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Control System of Parameters of the Azimuthal Module

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Control System of Parameters of the Azimuthal Module

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Abstract. Analytical and experimental studies of the azimuthal module of two-component vibrational micromechanical gyroscope were conducted. It is shown that the micromechanical gyroscope is a system with distributed parameters. The frequency analysis is performed using software T-Flex. The influence of mechanical disturbances on the movement of azimuthal module in the form of translational and angular oscillations is shown; the natural frequencies of the azimuth are defined.

1. Introduction

Micromechanical inertial sensors belong to the field of measuring technique and integrated electronics. They are used for measuring of two components of angular speed of object by one micromechanical component. Micromechanical gyroscopes (MMG) can be applied in production of digital camcorders and cameras, mobile phones, intellectual toys, as the measuring instruments of angular speeds in control systems of small-sized aircrafts, in updatable inertial strapdown systems, for systems of navigation and control of cars and other land vehicles and in the gyroscopic inclinometers which determine the direction of drilling. The use of the MMG allows reducing of weight and size characteristics and self-cost of these systems [1].

Features of micromechanical inertial sensors are minor dimensions, cost and power consumption [2-4]. The measured signal is very small; at present the MMG have enough low precision [5]. The efforts of developers are focused on creating of ways of improving of the precision of micromechanical gyroscopes [6–9]. Most of the MMG measures only one component of angular speed of the object.

2. Experimental

Development of the modern systems of orientation (SO) and movement control of objects for various purposes is associated with their miniaturization and reducing of energy and operating expenses.

One of the promising directions in the development of SO is application of micromechanical gyroscopes; they are made from the modern engineering materials, according to the new technologies in the micromechanics [1]. These devices have minor dimensions, cost and power consumption.

Currently, the MMG are inferior to other types of gyroscopes for precision, but they are exceeds them in weight and size characteristics, cost and power consumption.

With due regard for the high rate of improvement of accuracy parameters in this paper the dynamic characteristics of two-component micromechanical gyroscope and automatic setting of system parameters of MMG are considered at which are provided the best characteristics of SO, based on these gyroscopes.

SO are used for determining of position of devices and moving objects relatively of given basic directions.

Basic directions are at orientation in near-earth space:

- the direction of the midday line;
- the direction of the local vertical.

Geographically oriented coordinate system $o\xi\eta\varsigma$ is often used as a directional reference (Figure 1). Origin of this system is related to the object and moves with it.

Axis $o\xi$ and $o\eta$ lie in the horizon plane, the axis is directed on tangent to meridian to the north, the axis $o\varsigma$ is directed on vertical to the Zenith, the axis $o\eta$ is directed to the west.

The vector of angular speed of rotation of the Earth Ω_E is decomposed into two orthogonal components:

$$\Omega_H = \Omega_\xi = \Omega_E cos\varphi; \quad \Omega_V = \Omega_\eta = \Omega_E \sin\varphi,$$

where φ, λ are geographic latitude and longitude of the location of the object.

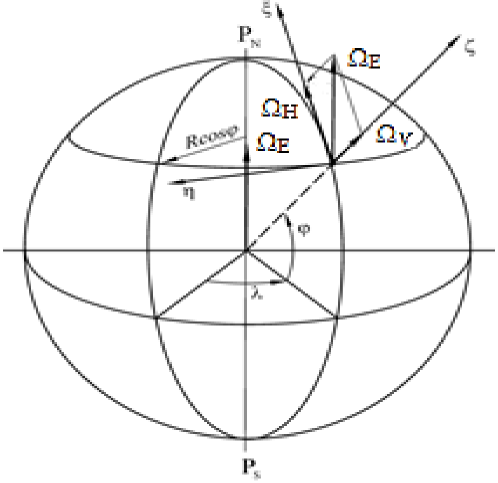


Figure 1. Geographically oriented earth axis system.

Orientation of object relatively to the reference coordinate system is shown in Figure 2.

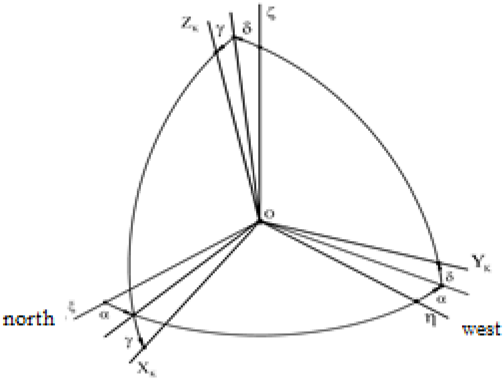


Figure 2. Coordinate systems for defining of orientation of the object.

According to Figure 2 the orientation of the object relative to the reference coordinate system is determined by the angles α, γ, δ, where α is azimuth of the object; γ, δ are angles of coverage of the object from the plane of the horizon; $OX_K Y_K Z_K$ is the coordinate system which associated with the object rigidly.

Principle scheme of micromechanical SO is presented in Figure 3. It contains the two-axis pendulum 2, which is fixed in the gimbal subweight 3. The pendulum performs a function of the geometrical vertical reference.

The sensing element (SE) of the azimuth module 1 is located on the pendulum. The signals x(t), y(t) are withdraw from the pendulum for determination of the azimuthal angle α.

Angle sensors 4 and 5 are on the axes of subweight of the pendulum; information about angles $\bar{\gamma}(t)$, $\bar{\delta}(t)$ is determined by these sensors.

Object deviations from the horizon plane are passed through the analog-digital converter (ADC) 6 to the computer 7 which provides:

- calculation of the orientation angles α, γ, δ and geographical latitude φ;
- filtering of signals;
- determining the ending of the transition process of the pendulum;
- generation of control signals by exciter;
- formation of control signals of the system of resonant settings of SE.

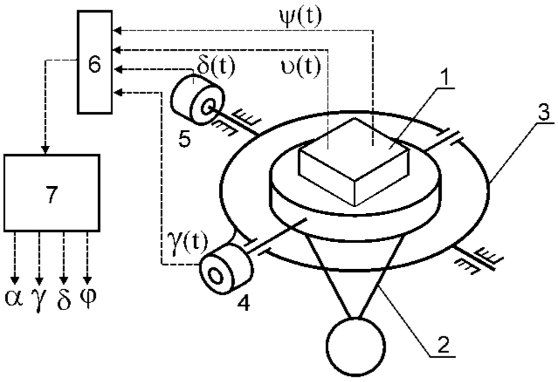


Figure 3: Principle scheme of orientation system.

Researched system has two independent channels:

- the azimuth channel (for measuring of azimuth of the object α);
- the horizontal channel (for measuring of angles of deviation of the object from the plane of the horizon γ, δ).

The sensing element of the azimuth channel is a two-component oscillatory vibratory micromechanical gyroscope [10].

The oscillations of the gyroscope are described by equations

$$\begin{gathered}(m+m_p)\ddot{x}+\mu\dot{x}+(2k_2-(m+m_p)(\Omega_z^2+\Omega_y^2))x-\\-2m\Omega_z\dot{y}+2(m+m_p)\Omega_y\dot{z}+m\Omega_x\Omega_y y+\\+(m+m_p)\Omega_z\Omega_x z=0;\\m\ddot{y}+\mu\dot{y}+(2k_1-m(\Omega_z^2+\Omega_x^2))y+2m\Omega_z\dot{x}-\\-2m\Omega_x\dot{z}+m\Omega_x\Omega_y x+m\Omega_z\Omega_y z=0,\end{gathered}$$

where m, m_p are inertial mass of the body and internal frame; x, y are motion of the inertial mass along the axes X, Y; μ_1, μ_2 are coefficients of forces of viscous friction; k_1, k_2 are stiffness of elastic elements of suspension, Ω_x, Ω_y, Ω_z are angular speeds of turning of the basis.

Sensibility and pass band are the main dynamic characteristics of the speed sensor. The amplitude on the one coordinate reaches the maximum values and it on the other coordinate reaches the values which are lower almost on two orders at the excitation of oscillations of inertial body on the one of the partial frequencies of the system [11–16].

$$\omega_{01} = \sqrt{\frac{k_1}{m}},\ \ \omega_{02} = \sqrt{\frac{k_2}{(m+m_p)}}\,.$$

The maximum sensitivity of the gyroscope is achieved by resonance tuning which corresponds to the equality of partial frequencies to the oscillation frequency of the exciter (Figure 4).

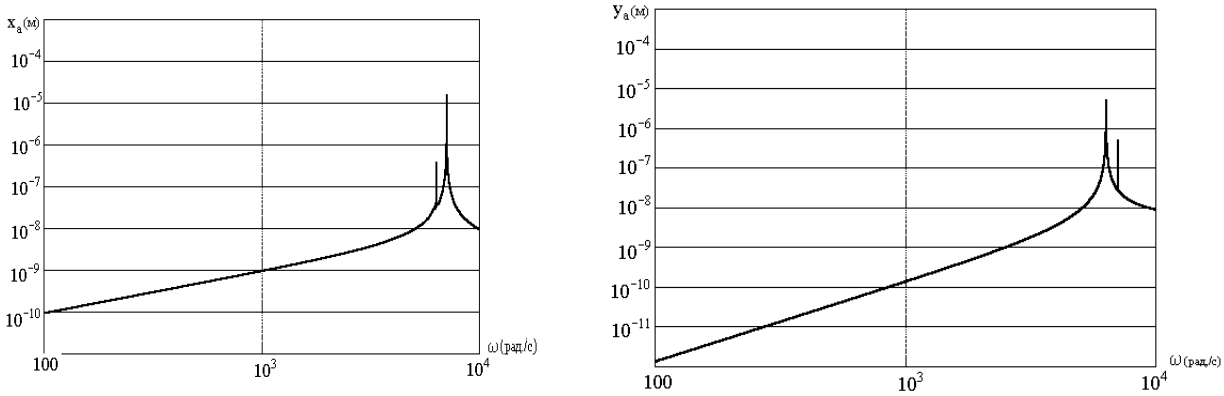
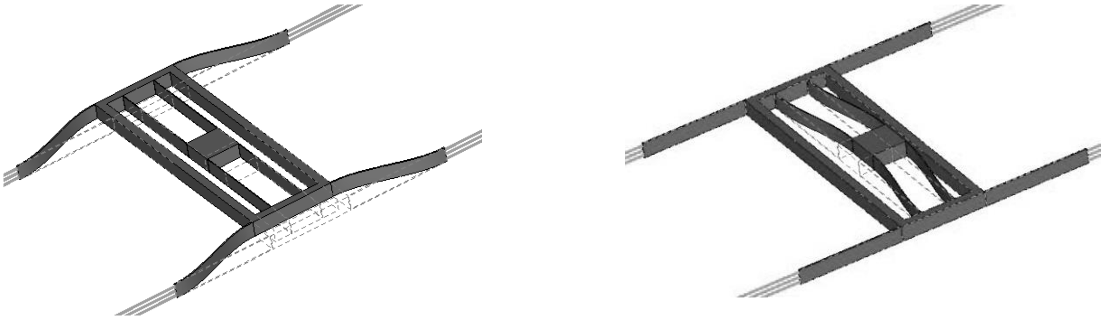


Figure 4. Amplitude - frequency characteristics of MMG.

Figure 5 shows the form of natural oscillations of MMG.



1106.8 Hz 1174.0 Hz

Figure 5. Form of natural oscillations of MMG.

The sensing element, which is an inertial body, converts the value of the current angular speed into the relative movement of construction elements. The electronic part is used for transformation of the measured capacity into voltage, for formation of control of primary oscillations of inertial body, for formation of control of secondary oscillations, for formation of output signal of gyroscope.

The change of temperature of surroundings causes change of the mechanical properties of the elastic subweight; it leads to change of natural frequencies. In addition, the natural frequencies depend on speeds and the design parameters of the gyroscope Ω_x, Ω_y. It is a cause of infringement of resonant setting of the device and emergence of additional errors in working.

Given the acute nature of resonance due to the high quality factor of silicon MMG, precise resonant tuning is required. The AFC system is used; this system can be realized through regulation of “stiffness” of the suspension by means of the vibrodrive. As the voltage of the drive electrodes varies, “stiffness” of the system changes; therefore, the natural frequency of the gyroscope changes as well.

3. Results and considerations

The algorithm of the system of locked loop of frequency is designed in such a way that the initial value of the stiffness k_0 is set on the first step. The value of this stiffness should be such that the system worked obviously not in resonance.

After then the current value of the stiffness *k* begins to strive for resonant value k_r, and it increases on size Δk at each step. If the amplitude did not increase at some step as at resonance, but it decreased, it means that the resonance is passed and it is necessary take a step back.

The work of system of locked loop of frequency is simulated using software Simulink MATLAB; the results are presented in Figure 6.

The first two graphs show the amplitudes of output signals of the gyroscope along the axes *OX* and *OY*. The third graph represents the dependence of the output signal of Microcontroller block, which implements the algorithm of work of system of the auto setting, from time.

On these graphs show, system of the auto setting of the frequency gradually increases stiffness, bringing the system to resonance.

Due to the last increasing of stiffness the amplitude of the output signal decreases. It suggests that the resonance is passed; the value of additive to the stiffness is exceeds the required value. On the basis of this information the system of auto-adjust of frequency decides to return on a step backwards and to stop the work. The considered system of auto-adjust of frequency is realized by a microcontroller.

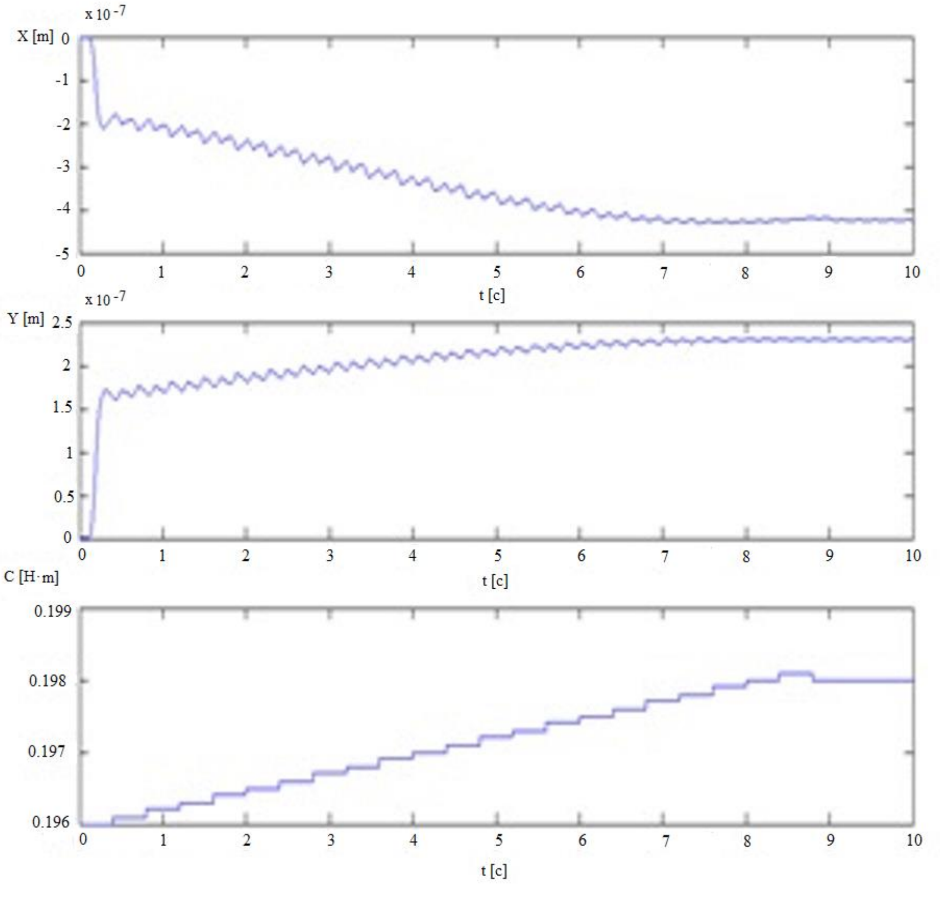


Figure 6. The output signals of MMG at auto-adjust of its own frequencies.

4. Conclusion

Thus, important characteristics of the inertial sensor are accuracy, measuring range, pass band, indication setting time, resistance to vibration, compatibility with GPS/ GLONASS, operability at low and high temperatures, analog and digital output signals.

Automatic resonance setting of the azimuthal module allows obtaining maximum sensitivity, which is especially important in micromechanical systems, where the amplitudes of the output signals are small.

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