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The goniometer on laser gyro base

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Abstract — The scheme of goniometer on laser gyro base and its operation algorithms are presented. Mathematical model for an angle measurement error is also presented. The analysis of measurement error components has been carried out. We paid special attention to the effect of the Earth's angular rate on the angle measurement error and showed the ways for reduction of this component of the error. International comparisons results are presented as wed.

Index Terms— goniometer, laser gyro, mathematical model, angle measurement.

1 Introduction

With a help of a laser gyro such instruments as goniometers, devices for measurement of the glass refractive index, geodesic and astronomical angle measuring devices and other can be developed [1-2]. The utilization of laser gyro in angle measuring instruments allows to increase the accuracy, reliability and measurement reproducibility, to decrease the time of measurements, to automate the process of angle measurements [3-6].

The first experimental goniometer on laser gyro (LG) base was designed at the D.I. Mendeleyev Institute for Metrology (St. Petersburg, Russia). The first commercial angle measuring instrument on LG base was produced in the early 1980s by the Arsenal plant (Kiev, Ukraine). It is the goniometer-spectrometer GS1L that is being produced on commercial basis and exploited at many plants in Ukraine and abroad. The commercial laser goniometer system EUP-1L is designed by the St. Petersburg Etectrotechnical University

The simplified scheme of the goniometer on LG base is given in the figure 1. On rotating device 1 are mounted: object table 2, prism 3 under check, the angles of which are to be measured, laser gyro 4. Rotating device 1 rotates with a constant speed with the aid of electric motor 5 controlled by electric drive unit 6. Close to table 2 mounted is photoelectrical slit autocollimator 7. During rotation of rotating device 1 with prism 3 the electrical pulses are received from each face of the prism at the autocollimator output. From the base face tie unit 8 the signal of selection of the first prism face is received. With the aid of this signal the control unit 9 selects the autocollimator pulse from the first face of prism 3. This pulse actuates pulse counter 11 which begins counting the number of signal periods of laser gyro 4. The counter 11 is stopped by autocollimator 7 pulse received from the second prism face and finishes counting the number of signal periods of laser gyro 4 while the counter 12 begins counting. With coming of autocollimator 7 pulse from the next prism 3 face, one counter turns on while another turns off. The information from counters 11 and 12 is transmitted to computer 14 with the aid of communication device 13.

Thus the numbers received by computer within one full turn of rotating device 1 are as follows:

from counter 11:

$$N_1 = \int_{t_1}^{t_2} f_{out}(t)dt,$$

$$N_3 = N_1 + \int_{t_3}^{t_4} f_{out}(t)dt,$$

...

$$N_{n-1} = N_{n-3} + \int_{t_{n-1}}^{t_n} f_{out}(t)dt,$$

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from counter 12:

$$N_2 = \int_{t_2}^{t_3} f_{out}(t)dt,$$

$$N_4 = N_2 + \int_{t_4}^{t_5} f_{out}(t)dt, \qquad (1)$$

$$\ldots$$

$$N_n = N_{n-2} + \int_{t_n}^{t_{n+1}} f_{out}(t)dt,$$

where t_1, t_2, t_3,..., t_n, t_{n+1} is the time of autocollimator pulse coming from the first, second, third, etc. prism faces and then again from the first prism face; $f_{out}(t)$ is the frequency at the output of laser gyro; n is the number of faces of the prism under check.

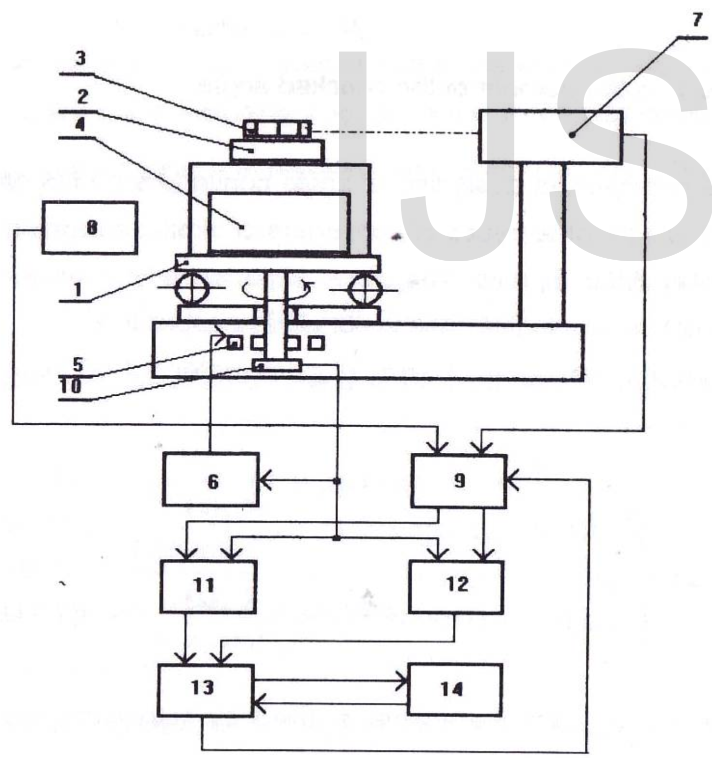

Fig. 1 The scheme of goniometer on laser gyro base

The checked angles are calculated by the computer from a formula:

$$\varphi_i = 2\pi \frac{N_{i-1} + N_i}{N_{n-1} + N_n} = 2\pi \frac{N_\varphi}{N_{2\pi}},$$

$$N_{i-1} = 0 \text{ when } i = 1, \qquad (2)$$

where i is the number of the checked angle.

As the principals of designing of angle converters on LG base considerably differ than that of principals for other types of converters of similar assigning, the sources of their errors is considerably differ as well. Therefore, experience of evaluation of the error for conventional angle converters in this case is not always applicable.

The angle measurement error of goniometer on LG base can be presented by the equation:

$$\Delta\varphi = 2\pi \frac{\int_{1}^{\varphi}\left[K(t)\omega_{LG}(t)\cos\alpha(t) + \frac{K_{-1}(t)}{\omega_{LG}(t)\cos\alpha(t)} + f_0(t)\right]dt + N_{q1}}{\int_{1}^{2\pi}\left[K(t)\omega_{LG}(t)\cos\alpha(t) + \frac{K_{-1}(t)}{\omega_{LG}(t)\cos\alpha(t)} + f_0(t)\right]dt + N_{q2}} + \Delta\varphi_{cal} - \varphi, \qquad (3)$$

where t1, tφ, t2π, are the moments (fixed by autocollimator) of the beginning of measurement, turning to the checked angle φ<p and the angle 2π respectively; *K(t)* is the laser gyro scale factor; ω_{LG} is an angular rate of rotating device turn; α(t) is the angle between rotation axis and sensitivity axis of laser gyro; $K_{-1}(t)$, $f_0(t)$ is the nonlinearity and zero bias of laser gyro output characteristic respectively; N_{q1}, N_{q2} is the noise and quantization discreteness of laser gyro signal; $\Delta\varphi_{cal}$ is the calculation error; φ is the real angle value.

Evaluation of $\Delta\varphi$ in according to formula (3) in general is a very complicated mathematical assignment.

To solve the practical tasks it is necessary to use the characteristics of specific types of the rotating device, autocollimator, laser gyro and other subsystems that are used in goniometers. This considerably simplifies a problem statement.

Time of beginning (or termination) of an angle reading can be written as a random value:

$$t = t_0 + t_{\det} + t_\xi, \qquad (4)$$

where t_0 is the exact time of forming of pulses for counters' control; $t_{\det}$, t_ξ are determinated and random components of the error respectively.

As a LG is an angular rate transducer in inertial space, the entire instrument is exposed to various types of the angular rates including angular rates of rotating device

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($\overline{\omega}(t)$), the Earth ($\overline{\omega}_e$) and the base of rotating device in relation to the Earth ($\overline{\omega}_{bas}(t)$). Thus a LG is exposed to the angular rate:

$$\overline{\omega}_{LG}(t) = \overline{\omega}(t) + \overline{\omega}_e + \overline{\omega}_{bas}(t). \quad (5)$$

In its turn, the angular rate of rotating device in general can be represented by the formula

$$\overline{\omega}(t) = \overline{c}\left[\omega_0 + \omega_1 t + \omega_{\det}(t) + \omega_\xi(t) + \omega_\xi\right], \quad (6)$$

where c is the unit vector; ω_0 is the constant component of the angular rate; ω_1 is the coefficient of linear drift; $\omega_{\det}(t)$ is the determinated component of angular rate (for instance, sine wave oscillations); $\omega_\xi(t)$ is the random component of angular rate (random process); ω_ξ is the variation of angular rate each time the device goes operational (random value).

Angle between rotation axis and sensitivity axis of laser gyro can be represented by the formula:

$$\alpha(t) = \alpha_0 + \alpha_\xi(t), \quad (7)$$

where α0 is the constant component; $\alpha_\xi(t)$ is the stationary Gaussian process with mathematical expectation $M\left[\alpha_\xi(t)\right] = 0$ and variance $D\left[\alpha_\xi(t)\right] = \sigma_\alpha^2$.

Studies of drift parameters of LG output characteristic showed that in case they are applied in specific conditions (short time of measurement, the implementation of self-calibration method, absence of external effects with sharp variations of parameters and so on) the scale factor can be described by the formula:

$$K(t) = K_0 + K_2 \cdot t + K_\xi(t), \quad (8)$$

where K0 is the constant component of scale factor; K_2 is the Gaussian random value; $K_\xi(t)$ is the stationary Gaussian process with mathematical expectation $M\left[K_\xi(t)\right] = 0$ and variance $D\left[K_\xi(t)\right] = \sigma_K^2$.

The parameters that determine nonlinearity and zero bias of LG output characteristic can be accepted as constant within the time of measurement:

$$K_{-1}(t) = K_{-1}; \; f_0(t) = f_0. \quad (9)$$

Considering concrete values of (4), (5), (6), (7), (8) and (9) the equation (3) can be solved by numerical methods on PC.

Conclusion

Implementation of laser gyros in angle measuring instruments allows to increase the accuracy, reliability, and measurement reproducibility, to considerably decrease the time of measurements, to automate the process of angle measurement. Studies of drift parameters of laser gyros output characteristic showed that in case they are applied in specific conditions (short time of measurement, the implementation of self-calibration method, absence of external effects with sharp variations of parameters and so on) the scale factor can be described by the obtained formula.

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