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MATHEMATICAL MODELING OF THE OPERATION OF AN AIRCRAFT GYROSCOPE

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Abstract: A dynamically tuned gyroscope used in a compact gyroscopic angular velocity vector meter of an aircraft is considered. Guided missile inclination methods are analyzed. Mathematical models of the gyroscope rotor motion on a fixed base and the angular motion of the aircraft missile gyroscope itself are presented.
Keywords: missile, drone, flight, system, guidance, homing, angular motion.

Introduction: Unmanned aerial vehicles used for peaceful purposes have been developed around the world. In Germany, drones have begun transporting cargo and mail to their destinations. In the US and China, unmanned car-planes are flying in the airspace. In aircraft - aircraft and rockets - a gyroscope is used as a guidance system. Early publications on gyroscopes, which utilized an elastic connection between the drive motor shaft and the gyroscopic flywheel, appeared in the early 1960s. Gyroscope designs were considered with an internal elastic flywheel suspension on the drive motor shaft, allowing the flywheel to tilt relative to the shaft. This design fully complies with the classical definition of a gyroscope as a rapidly rotating rigid body whose axis of rotation can change its orientation in inertial space. This design differs from the traditional gyroscope with an external gimbal suspension in that the drive (electric machine or high-speed bearings) does not participate in the angular motion of the flywheel axis relative to the base. Engine torque is transmitted to the flywheel through a movable joint rotating with the shaft [1].

Transmitting rotation through a sliding joint was not a new concept in technology when the dynamically tuned gyroscope was created. It's enough to recall the cardan mechanism of a car transmission or the flexible shaft of a dental drill. The peculiarity of a sliding joint is that in a gyroscope, such a unit must not only allow the flywheel to tilt relative to the shaft (within certain limits), accelerate the flywheel to a given speed, and maintain it with a given accuracy, but also restrain the flywheel from any noticeable translational movement relative to the shaft, and thus relative to the device body, i.e., act as a suspension. The strict constraints and overall dimensions of a gyroscope make it impractical to use plain bearings, much less rolling bearings, as hinges for such a rotating suspension. The most suitable elastic elements under these conditions are torsion bars, which operate in torsion, or flexible rods and plates, which operate in bending. One of the advantages of a gyroscope with an elastic rotating suspension is the efficient use of the gyroblock's internal volume, allowing its dimensions to be reduced to values slightly exceeding the diameter of the gyroscopic flywheel. The compact size of a dynamically adjustable gyroscope allows it to be used as a basis for creating compact gyroscopic angular velocity vector meters. However, due to the compact size of the gyroscope's internal structural components, it is necessary to know their permissible mechanical load in order to design systems within gyroscopic devices that protect sensitive elements from external mechanical influences [2].

Materials and Methods: A mathematical model of the dynamics of unmanned aerial missiles contains differential equations relating variables that are parameters of the aircraft's motion in space. Logrange's equations of the second kind are used for mathematical modeling of the complex spatial flight of unmanned aerial vehicles.

Results and Discussion: A guidance system is a set of equipment and devices designed to control a missile in flight. Guidance is a targeted action on a missile in flight using forces and moments: generated by the actuators of the missile's guidance system; ensuring its movement along a specified trajectory.

A homing head (BH) (Fig. 1) is an element of the homing system, the equipment for which is located in the nose cone of the missile. The BH uses infrared electromagnetic radiation emitted by the target. This placement creates certain design challenges, as the warhead must be placed behind the guidance equipment, thereby changing the aerodynamics of the missile's flight, which must be taken into account during design [3].

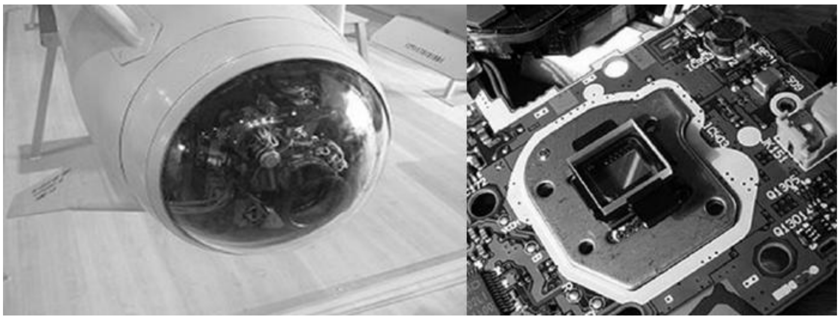

Fig. 1. The Kh-59 "Ovod" missile's television seeker and matrix photodetector

Now we examine the mounting of the missile's control system on the internal structure of the aircraft. We will examine the operation of the upper organizational layer (the layer for making decisions based on the analysis of external situations) of a multi-level intelligent control system for a homing missile.

Figure 2 shows a schematic diagram of a gyroscope, illustrating the relative positions of its elements. Axis 6, which is connected to the internal EO, can be rigidly attached to the housing or mounted in bearings. The axis can rotate at a speed w, and the rotor at a speed W, around the zp axis of the associated XpYpZp coordinate system.

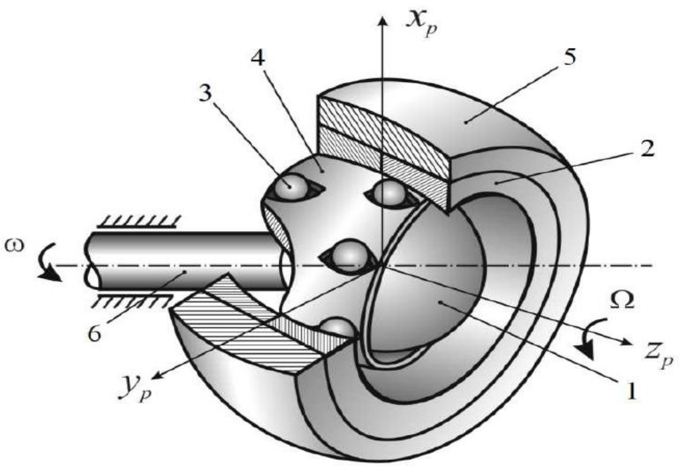

Figure 2. Schematic diagram of a three-degree gyroscope.

We will consider the torque rotation achieved by using a block of pulse motors as control elements. Based on the gyroscope, uncorrectable [4,5] and correctable [6,7] gyroscopic devices for operation as part of a gyroplatform have been created. A correctable gyroscopic device, in which the rotor is mounted relatively on bearings, has an additional degree of freedom, was also created based on this design. The dynamic characteristics of correctable and uncorrectable gyroscopes with a bearing support are due to the presence of specific cross and radial restoring moments. The coordinate system (CS) XYZ in Fig. 3 is associated with the housing, and the CS xyz, whose position is determined by angles a and b, is associated with the main axis of the gyroscope.

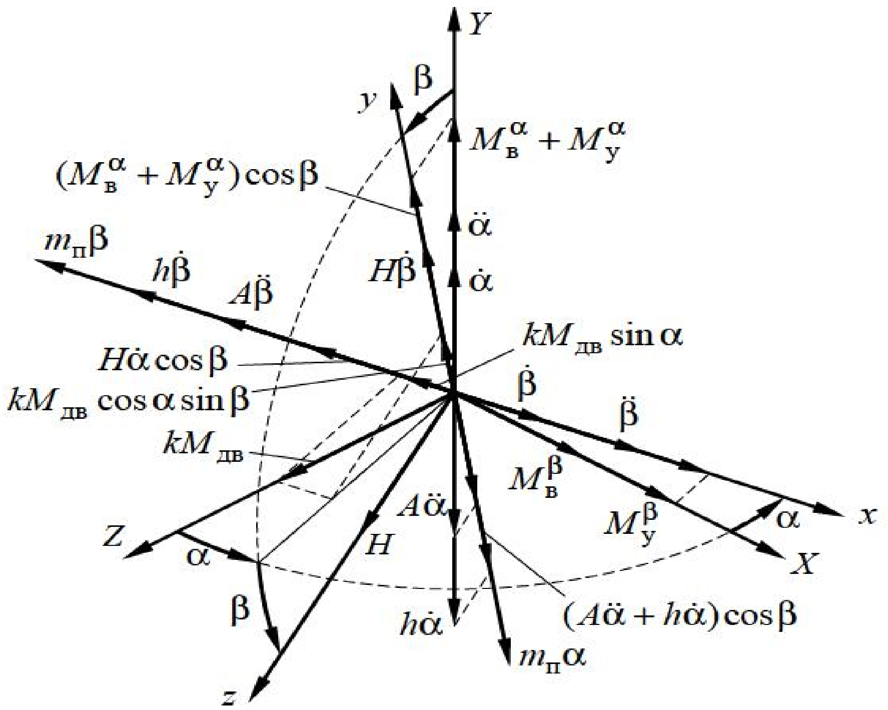

Fig. 3. Calculation scheme for deriving the equations of motion of a gyroscope

Using the above calculation scheme, we mathematically model the motion of a gyroscope rotor on a fixed base known [8] and taking into account the motion of the base with angular velocities, the projection of the absolute angular velocity of an aircraft, in particular an aircraft missile, on its main axes, denoted as $\omega_{ox},\omega_{oy},\omega_{oz}$, can be written as

$$\begin{cases} A(\ddot\alpha+\dot\omega_{0Y})+\left(h_{vn}+h_{sdv}+h_{tg}+h_{sd}\right)\dot\alpha+m_\Pi\alpha-C\dot\varphi\left(\omega_{0X}+\dot\beta-\omega_{0Z}\alpha\right)-m_{pB}\beta= \\ M_t^\alpha-M_{sdv}^\alpha-M_{tg}^\alpha-M_{sd}^\alpha, \\ A\left(\ddot\beta+\dot\omega_{0X}\right)+\left(h_{vn}+h_{sdv}+h_{tg}+h_{sd}\right)\dot\beta+m_\Pi\alpha-C\dot\varphi(\omega_{0Z}+\omega_{0Y+}\dot\alpha)-m_{pB}\alpha= \\ M_t^\beta-M_{sdv}^\beta-M_{tg}^\beta-M_{sd}^\beta, \\ C\dfrac{d^2\varphi}{dt^2}=M_d-M_n, \\ \left(A_X+B_X+C_X\right)\dot\omega_{0X}^2-\left(k_\alpha+k_\beta\right)=0, \\ \left(A_Y+B_Y+C_Y\right)\dot\omega_{0Y}^2-\left(k_\alpha+k_\beta\right)=0 \end{cases}$$

here A is the equatorial moment of inertia rotor; A_X, A_Y, B_X, B_Y, C_X, C_Y – moments of inertia of the suspension ring relative to the principal axes of inertia along the corresponding axes; h – damping coefficient; m_Π – specific cross moment; C – axial moment of inertia of the rotor; φ –

angle of rotation of the gyroscope rotor; $\dot{\varphi}$– angular velocity of the gyroscope rotor; M_d, M_n – electromagnetic moment and load moment, reduced to the motor shaft, respectively; m_{pB} – specific radial restoring moment; α, β – generalized coordinates of rotor motion; it is proposed to introduce new terms of the equation: h_{vn}– damping coefficient of internal force loads; h_{vn}- damping coefficient of the air pressure force; h_{tg} - damping coefficient of the mountain gravity and various spatial volumetric elements; h_{sd} - damping coefficient of high-density snow and rain; M_{sdv}^{α} - is the moment of air pressure; M_{tg}^{α} - is the gravitational moment of the mountain and various spatial volumetric elements; M_{tg}^{α} - is the moment of high-density snow and rain.

Conclusions: The motion of a gyroscope rotor on a fixed base and the angular motion of the aircraft missile gyroscope itself are mathematically modeled. Using this mathematical system of equations, algorithmic programming can be used to determine the possibility of precise motion of an aircraft missile.

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