer, for example the location of gyroscopes, shown in Fig. XX.3a.

In the first approximation, both in the first and in the second version of the location of the gyroscopes (see Fig. XX.3b and a) moment $M_{x_0}^{в.с}$ of external forces, which acts around axis x_0 of the platform of 1 gyrostabilizers, gives rise to gyro precession 2 around axis y_1 see Fig. XX.3a) with angular velocity $\dot{\rho}_{абс}$ and gyroscopic moment/torque $M_{x_0}^{г} = -H_1\dot{\rho}_{абс}$, counter-balance moment $M_{x_0}^{в.с}$ of external forces.

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Gyroscopic moment/torque $M_{y_0}^{г} = -H_2\dot{\sigma}_{абс}$, developed with gyroscope 3, analogous with gyroscope 2 counter-balance moment $M_{y_0}^{в.с}$, while gyroscopic moment/torque $M_{z_0}^{г} = -H_3\dot{\tau}_{абс}$, developed with gyroscope 3, moment/torque $M_{z}^{в.с}$.

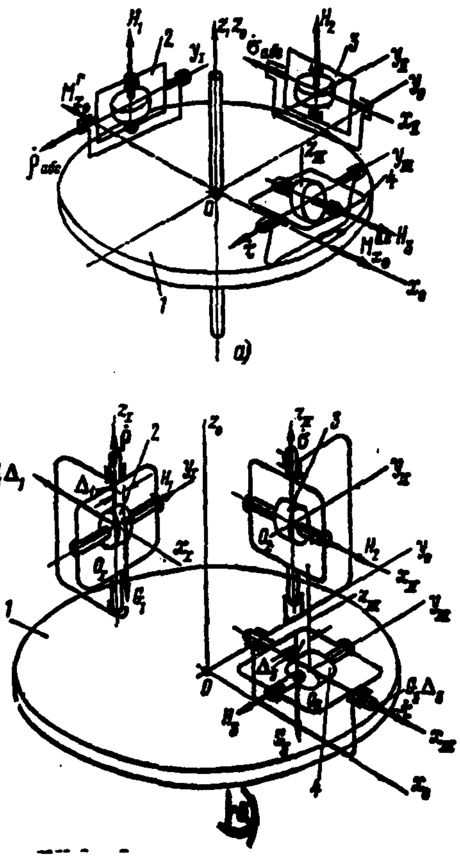

Fig. XX.3. Diagram of the layout of gyroscopes on the platform of three-dimensional/space gyrostabilizer.

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Gyroscope 2 participates in the stabilization of platform around axis $x_{\circ}$, gyroscope 3 - around axis $y_{\circ}$, while gyroscope 4 - around axis $z'_{\circ}$. At the same time in the general case the gyroscopes, placed on platform 1 for its stabilization around axes x_0, y_0, z'_0, must be established/installed so, in order to axis x_I, y_{II} and z_{III} (see Fig, XX.3a and b), perpendicular to the planes, which consist the axes of rotors and axis of precession of gyroscopes 2, 3 and 4, was parallel to axes x_0, y_0 and z'_0 the stabilization of platform respectively.

During the installation of gyroscopes on the platform around axes x_I, y_{II} and z_{III} in the principle it is possible to expand/develop them to any angle. The selection of one or the other version of the location of gyroscopes on the platform is connected with the diagram of its control and operating conditions of gyrostabilizer.

If, for example, to the moment sensor of 19 gyroscopes 18 (see Fig. XX.1) enters control signal, then platform together with the gyroscopes is turned around axis z'_0. The rotation of platform around axis z'_0, gives rise to the deviation of gyroscopes 6 and 9 around axes z_I and z_{II} (see Fig. XX.1) or gyroscopic moments/torques around axes y_I and z_{II} (see Fig. XX.3a) with the deviation of vectors H_1 and H_2 of the angle ρ and σ. By analogy with the biaxial twin-gyro stabilizers (Part V) appears the actual speed of the precession of the platform whose value depends on the location of gyroscopes on the platform (see Fig. XX.3a and b).

It is known that the actual speed of gyro precession is to a considerable extent determined by the instability of the center-of-gravity location of gyrorotor with respect to the axis of its precession. Let us examine the effect of the location of gyroscopes on the platform to the value of the actual speed of the precession of the platform of triaxial gyrostabilizer, which appears as a result of the center-of-gravity disturbance of gyrorotor in the direction of axis of its rotation. We assume that z axis of the platform of gyrostabilizer is held in the direction of the true vertical, and gyroscopes are arranged/located on the platform in the manner that this is shown in Fig. XX.1 and XX.3a.

In the case of using a similar instrument on the aircraft usually stationary flight conditions when flight altitude, speed of aircraft and its course remain constant/invariable on the time, predominates above the unsteady.

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In the stationary flight conditions by the basic perturbing point, for example, which acts around the axis of precession of gyroscope 4, is the moment of the forces of gravity of rotor and jacket/case/housing of gyroscope. This moment/torque is equal to $G_3\Delta_3$ (see Fig. XX.3b), where G_3 - weight of rotor and jacket/case/housing of gyromotor, and Δ_3 - center-of-gravity disturbance of gyromotor relative to axis z_{III} of gyro precession 4. Moment/torque $G_3\Delta_3$ is external moment/torque with respect to the gyroscope and gives rise to the precession of the platform of gyrostabilizer around z axis with an angular velocity of $G_3\Delta_3/H_3$. With the center-of-gravity disturbance of the gyromotor of gyroscope 2 in the direction of axis y_I of its rotor also appears moment/torque $G_1\Delta_1$. This moment/torque through the supports of gyroscope is transferred to platform. Thus, moment/torque $G_1\Delta_1$ is the moment of external forces for the platform of gyrostabilizer and by the counter-balance moment, developed with the appropriate discharging engine, without giving rise to the actual speed of the precession of platform. In the case of this location of gyroscopes, as shown in Fig. XX.3b, during the rotations of gyroscope 2 around axis z_I, of the directed along the true vertical of place, actual speed of the precession of platform from the action of moment/torque $G_1\Delta_1$ also does not appear. During the center-of-gravity disturbance of the gyromotor of gyroscope 2 along the axis of its rotor and the location of the axis of rotor in the direction by the truth of the vertical line (see Fig. XX.3a) moment/torque from the gravitational force of gyromotor also does not appear. However, with the misalignment of gyrorotor from the direction of the true vertical in the process of moving the platform of gyrostabilizer under the conditions for its operation (angle ρ in practice reaches several degrees) appears moment/torque $G_1\Delta_1 \sin\rho$, which acts around the axis of precession of gyroscope 2 and which gives rise to the actual speed of its precession. Thus, with respect to the actual speed of the precession of the platform of gyrostabilizer, given rise to the shift of Δ_1 of the center of gravity of gyromotor along the axis of its rotor, the location of gyroscopes 2 and 3, represented in Fig. XX.3b, is more successful than their location, accepted by Fig. XX.3a.

The location of gyroscope 4, shown in Fig. XX.3b and XX.3a, remains constant/invariable and, therefore, the effect of the shift Δ_3 of the center of gravity of gyromotor on the actual speed of precession of platform around its axis in both cases remains identical.

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Let us turn to Fig. XX.4 and will determine the resultant of the vectors of moments of momentum $\overline{H}_1$, $\overline{H}_2$, $\overline{H}_3$ for the first and second cases of the location of gyroscopes on the platform. In the first case of the location of the gyroscopes (see Fig. XX.3b and XX.4a) with $H_1=H_2=H_3=H$ unknown resultant to $\sum\bar{H}$ is equal to 0.4H, while in the case of $H_1=H_2=H$ and $H_3=1.4H$ $\sum\bar{H}=0$. In the second case of the location of the gyroscopes (see Fig. XX.3a and XX.4b) with $H_1=H_2=H_3=H$, $\sum\bar{H}=2.24H$, and if vectors $\overline{H}_1$ and $\overline{H}_2$ are directed to opposite sides, $\sum\bar{H}=H$. During the forced rotations of platform, for example, with the aid of the platform, for example, with the aid of the discharging engine or the arrestment together with the platform of gyrostabilizer are turned in the space and the gyroscopes, established/installed on the platform (we consider that the angles of rotation of the axes of gyrorotors relative to platform are small), and the gyroscopic moment/torque, equal to product $\sum\bar{H} \times \bar{\Omega}_{e}$, will create increment load on the discharging engines or arrestment ($\bar{\Omega}_{e}$ - the vector of the movable angular rate of rotation of platform).

In this case the location of gyroscopes on the platform, represented in Fig. XX.1 and XX.3b, is preferable.

Another important question of the selection of the design concept of power triaxial gyrostabilizer is determination of the type of the gimbal suspension.

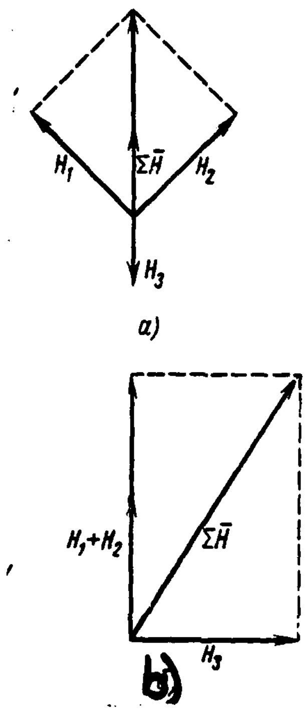

Fig. XX.4. To the sitting of the vectors of the moments of momentum of gyroscopes on the platform.

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Are known two basic types of the gimbal suspensions: external (see Fig. XX.1) and internal (Fig. XX.5). It is possible to visualize the diverse variants of the design concepts of triaxial gyrostabilizers with the internal gimbal suspension, one of such diagrams is shown in Fig. XX.5.

In the first case (see Fig. XX.1) the platform of gyrostabilizer with placed on it gyroscopes and devices/equipment (accelerometers, optical system, etc.) stabilized in the space is covered by the framework of the gimbal suspension. In the second case (see Fig. XX.5) the gimbal suspension is cross piece 2, placed within the base of 6 gyrostabilizers and Cardan ring 5 with platform 4 and gyroscopes 1, 3 and 7 established/installed on it (gyroscope 7 Fig. XX.5 does not show), and also stabilized in the space devices/equipment (Fig. XX.5 the stabilized devices/equipment does not show). External gimbal suspension provides the unlimited angles of rotation of platform around the axes of the gimbal suspension.

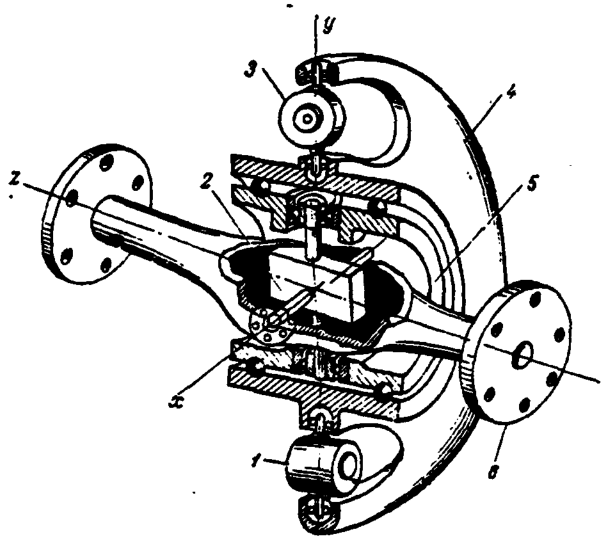

Fig. XX.5. Diagram of three-dimensional/space gyrostabilizer with the internal gimbal suspension.

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True, and in this case the angle of rotation of the internal framework of the gimbal suspension proves to be a limited value less than +-90°, for reasons, which escape/ensue from the operating principle of three-dimensional/space gyrostabilizer. The angles of rotation of the platform of gyrostabilizer with the internal gimbal suspension around x and y axes of cross piece are limited and only the angle of rotation of platform around z axis of Cardan ring 5 is not limited.

The advantage of gyrostabilizers with the internal gimbal suspension is the possibility of obtaining a small moment of the inertia of cross piece and Cardan ring in comparison with the moments of the inertia of the framework of the gimbal suspension of gyrostabilizer with the external gimbal suspension.

The selection of one or the other form of the gimbal suspension of gyrostabilizer, the location of gyroscopes on the platform and the type of the gyroscopes, adjusted on the platform, is conducted depending on the requirements, presented to the accuracy of the stabilization of platform and operating conditions of gyrostabilizer.