**"Gyroskopiya i Navigatsiya" №1, 2000**

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| This paper presents an overview of how inertial sensor technology is applied in current applications, and how it is expected to be applied in near- and far- term applications. The ongoing trends in inertial sensor technology development are discussed, namely interferometric fiber-optic gyros, micromechanical gyros and accelerometers, and micro-optical sensors. Micromechanical sensors and improved fiber-optic gyros are expected to replace many of the current systems using ring laser gyroscopes or mechanical sensors. The successful introduction of the new technologies is primarily driven by cost, and cost projections for systems using these new technologies are presented. Externally aiding the inertial navigation system (INS) with the global positioning system (GPS) has opened up the ability to navigate a wide variety of new, large-volume applications, such as guided artillery shells. These new applications are driving the need for extremely low-cost, batch-producible sensors. | |  |
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| In the work a new approach to calibration of gimbaled Inertial Navigation system (INS) based on two electrostatically suspended gyros (ESG) is considered. The automatic calibration procedure of the inertial measuring unit (IMU) error models parameters, namely, the gimbal pick-off errors, is examined. The measurement errors for angle rotor position are described by equation (1). The gimbal pick-off errors are described by equation (3). The relationship between the gimbal pick-off errors and INS output errors is described by equation (14). The Kalman filter observation equation is received. The IMU calibration procedure is tested by the experimental study. The tests results are shown in Fig.1. It was shown, that the calibration errors are equal to (5……..10) %. The calibration time is equal to 5 hours. | |  |
| **S.P.Dmitriev, O.A.Stepanov** | **Noninvariante Algorithms for Information Processing of Inertial Navigation System** | **24** |
| The classical approach to the development of the algorithms for various inertial navigation systems (INS) is based on kinematic equations of mechanics for navigation parameters (NP) (vehicle coordinates, velocity, and orientation angles). These algorithms are reduced to the solution of differential equations whose right parts contain measurements of INS sensors: accelerometers and gyros. NP generated by these algorithms using error-free (ideal) measurements will also be error-free. That is why these algorithms are often called the «ideal operation» algorithms. When the external aids are available, the «ideal operation» algorithms are complemented by the filtering algorithm. The aim of this complement is to estimate INS error on the background of errors of external navigation meters. The measurements for this filtering problem are formed by comparing the readings of the INS and those of the external meters. It is essential that navigation parameters are not included in the state-vector. Due to this approach the errors of the parameters under estimation do not depend on realizations of the parameters in the case of the linear character of differential equations for the "ideal operation" algorithms. As a consequence, the algorithms obtained on the basis of this approach are frequently called invariant algorithms. The advantages of invariant INS algorithms are their comparative simplicity and little error dependence on the character of NP changes. However, they have an essential drawback, as the NP properties generated by the vehicle dynamics are not taken account of.  The aim of the paper is to optimize INS algorithms using this additional information about the NP properties. In order to take into account this information, the equations of the vehicle's dynamics are included into the equation for the state vector. Thus, the navigation parameters are described as stochastic processes and their estimates are calculated as a result of solving the filtering problem for the navigation parameters themselves. The accelerometer and gyro readings are used directly (along with possible external data) as measurements in the filtering problem. It is essential that the obtained algorithms will lose the invariance property that justifies their definition as non-invariant algorithms. At the same time these algorithms are adaptive ones as they are adjusted to the dynamic properties of the vehicle where the INS is mounted.  Optimization of the INS algorithm and the analysis of its accuracy are oriented at strapdown inertial navigation systems (SINS). These systems are widely used due to the simplicity of their construction and a comparatively low cost.  The efficiency of the approach suggested is illustrated when estimation problem is solved for marine ship NPs using data from SINS and satellite system. | |  |
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| The results of gravimetric survey carried out using the gravimetric complex Chekan - A during the seismic work in one of the North Sea regions are analyzed in the paper. The peculiarities of complex construction are considered. The measurement accuracy dependence on sea states and parameters of digital smoothing filter is studied. The measurement error evaluation on data of base measurements and difference of anomaly values in the free air in the points of tack crossing is given. The comparison of gravimetric data with seismic profile is effected. | |  |
| **P.K.Plotnikov, V.Yu.Musatov, A.I.Sinev** | **Algorithms for Underground Pipeline Routes Positioning Using Inertial Magnetometric System** | **51** |
| The state-of-the-art of technological processes for manufacturing of low-cost compound hemispherical resonators are presented in this paper. The compound resonator consists of hemispherical shell (meniscus) and stem, which are made separately with use of the well fulfilled technology of spherical and cylindrical optics. Manufacturing technology of compound resonator elements is described in the paper. Geometrical and dynamic characteristics of meniscus are given.  The use of highly effective technologies of optical production when manufacturing resonators hemispherical resonator gyroscopes (HRG) allows us to considerably reduce the production cost and to save, at the same time, their dynamic characteristics at a level of resonators made of one-piece of glass.  With the purpose of increasing of adaptability to manufacture and cost reduction we offer a construction of a compound resonator [1-3]. For checking the design parameters of resonator's parts during their manufacturing well worked methods and equipment are also applicable [4]. It is expected that the Q-factor of the developed resonators will be rather high and mismatches in the Q-factor and in frequency will be rather low (Table 1). This is because one of the main reasons of energy dissipation in hemispherical quartz resonator are the losses in a surface layer [3,5], and in the compound resonator a level of a surface roughness about 0.032 microns can be achieved (Fig.2).  Other major reason of HRG error is the technological defects of a resonator. Due to application of accurate methods of checking of geometric parameters of resonator's parts it is possible to considerably reduce a technological defects during manufacturing, which influence on mismatches in Q-factor and in eigen frequency (due to checking of such parameters as difference in thickness of a resonator, eccentricity, tilt of a resonator stem axis etc.).  The dynamic model of a resonator, taking into account its stem and rigidity of connection stem and hemisphere is considered in this work. The analysis of a loss function and relative Q-factor is given, that will allow us to qualitatively evaluate various designs of resonators, and also resonators made of various materials, to define conditions for optimization of the stem parameters, to define the influence of a rigidity of its fixing.  Experimental investigation results of dynamic characteristics of various resonator's design and also made of various materials are analyzed.  The work was executed within the framework of the project 558 of Science and Technology Center in Ukraine (STCU). | |  |

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| **J.Mark, D.Tazartes** | **Application of Coning Algorithms to Frequency Shaped Gyro Data** | **65** |
| A key parameter of a strapdown inertial navigation system is its response to coning motion. Substantial efforts have gone into the development of sophisticated algorithms which reduce system drift errors in the presence of coning motion. Present-day algorithms use incremental angle outputs from the gyros to form high- order correction terms which reduce net coning errors. These algorithms assume a flat transfer function for the processing of the incremental angle outputs and are structured to yield very high order responses. Techniques such as resolution enhancement shape the frequency response of the gyro data and consequently degrade the performance of the conventional coning algorithms. Likewise, many gyros exhibit complex frequency responses and violate the assumptions used in deriving the previously developed coning algorithms. The mismatch between the assumed and actual frequency response of the gyro data leads to degradation of performance in a coning environment as well as amplification of pseudo-coning errors. This paper discusses a method of deriving algorithms which are tailored to the frequency response of the particular type of gyros used. These algorithms can be designed to arbitrarily high order and can also supply an extremely sharp high- frequency cutoff to minimize pseudo-coning errors. This work was motivated by the desire to use resolution enhanced ZLG data to form the strapdown attitude solution and was heavily influenced by the most recent work in Russia on coning algorithms by Yury Litmanovich. However, the techniques developed equally apply to mechanical, fiber-optic, and other types of gyros. Extensive simulation of the new algorithms has been performed and we are now in a position to incorporate them in the Litton ZLG product line. | |  |
| **M.Yu.Shatalov, B.S.Lunin** | **Influence of Prestress on Dynamics of Hemispherical Resonator Gyroscope** | **78** |
| Inner prestresses result from the mechanical treatment of a resonator or from inertial motion of the gyroscope, for example, its rotation. The analysis is complex from the theoretical viewpoint because it is necessary to consider the nonlinear geometry of the shell. It is also difficult from the view point of numerical analysis by means of finite element methods due to infinity of different possibilities for inner prestress distributions. This problem of influence of the prestress on dynamics of a hemispherical resonator gyroscope is investigated analytically. On the basis of analysis of nonlinear geometry of a hemisphere the terms responsible for the prestresses are introduced in the expression for the strain energy of the resonator and the problem is solved in linear approximation. The example of an important case of a particular distribution of local stresses is considered. The special case of influence of centrifugal forces on the dynamics of a rotating gyroscope is investigated. | |  |
| **S.F.Petrenko, Yu.A.Yatsenko, V.V.Vovk, V.V.Chikovani** | **Technological Aspects of Manufacturing of Compound Hemispherical Resonators for Small-Sized Vibratory Gyroscopes** | **88** |
| The state-of-the-art of technological processes for manufacturing of low-cost compound hemispherical resonators microns can be achieved (Fig.2).  Other major reason of HRG error is the technological defects of a resonator. Due to application of accurate methods of checking of geometric parameters of resonator's parts it is possible to considerably reduce a technological defects during manufacturing, which influence on mismatches in Q-factor and in eigen frequency (due to checking are presented in this paper. The compound resonator consists of hemispherical shell (meniscus) and stem, which are made separately with use of the well fulfilled technology of spherical and cylindrical optics. Manufacturing technology of compound resonator elements is described in the paper. Geometrical and dynamic characteristics of meniscus are given.  The use of highly effective technologies of optical production when manufacturing resonators hemispherical resonator gyroscopes (HRG) allows us to considerably reduce the production cost and to save, at the same time, their dynamic characteristics at a level of resonators made of one-piece of glass.  With the purpose of increasing of adaptability to manufacture and cost reduction we offer a construction of a compound resonator [1-3]. For checking the design parameters of resonator's parts during their manufacturing well worked methods and equipment are also applicable [4]. It is expected that the Q-factor of the developed resonators will be rather high and mismatches in the Q-factor and in frequency will be rather low (Table 1). This is because one of the main reasons of energy dissipation in hemispherical quartz resonator are the losses in a surface layer [3,5], and in the compound resonator a level of a surface roughness about 0.032 of such parameters as difference in thickness of a resonator, eccentricity, tilt of a resonator stem axis etc.).  The dynamic model of a resonator, taking into account its stem and rigidity of connection stem and hemisphere is considered in this work. The analysis of a loss function and relative Q-factor is given, that will allow us to qualitatively evaluate various designs of resonators, and also resonators made of various materials, to define conditions for optimization of the stem parameters, to define the influence of a rigidity of its fixing.  Experimental investigation results of dynamic characteristics of various resonator's design and also made of various materials are analyzed.  The work was executed within the framework of the project 558 of Science and Technology Center in Ukraine (STCU). | |  |

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| **S.A.Shestov, S.V.Mokryshev** | **Development of Ground Gyroscopes Based on Gyroscopic Tachometers** | **95** |
| On materials of an open domestic and foreign seal [1, 5-8, 18, 19] the historico- analytical the review of development of gyrocompasses (GC'es), constructed on the basis of gyrotachometeres (GT'es) is made. Volume of knowledge on such GC'es is systematized. The analysis of the various circuits of construction (Fig. 3, 4, 5, 6) GC'es and their comparison by criteria is carried out: accuracy (7), (16), (21), (24), (29), (30), speed, protection against external influences and complexity of realization. The technical characteristics of some samples GC'es, constructed on the basis of GT'es are given. | |  |

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