ISSN 2229-5518

# Analysis of ways to increase accuracy of aviation gravimeters

Igor Korobiichuk

**Abstract**— The article considers all types of aviation gravimeters and presents conclusion on the potential of using gyroscopic gravimeters which have significant advantages over others, as they are able to provide higher accuracy and speed, have small dimensions and high sensitivity.

**Index Terms**— aviation gravimeter, accuracy, gravimeter.

## 1 Introduction

Knowledge of Earth's gravitational field parameters is necessary for many branches of science and technology: for mineral exploration, especially in remote areas, mountains and oceans, in geology and geodesy, for correction of inertial navigation systems in aerospace industry [1], etc. Accuracy and speed of measurements of Earth's gravitational field parameters (their anomalies $\Delta g$ ) depend, first of all, on the choice of gravimeter. Therefore gravimeter, as a major sensor of aviation gravimetric system (AGS) [2] should have high metrological characteristics: accuracy, sensitivity, speed and reliability [3]. Level of requirements to gravimeters is growing, inducing to create improved gravimeters of new types.

**2. Emphasis of unsolved aspects of the general problem, to which the article is devoted.** However, there is a lack of thorough analysis of aviation gravimeters in the literature [4-8 and others]. Some disembodied data relate to certain aviation gravimetric measurements or their certain aspects [4-8]. Generally, it should be noted that there are no overall systematic analysis of works in the field of aviation gravimetry. The National Technical University of Ukraine "KPI" and Industrial Research Institute for Automation and Measurements PIAP, conduct scientific and implementation works on research of accuracy characteristics of the most advanced aviation gravimeters of new types, i.e. single and double-ring dynamically configurable gravimeters (DCG) [9]. Solution of the scientific and practical problems makes it possible to greatly improve accuracy and speed of dynamically configurable aviation gravimeters.

**3. Objective of the article** is analytical review of available aviation gravimeters.

• *Igor Korobiichuk is with Industrial Research Institute for Automation and Measurements PIAP, Jerozolimskie 202, 02-486 Warsaw, Poland*
ikorobiichuk@piap.pl

**4. Analysis of recent researches.** Great contribution to the theory and practice of land, sea and aviation gravimetric measurements was made by a number of prominent scientists-gravimetrists: V.O. Bagromyanets, Y.D. Bulanzhe, K.E. Veselov, A.M. Lozynska, A.A. Mykhaylov, S.A. Piddubnyy, Y.I. Popov, V.A. Tulin, V.V. Fedynskyy, M.Y. Heifetz and others.

Native gravimetry is closely connected with the names of such famous scientists as S.Y. Aleksandrov, A.M. Bereza, B.A. Blazhnov, G.B. Wolfson, M.P. Grushynskyy, M.P. Gusyev, S.K. Ismamkhotzhayev, A.V. Kostrov, A.A. Krasovskyy, V.A. Kuzyvanov, P.I. Lukavchenko, B.M. Malakhov, IA Maslov, I.I. Naumenko-Bondarenko, AP Nesenyuk, V.L. Panteleeva, A.P. Pellinen, L.G. Polyakov, V.A. Romanyuk, S.S. Rivkin, A.I. Soroka, L.V. Sorokin, L.P. Smirnov, V.N. Stadnichenko, A.V. Thil and others.

Important role in the development of gravitation measurements has been given to the works of foreign scientists: L. La Costa, D. Harrison, A. Graf, J. Tomody, M. Holvani and others [10-12].

In recent decades, gravimetric and gradiometric researches have been mainly carried out at the bottom of the sea, on submarines and ships.

Marine facilities are most intensively studied in such research centers as CRI "Azimuth" (St. Petersburg) under supervision of L.P. Nesenyuk, G.B. Wolfson, B.A. Blazhnov; M.Y. Zhukovskyy Air Force Academy (Moscow) under supervision of A.A. Krasovskyy, A.I. Soroka; Higher Military Aviation Engineering School (Riga) under supervision of A.A. Veselov; Minsk Polytechnic Institute under supervision of I.Z. Dzhylavdari.

Since 1958 until now the most important works [4-8 and others] in the field of aviation gravimetric measurements in the CIS have considered to be those performed under supervision of Y.I. Popov at the Institute of Physics of the Earth of the Russian Academy of Sciences with the use of greatly damped gravimeters GAL-S and V.O. Bogromyanets, and earlier under supervision of A.M. Lozinska in All-Russian Research Institute of Geophysics with the use of equipment set on the basis of GS string gravimeters; LG Polyakov at the Moscow Research Institute of Electromechanics and Automation NTUU; O.M. Bezvesilna in NTUU "KPI" with the use of equipment set on the basis of linear acceleration gyroscopic integrator and gyroscopic accelerometer (a single-ring DCG).

A lot of gravimetric studies has been conducted in the United States with various types of gravimeters (Bell BGM - 2, Bell VMIX; Autonetics VM-4G, Autonetics VM-76; Arma Lot D, Arma D4E; PIGA-16, PIGA-25, etc.) since 1958.

**5. Presentation of basic material of the article.** However, the literature contains only disembodied data related to certain types of aviation gravimeters. There is no sequential analysis of key features of aviation gravimeters. Theoretical basis and construction of the first static gravimeter with liquid damping and quartz sensing elements were developed in 1954. This instrument is considered to be SD (strongly damped) marine gravimeter with horizontal elastic string and photographic recording system. Since 1957 several types of GAL gravimeters (gravimeter of aerogravimetric laboratory) with quartz sensing elements have been developed and found practical application at the Institute of Physics of the Earth (IPE) of the AS USSR. GAL advantages: it is of a small size, has photographic recording system and is not affected by resonances.
GAL includes electro-mechanic-optical converter of useful signal, digital filter for compensation of noise impact and automated measurement results.

In 1960 gravimetric equipment complex IPE AS USSR consisted of gravimeters GAG-S or GAL-F, device RUG and gyro-stabilized system H-55 for stabilization of aerophotographic camera during aerial phototopographic survey. However, quartz aviation gravimeters GAL-S have insufficient speed and accuracy, i.e. only 6-8 mGl [4-6]. Dynamic gravimeters should be used for aviation gravimetric measurements. The advantage of dynamic instruments (pendulum, string gravimeter) in measurements consists in their inertialessness due to relatively high oscillation frequency of a pendulum and a string. These devices record measurements of gravity almost with no distortion, which is important in areas where gravitational field abruptly changes. However, further processing of dynamic instruments' records requires solution of filtering problems. Disadvantages of dynamic instruments consist in the dependence of the output signal on the device point acceleration; resonances extremely affect operation of dynamic gravimeters. Their accuracy (6-8 mGl [4-8]) and speed are insufficient.

Gravimeters with identical closed-circuit metal elastic systems are used abroad. Askania GSS-2 (Germany, 1956) is one of the most common gravimeters. Sensitive element is a weigh beam (aluminum rod), which is suspended on a horizontal twisted springs. La Costa Romberg gravimeter, to which the principle of Golitsyn's vertical seismograph is applied, is also used. It includes a greatly damped sensitive element, i.e. a horizontal rod with a weight at one end and with the other end fastened. String gravimeters MIT and VSA (USA) are as well used. Accuracy (6-8 mGl) and speed of foreign aviation gravimeters are insufficient [10-14].

Measurement of gravitation anomalies on board inflight is specific and more complex than measurements on ships:

- Instability of speed and direction shall be taken into account and, therefore, continuously recorded;

- In calculation of Eotvos correction the second term of correction formula shall not be ignored;

- Change of $\Delta g$ shall be taken into account along with a change of aircraft flight altitude;

- There are very difficult measurement conditions: gravimeter senses influence of aircraft vibration, rotation of aircraft along its longitudinal and transverse axes observed throughout the flight, in-flight bumps, etc.

- Long-period vertical accelerations shall be taken into account and eliminated.

Note: Accuracy of 1 mGl is achievable for marine gravimetric measurement, whereas such accuracy for aviation gravimetric measurement is yet problematic.

CIS used the following gravimeters for research in the field of aviation gravimetric measurements: marine gravimeter GAL-S developed under supervision of YI Popov at the Institute of Physics of the Earth RAS; string gravimeter GS developed at the All-Russian Research Institute of Geophysics under supervision of AM Lozinska (further effective researches and tests of GS were supervised by VA Bagromyanets); GAL-S developed at the Moscow Institute of Electromechanics and Automation (MIEiA) under supervision of LG Polyakov.

Studies have shown that accuracy [6-8 mGl] and speed of measurement of gravitation anomalies from aircraft are insufficient.

The results of GAL-S and GS measurements were handled after test flights for months.

Aviation gravimetric measurements conducted in the USA with vibration accelerometers Arma Lot D, Arma D4E; pendulum accelerometers VM-76 produced by Automation Division; accelerometers Bell BGM-2, VMIX; pendulum gyroscopic accelerometers PIGA-16, PIGA-25; and La Costa gravimeter have shown that accuracy of measurement error $\Delta g$ (6...8 mGl) and speed are insufficient and have proved that aviation gravimetric measurements should be made with the use of missile control system accelerometers modified to AGS conditions, for the following reasons:

- There are no fundamental differences between accelerometers of inertial navigation systems (INS) and AGS gravimeters as their purpose and operating principle are the same;

- Necessity of precise measurements requires stabilization of sensitive axes of both INS accelerometers and AGS gravimeters;

- Dynamic conditions of INS accelerometers in an aircraft, performing gravity measurement are much simpler, so if the specified accelerometers are used as AGS gravimeters, requirements should be reduced in relation to the accelerometers rather than AGS gravimeters. And it is one of the significant advantages of such solution to the problem of choice of AGS sensitive element.

Works [3, 9, 13] presents study of possibility and feasibility of using gyroscopic accelerometer as AGS gravimeter. AGS measurement error $\Delta g$ on the basis of gravimeter was [3, 9, 13] 1 mGl. OM Bezvesilna have justified the use of single-ring dynamically configurable gyroscope (DCG) as AGS gravimeter, where AGS measurement error $\Delta g$ is 1mGl.

DCGs have the following key advantages over other gyroscopic gravimeters:

- Absence of friction in the suspension point of rotor:

- Suspension stiffness approaches to zero and sensitivity and accuracy of the device increase greatly, given the dynamic setting of DCG;

- DCG has small dimensions (diameter 54x46 mm) and low weight (0.35 kg), i.e. smaller and lower than other gyroscopic gravimeters;

- DCG has output signal automatic processing, i.e. its speed is much higher than in other types of aircraft gravimeters.

Works [4, 5, 14] have proved that a gyroscopic gravimeters has much greater accuracy and speed than other gravimeters. Therefore, it is advisable to further explore possibility of using modified DCG as a gravimeter of aviation gravimetric system, since it is most advanced among other famous aviation gravimeters.

**Conclusions:**

It is shown that the most advanced aviation gravimeters are considered to be those on the basis of a dynamically configurable gyroscope, which have advantages in accuracy and dimensions as compared to other gravimeters. It has been proved that further development of aviation gravimeters is associated with creation of gyroscopic gravimeters, which, in turn, has a number of advantages in accuracy. In the future, it is advisable to study dynamic and static errors of a gyroscopic gravimeters, including on computers and experimentally. These studies will justify the feasibility of using gyroscopic gravimeters for aviation gravimetric measurements.

## REFERENCES

[1] Bezvesilna O.M.: Study of a new precision inertial navigation system at aviation gravimetric measurements: monograph. Zhytomyr: ZSTU, 2012, 476 p. [in Ukraine]

[2] Korobiichuk I., Bezvesilna O., Tkachuk A., Nowicki M., Szewczyk R., Shadura V. Aviation gravimetric system. International Journal of Scientific & Engineering Research, Volume 6, Issue 7, July-2015 p. 1122-1127.

[3] Bezvesilna O.M. Acceleration Measurements. Textbook. - Kyiv. Lybid, 2001. - 264. [in Ukrainian]

[4] Pyelpor D.S., Matveev V.S., Arsentyev V.D. Dynamically Configurable Gyroscopes: Theory and Structure. - M. Mashynostroyenie, 1998. – 264 p. [in Russian]

[5] Novikov L.Z, Shatalov M.Y. Mechanism of Dynamically Configurable Gyroscopes. M. Nauka, 1985. - 244 p. [in Russian]

[6] Veselov K.Y., Sagitov M.U. Gravitational Exploration. - M.: Nedra, 1968. - 512 p. [in Russian]

[7] Yuzefovich A.P. Gravimetry. - M.: Nedra, 1980. - 319 p. [in Russian]

[8] Shokin P.F. Gravimetry. - M.: Geodezizdat, 1960. - 316 p. [in Russian]

[9] KorobiichukI., Nowicki M., Szewczyk R. Design of the novel double-ring dynamical gravimeter. Journal of Automation, Mobile Robotics and Intelligent Systems, Industrial Research Institute for Automation and Measurements "PIAP", vol. 9, nr 3, 2015, p. 47-52.

[10] Liard, J., Gagnon, C. The new A-10 absolute gravimeter at the 2001 International Comparison of Absolute Gravimeters . Metrologia. Volume 39, Issue 5, 2002, Pages 477-483.

[11] H. Baumann, E.E. Klingel´e, I. Marson. Absolute airborne gravimetry: a feasibility study. Geophysical Prospecting, 2012, 60, 361–372.

[12] Sharapov V.M., Musyenko M.P., Sharapova E.V. Piezoelectric sensors/ pod red. V.M. Sharapov. – M.: Tehnosfera, 2006. – 632 s. [in Russian]

[13] Jentzsch, G., Schulz, R., Weise, A. A well-known principle in a new gravimeter: The automated Burris Gravity Meter . AVN Allgemeine Vermessungs-Nachrichten. Volume 122, Issue 5, 1 January 2015, Pages 168-175.

[14] Stamenkovich, Mikan, Carvil, John, Application of the Digital Nautical Chart (DNC) database to help identify areas of vertical deflection in the Ring Laser Gyro Inertial Navigator (AN/WSN-7). Record - IEEE PLANS, Position Location and Navigation Symposium 2000, Pages 299-303.