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Stabilization system of aviation gravimeter

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Abstract— The article analyzes the existing aviation gravimetric system and their characteristics. Also the article analyzes of the most precise aviation gravimeters. Analyzed the methods of reducing the impact of factors on the output signal of aviation gravimeters, which allows to increase accuracy.

Index Terms— aviation gravimeter, stabilization system, gravimeter.

1 Introduction

The information about the gravity is needed in aviation and space technique (correction of the systems of inertial navigation of rockets, planes), for realization of aims of engineering geology, archaeology, prognosis of earthquakes. To determine the characteristics of the Earth's gravity field is most useful aviation gravimetric system (AGS).

The indication of gravity anomalies from aircraft requires a combination of several instrumentation components, each of which is designed for the role of measurement or signal processing [1, 2]. The aggregate assemblage of these components constitutes an AGS. Subsets of this assemblage of components which relate system outputs to inputs will be termed the subsystems of the airborne gravimetric system. The present task is therefore to determine the number, function, and accuracy of the subsystems which make up an airborne gravimetric system.

Gravimeter is a sensitive element of AGS that measures the gravity and the accuracy of which, basically, determines the accuracy of all AGS [3].

A new piezoelectric gravimeter that has greater accuracy from known aircraft gravimeters is proposed in [4, 5], and new the novel double-ring dynamical gravimeter is proposed in [6].

The most perspective type of electromechanical gravimeter based on dynamically customized gyroscope. The examples of realizations such gravimeters are reduced in. However many errors is inherent in it gravimeter. These errors can essentially distort result of measurements.

These errors are stipulated by that gravimeter measures a collection of acceleration of gravity (useful component of result of a measurement) and inertial absolute acceleration (parasite signal calling an errors of result of measurements). The inertial absolute acceleration is called by vertical acceleration of the plane, on which is installed gravimeter. The magnitude of such parasite signal can exceed magnitude useful component in result of measurements. The forward and angular vibrations of the plane also can reduce in essential errors of result of measurements.

1. Aviation gravimetric system

The aviation gravimetric system consists of five functional subsystems for [7-9]:

Specific force measurement;

Geometric stabilization;

Terrestrial navigation;

Altimetry;

Computation.

In determining the accuracy required of such a system, or in evaluating the utility of a given system, we must recall that the only use for global gravity data is the computation of geoid heights and deflections of the vertical. Overall system accuracy should than be evaluated in terms of the resulting accuracy in these computations. Although measurement accuracies on the order of 1 to 3 mGal may ultimately be required, significant improvement in the existing gravity net would result from measurements accurate to 10 mGal.

Compensation error due a given velocity measurement error varies with both aircraft heading and latitude, the minimum sensitivity for any latitude occurring on a due west heading.

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The aviation gravimetric system capable of measurement accuracy of the order 3 mGal, must be capable of nominal subsystem accuracies as follows:

velocity no heading restriction	0,18 knot
no westerly headings	0,4 knot
latitude	0,5 mile
verticality	1 arc minute
sea-level altitude	10 feet
specific force measurement	1 mGal

2. Electromechanical gyroscopic gravimeter

In the fields of navigation and guidance, specific force sensors play a leading role in most system mechanizations. Thou, as might be expected, a broad spectrum of specific force sensors have been developed for use in guidance and navigation, but until recently the possibility of their use in gravimetry had been largely ignored. Perhaps the most promising of these instruments is the pendulous gyro accelerometer (PIGA). It is interesting to note that a device somewhat similar the PIGA was patented in Russia by V.V. Kochegura in 1960.

At the heart of the device is a single-degree-of-freedom which has been made pendulous by the addition of an unbalancing mass along its spin axis. The gyro wheel is held in supporting gimbals free to rotate about only one axis, referred to as the output axis. On the output axis is mounted an electromagnetic pickoff which produces a signal proportional to the rotational displacements of the wheel support relativity the platform, and an electromagnetic torque, which applies torque about the output axis in response to input current.

The unbalances mass along the spin axis produces a torque about the gyro output axis, and the resulting rotation about this axis is sensed by the signal Pickoff. This signal is amplified and fed to the platform motor which rotates the platform at an angular velocity sufficient to cause a gyroscopic reaction torqe about the gyro output axis which exactly balances the gravity torque. Under these conditions, the angular velocity of the platform is a measure of the specific force acting on the unbalancing mass. The gyro wheel is enclosed and floated in a viscous fluid which provides both support and damping. It is this floated member, referred to as the float of the gyro, which acts as a torque summing device. It is acted on by torques due to the pendulous mass and gyroscopic torques due to the inertial angular velocity about its input axis. Torque may also be applied to the float by application of a command current to the torque generator.

The steady state sensitivity of the PIGA can be shown to be

$$\frac{\Omega}{a_i} = \frac{P}{H},$$

Ω – angular velocity of the platform,

a_i – input acceleration,

P – pendulosity of the gyro floats about the output axis,

H – gyro wheel angular momentum.

The platform angular velocity is usually read out by means of either an optical or electromagnetic digital encoder. These devices produce a pluses train whose frequency varies with the platform angular velocity.

If a pendulous gyro accelerometer is carried in an instrumented geographic coordinate frame, there will exist a component of the earth's angular velocity about the sensitive axis, the resulting specific force error will be in the range of a few mGal to a fraction of an mGal depending on the scale factor of the particular instrument. For the instrument described above, the error would be about 1 mGal at the poles. If the error is significant, it can compensated by either introducing a compensating torque to the gyro float through the torque generator, or by mounting the instrument on a table driven about the vertical so as to null the vertical component of earth rate.

A PICA is currently being prepared for flight testing as a gravimeter by MIEIA institute in Moscow.

Several sensors developed for land or sea use, such as the LaCoste-Romberg, the Askania-Graf, and the Worden, has been modified for airborne use. These devices all have been successfully tested in an airborne environment, but they do have some disadvantages, primarily in the areas of data readout and dynamic range. There exists a large class of specific force sensors developed for use as accelerometers in guidance and navigation system. Several of these sensors seem particularly well suited to use in AGS. One of the more promising devices, the pendulous integrating gyro accelerometer or PIGA, is currently being readied for flight tests by the MIT Experimental Astronomy Laboratory under Air Force Cambridge Research Laboratory sponsorship. It is probably neither economically nor technically feasible to choose a single navigation technique such as Doppler, inertial, etc. That can fully meet the requirements of as AGS. Such system should be capable of indicating velocity to 0.5 knot or better and position to 0.5 mile or better for long duration flights at 500 knots. An examination of the currently available sources of altitude data shows that a direct and continuous determination of sea-level altitude to the accuracy required by an AGS is not possible using any single source of information. Radar altimeter appears capable of supplying data on sea-level altitude to a sufficient accuracy, but only when over regular terrain or water of known elevation.

Combination of air-mass velocity measurements with ground velocity and heading information from the navigation system can, through use of Henry's correction, yield information on the slope of the isobaric surface being flown. Additional data on the height of this isobaric surface can be provided by periodic radar measurements, and by measurements made at surface weather stations.

Data from various sources can be combined in a manner assigned to minimize the mean-squared error in the resulting estimate. This estimate of isobaric surface height, together with the output of a hypsometer, can provide the required altitude data for gravimeter compensation.

The nature of the signal processing and filtering problem is, in most cases, such that post-flight data processing is possible. This allows the design of a filter free of the usual readability constraints. The noise present in the gravimeter output before filtering is mostly due to aerodynamic, wind, and turbulence loading of the airframe. These interfering forces result in aircraft accelerative that are partially counteracted by the autopilot system. The characteristics of the airframe – autopilot system will, in general, change with time, thus the truly optimum; filter should be adaptive in nature.

3. The stabilization system for gravimeter

In order in carry out a gravity survey from a moving vehicle some means of stabilizing the electromechanical gravimeter along a reference direction is required. Since it is ultimately necessary to deduce the specific force in the direction of the local geographic vertical, the direct instrumentation of the vertical provides the most desirable measurement environment [5].

Instrumentation of the vertical on a moving base requires however, a rather complex subsystem using high-grade inertial navigation data. The drawbacks of complexity are reduced somewhat by the fact that such a stabilization system can also serve as the heart of a geographic inertial navigator [10].

As an alternate to stabilization along the vertical, the gravimeter may be allowed to track the apparent vertical, provided the proper compensation term is added to the gravimeter output. Stabilization along the apparent vertical also places a greater load on any gravimeter output-filtering [11] scheme due to the presence of components of short term horizontal acceleration in the gravimeter output.

The AGS may be thought of as the instrumentation of a single dynamic equation, relating the outputs of the required subsystem to the indicated gravity anomaly. As this equation shows, the indicated gravity anomalies are obtained by compensating the output of a specific force sensor (gravimeter) which is stabilized along a vertical or apparent vertical axis. Four types of compensation term appear:

1) vertical accelerations of the aircraft;
2) Coriolis and centrifugal force corrections;
3) free air gravity reduction terms;
4) the computed reference value of gravity at sea level.

If an apparent vertical stabilization system is used, the Browne correction must also be applied. All but the first of these compensation terms can be easily computed from the outputs of the previously specified subsystems.

The sensitivities of the other, more readily computed compensation terms, to errors in the navigation and altimeter subsystem outputs. Compensation error due a given velocity measurement error varies with, both aircraft heading and latitude, the minimum sensitivity for any latitude occurring on a due west heading.

Conclusions:

For a given specific force sensor uncertainty, the minimum system uncertainty results when the sensor is physically stabilized along the z axis (vertical axis) of an instrumented local geographic coordinate frame. Errors in the z axis alignment of such a frame result in 1…20 mGal error for each arc minute of misalignment due to projection of horizontal Coriolis forces along the measurement axis, and a smaller second order error which reaches 0.4 mGal at 3 arc minutes vertically error.

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