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HARDWARE CONFIGURATION IN SYSTEMS FOR STABILIZATION OF INFORMATION AND MEASURING DEVICES

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Abstract**—***The paper deals with problems of hardware configuration in systems for stabilization of information and measuring devices operated at vehicles of the wide class in difficult conditions of disturbances action. Analysis of modern devices and units used in stabilization systems is carried out. Recommendations to choice of hardware configuration in stabilization systems of ground and marine vehicles are given.*

Index Terms—Vehicles; stabilization systems; information and measuring devices; gyro devices; hardware configuration.

I. INTRODUCTION

Performances of systems for stabilization of information and measuring devices operated at vehicles are extensively defined by their hardware configuration. The important components of such systems are gyro devices, which are now produced in the wide range by basic performances, dimensions and costs. The bandwidth and noise are the most critical parameters of gyro devices used for such application as stabilization of information and measuring devices operated at vehicles of the wide class. In studied systems the gyro devices, as a rule, are used for feedback implementation. In this case, the gyro devices bandwidth and dynamic performances define the bandwidth of a stabilization system in whole [1]. Therefore for the most important applications are chosen the gyros with the wide bandwidth. The noise of the gyro devices influences significantly on the system performances. At the same time the stability of the scale factor and the drift value have significance for precision systems only [1].

For successful operation of a system the choice of accelerometers, angular position sensors and actuators has great significance.

Problems of construction characteristics must be considered too.

II. HARDWARE CONFIGURATION

To provide stabilization of a platform with mounted on it useful loading (observation equipment) and measuring instruments is possible using gyro devices of the different type. For the most responsible cases, traditional electro-mechanical gyros may be used up to now due to their high accuracy and dynamic performances. The integrating gyros and dynamically tuned gyros belong to such devices. Now the fiber-optic rate gyros become widespread as they have the high dynamic performances and the greater operation resource in comparison with the electro-mechanical gyros [2]. The ring laser gyros, which are widely used in the inertial navigation due to the low drifts and stability of the scale factor, are rarely applied for stabilization of information and measuring devices taking in consideration their large dimensions and significant quantization noise. For applications of the middle accuracy the requirements to low dimensions and cost become important. In this case, the rate gyros based on MEMS-technology may be used [3].

Now in Ukraine are carried tests of the Coriolis vibratory gyros with the target to define the possibilities of their usage in system of stabilization and control by lines of sight of direction-finding devices operated at vehicles of the wide class. Usage of such devices in the differential mode of operation allows to increase stability of the scale factor and to correct an error of the zero bias of the rate gyro [4]. These advantages allow to improve essentially the quality of processes of stabilization and tracking. The scheme of the vibratory gyro proposed in [5] includes the beam-type resonator with electrodes of excitation and information extraction and the block of primary oscillations excitation. This block differs from the known ones by introducing of the phase detector, one input of which is connected with the electrode of primary oscillations pickup, and a signal from another output is proportional to the angular rate of rotation.

The principle of operation of the above described vibratory gyro is as follows [5]. The Coriolis force arises during presence of the angular rate of rotation Ω relative the axis parallel to the longitudinal axis of the beam. This force causes the secondary oscillations $Y(t)$ relative to the axis proportional to the axis of the primary oscillations. A signal of secondary oscillations taken off from the electrode gives information about the angular rate of beam rotation Ω. It may be described by the following expression [5]

$$Y(t) = K\Omega_0 \sin\omega_r t + A_q \cos\omega_r t = \sqrt{(K\Omega)^2 + A_q^2}\cos(\omega_r t - \varphi), \quad (1)$$

where A_q is the amplitude of a quadrature signal; K is the scale factor.

Further signal (1) enters to the input of the phase detector. The output signal of the phase detector represents a signal of the phase difference [5]

$$\varphi = \mathrm{arctg}\frac{K\Omega}{A_q} \approx \frac{K}{A_q}\Omega \text{ for } \Omega << 1, \quad (2)$$

which is proportional to Ω for small angular rates.

Notice, that a value of A_q always differs from zero because characterizes manufacturing beam error, which may not be ideal. The suggested scheme satisfies accuracy requirements in the mode of stabilization of the information and measuring devices operated at the vehicles due to small range of stabilization angular rates. The suggested gyro has important advantages [5]. Its usage simplifies processing the secondary information, because the phase difference signal may enter to a computer without using a digital-analog-converter. Therefore the reliability of the gyro improves and cost of gyro manufacturing decreases. Furthermore, this engineering solution decreases the gyro noise on the value of the digital-analog converter.

In [6] is proposed to implement compensation of the zero bias due to detection of the minimum quality factor axis and generation of resonator oscillations along this axis. Such approach ensures simplification of information processing due to measurement of difference of the primary and secondary oscillations phases. The engineering solution is provided due to introducing the additional block of primary oscillations excitation.

It is known, that the zero bias in vibratory gyros is determined by the following relationship [7]

$$\Delta_0 = \frac{\omega_r}{4k}\left(\frac{1}{Q_1} - \frac{1}{Q_2}\right)\sin[n(\theta_\tau - \theta)], \quad (3)$$

where Q_1, Q_2 are maximum and minimum quality factors; n is a number of oscillations mode, k is a constant depending on resonator geometry. Taking into consideration that for the beam resonator $k = 1$, $n = 1$, the expression (3) may be transformed to the following form [6]

$$\Delta_0 = \frac{\omega_r}{4k}\left(\frac{1}{Q_1} - \frac{1}{Q_2}\right)\sin(\theta_\tau - \theta). \quad (4)$$

Analysis of the expression (4) shows that the gyro bias is equal to zero if oscillations direction coincides with the minimum quality factor axis. In this case $\theta_\tau - \theta = \theta$.

The signal of secondary oscillations picked up from the electrode includes information about angular rate of beam rotation Ω. It may be represented by the following expression [6]

$$Y(t) = K\Omega_0 \cos(\theta_\tau - \theta)\sin\omega_r t + A_q \cos\omega_r t = \sqrt{(K\Omega)^2 + A_q^2}\sin(\theta_\tau - \theta + \pi/2)\cos(\omega_r t - \varphi) = \sqrt{(K\Omega)^2 + A_q^2}\cos(\theta_\tau - \theta)\cos(\omega_r t - \varphi). \quad (5)$$

Further the signal (5) enters to the first input of the phase detector. Signal $X(t) = A\cos(\omega_r t)$ enters to the second input. As $\theta = \theta_r$ and $\cos(\theta_\tau - \theta) = 1$, the output signal of the phase detector will be described by the expression (2) [6].

In the suggested gyro simplification of information processing is ensured due to measurement of difference of the primary and secondary oscillations phases [6].

The most important performances of accelerometers used in systems of information and measuring instruments stabilization are accuracy, range of measurements and resistance to the external disturbances. Accelerometers with the pendulum correction are the most widespread for considered application.

In addition to inertial measuring instruments, the gimbaled stabilization systems use the angular position sensors mounted at the gimbals axes. These measurements are necessary for determination of location of gimbals relative to a vehicle. Such sensors may be used in feed-forward stabilization systems. The most important performances of the sensors are accuracy and resolution. The first characteristic ensures control of the line if sight in the mode of tracking. The second one has significance for keeping a line of sight in the same position.

Accuracy of angular position sensors depends on eccentricity of mounting and other disturbances. Traditionally inductive transducers, for example, sine-cosine rotary transformers and inductosyns are used for angular position measurement due to their accuracy and reliability. In practice of inertially stabilized platforms design it is desirable to use the multi-wound sensors due to their high resolution.

Now the increment decoders become widespread. They may ensure the high resolution about μ rad due to interpolation of the analog detector signal [1]. These sensors have small dimensions in comparison with inductive transducers but they require special mounting or using some sensing heads for averaging of eccentricity of mounting to achieve the high accuracy [1]. Encoders have also better dynamic performances in comparison with inductive transducers. To satisfy requirements to accuracy it is desirable to implement calibration not depending on the type of a sensor.

Critical parameters, which define choice of the platform gimbals, are friction and rigidity of the bearing construction [1]. These requirements are conflicting as in many cases rigid gimbals cause the maximum friction. Now ball bearings are the most widespread for the inertially stabilized platforms design. In conditions of gimbals small angular rates the hinges and the pins may be used [1]. Although these units have very low friction, their rigidity influences on a system in whole. The high accuracy requirements are given to systems applied in the inertial navigation. For such applications the liquid suspension may be used. In conditions of rigid requirements to friction moments and presence of the additional place the magnetic suspensions and gas bearings may be applied. But these units are very complex for mounting and problematic for achievement of the necessary rigidity [1].

The inertially stabilized platforms require using actuators able to create necessary moments and rates without using excessive coupling and hysteresis [1]. An actuator must create a moment able to attenuate disturbances and form command signals for control by motion of the gimbals and lines of sights of measuring devices. It must react on high frequency noise specific for a system with a wide bandwidth too. For systems with small angular rates the steel ribbons may be used [1]. This allows to achieve the necessary reduction ratio due to absence of backlashes and errors due to division of the circle by the parts, that is specific to the gear.

In general usage of gearing in inertially stabilized platforms is accompanied by some disadvantages. The reaction moment of actuator with gearing represents the disturbance moment, which makes worse the stabilization system performances. Furthermore, gearing causes the additional friction and the torsion resonance in a system. Therefore it is desirable use actuators without gearing in the cases when it is possible to satisfy the requirements given to a system. Examples of such actuators are the direct current motors with constant magnets able to create large moments at small angular rates [1].

Features of gimbaled platforms construction have great significance for successful design of a stabilization system in whole. Dynamic features of construction are defined by all its components such as useful loading, gimbals and platform. As a rule, stabilization plants such as optical viewing devices, antennas and different apparatus have complex geometrical form and construction. Influence of construction on functioning systems includes three factors [1].

The first factor is connected with the possible displacement of the line of sight due to bend of the useful loading mounted at gimbals as it is shown in Fig. 1 [1]. A displacement of the line of sight may be caused by platform vibrations, disturbances acting on gimbals and reaction to torsion moments due to action of an actuator. Analysis of this factor may be implemented by introducing of transfer functions taking into consideration features of the platform critical motion. A displacement of the line of sight due to bend of construction elements is often not sensed by gyro devices and sensed motion is implemented on frequencies, which sufficiently exceed operating frequencies of the servo system [8].

To decrease motion of the line of sight due to bend of construction elements it is necessary to increase construction rigidity. But in some cases, these measures are insufficient and it is necessary to use another approaches [1].

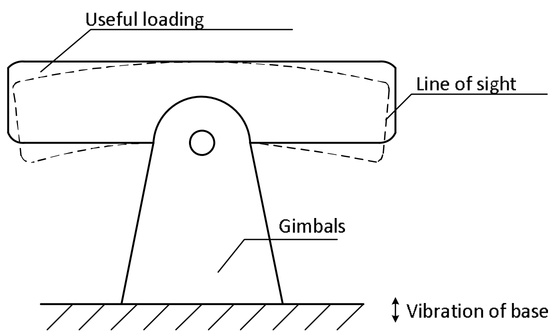

Fig. 1. Bending of a line of the sight due to useful loading

In some precision systems for compensation of motion of the line of sight are used such devices as electronic autocollimators and rapid deflecting mirrors. In systems operated at spacecrafts the basic sources of vibration are actuators of servo system. In this case, the precision wheels are used, which may prevent reaction of an actuator on construction dynamics [1].

If the basic disturbance represents the base vibration, the most widespread approach is usage of active and passive vibration isolation systems. But additional motion between a base and gimbals complicates process of measurements [9].

The second factor lies in influence of construction elements [1]. If not take into consideration dynamics of environment, this factor lies in bandwidth limiting that may be critical for system operating performances. This connection may be described by the transfer function from the actuator input to the stabilization plant output. The transfer function characterizes reaction to torsion moments. The appropriate structural scheme is represented in Fig. 2 [1].

The most widespread approach to this problem solution is increase of construction rigidity that leads to change of the appropriate transfer function. Nevertheless, the necessary rigidity may not be achieved in any case. Therefore in many cases it is necessary to use one or more narrow band filters which unfortunately may create the phase delay in the control contour [10].

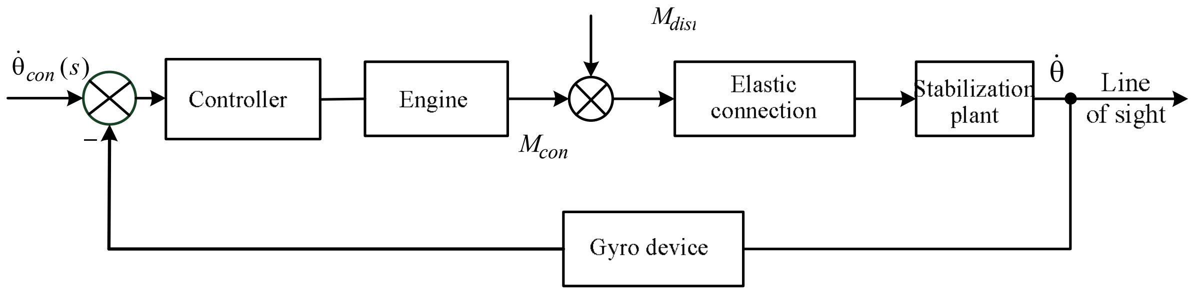

Fig. 2. Structural scheme of the stabilization system taking into consideration elastic connection

The third factor is an elastic deformation due to system mounting [1]. This factor is caused by connection of the inertially stabilized platform and construction of base, on which it is mounted. Interconnection of gimbals construction elements with base, on which it is mounted, is shown in Fig. 3 [1]. This connection may be shown if a platform is mounted on vibration-isolating washers or spring elements [3].

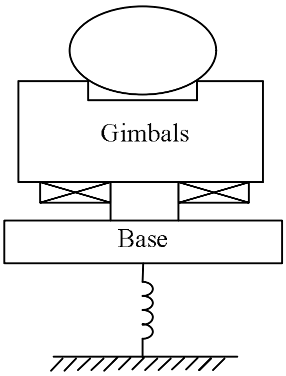

Fig. 3. Elastic deformation of a system

Methods of this factor elimination include increase of rigidity of mounting elements, usage of an additional mass in gimbals construction and narrow band filters in the servo system. In some cases vibration isolation systems are used.

Carried out analysis allows to implement a choice of devices for systems of studied type, which are mounted at ground and marine vehicles.

For example, as sensors of the system for ground application it is convenient to choose such gyro devices as rate gyros (electromechanical or vibratory) that allows to ensure the sufficient accuracy of the designed system. Precision systems of marine destination require to use precision sensors, for example dynamically tuned gyros.

Taking into consideration the large mass and inertia moment of the stabilization plant for ground systems it is convenient to choose drive with gearing. It is desirable to choose direct current motor with direct control by the rotor to ensure the minimum inertia of the drive. On contrary, stabilization systems of marine application have small masses and inertia moments. This allows to use actuators without gearing that influences positively on the system accuracy performances.

Choosing devices for the inertial stabilized platforms it is necessary remember that first of all the accuracy and reliability of a system must be ensured. The high accuracy may be provided by increase of scale factor stability and decrease of the systematic and alignment errors, and sensitivity of these parameters to such factors of environment as temperature, acceleration, electromagnetic radiation, shocks and vibration. During operation of inertially stabilized platforms the most significance has creation of favorable conditions for functioning information and measuring devices mounted on it. The basic target is decrease of temperature, shocks and vibration influence. During design of inertial navigation systems the most significance have algorithms of navigation information processing and improvement of accuracy in conditions of unfavorable factors of environment. Rigid requirements must be given to calibration of information and measuring devices and alignment of a platform. To align a platform with acceptable accuracy gyro devices must be characterized by low random drifts of angles and angular rates [11].

Choice of gyros is the main problem of inertially stabilized platforms design. To achieve acceptable accuracy the gyro devices must be characterized by the small drifts by angle and angular rate and small non-stability of zero bias. Requirements to stability of the scale factor depend on type of the stabilization plant and also quantity of frames in gimbals. Requirements to stability of the scale factor may be decreased if the trajectory of the platform motion allows keeping constant position of gyros in the inertial space. Requirements to stability and linearity must be more rigid if a platform is rotated together with a plant during its motion [1].

Precision inertial navigation systems require using accelerometers and gyro devices of high accuracy. And these performances must be kept in difficult conditions of operation. Gyro devices must be also resistant to external disturbances.

Precision inertial navigation systems must be designed to resist to factors of environment in the best way. For example, in such systems protection from the temperature influence is carried out on three levels [11]. At the first level temperature of measuring instruments by means of thermistors and heating elements is carried out. At the second level check of the temperature level is implemented by means of the heat receiver mounted in the case of the inertial measuring unit. As result, the rigid temperature requirements will be satisfied in the significant range of temperature change.

In rigid operation conditions the inertial measuring unit is subjected to large shocks and vibrations. Elastic connections cause random vibration. Functioning engines leads to random and harmonic vibrations. Therefore it is necessary to implement measures for sensors protection from vibrations and shocks.

For precision navigation systems calibration and alignment have great significance [11]. Performances of navigation measuring instruments such as systematical error, scale factor, alignment error, non-linearity and sensitivity to accelerations are changed with time and influence of environment. To provide the high accuracy of navigation measurements it is necessary to specify values of navigation measuring instruments basic errors and use them for compensation in the form of control laws components. Information about changes of navigation instrumental errors is obtained by means of calibration.

A feature of precision inertial navigation system operation is the necessity to carry out the accurate initial alignment of a platform relative to the given reference frame [11]. This process includes leveling (setting to the horizon plane) and setting to the meridian. Leveling represents a process of setting a platform with installed on it measuring instruments to the horizon plane. For marine vehicles the previous and accurate leveling are used. Previous leveling is implemented based on accelerometers signals. To realize accurate leveling the accelerometers and gyro devices at the same time are used. Setting to a meridian is implemented by rotation of a platform relative to the vertical axis. Position of the vertical axis is defined by the process of previous leveling. In comparison with the accurate leveling the setting to a meridian is less accurate process. As result the initial error in azimuth is sufficiently more than finite inclinations of a platform in the horizon plane.

Components of sensor errors are determined based on simulation and tests. During system operation every error component may be estimated and compensated by algorithmic means. Compensation corrections may be determined based on tests on the instrumental level.

Analysis of possible ways of precision inertial navigation systems structure organization is represented in paper [12]. In this paper the precision gyrocompass and the systems of stabilization and course determination using the two-axes and three-axes platforms are described. The biaxial system is assigned for applications in conditions of mass and dimensions restrictions. In this case keeping the high accuracy is ensured by the possibility to rotate the course gyro by the third axis (in the azimuth plane) by means of the turn device. In the suggested scheme one more turn device is used. On this device the gyro measuring instrument carrying out functions of the gyro vertical is mounted. This unit may be used for calibration of the gyro instrument and determination of corrections for errors. The triaxial scheme is more traditional. It includes three accelerometers that allows to compensate an error caused by the vertical component of the vehicle speed, course gyro and gyro vertical. Compensation algorithms for systems of marine application are enough complex. This is caused by the necessity to compensate instrumental and methodical errors. The methodical errors first of all are caused by the Coriolis accelerations, Earth rotation, plant motion and non-sphericity of the Earth [13].

Now, that strapdown systems with correction from GPS are widely used. Actuality of the gimbaled inertial navigation systems is caused by disadvantages of usage GPS as a navigation tool. In this sense advantages of gimbaled navigation systems for strategic applications give not rise to doubt. GPS has such disadvantages as dispersion of GPS signals in the space (troposphere, ionosphere), dispersion of signals of the ground transmitter, possible inaccessibility of the necessary quantity of GPS satellites, non-taking into consideration the local relief (mountains, tunnels, woods, bridges), vulnerability to special means of signals elimination [14].

Application of satellite navigation system data as input signals of navigation algorithms is complicated by the following causes such as non-stability of operation during disturbances action; duration of time of the first reliable information obtaining (no less 8-14 s); low resistance to noise; low speed of operation (no more than 10 Hz) [14].

It is necessary to take into consideration problems of reliability of the satellite navigation system data in countries which have no checking by control of satellites.

Now, precision navigation systems are used in the case of the necessity to satisfy such basic requirements as high accuracy in conditions of system autonomy, high functional reliability and ability to operate in conditions of unfavorable conditions of environment.

III. Conclusions

Comparative analysis of device composition of the inertially stabilized platforms is carried out. Recommendations to choice of components of systems for stabilization of information and measuring devices are given. Features of brace gyros applied for stabilization systems are discussed.

References

[1] Hilkert, J. M. "Inertially stabilized platform technology". *IEEE Control Systems Magazine*. 2008. vol. 28. no. 1. pp. 26–46.

[2] Sushchenko, O. A.; Palchik V. V. "Review of modern status of angular rates fiber-optic sensors and trend of their development". *Electronics and Control Systems*. 2010. no. 4(26). pp. 36–41. (in Russian).

[3] Sushchenko, O. A.; Karasyov, V. S. "Research of influence of device composition on performances of system for stabilization of information and measuring devices". *Electronics and Control Systems*. 2011. no.2(28). pp. 65–70. (in Ukrainian).

[4] Chikovani V. V.; Sushchenko, O. A. "Differential mode of operation for Coriolis vibratory gyro with ring-like resonator". *Electronics and Nanotechnology (ELNANO)*, April, 15-18, 2014: proceedings. Kyiv NAU, 2014. pp. 336–339.

[5] Chikovani, V. V; Sushchenko, O. A. Brace vibratory gyro for stabilization system. Pat. N85316. Ukraine MPK G01C. 19/00. – N201308114; Decl. 26.06.2013. Publ. 11.11.2013, Bul. N21. 3 p. (in Ukrainian).

[6] Chikovani, V. V; Sushchenko, O. A. Brace vibratory gyro with compensation of zero bias. Pat. N85766. Ukraine, MPK G01C. 19/56. – N201308113; Decl. 26.06.2013. Publ. 25.11.2013, Bul. N22. 4 p. (in Ukrainian).

[7] Lynch, D. D. "Coriolis vibratory gyros". *Symposium Gyro Technology*, Stuttgart, Germany, 21-23 September, 1998, pp. 3.1–3.14.

[8] Debruin, D. "Control systems for mobile satcom antennas". *IEEE Control Systems Magazine*. 2008. vol. 28. no. 1. pp. 86 –101.

[9] Wie, B. "Experimental demonstration of a classical approach to flexible structure control". *AIAA J. Guid. Control Dyn*. 1992. vol. 15. no.6. pp. 1327–1333.

[10] Balas, G.; Young, P. "Control design for variations in structural natural frequencies" *AIAA J. Guid. Control Dyn*. 1995. vol. 18. no.2. pp. 325–332.

[11] Wang, H. G.; Williams T. C. "Strategic inertial navigation systems". *IEEE Control Systems Magazine*. 2008. vol. 28. no 1. pp. 65–85.

[12] Sushchenko, O. A. "Comparative analysis of approaches to construction of systems of vehicle attitude reference systems". *Electronics and Control Systems*. 2006. no. 2(8). pp. 92–95. (in Ukrainian).

[13] Rivkin, S. S. 1964. Theory of gyro devices. vol. 1. Leningrad. Sudostroenie. 521 p. (in Russian).

[14] Rounds, S. F.; Marmar, G. "Stellar-inertial guidance capabilities for advanced ICBM". *Proc. AIAA GNC Cont*. 1983. no. 83-2297, pp. 849–855.

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О. А. Сущенко. Приладова конфігурація систем стабілізації інформаційно-вимірювальних пристроїв

Розглянуто проблеми приладової конфігурації систем стабілізації інформаційно-вимірювальних пристроїв, які експлуатуються на рухомих об'єктах широкого класу в складних умовах впливу збурень. Виконано аналіз сучасних приладів і пристроїв, що використовуються для систем стабілізації досліджуваного класу. Надано рекомендації відносно вибору приладової конфігурації в системах стабілізації наземного та морського призначення.

Ключові слова: рухомі об'єкти; системи стабілізації; інформаційно-вимірювальні пристрої; гіроскопічні пристрої; приладова конфігурація.

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Кількість публікацій: 120.

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О. А. Сущенко. Приборная конфигурация систем стабилизации информационно-измерительных устройств

Рассмотрены проблемы приборной конфигурации систем стабилизации информационно-измерительных устройств, эксплуатируемых на подвижных объектах широкого класса в сложных условиях воздействия возмущений. Выполнен анализ современных приборов и устройств, используемых для систем стабилизации исследуемого класса. Даны рекомендации относительно выбора приборной конфигурации в системах стабилизации наземного и морского назначения.

Ключевые слова: подвижные объекты; системы стабилизации; информационно-измерительные устройства; гироскопические приборы; приборная конфигурация.

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Направление научной деятельности: системы стабилизации информационно-измерительных устройств, эксплуатируемых на подвижных объектах широкого класса.

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