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DEVELOPMENT OF METHOD OF INCREASING ACCURACY OF MEASURING ANGULAR VELOCITY AND ACCELERATION OF GYROSTABILIZED PLATFORM

Сучасні рухомі об'єкти мають значно більші швидкості, на них діють значно більші перевантаження та неконтрольовані механічні збурення (удари, вібрації). Тому вимоги до точності засобів та методів вимірювання визначених вище механічних величин приладового навігаційного комплексу стали значно вищими. Однак недосконалість елементної бази, відсутність нових сучасних чутливих елементів, відсутність використання нової удосконаленої системи ударо-віброзахисту, відсутність використання сучасних алгоритмічних методів не дозволяють суттєво підвищити точність, покращити тактико-технічні характеристики.

Об'єктом дослідження в даній роботі є процес вимірювання кутової швидкості та прискорення гіростабілізованої платформи.

Забезпечення підвищення точності стабілізатора озброєння є найважливішою проблемою сучасності, вирішення якої забезпечує безпеку України. По тактичним характеристикам новий стабілізатор озброєння розширює бойові можливості бронетехніки за рахунок більш точного наведення і стабілізації на ціль, полегшує можливості екіпажу по управлінню баштою.

Приладові комплекси стабілізаторів озброєння призначені для стабілізованого наведення і супроводу у горизонтальній та вертикальній площинах наземних, повітряних і надводних цілей. Використання сучасної елементної бази дозволило значно покращити характеристики всього комплексу стабілізатора озброєння. По технічним характеристикам стабілізатора озброєння розширює бойові можливості бронетехніки за рахунок більш точного наведення і стабілізації на ціль, полегшує можливості екіпажу по управлінню баштою. А також не вимагає перенаведення на ту ж ціль після пострілу.

У роботі розглянуто алгоритм, що застосовується при коригуванні положення гармати відносно цілі при швидкому сумісному русі башти та машини. Алгоритм обраховується у математичному блоці системи стабілізації. Алгоритм базується на математичному аналізі теорії руху гіроскопів та покращений від попередніх за рахунок доповнення рівняння руху. Виведено формулу в аналітичному вигляді для подальшого її застосування в математичних блоках системи стабілізації та наведено розрахунки, в результаті яких отримано математичну модель. Якщо дану математичну модель буде введено в алгоритмічний блок системи стабілізації, це дозволить підвищити точність стабілізації.

У висновках проаналізовані результати та надані рекомендації щодо застосування алгоритму

Ключові слова: *стабілізатор озброєння, гіростабілізована платформа, вимірювання кутової швидкості, вимірювання прискорення*

1. Introduction

The object of research is the non-renewable stabilization system of various types used today in navigational devices and control systems for ships, aircrafts, vehicles, as well as in antennas, telescopes and other devices mounted on moving objects. Due to the fact that the required accuracy of such devices is continuously increasing, the accuracy requirements imposed on stabilization complexes are also growing.

In the conditions of carrying out an anti-terrorist operation in the east of Ukraine, works devoted to enhancing the defense capability of the state are extremely topical. One of these is the new instrument complex of the stabilizer of armament of light armored vehicles SVU-500, developed at PJSC «RPA «Kyiv Automatics Plant» (Ukraine). This complex is designed for stabilized guidance and tracking in the horizontal and vertical planes of surface, air and surface targets for effective firing from the ground, on the move and afloat.

The weapon stabilizer is a device that stabilizes the aiming of the weapon while moving the platform on which the weapon is mounted. The weapon stabilizer is designed to simplify the aiming with the movement of light armored vehicles and to increase the accuracy of the fire on the move. It is also part of the fire control system. Technically, the stabilizer is a set of sensors and a computer complex connected to a gun drive.

The existing stabilization systems can't today sufficiently effectively perform the tasks assigned to them. According to the experience of military conflicts, most of the losses of the fleet of armored vehicles are the result of the use

of inefficient weapons stabilization systems. Therefore, ensuring the improvement of the operational characteristics of the Arms Complex for light armored vehicles (LAV) is the most important modern problem, the solution of which ensures the navigation security of Ukraine.

2. The object of research and its technological audit

The object of research is the process of measuring the mechanical quantities of the modern instrumentation of the stabilizer complex (SC) of LAV armament by using the proposed precision instruments on new physical principles, equipment and methods.

The weapon stabilizer is a technical device that stabilizes the aiming of the weapon while moving the platform on which these weapons are installed. The weapon stabilizer is designed to simplify the aiming while moving the platform and improve the accuracy of the fire from the move. It is widely used in modern armored vehicles and ship artillery. Technically, the stabilizer is a set of sensors and a computer complex connected to a gun drive. Based on the readings of the sensors, the parameters for moving the platform are determined and control commands are given about the gun, which compensates for the deviations.

At the present stage of the development of technology, one of the key shortcomings, over which the design and technology bureaus work, is the accuracy of aiming at the target.

3. The aim and objectives of research

The aim of research is the development of weapon stabilizer for light armored vehicles using a small-sized angle sensor and a system for vibration and shock impact for it.

To achieve this aim, it is necessary to perform the following tasks:

1. Analyze equations of the theory of motion of gyroscopes.

2. Supplement the equations of the theory of motion of gyroscopes with a new component, proceeding from the technical capabilities of modern instrument-making.

4. Research of existing solutions of the problem

The weapon stabilizer is a technical device, it stabilizes the aiming of the weapon while moving the platform on which these weapons are installed. The weapon stabilizer is designed to simplify the aiming during the movement and improve the accuracy of the fire, is part of the fire control system. It is widely used in modern armored vehicles and ship artillery.

Technically, the stabilizer is a set of sensors and a computer complex connected to a gun drive. Based on the readings of the sensors, the parameters for moving the platform are determined and control commands are issued about the gun, which compensates for the deviations [1].

As a stabilization system in work, the automatic control system [2] is considered, it ensures, on a moving object, the preservation of a certain angular orientation of the tower relative to a coordinate system whose axes are oriented in a certain way in space. This coordinate system is either reference or fixed. Depending on the specific task, this can be, for example, an inertial coordinate system or a system whose axes are directed along the vertical of the place where the moving system is located [3].

The stabilization system ensures the constancy of the angles between the axes of the fixed coordinate system and the axes rigidly connected with the stabilization object, which will henceforth be called the stabilizing platform [4, 5].

To the stabilizing moments, in addition to the moments of the executive motors or other actuators, the moments of gyroscopic reaction of the gyroscopes installed on the platform may also apply. Systems in which gyroscopic reaction moments directly affect the stabilized platform have power gyroscopic stabilizers.

Stabilization systems in which stabilizing moments are created only by executive motors or other actuators, and gyroscopic gyro response moments are not used for direct compensation of moments, excite the platform, will be called indirect stabilization systems. Gyroscopic elements in indirect stabilization systems can be used only to detect deviations of the platform from a given position and to generate control signals [6, 7].

A separate view is represented by multistage stabilizers [8], among which two-stage stabilization systems are of practical importance. In such system discussed above, the platform is an element of the first degree of stabilization. On it is additionally installed in a separate cardan suspension the second platform. This is the second stage of stabilization, there is an error of stabilization (caused by «swing residues») of the first platform. The second platform stabilizes in space with high accuracy, than the first [9, 10].

The existing stabilization systems [11, 12] for today can't perform their tasks effectively enough. According to the experience of military conflicts, most of the losses of a fleet of armored vehicles are the result of the use of inefficient stabilization systems. Therefore, ensuring the improvement of the operational characteristics of the stabilization complex is the most important modern problem, the solution of which provides security.

5. Methods of research

As a result of research, the following are used:
– the theory of gyroscopes for deriving augmented equation of motion of the platform;
– the theory of linear systems of automatic control for deterministic and random effects for estimating the magnitude of the increase in accuracy;
– method of logarithmic frequency characteristics;
– mathematical statistics for the processing of statistical data;
– experimental laboratory tests to obtain statistical data, processing and analysis of the results obtained.

6. Research results

The angular velocities and accelerations that the stabilization system must work out largely determine the attainable stabilization accuracy [13]. The increase in velocities and accelerations leads to a complication of the structure of the system, an increase in its dimensions. On the other hand, the maximum velocity and acceleration of the stabilization system are different for the same swing parameters, depending on the number and location of the axle and suspension rings of the platform [14].

Stabilized platform in a triaxial suspension. Due to the stabilization, the platform P (Fig. 1) and the coordinate system $O\xi\eta\zeta$ connected with it are fixed in space. The moving coordinate system $Oxyz$ (associated with LAV) in the absence of oscillation coincides with the fixed coordinate system $O\xi\eta\zeta$; The Oy axis of the outer ring is directed along the longitudinal axis of the LAV. When rolling the LAV turret, the transition from a fixed coordinate system to a mobile one is determined by three non-coring angles φ, γ, θ [15, 16].
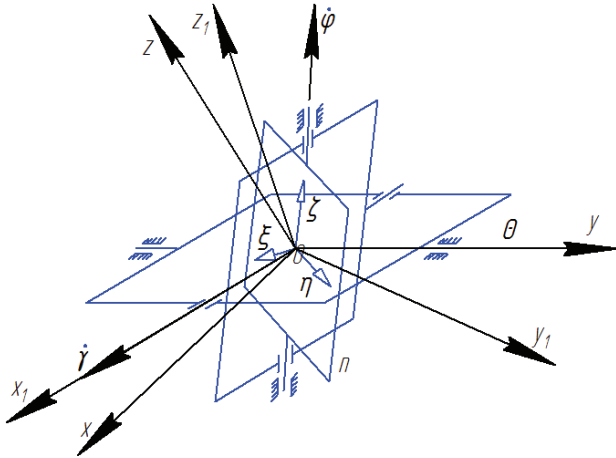

Fig. 1. Stabilizing platform in triaxial suspension

The transition from the fixed coordinate system (the stabilizing platform) to the mobile (LAV coordinate system) is determined by the matrix written in the form (1):

$$A = \begin{vmatrix} \cos\theta\cos\varphi - \sin\theta\sin\gamma\sin\varphi & \cos\theta\sin\varphi + \sin\theta\sin\gamma\cos\varphi & -\sin\theta\cos\varphi \\ -\cos\gamma\sin\varphi & \cos\gamma\cos\varphi & \sin\gamma \\ \sin\theta\cos\varphi + \cos\theta\sin\gamma\sin\varphi & \sin\theta\cos\varphi - \cos\theta\sin\gamma\cos\varphi & \cos\theta\sin\gamma \end{vmatrix}. \quad (1)$$

The velocities of running-in of the suspension rings $\dot\varphi$, $\dot\gamma$, $\dot\theta$, that is, the velocities that should be provided by the stabilization system, is determined by the condition that the sum of the projections of the rolling-in velocities of the rings and the rolling velocities of the object on each of the axes of the fixed coordinate system should be zero [7].

This condition gives a system of three equations:

$$\Omega_{0\xi} + \Omega_{k\xi} = 0; \ \Omega_{0\eta} + \Omega_{k\eta} = 0; \ \Omega_{0\zeta} + \Omega_{k\zeta} = 0, \quad (2)$$

where $\Omega_{0\xi}$, $\Omega_{0\eta}$, $\Omega_{0\zeta}$ – the projections of the running-in velocities on the axis of the coordinate system $O\xi\eta\zeta$, and $\Omega_{k\xi}$, $\Omega_{k\eta}$, $\Omega_{k\zeta}$ – the projections of the rolling velocities on the same axes.

Projections of running-in velocities are:

$$\left. \begin{aligned} \Omega_{0\xi} &= \dot\varphi\cos(\xi,\zeta) + \dot\gamma\cos(\xi,x_1) + \dot\theta\cos(\xi,y) \\ \Omega_{0\eta} &= \dot\varphi\cos(\eta,\zeta) + \dot\gamma\cos(\eta,x_1) + \dot\theta\cos(\eta,y) \\ \Omega_{0\zeta} &= \dot\varphi\cos(\zeta,\zeta) + \dot\gamma\cos(\zeta,x_1) + \dot\theta\cos(\zeta,y) \end{aligned} \right\}. \quad (3)$$

Projections of the rolling velocities of the LAV turret Ω_x, Ω_y, Ω_z around the axes Ox, Oz, Oy on the axis of the fixed coordinate system level:

$$\left. \begin{aligned} \Omega_{k\xi} &= \Omega_x\cos(\xi,x) + \Omega_y\cos(\xi,y) + \Omega_z\cos(\xi,z) \\ \Omega_{k\eta} &= \Omega_x\cos(\eta,x) + \Omega_y\cos(\eta,y) + \Omega_z\cos(\eta,z) \\ \Omega_{k\zeta} &= \Omega_x\cos(\zeta,x) + \Omega_y\cos(\zeta,y) + \Omega_z\cos(\zeta,z) \end{aligned} \right\}. \quad (4)$$

The cosines of the angles between the axes of the fixed and mobile systems entering into equation (4) are equal to the corresponding elements of the matrix (1). The direction cosines of the Ox axis in the fixed coordinate system entering into equation (3) are determined by the elements of the first row of the matrix (1).

In the solution of equations (2)–(4) let's find the running-in velocity of the suspension around its inner, middle and outer axes:

$$\dot\varphi = \frac{1}{\cos\gamma}(\Omega_x\sin\theta - \Omega_z\cos\theta), \quad (5)$$

$$\dot\gamma = -\Omega_x\cos\theta - \Omega_z\sin\theta, \quad (6)$$

$$\dot\theta = -\Omega_x\sin\theta\,\mathrm{tg}\,\gamma - \Omega_y + \Omega_z\cos\theta\,\mathrm{tg}\,\gamma. \quad (7)$$

Hence the running-in velocity is also determined:

$$\dot\varphi = \frac{1}{\cos\gamma}(\dot\Omega_x\sin\theta - \dot\Omega_z\cos\theta), \quad (8)$$

$$\dot\gamma = -\dot\Omega_x\cos\theta - \dot\Omega_z\sin\theta, \quad (9)$$

$$\dot\theta = -\dot\Omega_x\sin\theta\,\mathrm{tg}\,\gamma - \dot\Omega_y + \dot\Omega_z\cos\theta\,\mathrm{tg}\,\gamma. \quad (10)$$

The velocity and acceleration of running-in along the axes (6) and (9) do not exceed the velocity and acceleration of the rolling. The velocities and accelerations of the run-in along the roll axes (5), (7), (8) and (10) follow to infinity as $y \to 90°$.

Given the largest velocities and acceleration of the running-in achievable in the stabilization system, the relationship (5), (7), (8) and (10) allows to find the largest permissible value of the angle γ. The angles φ and θ for the considered arrangement of the suspension axes are not limited from the point of view of obtaining final velocities and acceleration accelerations (5)–(7).

To obtain unlimited values of the angle in the triaxial suspension, it is necessary to change the location of its axes while simultaneously limiting any other of the swing angles. In this case, the axis of the inner ring must be perpendicular to the sauntering axis. If, for example, the heeling angle θ is limited, then the axis of the inner ring must be directed along the roll axis. In this case let's obtain a triaxial suspension, returned in the horizontal plane by 90° with respect to the suspension shown in Fig. 2. The velocities and accelerations of the running-up of rings in such suspension are determined from relations (5)–(10) after the angles φ and θ change places in them.

Telescope in a biaxial suspension with a vertical arrangement of the axis of the outer ring. The telescope monitors the target associated with the object with the help of a biaxial suspension (Fig. 2), has a horizontal (Oz axis of the outer ring) and a vertical (Ou axis of the inner ring

rigidly connected to the telescope) guidance [17, 18]. The axes of the mobile coordinate system $Oxyz$ are stationary in space when there is no oscillation. In this case, the position of the target is determined in this coordinate system by the course angle q and height h [19].

With the inner suspension ring and telescope, the coordinate system $Ouv\omega$ is rigidly connected, the axis $Ouv\omega$ is directed along the axis of the inner ring, and $Ouv\omega$ is along the optical axis of the telescope perpendicular to the plane of the inner ring. The axes of the system $Ouv\omega$ at $q = h = 0$ coincide with the corresponding axes of the moving coordinate system.
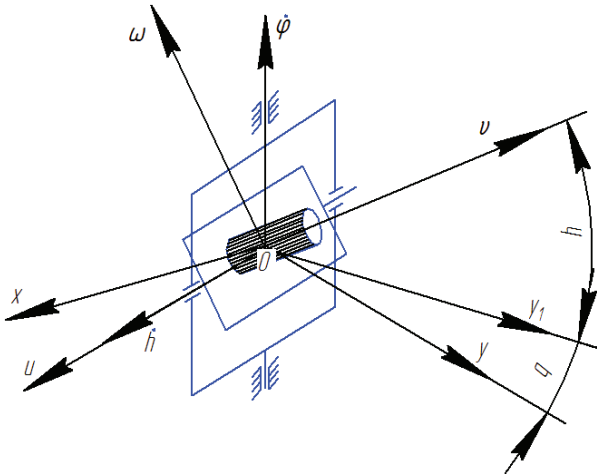

Fig. 2. Telescope in a biaxial suspension with horizontal axes Oz and vertical Ou guidance

In general, for any angles q and h, the transition from the moving coordinate system to the system $Ouv\omega$ is obtained by rotating the outer ring of the suspension together with the inner ring by an angle q around the vertical axis Oz. So, when moving from the moving coordinate system to the horizontal axis, and further rotating the obtained coordinate system Ouy_1z together with the inner suspension ring by an angle h about the axis Ou, they become vertical guidance axes.

The specified coordinate transformations have the form:

$$[u, y_1, z] = A_q[x, y, z] \qquad (11)$$

and

$$[u, v, \omega] = A_h[u, y_1, z] \qquad (12)$$

or

$$[u, v, \omega] = A[u, y, z], \qquad (13)$$

where

$$A_q = \begin{vmatrix} \cos q & \sin q & 0 \\ -\sin q & \cos q & 0 \\ 0 & 0 & 1 \end{vmatrix}, \qquad (14)$$

$$A_h = \begin{vmatrix} 1 & 0 & 0 \\ 0 & \cosh & \sinh \\ 0 & -\sinh & \cosh \end{vmatrix}, \qquad (15)$$

$$A = A_h A_q = \begin{vmatrix} \cos q & \sin q & 0 \\ -\sin q \cosh & \cos q \cosh & \sinh \\ \sin q \sinh & \cos q \sinh & \cosh \end{vmatrix}. \qquad (16)$$

As a result of these two rotations of the suspension rings, the axis Ov, perpendicular to the plane of the inner ring and coincides with the optical axis of the telescope, will be directed at the target, and the axes Ou and Ov will be perpendicular to the direction to the target. When the object is runned, the directions of the axes of the $Ouv\omega$ system are indicated, which will be preserved due to the running-up of the suspension rings around the axes of horizontal and vertical guidance.

Let the velocity of guidance, due to the movement of the object and the daily rotation of the Earth, be insignificant in comparison with the velocities caused by rolling. Then the velocities of running-up-in of the rings q and h are determined from the equations:

$$\Omega_{ou} + \Omega_{ku} = 0;$$
$$\Omega_{o\omega} + \Omega_{k\omega} = 0, \qquad (17)$$

where Ω_{ou}, $\Omega_{o\omega}$ – the projections of the velocities of the running-up of the rings on the axes Ou and $O\omega$, and Ω_{ku}, $\Omega_{k\omega}$ – are the projections of the rolling velocities of the object on the same axes.

When conditions (17) are satisfied, the telescope can rotate about its own optical axis, but the latter remains directed to the target. Projections of velocities of break-in level:

$$\Omega_{ou} = \dot{h}\cos(u,u) + \dot{q} + \cos(u,z);$$
$$\Omega_{o\omega} = \dot{h}\cos(\omega,u) + \dot{q} + \cos(\omega,z). \qquad (18)$$

Projections of the running-up object Ω_x, Ω_y, Ω_z around the axes Ox, Oy, Oz on the axis Ou and Ou level:

$$\Omega_{ku} = \Omega_x \cos(u,x) + \Omega_y \cos(u,y) + \Omega_z \cos(u,z);$$
$$\Omega_{k\omega} = \Omega_x \cos(\omega,x) + \Omega_y \cos(\omega,y) + \Omega_z \cos(\omega,z). \qquad (19)$$

The cosines of the angles between the axes Ou and $O\omega$ perpendicular to the direction to the target and the axes of the moving coordinate system appearing in expressions (18) and (19) are equal to the corresponding elements of the first and third rows of the matrix (16). The simultaneous solution of equations (17)–(19) gives the velocity of running-in of the suspension rings along the axes of horizontal and vertical induction, caused by oscillations:

$$\dot{q} = \Omega_x \sin q \, \text{tg} h + \Omega_y \cos q \, \text{tg} h - \Omega_z;$$
$$\dot{h} = -\Omega_x \sin q - \Omega_y \sin q. \qquad (20)$$

Hence, the acceleration of the rolling of the rings on the rolling is also approximately determined:

$$\ddot{q} = \dot{\Omega}_x \sin q \, \text{tg} h + \dot{\Omega}_y \cos q \, \text{tg} h - \dot{\Omega}_z;$$
$$\ddot{h} = -\dot{\Omega}_x \sin q - \dot{\Omega}_y \sin q. \qquad (21)$$

The velocity and acceleration along the vertical guidance axis (20) and (21) do not exceed the velocity and

rolling acceleration. The velocity and acceleration along the horizontal guidance axis (20) and (21) as they approach the target, tend to infinity. Since the achievable velocities and accelerations of the telescope stabilization system are always limited, stabilization of the direction to the target will be possible only at some limiting distance h. The latter is determined from expressions (20) and (21) for given velocities and acceleration of rolling and achievable velocities and acceleration of stabilization. Thus, in the case of the biaxial suspension of a telescope with a vertical arrangement of the axis of the outer ring, the stabilization system has a «dead zone» swing. That is, an area in which stabilization is not provided, in the form of a circle (if any course of the object is possible).

Telescope in a biaxial suspension with a horizontal arrangement of the axis of the outer ring. This case differs from the previous one only in the arrangement of the axes of the rings. Here, Ox of the outer ring (Fig. 3) is directed along the transverse axis of the LAV, but the $O\omega$ of the inner ring lies in the diametral plane. With the inner suspension ring and the telescope, the coordinate system $Ou\upsilon\omega$ is rigidly connected, with the $O\upsilon$ axis directed along the optical axis of the telescope, and $O\omega$ along the axis of the inner ring. This coordinate system comes out of the coordinate system $Oxyz$ associated with the object (motionless in the absence of rolling) by two turns. The first of them – a rotation through an angle α around the axis Ox, that is, the axis of the outer ring of the suspension – transforms the $Oxyz$ system into the $Oxy_1\omega$ system. The second is a rotation through an angle β around the axis $O\omega$, that is, the axis of the inner ring of the suspension – gives the coordinate system $Ou\upsilon\omega$. In this case, the position of the target is determined in the fixed coordinate system by the angles α and β.

The velocities of running-in of the rings α and β are determined, as in the previous case, by equations (17) and (19) and by equations analogous to (18). The cosines of the angles between the axes of the moving coordinate system and the axes $O\upsilon$ and $O\omega$ perpendicular to the direction to the target are easier to obtain as the corresponding elements of the matrix that transforms the system $Oxyz$ into the system $Ou\upsilon\omega$. These cosines are indicated in Table 1.

Table 1

The direction cosines of the $O\upsilon$ and $O\omega$ axes in the $Oxyz$ system

Direction	Ox	$O\omega$	Oz
$O\upsilon$	$\cos\beta$	$\cos\alpha\sin\beta$	$\sin\alpha\sin\beta$
$O\omega$	0	$-\sin\alpha$	$\cos\alpha$

The velocity of running-in of the stabilization system of the telescope around the axes of the outer and inner rings is equal to:

$$\dot\alpha = -\Omega_x - \Omega_y \cos\alpha\, \mathrm{tg}\,\beta;$$
$$\dot\beta = \Omega_y \sin\alpha - \Omega_z \cos\alpha. \tag{22}$$

Running-up acceleration:

$$\ddot\alpha = -\dot\Omega_x - \dot\Omega_y \cos\alpha\, \mathrm{tg}\,\beta;$$
$$\ddot\beta = \dot\Omega_y \sin\alpha - \dot\Omega_z \cos\alpha. \tag{23}$$

Velocity and acceleration along the axis of the inner ring (22) and (23) do not exceed the velocity and acceleration of rolling. The velocity and acceleration along the axis of the outer ring (22) and (23), respectively, can be much larger. They go to infinity at $\beta \to 90°$, that is, when the target approaches the horizon line on the extensions of the Ox axis. The greatest value of β, at which stabilization is possible, is determined from relations (22) and (23) at given velocities and accelerations of the duck and achievable velocities and acceleration of stabilization. The corresponding lowest goal height is $h = 90° - \beta$.

If take another biaxial suspension of the telescope, obtained from the axis of the external suspension considered from the turn, until it coincides with the longitudinal axis of the object, then the most severe stabilization conditions for rolling will come out for purposes located near the horizon along the longitudinal axis of the object. In all cases of a biaxial suspension with a horizontal arrangement of the axis of the outer ring, there are no difficulties in observing targets, that is, at $\alpha \to 90°$ and $\beta \to 0$, as follows from Equations (22), (23).
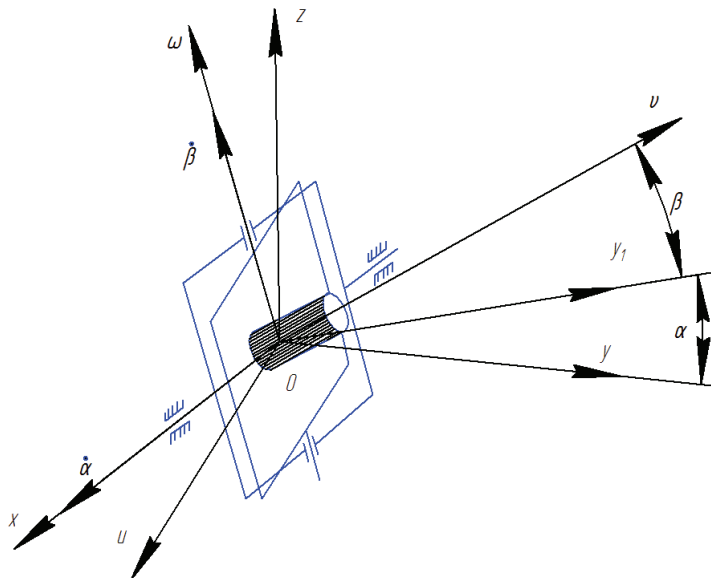

Fig. 3. A telescope in a biaxial suspension with the location of the axis Ox in the plane of the turret and the axis of the inner ring $O\omega$ in the diametrical plane

Let's note that the expressions for the velocities and accelerations of running-in of the biaxial suspension rings are obtained without taking into account the increase in the rolling angles, which is the case for small values of the latter. At large swing angles, the analysis is similar to the previous one, but the expressions for velocities and accelerations are accommodated.

7. SWOT analysis of research results

Strengths. Formulas are derived for improving the accuracy characteristics of the stabilization system and increasing its velocity, which allows to raise the characteristics of equipment to a new level, higher than foreign counterparts.

In comparison with analogues, it is more advantageous, namely:

– the productivity of the gyrostabilized complex is increased;

– increased accuracy of the calculation of the coordinates of the guidance.

Weaknesses. The weak side can be considered that to improve the performance it is necessary to make more accurate calculations and calculate a larger data set, leading to the use of a new element base of the device. The negative internal factor is the increase in the cost of production.

Opportunities. It increases the accuracy of aiming at the target, facilitates the control of the tower of the object during its movement. Improve the tactical and technical characteristics of lightly armored vehicles. This method can increase the monetary income of enterprises of suppliers by selling equipment abroad.

Threats. The absence of precision machinery at the machine tool park. The enterprise wants to master this method and must purchase precision equipment for manufacturing and testing of high-precision position sensors in space.

8. Conclusions

1. The system of coordinates for the derivation and analysis of the mathematical model of the instrument complex of the weapon stabilizer for lightly armored vehicles has been identified. Namely, it is established that the best model will be when the telescope is in a biaxial suspension with the vertical arrangement of the axis of the outer ring.

2. It is established that the angular velocities and accelerations that the stabilization system must work out determine to a large extent the achievable accuracy of stabilization. Formulas (20)–(23) are derived in an analytical form for their further application in the digital block of the stabilization system.

3. Methods of structural and parametric optimization are proposed to ensure the specified maximum possible accuracy of the stabilizer. Equations of motion of the stabilization system, and the equation itself for calculating the velocities and accelerating the gyro's oscillation of the stabilization system are complemented by the angles q and h, which can arise when the gyrostabilized platform is complex.

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