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Features of inertially stabilized platforms research by means of simulation

The problem of research of inertially stabilized platforms by means of simulation is considered. The approaches to testing ISP operated on ground vehicles by means of simulation are represented.

Important problems of design of inertially stabilized platforms (ISP) can be solved using principles of inertial stabilization. Modern ISPs are operated on aircrafts, marine and unmanned aerial vehicles. Keeping of the stable orientation of information and measuring devices in direction of an observation object becomes a difficult problem if they are mounted on vehicles. Control by orientation of information and measuring instruments lines-of-sight allows to solve this problem.

The necessity to improve ISPs is caused by some factors. It should be noted, that accuracy and other operating performances of information and measuring devices have been significantly increased during last years. These achievements could not be implemented without respective progress in stabilization systems. This causes the necessity to increase precision and dynamic performances of ISPs including improvement of techniques of a designed system research.

In the general case the problem of inertial stabilization represents a task of control by orientation of information and measuring devices of the wide class [1]. A main feature of the inertial stabilization lies in using of inertial sensors of control contours. In accordance with standards developed by the Institute of Electrical and Electronics Engineers in USA and adapted by many countries (Europe, Japan and Canada) the inertial sensor represents a fully autonomous sensor of determination of object's location, spatial orientation and motion parameters except for additional information necessary for its alignment [2].

The issue of research is approach to checking and testing of ISP providing stabilization and tracking of observation equipment operated on ground vehicles in difficult conditions of real functioning. Such ISPs are characterized by significant changes (±50%) of such parameters as inertia moment and rigidity of elastic connection between actuator and moving platform. It is necessary also to take into consideration influence of coordinate disturbances caused by unbalance moment and moment due to angular rate caused by irregularities of road or terrain relief.

The researched system includes the stabilization object, measuring system, actuator and controller. Usage of the robust controller is convenient for such systems as they are subjected to intensive and various parametrical and coordinate disturbances during real operation.

Basic trends of ISP design are represented in [1, 3]. An algorithm of design of robust system of platform angular motion, which is represented in [4], provides synthesis of a system capable to function in difficult conditions of real operation.

The modern approach to synthesis of robust systems consists of two stages [5]. The proper synthesis of the robust system is carried at the first stage. Checking of the synthesized system performances is carried out at the second stage. After results of this checking the repetition of the synthesis procedure is possible after correction of optimization criterion, weighting coefficients and initial conditions. Features of the first design stage are represented in scientific-technical literature in detail. And features checking during the second stage require further research.

For systems of control by angular motion of ISPs the transient quality indices are of great importance such as speed of operation, dynamic error, and angular rigidity by a moment [6]. Dynamic errors of stabilization systems are all errors arising during dynamic processes, for example, influence of changed controls.

In the general case ISP operated on ground vehicles can function in three modes such as tracking, stabilization and combined previous modes. A platform with payload is controlled by the signal $U_c(t)$, which is given from the control console. And vehicle's angular rate $\omega_{\tilde{n}}$ may be considered as disturbance. During ISP check organization it is necessary to take into consideration two features. In the first place, vehicle's motion is translational. Proper stabilization is implemented on the basis of measurements of platform absolute angular rate. In the second place, it is necessary to take into account unbalance moment acting on the actuator.

There are three basic components of ISP errors [6]. The first component is tracking error. It characterizes error of the reference signal and is defined by the expression

$$x_{tr} = \frac{U_c}{[1+W(p)]}, \tag{1}$$

here $W(p)$ is the transfer function of the open-loop system of platform motion control. The second component characterizes an error caused by action of the external moments. Usually this error is determined relative to an angle of platform position. It can be described by the expression

$$x_m = \frac{W_{m1}(p)M_{um}}{[1+W(p)]p}, \tag{2}$$

here W_{m_1} is the transfer function by the unbalance moment; M_{um} is the unbalance moment. The third component is stabilization error. It takes into account influence of ground vehicle's angular rate. It is determined relative to the angle of platform position and takes into account a moment of rotation, which is caused by ground vehicle angular rate. The total stabilization error is defined by the expression

$$x_{st} = \frac{\left(1-W_{m_2}(p)W_d(p)Jp\right)\omega_{i}}{[1+W(p)]p}, \tag{3}$$

here $W_{m2}(p)$ is the transfer function by the rotation moment caused by the ground vehicle angular rate; $W_d(p)$ is the transfer function of the reduced moment caused by the vehicle angular rate; J is the moment of the stabilized platform inertia.

The tracking error is determined by the given voltage of the control console and estimation of the appropriate angular rate. For simplification the simulation it is convenient to carry out in conditions of ground vehicle immovability. Then the tracking error (1) will be determined by the transient equation $x_{tr} = x_{st}h(t)$.

For estimation of the error by the moment (2) it is convenient to give the step signal corresponding to unbalance moment and to determine the difference of angles defining position of the platform before and after moment application. Simulation is carried out in conditions of the ground vehicle immovability. Such approach allows estimating the system angular rigidity by a moment.

Stabilization error can be estimated by simulation of ground vehicle angular motion changing by the harmonic law, which corresponds to the check route. In this case direction of ground vehicle motion and respectively direction of dry friction forces action are continuously changed. An error of platform position determination in the steady mode will also change by the harmonic law $x(t) = x_{\max}\sin(\omega_k t + \psi)$.

Accuracy of stabilization can be estimated by the maximum amplitude of the error. Value of the amplitude can be determined by the symbol method by means of substitution $p = j\omega_k$ into the expression (3)

$$x_{\max} = \frac{\omega_c - |W_{m_2}(j\omega)W_p(j\omega)Jj\omega|\,\omega_c}{|1+W(j\omega)|\,j\omega}. \qquad (4)$$

As the amplitude of an error is sufficiently less than the amplitude of the reference command, the expression (4) can be changed by the approximate expression [7]

$$x_{\max} = \frac{\omega_c - |W_{m_2}(j\omega)W_p(j\omega)Jj\omega|\,\omega_c}{|W(j\omega)|\,j\omega}, \qquad (5)$$

here $|W(j\omega)|$ is the modulus of the frequency transfer function of the open-loop system, $\omega = \omega_c$. Maximum amplitude value calculated based on the formula (5) is 5 arc min.

Disadvantage of such approach to simulation is dependence on the concrete value of the test signal. To avoid such disadvantage it is possible using the relative amplitude error. For this it is necessary to carry out two test measurements in conditions of influence of angular rates $\omega_{c_1}, \omega_{c_2}$, which, for example, correspond to maximum values of angles 2 and 2.5 deg., and consider the relative error

$$\Delta x_{\max} = \left(\frac{x_{\max_1}}{\varphi_{\max_1}} - \frac{x_{\max_2}}{\varphi_{\max_2}}\right)\cdot 100\%.$$

The expression (5) allows forming of requirements to the logarithmic amplitude characteristic of the system. If these requirements will be satisfied, the stabilization error amplitude in the steady mode will not exceed a given value. These requirements can be determined by the condition [7]

$$L(\omega_c) \geq 20\lg A(\omega_c) \geq 20\lg\frac{\omega_c - |W_{m_2}(j\omega)W_p(j\omega)Jj\omega|\,\omega_c}{x_{\max}}.$$

Results of simulation are represented in Figs 1, 2.

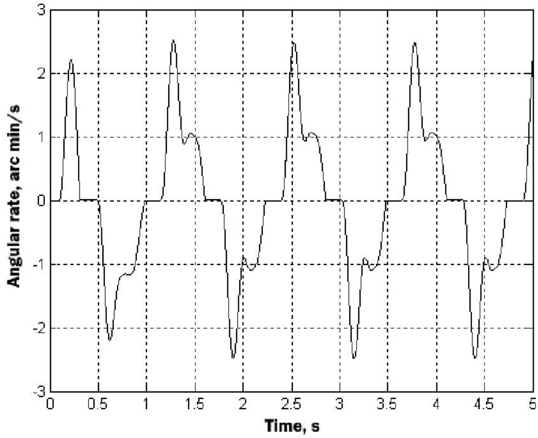

Fig. 1. Angular rate of ISP

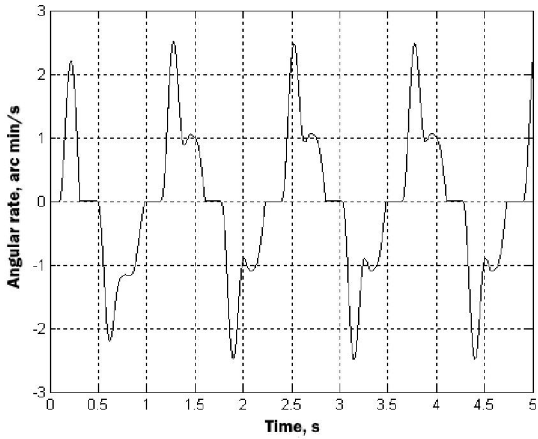

Fig. 2. Angular position of ISP

To provide correspondence of simulation to checks on the test route it is necessary to take into consideration features of test equipment. Therefore it is necessary to study ways of definition of test signals, which must correspond to disturbances of the test route. This is carried out by means of bench assigned for tests of the system of platform angular motion. In the first place, the test signal may be given at the integrator input as a voltage; in the second place – in the integrator circuit after demodulator; in the third place – at the gyro rate sensor in the form of signal proportional to the angular rate. Results of simulation represented in Figs 1, 2, correspond to the first case of test signal determination.

During design of system of platform angular motion control is important to research dependence of accuracy and dynamic parameters on the residue unbalance moment. This dependence can be represented in the following form

$$\Delta M_{ub} = -M_{ub}\cos\varphi_p + k_s A, \qquad (6)$$

here φ_p is angle of turn of platform turn, k_s is transfer coefficient of the spring compensator; A is an angle of spring setting.

Conclusions

The concept of ISP is analyzed. The approach to organization of checks of the synthesized system taking into consideration features of ISPs assigned for operation on the ground vehicles. The way to estimate the dynamic error and angular rigidity of the system of stabilized platform motion control operated on the ground vehicle is proposed. The expression for research influence of the unbalance moment on the system performances is given. The simulation results are represented. Perspectives of the further development of the represented researches lie in spreading of the represented approaches on other types of vehicles.

References

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