UDC 681.2

O.M. Bezvesilna, doctor of technical sciences (National Technical University of Ukraine «Igor Sikorsky Kyiv Polytechnic Institute», Ukraine, Kyiv)
A.H. Tkachuk, PhD (Zhytomyr State Technological University, Ukraine, Zhytomyr)

Gravimetr for gravimetric complexes on air- and spacecraft

The article presents and describes the new piezoelectric gravimeter of automated aviation complexes on air- and spacecraft, which has a higher accuracy (1mGal) than other types of gravimeters known to date and automated signal processing.

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) [1,2].

All kinds of modern gravimeters analyzed in [1, 3-5], which describes their design and operating principle. The speed is slow as well. They are not automated. Results are processed on Earth after flight in a time-consuming process. Besides, these gravimeters measure vertical acceleration z along with gravitational acceleration. High-accuracy measurement of z is a complex scientific and technical challenge and requires the use of additional filters.

Therefore, improvement of accuracy and speed of gravity measurement by creating a new gravimeter of automated AGS is a relevant scientific and technical challenge. The objective of the article is to describe the structure and features of a new piezoelectric gravimeter (PG) of automated aviation gravimetric system which has a higher accuracy and speed that other gravimeters known today/

A new piezoelectric gravimeter (PG) of automated aviation gravimetric system has been developed at Instrument Engineering Department of KPI under supervision of the honored master of sciences and engineering of Ukraine, Prof. Dr.-Ing. O. Bezvesilna [1, 4]. This gravimeter has an accuracy of 1 mGal. The sensitive element of PG (Fig. 1) consists of a piezoelectric element (PE) 5, which operates on the compression-stretching deformation, insulators 7 at the ends of PE and inertial mass (IM) 6. A sensitive element is elastically attached to the basis 8 by a screw 10 with purpose to increase reliability and durability of the structure. Due to cable 11 PG is connected to an operational amplifier. Piezoelectric element 5 is a multi-layer structure (piezoelectric packet) consisting of layers of crystalline lithium niobate [5-6].

Let us consider PG oscillation system that includes the following elements: MI (m), stiffening element (k) and damping element (n). Air creating resistance to motion of IM is a damping element. Stiffening element is characterized by elastic properties of PE [5].

The principle of operation and design features of this gravimeter is shown in [5].

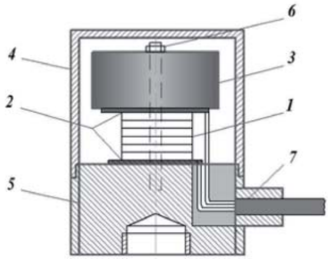

Fig.1. Structure of PG: 1 –PE; 2 – insulators; 3 – IM; 4 – basis; 5 – hermetic enclosure; 6 – screw; 7 – inlet cable

Paper [1, 5, 6, 7] presents analytical expressions of useful signal spectral densities □(ω) and vertical aircraft acceleration □(ω) and their characteristics (Fig. 2).

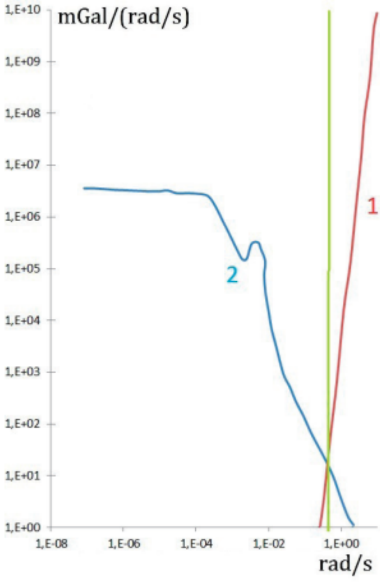

Fig. 2. Graph of useful signal spectral density (2) and vertical aircraft acceleration (1) [1]

As shown in Fig. 2, automatic pilot system significantly reduces the effects of vertical acceleration at frequencies lower than 0.1 rad/s; spectral density of vertical acceleration tends to infinity at frequencies above 0.1 rad/s. It is therefore necessary to ensure filtering process for PG output signal with frequency of 0.1 rad/s. The most common method of constructive implementation of this process in known gravimeters is to use low-pass filters with a cutoff frequency of 0.1 rad/s. However, operation of filter electronic components becomes unstable within terms of PG usage, thereby changing its cutoff frequency. Ultimately, filter lets the interference pass to PG output or doesn't let the part of signal pass at all. Therefore, low-pass filter as a separate unit of a gravimeter significantly reduces, primarily, reliability and accuracy of the device. There is a suggestion regarding PG output signal filtering technique which consists in creation of an element of a new gravimeter of automated AGS in the form of piezoelectric packet, the natural oscillation frequency ω_0 of which equals to the highest frequency of gravitational accelerations which may be measured against interference – 0.1 rad/s:

$$\omega_0 = \sqrt{S_p E_p / h_p m} = 0.1 rad/s$$

where m is weight of inertial mass; S_p, E_p and h_p are area, material modulus of elasticity and height of piezoelement, respectively.

It is low-frequency filtration with a cutoff frequency of 0.1 rad/s through which can be separated from g_z with an accuracy of 1 mGal. Besides, other components of perturbations with predominant frequency of more than 0.1 rad/s are also removed from PG output signal. These perturbations includes translational vibration acceleration with predominant frequency of 3140 rad/s; angular accelerations with predominant frequency of more than 0.1 rad/s [5–7].

Existing gravimeters measure only the gravity g_z along the vertical axis Oz, what are the components of gravity g_x and g_y along the axes Ox and Oy are equal to zero because of their small size [2]. However, to achieve the accuracy of measurement of gravity high for 1 mGal, the above components must be taken into account. For example, if g_x=g_y=0,9 mGal [4], then the module of these accelerations will be equal to:

$$|g_{xy}| = \sqrt{g_x^2 + g_y^2} = \sqrt{2 \cdot 0{,}9^2} = 1{,}27 \text{mGal}$$

As you can see, the neglect of g_x and g_y leads to the emergence of significant errors, which is unacceptable.

Improving the accuracy of measurement in three-axis low-frequency gravimeter is assured by the fact that for each measurement axis Oz and Ox, Oy, the gravity is mounted the sensing element Az, Ax, Ay, done with two channels, each with one equipped by piezoelectric elements that are identical. Inertial mass is attached to the bottom of piezoelectric element one channel and to the top of piezoelectric element of the second channel. The piezoelectric element of the first channel of each sensing element operates on the basis of tensile deformation, and the piezoelectric element of the second channel – compressing deformation.

Output electrical signals of the piezoelectric elements both channels all sensing elements are received at the inputs of operational amplifiers that, in addition to strengthen perform and function the summation of the signals from the inputs of BCOM.

In BCOM will be carried out the necessary calculations to determine the value of the full vector $\overline{g}$ and the module $|g|$ of the gravity.

So, by using three sensing elements Az, Ax, Ay it is possible to measure the complete vector of gravity $\vec{g}$: $\overrightarrow{g} = \overrightarrow{g_x} + \overrightarrow{g_y} + \overrightarrow{g_z}$ and not just one component g_z, as in the prototype.

In new sensor what is offered at each axis measurement set the sensing element is made with two channels, each with piezoelectric element 1 and 2 along the axis *Oz*, 3 and 4 along the axis O*x*, 5 and 6 on the axis *Oy*.

Conclusion

The paper considers a new piezoelectric gravimeter of automated AGS, which has higher accuracy (1 mGal) and speed (fully automated) than gravimeters known to date. It also describes the operation principle of a piezoelectric gravimeter and presents its mathematical model. It has been found that it is possible to set piezoelectric gravimeter natural frequency of rad/s and avoid the need to use low-pass filter in automated AGS due to selection of design parameters for a sensitive element of piezoelectric gravimeter. The paper analyzes the prospects for further improvement of accuracy of a new piezoelectric gravimeter by implementing the process of instrumental error compensation resulting from effects of changes in temperature, humidity and pressure of environment that are significant in extreme conditions, associated with gravimetric measurements on an aircraft

References

1.Bezvesilna O.M., *Aviation gravimetric systems and gravimeters*, Zhytomyr: ZSTU, 2007, 604 p.

2.Bezvesilna O., Tkachuk A., Chepyuk L., Nechai S., Khylchenko T. (2017). Introducing the principle of constructing an aviation gravimetric system with any type of gravimeter. *EasternEuropean Journal of Enterprise Technologies*, Vol. 1, No 7 (85), 45-56 pp.

3.Korobiichuk I., Nowicki M., Bezvesilna O., Tkachuk A. (2015). Stabilization system of aviation gravimeter. *International Journal of Scientific & Engineering Research*, №6 (8), 956-959 pp.

4.Bezvesilna O.M., Tkachuk A.H. (2013) *Piezoelectric gravimeter of aviation gravimetric system*, Zhytomyr: ZSTU, 240 p.

5.Bezvesilna O. M., Tkachuk A.H. (2012). Piezogravimeter, Ukraine. Pat. 99084.

6.Korobiichuk I., Bezvesilna O., Tkachuk A., Nowicki M., Szewczyk R. (2016). Design of piezoelectric gravimeter for automated aviation gravimetric system. *Journal of Automation, Mobile Robotics and Intelligent Systems*, Volume 10, no.1, 43-47 pp.

7.Korobiichuk I., Bezvesilna O., Tkachuk A., Nowicki M., Szewczyk R. (2016). Piezoelectric gravimeter of the aviation gravimetric system. *Advances in Intelligent Systems and Computing*, Volume 440, 753-761 pp.