fully completed and accepted until the onset of cold weather.

Before laying the road surface in winter conditions, it is necessary to clean the surface of the area of the sidewalk or the lower layer of the pavement from the snow and ice. It is forbidden to carry out the specified work when it is snowing and blizzard, as well as when the ice begins to melt.

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DEVICE FOR POSTING THE SENSITIVITY GRAVIMETER AXIS

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Abstract

Angle measurement means are one of the advanced directions for the application of gas ring lasers. The requirements of ring lasers used in angle measurement devices are different, in many respects, from those used in navigation. A simple ring laser developed for implementation in high-precision angle measurement instruments is described. The main specifications are presented. Methods of the accelerated tests are imperfect for determining a term of storage; therefore, tests during a real storage term remain the most reliable. Operation of the ring lasers in angle measuring instruments during 20 years has demonstrated their high stability. Using the described ring laser the angle measurement means of accuracy that exceeds an accuracy of the existing National Standards for a plane angle can be developed.

Keywords: aviation gravimetric system, ring laser, gravimeter, angle measurement systems.

Stating of the problem. The basic components of aviation gravimetric system (AGS) for measuring gravity anomalies are proposed in [1]. Those are devices for measuring speed and location coordinates of the aircraft, devices for measuring the height and gravity and airborne digital computer. Gravimeter is a sensitive element of AGS that measures the gravity and the accuracy of which, basically, determines the accuracy of all AGS.

A new piezoelectric gravimeter that has greater accuracy from known aircraft gravimeters is proposed in [1, 2, 3].

The accuracy of the previous posting gravimeter sensitivity axis significantly influences on the accuracy of AGS gravimeter. Therefore for precision posting gravimeters axis proposed use laser angle measurement device [3].

Ring lasers can be used in angle measurement devices of different purposes.

A significant attention is paid to the development of goniometers. For example, in [4, 5] the designs of goniometers as well as test results are described. In [6] a specialized goniometer used in workshop conditions for the measurement of polygons angles is described. In [5] the first commercial automatic angle measurement system (goniometer-spectrometer) GS1L is described. The system is designed for the measurement of plane angles and pyramidality of the prism faces as well as refractive index of optical media. This system is produced in lots and widely used at many plants and metrological centers. With using a ring laser for such instruments as devices for the measurement of involutes profiles of tooth spiral of gear wheels [6] and a device for reproducing of linear accelerations are developed.

On the basis of ring lasers it is also possible to develop automatic devices for the measurement of shaft rotation angles, devices for checking the angle parameters of limbs, modulators, circular optical encoders and other angle structures, as well as devices for determining the angles between marks, stars, geodesic and astronomical devices, laser location devices and others. The advantages of ring laser implementation in the systems for stabilization of rotation rate [5] are shown experimentally.

The ring lasers designed for navigation were used in the first angle measurement devices.

In connection with the specificity of the application of ring lasers for angle measurement systems and because of serial production of angle measurement means on their basis, the ring laser has been specially designed for angle measurement devices.

Scientific research analysis. Studies have shown that a great contribution to the theory and practice of gravimetric measurements in CIS was made by a wide range of prominent scientists such as V.O. Bagromianets, A.M. Lozynska, V.V. Fedinskyi, N.P. Grushynskyi, E.I. Popov and others. Foreign scientists made a great contributions too, among which A. Graf, V. Torge, M. Golvani, D. Garrison.

Various types of gyroscopic gravimeters have been researched by O. M. Bezvesilna, a well-known, Honored Scientist and Engineer of Ukraine, Doctor of Science, Professor.

The development of the piezoelectric transducers theory is related to the names and scientific works of A.A. Andreeva, A.E. Kolesnikova, N.A. Shulgy, V.V. Lavrinenko, S.I. Pugachyova, V.V. Malova, P.O. Gribovskoho, V.M. Sharapova and others.

Outline of the main idea.

Most gas ring lasers are used in military and civil navigation systems. The requirements of these ring lasers are high. For example, they must have a minimal lock-in zone, a special frequency separation unit for low angular rate measurements; they also must provide the operation in a wide temperature range, in conditions of shocks, vibrations, radiation exposure, etc. The most important characteristic of the ring laser is scale factor stability during a long period of time. There are rigid weight and dimension restrictions for such devices. Therefore, the ring lasers used in navigation systems are costly.

The requirements of parameters of ring lasers used in industrial angle measurement means are different in many aspects. Generally, such devices operate in a narrow temperature range. They are not exposed to vibrations and shocks during the measurement process. Generally, they don't require a frequency separation unit. The implementation of self-calibration method [6] in angle measurement devices such as goniometers allows decreasing considerably the requirements for a long-term stability of the ring laser scale factor. For most applications, the requirements of minimum dimensions and weight are not the basic ones. Therefore, a design of such lasers is simpler and they are cheaper. Furthermore, their cost falls due to decrease of tests number.

At the same time, additional requirements are imposed to such lasers. For example, in many cases such expensive, high-precision angle measurement devices operate for several decades. Therefore, the ring lasers implemented must have a service life of the order of 20 - 30 years. An operating life must be from several thousand to tens of thousands of hours. To obtain a high precision the ring laser must have a high angular resolution.

For angle measurement devices of different purposes several types of the ring lasers have to be developed. There are three groups of angle measurement means, which need special ring lasers.

The highest accuracy installations including National standards are concerned with the first group of the angle measurement means. As a rule it is stationary equipment without rigid requirements for dimensions of the ring lasers comprising this equipment.

Workshop's angle measurement means is concerned with the second group. These are portable devices, in which ring lasers weight and dimensions must be limited.

Compact mobile devices are concerned with the third group of angle measurement means. For these devices, there are rigid limitations on dimensions and weight of the subsystems including the ring lasers. Their precision is lower than that of the first and second groups.

During investigations, the ring laser perimeter stabilization system-and radiation power stabilization system were used.

The perimeter stabilization system is an extreme one. A modulating signal of 11 kHz frequency is fed to the piezoelectric transducer mounted together with the mirror. A sign and value of discrepancy with respect to a Doppler curve are determined by means of a phase

detector to which the information and modulating signals are fed and then a direct voltage, displacing an operating point to the top of this curve, is applied to the piezoelectric transducer.

The radiation power stabilization system is based on the principle of comparison of the electric signal received from the photodetector (to which one of the ring laser beams is fed) with a reference voltage. Accordingly, the pumping current of the ring laser is controlled during the discrepancy.

On the basis of information signals of the ring laser, the output pulses with a discrete quantization of 180 electrical degrees are generated. Then the counters count up these pulses.

The estimations of the scale factor and zero shift of the output characteristic have been carried out in the following way. The ring laser under check together with the electronic units for setting of operating modes was mounted on a rotary table rotating clockwise and counterclockwise alternatively.

A turn of the rotary table through the angle 2π was registered by a stationary slit photoelectric autocollimator with a focal length of 1000 mm and a mirror reflector mounted on the moving part of the rotary table.

The measurements were carried out in cycles during which after acceleration of rotary table determined was a number of periods of the ring laser signal every 5 revolutions while rotating clockwise and counterclockwise respectively. For one revolution of the ring laser through the angle 2π counterclockwise, a number of periods at the output is obtained as follows:

$$N_+ = KWt_+ + KWt_E \sin Yt_+ + F_0 t_+, \qquad (1)$$

and at rotation of the ring laser clockwise:

$$N_- = KWt_- - KWt_E \sin Yt_- - F_0 t_-, \qquad (2)$$

where K is the scale factor of the ring laser; W, W_E are the angular rates of the rotary table and the Earth rate respectively; t_+, t_- are the time periods of revolution of the rotary table through the angle 2π when rotated counterclockwise and clockwise respectively; Y is a geographical latitude at which the measurements are carried out; F_0 is the zero shift frequency of the ring laser output characteristic. The measurements were carried out at the rotation of the rotary table with an angular rate W= 90 degrees/sec, latitude of measurement Y = 50 degree and 27 arc min, $t_+ = t_- = t = 4s$. The scale factor determination error depends on an accuracy of the photoelectric autocallimator, instability of rotary table angular rate, quantization of the ring laser signal, etc. To improve accuracy, an average value of periods number of the ring laser signal $\overline{N}_+$ for 5 measuring revolutions of the rotary table at rotation counterclockwise (first measurement subcycle) and then $\overline{N}_-$ for the same number of measuring revolutions at rotation clockwise (second measurement subcycle) was calculated. Two measurement subcycles formed one measurement cycle.

The average values N+ and N- for each of 50 measurement subcycles are given in Fig. 1.

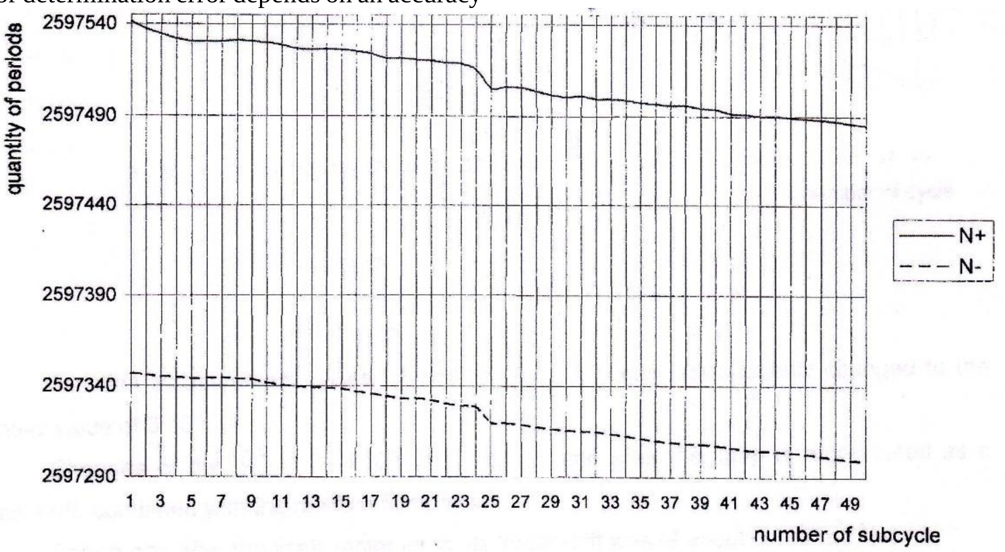

Fig.1. The average values of $\overline{N}_+$ *and* $\overline{N}_-$

The scale factor of the ring laser for each measurement cycle was estimated by the formula:

$$K = \frac{\overline{N}_+ + \overline{N}_-}{4\pi}. \quad (3)$$

Figure 2 shows the scale factor for each of 50 measurement cycles.

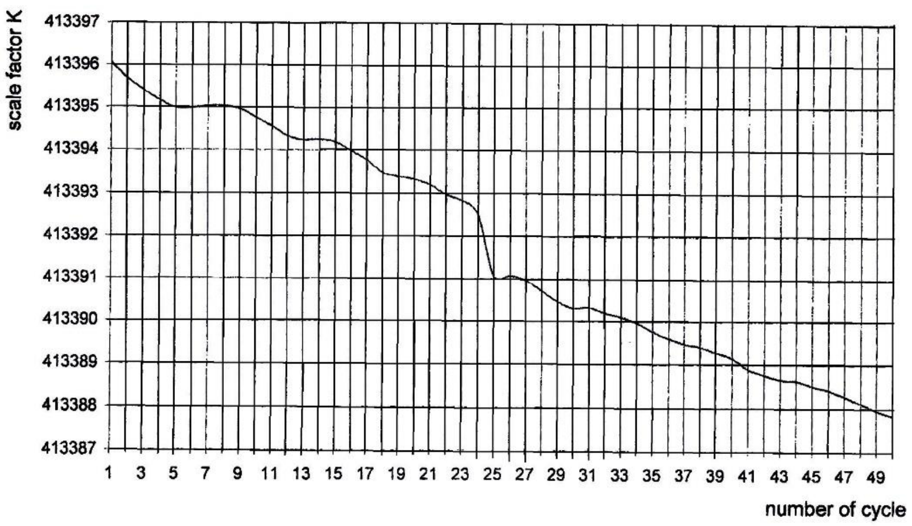

Fig. 2. Scale factor jump

Between measurement cycles 24 and 25. a scale factor has suddenly changed to the relative value of $3 \cdot 10^{-6}$. Changes of the ring laser scale factor before and after the jump is represented as a linear drift, combined with the random fluctuations.

Before and after the scale factor jump, its linear drift was of about 0,002 rad^{-1} /sec.

To improve angle measurement accuracy, the angular rate of the rotary table can be increased; cumulative processing of several measurement cycles allows for the estimation of the scale factor drift and by means of corresponding calculations for decreasing a component of the error, caused by this drift.

Difference

$$\Delta N = \overline{N}_{+} - \overline{N}_{-} = 2KW_E \sin Yt + 2F_0 t \qquad (4)$$

represents a zero shift of the ring laser output characteristic.

Figure 3 shows ΔN for 50 measurement cycles.

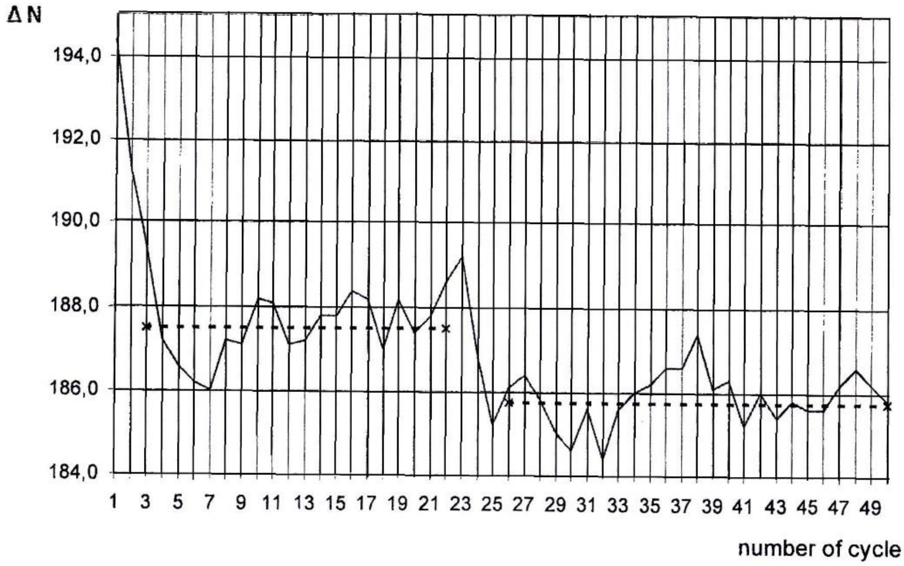

Fig.3. Difference between average values of two subcycles making one measurement cycle.

With the except of a transient process at the beginning of measurements (cycles 1,2) and one cycle before and one cycle after jump, the average value ΔN of cycles from 3 to 22 is 187,51 and that of cycles from 26 to 50 is 185,74. Thus the changes of ring laser parameters between measurement cycles 24 and 25 result in a change of both a scale factor and a zero shift of the output characteristic.

Frequency of the zero shift of the output characteristic was estimated as:

$$F_0 = \frac{(\overline{N}_{+} - \overline{N}_{-}) - 2KW_E t \cdot \sin Y}{2t}. \qquad (5)$$

The average value of zero shift for cycles from 3 to 22 was F_0 = 0,34 Hz; and that for cycles from 26 to 50 was F_0 = 0,12 Hz. Such frequency of a zero shift is lower considerably than a frequency caused by the Earth angular rate. Estimation of the operating stability at clockwise and counterclockwise rotation was carried out by calculating the rms-deviation of the number of periods for 5 revolutions in each measurement subcycle. Figure 4 shows the rms-deviation at rotation counterclockwise (continuous line) and clockwise (dotted line).

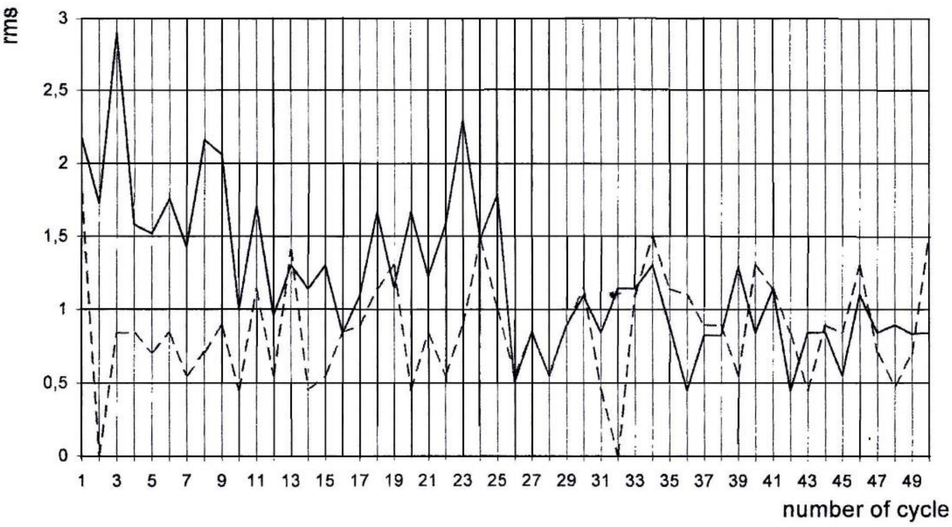

Fig. 4. RMS-deviation for each of measurement subcycles

Before the scale factor jump, the rms-deviation at rotation counterclockwise is higher than that at rotation clockwise, however after this jump the rms-deviations at rotation counterclockwise and clockwise are identical. It proves that after the scale factor jump the cavity readjustment occurred.

Estimation of the rms-deviation in the case of the bi-directional rotation can be used for the check of ring laser operation.

The accuracy of angle measurements when using angle measurement means on the basis of a ring laser is determined by many factors resulting from the parameters of subsystems of such devices. For example, for the goniometer, it is the instability of rotary table angular rate, the registration inaccuracy of the beginning and end of readout of the angle under check, quantization of the information signal, etc [5].

The ring laser introduces into a common angle measurement error its own error components caused by a nonlinearity and zero shift of the output characteristic, instability of the scale factor, signal-to-noise ratio of information signal, etc.

The error caused by a nonlinearity of its output characteristic is easily reduced when operating in a dynamic mode at an increased angular rate. A zero shift of the output characteristic is decreased due to a design of the ring laser used and its subsystems as well as due to a current balance at the shoulders of the ring laser supply.

The angle measurements using the GS1L system are carried out at the angular rate of 90 degrees/sec. A self-calibration method is used, i.e. for one full revolution of the ring laser the angle period value of the information signal is determined and then on the basis of this value the measured angles are calculated. Therefore, the scale factor stability must be provided for a time period of 4 sec. This fact considerably decreases the requirements for a long-term stability of a scale factor.

Measurements are carried out at the bi-directional rotation. Scale factor jump during the measurements results in the increase of an error. Thus, the reliable check systems for the device subsystems including those for the ring laser are required to perform the measurements.

For this purpose, a difference of the same angles, measured at rotation in both directions is calculated. If the difference exceeds the allowable value the measurement is considered to be nonreliable and excluded from the further processing. Such check is simple in use and effective. It allows registering not only the degradation of the device subsystem parameters but also to supervise the external influences, for example, inadmissible vibrations of the floor on which the device is installed, random shock influences, etc.

Estimation of angle measurement error on the GS1L system was carried out by comparison of the polygons measurement results. The measurements were conducted in Slovakian Institute for Metrology (SMU, Bratislava, Slovakia) on the GS1L system using special methods and Physical Technical Institute (PTB, Braunschweig, Germany) on angle measurement laboratory set of PTB. The comparisons have demonstrated that a difference of the measured polygon angles doesn't exceed ± 0,08 arc. sec.

Angle measurement accuracy of GS1L system is limited not by ring laser parameters but the influences of other subsystems.

With GS1L system on the basis of the ring laser the National Standard for a plane angle of Slovak republic has been introduced.

One of the most important problems in the development of angle measurement means is the serviceability of the ring laser during a long storage term.

A storage term of the ring laser is determined by gassing and gettering of getters, monoblock material, cathode, anodes, degree of cavities clearing, presence of microcracks, and so on.

Moreover, the ring laser operation is determined by the quality of mirrors and their stability, stability of parameters of the piezoelectric transducer, mixing optics, photodetectors, etc. When manufacturing the ring laser the operation of design components (mirrors, cathode, getters and so on) as well as the entire design should be predicted. There are several methods of accelerated tests (for example, radiation, thermocyclic) that give us certain information about the laser operation during a storage term, but these methods have a low degree of authenticity. The most reliable tests are those conducted at a natural course of time.

The operation of 5 ring lasers 3.970.029 for different GS1L systems has being evaluated for the period of 20 years. The checked ring lasers were in operation from 1200 till 4500 hours and did not change their parameters. The tests on determining of a storage term are continuing.

Conclusions

The additional theoretical and experimental investigations have shown that on the basis of the described ring laser featuring a simple design and low cost the goniometers with an accuracy exceeding the accuracy of the existing National Standards for a plane angle can be developed.

Further increase of angle measurement accuracy by using the described ring laser can be achieved first of all due to the improvement of subsystem parameters of an angle measurement device, and due to application of more perfect electronic circuits for perimeter and radiation power stabilization as well as corresponding information processing with taking into account an estimation of the scale factor drift of the ring laser.

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