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EXPERIMENTAL STUDIES ON MEASURING GRAVITY ACCELERATION WITH A BALLISTIC TRANSFORMER GRAVIMETER

The article presents information on the methodology for conducting experimental studies on measuring the acceleration of gravity using a ballistic transformer gravimeter. The composition and principle of operation of the experimental setup for research on a ballistic transformer gravimeter are considered.

An urgent scientific and technical task is to increase the accuracy and speed of measurements of the magnitude of the acceleration of gravity by applying the proposed new methodology for conducting experimental studies of BTG.

In this regard, the purpose of the article is to present the methodology for conducting experimental studies for measuring the acceleration of gravity with a new ballistic transformer gravimeter [4].

The object of the article is the process of conducting experimental studies for measuring the acceleration of gravity with a new ballistic transformer gravimeter. The subject of the article is a new methodology for conducting experimental studies of BTG.

In a ballistic transformer gravimeter, the free motion of a test body (interferometer mirror) in the Earth's gravitational field is used to determine the absolute value of the acceleration of gravity.

In order to cancel the resistance forces proportional to the speed of the test body (interferometer mirror), the symmetric movement of the interferometer mirror is implemented in the experimental gravimetric system. The measurement of its motion parameters is carried out on the ascending and descending branches of the trajectory.

To determine the absolute value of the acceleration of gravity during the movement of the test body, the path and time are measured by the interference method.

An optical quantum generator is used to measure the path, and a reference quartz oscillator is used to measure the time.

The experimental gravimetric system includes: a dynamic device; a laser interferometer; a path and time meter; a control device; a laser stabilization device; a control device; a specialized computer.

Keywords: *gravitational acceleration, ballistic transformer gravimeter, experimental research.*

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ЕКСПЕРИМЕНТАЛЬНІ ДОСЛІДЖЕННЯ ВИМІРЮВАННЯ ПРИСКОРЕННЯ ГРАВІТАЦІЇ ЗА ДОПОМОГОЮ БАЛІСТИЧНОГО ТРАНСФОРМЕРНОГО ГРАВІМЕТРА

У статті представлено інформацію про методологію проведення експериментальних досліджень з вимірювання прискорення сили тяжіння за допомогою балістичного трансформаторного гравіметра. Розглянуто склад та принцип роботи експериментальної установки для досліджень балістичного трансформаторного гравіметра.

Актуальною науково-технічною задачею є підвищення точності та швидкодії вимірювань величини прискорення сили тяжіння шляхом застосування запропонованої нової методики проведення експериментальних досліджень БТГ.

У зв'язку з цим, метою статті є викладення методики проведення експериментальних досліджень для вимірювання прискорення сили тяжіння новим балістичним трансформаторним гравіметром [4].

Об'єкт статті – процес проведення експериментальних досліджень для вимірювання прискорення сили тяжіння новим балістичним трансформаторним гравіметром.

Предмет статті - нова методика проведення експериментальних досліджень БТГ.

У балістичному трансформаторному гравіметрі для визначення абсолютного значення прискорення сили тяжіння використовується вільний рух пробного тіла (дзеркала інтерферометра) у полі сили тяжіння Землі.

З метою скасування сил опору, пропорційних швидкості руху пробного тіла (дзеркала інтерферометра), в експериментальній гравіметричній системі реалізується симетричний рух дзеркала інтерферометра. Вимірювання параметрів його руху проводиться на висхідній та низхідній гілках траєкторії.

Для визначення абсолютного значення прискорення сили тяжіння у процесі руху пробного тіла вимірюється шлях інтерференційним методом та час. Для вимірювання шляху використовуються оптичний квантовий генератор, а для вимірювання часу – опорний кварцовий генератор.

Експериментальна гравіметрична система включає у себе: прилад динамічний; інтерферометр лазерний; вимірювач шляху та часу; прилад управління; прилад стабілізації лазера; прилад контролю; обчислювач спеціалізований.

Ключові слова: *гравітаційне прискорення, балістичний трансформаторний гравіметр, експериментальні дослідження*

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General statement of the problem and its relevance

Today, ground-based absolute gravimetric measurements are the most accurate. Measuring the absolute value of the acceleration of gravity (AG) g with high accuracy is necessary for determining the shape of the Earth, correcting inertial navigation systems, assessing the shape of the Earth, predicting earthquakes, finding deep density inhomogeneities in the Earth's crust, searching for mineral deposits, etc. Gravimeters are designed to determine g. Among them, the most famous and accurate for ground-based measurements are ballistic transformer gravimeters (BTG) [1-7].

A significant contribution to the development of methods and means of gravimetric measurements was made by scientific schools formed at the Institute of Geophysics under the leadership of Academician of the National Academy of Sciences of Ukraine Starostenko V.I. (Kyiv), at the National Research Center "Institute of Metrology" (Kharkiv) under the leadership of Ph.D. Sydorenko G.S. and at the Igor Sikorsky Kyiv Polytechnic Institute under the leadership of Ph.D., Prof. Bezvesilna O.M. (Kyiv). In [1] a new ballistic transformer gravimeter of greater accuracy and speed than the known ones is presented.

However, in the literature [1-7, etc.] there is no information on the development of a methodology for experimental studies of BTG of g on Earth is a complex scientific and technical problem and requires the use of a new experimental research methodology to measure the acceleration of gravity with a new ballistic transformer gravimeter.

Therefore, an urgent scientific and technical task is to increase the accuracy and speed of measurements of the magnitude of the acceleration of gravity by applying the proposed new methodology for conducting experimental studies of BTG.

In this regard, the purpose of the article is to present a methodology for conducting experimental studies to measure the acceleration of gravity with a new ballistic transformer gravimeter [4].

Analysis of research and publications

The most famous in the field of gravimetric measurements are the works of prominent scientists Popov E.I. with strongly damped gravimeters GAL, Bagromyants V.O., and earlier - Lozynska A.M. with a complex of equipment based on string gravimeters GS and foreign scientists L. La Costa, D. Harrison, A. Graf, Y. Preston-Tomoda, M. Galvani and others.

From the analysis of the literature [1-7 and others] it is clear that the most well-known modern ground-based gravimeters have insufficient accuracy (more than 1 μGal) and speed (processing of measurement results within months). Their accuracy largely depends on the perfection of determining the measured quantities. But the presented analysis of the literature [1-7 and others] showed that there are no methods for conducting experimental studies of the AG using BTG.

Therefore, consideration of the general composition, the principle of operation of the experimental setup, and presentation of the methodology for conducting experimental studies to measure the acceleration of gravity with a ballistic transformer gravimeter [4] is an urgent task.

Presentation of the main research material

In a ballistic transformer gravimeter, the free motion of a test body (interferometer mirror) in the Earth's gravitational field is used to determine the absolute value of the acceleration of gravity.

In order to cancel the resistance forces proportional to the speed of the test body (interferometer mirror), a symmetrical motion of the interferometer mirror is implemented in the experimental gravimetric system. The parameters of its motion are measured on the ascending and descending branches of the trajectory.

To determine the absolute value of the acceleration of gravity during the movement of the test body, the path and time are measured by the interference method.

An optical quantum oscillator is used to measure the path, and a reference quartz oscillator is used to measure the time.

The AG measurement method used in the experimental gravimetric system consists of the following steps T_0 are formed with respect to the top of the trajectory of the test body and the time segments H_1 and H_2 passed by the test body during the upward and downward movement, respectively, are measured. In addition, the interval T between the beginnings of the time intervals T_0 is measured (Fig. 1.).

The value of AG is determined by the formula:

$$g = \frac{H_1 + H_2}{2TT_0},$$

where H_1 and H_2 are the paths traveled by the test body (in wavelengths of the optical quantum generator or OCG) when moving up and down; T is the time between the beginnings of the intervals T_0 in each individual measurement.

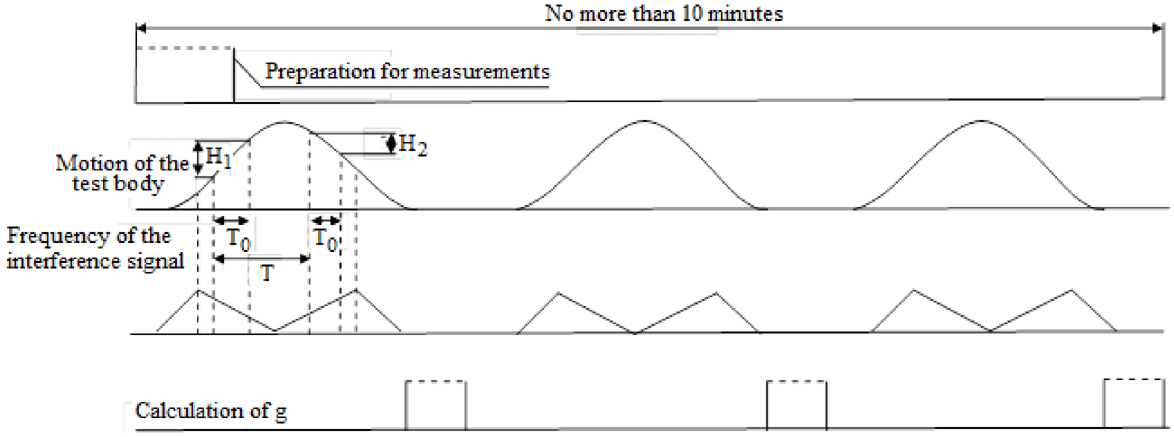

Fig. 1. BTG operation cycle diagram

The experimental gravimetric system includes: dynamic device – DD; interferometer laser– IL; distance and time meter – DTM; manages device – MD; laser stabilization device – LSD; control device – CD; specialized computer - SC.

A manages device (MD) designed to generate current pulses that control the electromagnets of the catcher and pusher of the dynamic device (DD).

A laser interferometer (LI) is designed to measure the path traveled by a test object during the measurement process.

The source of monochromatic radiation is a laser.

The path and time meter (PTM) is designed to process the electrical signal coming from the interferometer in order to obtain information about the parameters of the motion of the test body - the values of the measured path segment and the corresponding time interval. The results of path and time measurement are provided in digital form and after each measured cycle are output as a sequence of code pulses for further processing.

The dynamic device (DD) is designed to implement free movement of the test body and is a vacuum chamber, inside which the test body is located. The test body is thrown up using an electromagnet. For soft reception, a special catcher is provided, controlled by an electromagnet.

The laser stabilization device (LSD) is designed to power and automatically stabilize the frequency (wavelength) of laser radiation that is part of a laser interferometer (LI), as well as provide signals in case of malfunction of the PSD and LI.

The control device (CD) is designed to monitor the performance of the experimental gravimetric system.

The device implements automatic detection of malfunctions during operation, signaling about deviations in the supply voltage, signaling about unauthorized disconnection of connectors. The assessment of the state and quality of the experimental gravimetric system during measurements is carried out using logic level signals obtained as a result of solving test control problems in individual measurements.

The specialized computer (SC) performs the following tasks:

1) calculation of current AG values from measured path and time values;
2) calculation of average AG values;
3) selection of the required number of measurements to obtain the specified accuracy;
4) control of current AG values for the absence of gross errors;
5) issuing an indication of unreliable measurement;
6) comparison of the obtained AG values;
7) self-control in the mode of solving a control problem;
8) issuing control signals for the gravimetric system.

The gravimetric system itself is installed in the hardware department.

Preparation for the work of the BTG consists of several stages.

Before using BTG, the following operations are performed:

1) when transferring from storage mode to operating mode, the equipment was preheated for an hour;
2) an external inspection of the equipment was carried out to remove contamination from the exit windows of the IL and the dynamic device (DD);
3) twice a day (before and after work), the pressure inside the dynamic device was monitored to detect a possible leak.

When measuring the AG at individual points of the route, the working area was selected in such a way that its slope to the horizon did not exceed 5-6º.

AG measurement at route points is performed in two stages:

1) *preparation stage*, which includes performing control tasks of the DTM and SC devices, entering limit values $g_{\min}$, $g_{\max}$, as well as optical adjustment of the PLD and IL devices.

Performing control tasks to check the serviceability of the DTM and SC.

Entering values $g_{\min}$, $g_{\max}$ protects the measurement result from the possibility of gross errors.

Optical alignment of DD and IL devices, which consists in setting the vertical of the IL working beam and combining the working and reference light beams, provides a contrasting interference pattern when moving the test body;

2) AG *measurement stage at the route point.*

The operation of the experimental gravimetric system at the measurement stage is automatic and, in the case of normal operation, does not require operator intervention. The mutual arrangement in time of the main electrical operations and signals during the operation of the experimental system is illustrated in Fig. 2.

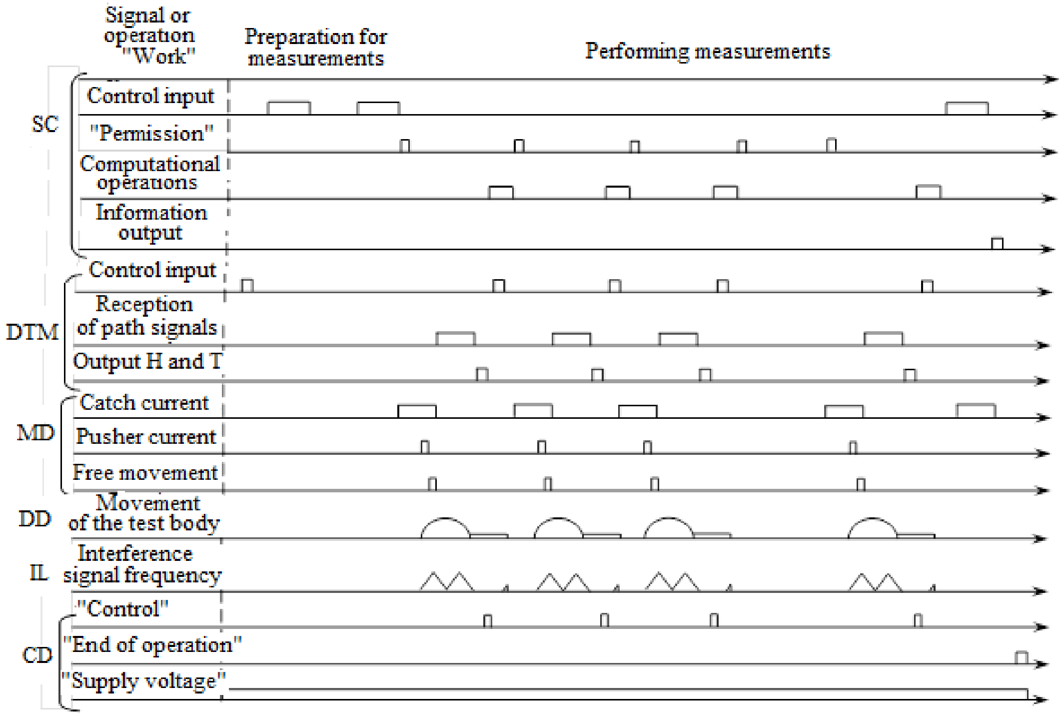

Fig. 2. Basic electrical operations and signals during system operation

Measurements were started by pressing the “Run” button on the front panel of the SC device, which led to the launch of the computer’s control task.

After the test task was completed, the obtained values were compared with the values stored in memory. If the comparison result was positive, then the SC sent a signal “Permission D” to the MD.

Upon receiving the “Permission D” signal, the MD generated current pulses that controlled the catcher and pusher of the DD device, which caused the test body to be thrown.

During the flight of the test body, a "Dynamics" signal was sent from the MD device to the CD, which caused the corresponding LED on the front panel of the CD to briefly turn off, thereby informing the operator about the toss.

The “Free movement” signal was received from the MD device on the DTM, which allowed the start of the path signal coming from the IL.

The path signal represented a sequence of pulses corresponding to interference fringes formed in the IL during the motion of the test body, the DTM device measured the values of *H* and *T*.

After the free motion of the test body was completed, the obtained values of H and T were transmitted from the DTM to SC in the form of pulses of parallel-serial binary-decimal code, accompanied by sync pulses.

Under the influence of the first of the synchronization pulses, which, in addition to SC, also arrive at the CD device, the CD generated the " DTM Control" signal, which caused the automatic launch of the DTM control task.

After receiving the information, the SC device processed it.

Having finished processing the information obtained during this toss, SC produced the "Permission D" signal, which was sent to the MD and initiated the next measurement cycle.

After completing the measurement cycles, the SC device re-started its control task.

If the control problem was solved correctly, the calculated value of g was transferred to the storage device in the form of synchronization pulses of a sequential binary-decimal code. The fidelity of the information received was controlled by its reverse transmission and comparison with the original values.

After checking the correctness of the information transfer in the storage device, the SC device generated the "End of work" signal, which was sent to the CD and illuminated the corresponding LED.

In the case of a negative result of the control of the correctness of the information transmission, the SC device transmitted a "Discrepancy" signal to the storage device.

The “End of work” signal indicated to the operator the end of this series of measurements.

Conclusions

The article presents a methodology for conducting experimental studies to measure the acceleration of gravity with a new ballistic transformer gravimeter. The general composition and principle of operation of the experimental gravimetric system for conducting experimental studies of a ballistic transformer gravimeter are considered, which ensures increased accuracy and speed of the BTG.

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