UDC 629.735.018.7: 681.325.53 (045)

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ESTIMATION OF ACCURACY CHARACTERISTICS OF ONBOARD VERTICAL METERS BASED ON PHOTOPOLARIMETRIC METHOD

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This work is devoted to the development and description of the method of estimating the accuracy characteristics of onboard vertical meters, which is based on the photopolarimetric registration of aircraft rotation angles along the longitudinal axis.

Keywords: Vertical Meter, photopolarimeter, ferrimagnetic crystal, roll angle.

Introduction. Aircraft flight tests of the last generation aircraft revealed acute problem of estimating the navigation equipment, which measures the position of aircraft relative to the vertical line, i. e. determines the pitch and roll angles. This is because the accuracy of the estimated aircraft system is comparable, or even superior to the accuracy of estimating equipment [1]. For example, modern inertial navigation systems can determine the angular position of the aircraft in space with an error lower than 3 – 5 angular minutes. To estimate these systems even photogrammetry methods, based on the comparison of the angular parameters recorded onboard the aircraft, with those obtained during photographing objects with known coordinates, are not precise enough. In addition, the complexity and long-term processing of flight tests results, the need of topogeodetic support and high requirements for weather conditions during testing impede application of photogrammetry for the continuous and high accurate estimation of onboard aircraft navigation equipment.

One of the solutions in this situation is the development of indirect estimation methods of certain navigation parameters through the estimation of other parameters measured with high accuracy. They allow determining estimated measurers' errors with minimum cost without external measurement facilities [2]. However, to estimate the modern onboard navigation equipment precise facilities are to be used, according to indications of estimating tested systems' characteristics. These methods use complicated mathematical apparatus, which impedes their usage.

Description. In this paper we propose a new method of estimating onboard aircraft navigation equipment based on a photopolarimeter described in [3; 4]. In [5] the use of this photopolarimeter in case when the optical beam along its way passes through depolarizing and scattering turbid medium is described. To measure rotation angles this photopolarimeter uses a dependence of intensity of the light transmitted through the analyzer to the angle of its rotation with respect to preferred direction. A feature of this photopolarimeter is magneto-optical modulator based on Faraday effect with optically transparent ferrimagnetic crystal used as an active element. In such crystals the polarization plane rotation reaches 100º at relatively low magnetic fields of 80 A/m, thus increasing the sensitivity and accuracy. It was noted that because of a large polarization plane rotation angle in ferrimagnetic crystals the photopolarimeter sensitivity is not significantly reduced while using low quality optical channels, that becomes important when it is used in industrial and real conditions. Photopolarimeter described in [3; 4] measures the polarization plane rotation angle with accuracy up to 0,0002º.

Block diagram of photopolarimetric aircraft roll meter is shown in fig. 1. The proposed meter consists of two units: one is on the ground, and the second is set onboard the aircraft. The light from the source 1, passing polarizer 2, magneto-optical modulator 3 and analyzer 7, gets to the photodetector 8, where it is converted into electrical signal. Polarizer 2 and analyzer 7 are adjusted beforehand so the signal disappears at photodetector output 8. When the optical channel is ideal, polarizer and analyzer are perpendicular to each other. Analyzer 7 is fixed at the plane housing and rotates synchronously with the aircraft. The setting should be performed before each test, because when environment changes the balance of the optical system will be disturbed.

For full estimation of the onboard navigation equipment accuracy characteristics should make registration of roll angles with system sensing unit in standard position and rotated on 90º. In the first case roll angles measured by aircraft onboard navigation equipment will be estimated, and in the second – pitch angles measuring.

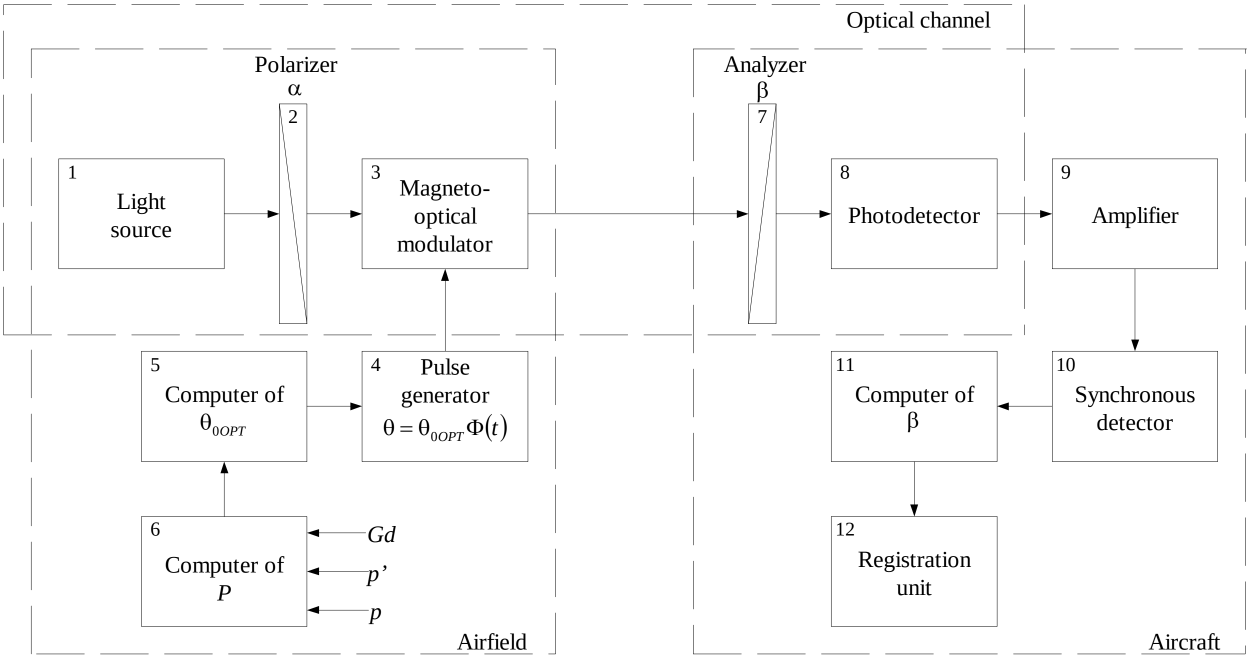

Fig. 1. Block diagram of the photopolarimetric aircraft roll angles meter

In [3 – 5] the calculation of such optical channel is provided (see fig. 1). Light intensity at the channel output is:

$$I = \frac{I_0}{4}(1-R)^2 e^{-\gamma} \times \left[(k_1+k_2)^2 + (k_1-k_2)^2 \, pp'\cos 2(\alpha-\beta+\theta) \right] =$$

$$= \frac{I_0}{4}(1-R)^2 e^{-\gamma} (k_1+k_2)^2 \left[1 - P\cos 2\theta + 2\Delta P \sin 2\theta \right],$$

where I_0 is the light beam intensity at the system input; R, γ are the reflection and absorption of light by environment respectively; k_1, k_2 are principal transmittances of polarizing prisms; p is the polarization degree of light in the environment; p' is the polarization degree of light in the modulator; α is the azimuth of the analyzer maximum transmittance plane; β is the azimuth of the polarizer maximum transmittance plane; θ is the angular amplitude of polarization plane vibrations, changing according to the periodic law: $\theta = \theta_0 \Phi(t)$, where Φ($t$) is the arbitrary periodic function, which is varied in time with frequency Ω; $P = (1-2Gd)^2 \, pp'$ is the polarization degree of the light in the optical channel [6]; $Gd = \frac{k_2}{k_1+k_2}$ is polarizing defect of prism.

In this case, the polarizer and analyzer are set perpendicular to each other up to a system sensitivity Δ:

$$\alpha - \beta = \frac{\pi}{2} + \Delta .$$

Error depends on the accuracy of the described optical system, which in turn is connected to a signal-to-noise ratio on the photodetector output, which has the form [3 – 5]:

$$\frac{S}{N}=\frac{U_S^2}{U_{TH}^2+U_{SH}^2}=A_1\left(k_1+k_2\right)^2\Delta^2\times\frac{4P^2\sin^2 2\theta}{\dfrac{U_{TH}^2}{A_2\left(k_1+k_2\right)^2}+1-P\cos 2\theta},$$

where U_S, U_T, U_{SH} are, voltages generated by signal, thermal and shot noises, respectively; A_1, A_2 are constants depending on the properties of the photodetector.

The basis of described method of measuring aircraft roll angles is selecting the maximum signal-to-noise ratio [3; 4]. In [6] it was noted that the use of the parameter P in the calculations would help to provide complete analysis of the system and the results obtained, as this parameter depends on the properties of the optical elements and the environment, i. e. the properties of the optical channel as a whole. Thus, the use of the parameter P will consider the influence of the environment (weather conditions) in the light beam propagation path, increasing the accuracy of measuring aircraft roll angles. In addition, the pre-calculation of the polarization degree of the optical channel allows operating at optimum modulation signals amplitude, i. e. with maximum signal-to-noise ratio. During a strong deterioration of the optical channel the maximum value of the signal-to-noise ratio decreased insignificantly (fig. 2). Thus, working at the points where the signal-to-noise ratio is maximum, can improve the accuracy and sensitivity when working with low-quality optical channels, i. e. in bad weather conditions (fog, dust, etc.).

Receiving the parameters of polarizing prisms *Gd*, modulator *p’* and the environment *p*, computer 5 determines the polarization degree of optical channel *P*. According to unit 5 data, computer 6 calculates the optimal amplitude of control modulation signals applied to modulator 3 by pulse generator 4.

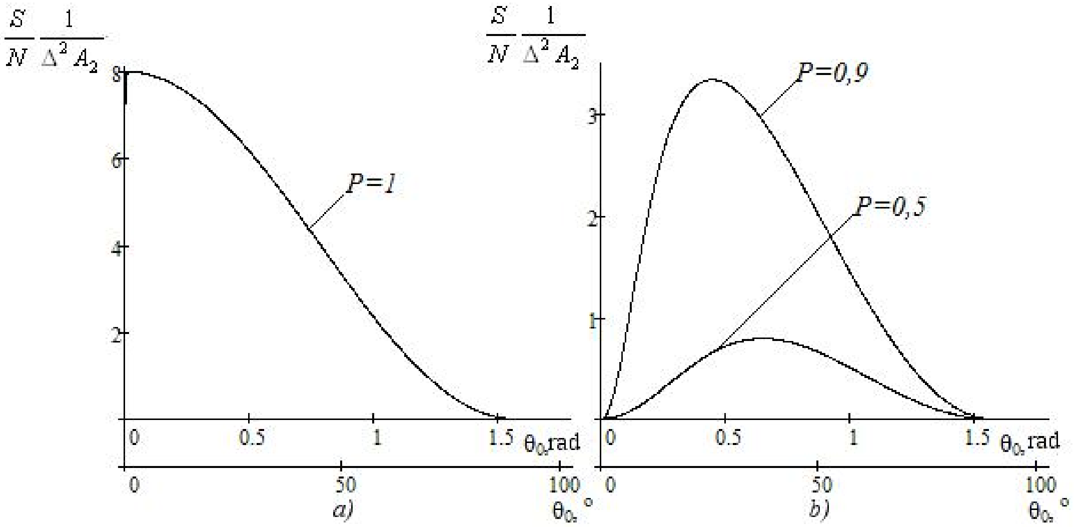

Fig. 2. Dependence of the signal-to-noise ratio of the squarewave modulation signals amplitude: *a*) non-scattering and non-depolarizing media; *b*) scattering and depolarizing medium with a polarizing degree P = 0,9 and P = 0,5

When aircraft rotates along longitudinal axis at the photodetector output 8 signal appears, depending on the roll angle. This signal is fed into the computer 11, where is then processed. The resulting roll angle enters the registration unit 12, where it is recorded for further estimation.

It should be noted that elements of the measurer optical channel 1 – 8 should be situated on one line. It is possible when aircraft is landing, when the beam from light source 1 is directed along the glideslope to analyzer 7, situated onboard. However, it is almost impossible to achieve, because aircraft approach speed is very high, that is why the light beam incident angle on the analyzer will change.

Analysis of polarization device for measuring the azimuth angles errors caused by the mutual displacements and slopes of polarization elements is given in [8]. Therefore it is necessary to evaluate the effect of the incidence angle varying on the measuring accuracy of aircraft roll angles, what will be done in future studies.

Conclusions.

1. The described photopolarimetric method allows us to register the deviation of aircraft roll angles directly and accurately, which can be used for estimating accuracy characteristics of onboard vertical meters.
2. The magneto-optical modulator with optically transparent ferrimagnetic crystal by large polarization plane rotation allows working even with low-quality optical channel, i. e. under bad weather conditions, expanding the application field of the method.
3. The polarization degree of the optical channel P precalculation and its use in the computation will consider the changes in meteorological conditions during each phase of flight testing.
4. This method allows measuring at the maximum signal-to-noise ratio, thus increasing the accuracy and sensitivity of aircraft roll angles detection.
5. The disadvantage of the method is having additional units onboard the aircraft, as well as the restriction or limitation of the method to the airfield.

References

1. *Рогожин В. А.* Оценка точностных характеристик измерителей вертикали на этапе летных испытаний с помощью спутниковой системы навигации / В. А. Рогожин, Ю. А. Друк, Т. И Лукинова // Електроніка та системи управління, К., – № 2 (8), 2006. – С. 8–10.
   [*Rogozhin V. A.* Evaluation of accuracy characteristics of vertical meters during flight tests using a satellite navigation system / V. A. Rogozhin, Yu. A. Druk, T. I. Lukinova // Elektronica ta systemy upravlinnya, K., – No 2 (8), 2006. – P. 8–10] (in Russian).
2. *Филяшкин Н. К.* Использование косвенных методов измерений при оценке точностных характеристик измерителей вертикали на этапе летных испытаний / Н. К. Филяшкин, В. А. Рогожин // Електроніка та системи управління, К., – № 2 (28), 2011 – С. 39–45.
   [*Filyashkin N. K.* The use of indirect methods of measurement during evaluation of accuracy characteristics of vertical meters during flight tests / N. K. Filyashkin, V. A. Rogozhin // Elektronica ta systemy upravlinnya, K., – No 2 (28), 2011 – P. 39–45] (in Russian).
3. *Ванюрихин А. И.* Регистрация угла плоскости колебания линейно поляризованного инфракрасного излучения / А. И. Ванюрихин, Ю. А. Кузнецов, В. Ф. Майстренко, В. Д. Тронько // Оптико-механическая промышленность – № 8, 1970. – С. 30–33.
   [*Vanyurihin A. I.* Join the oscillation angle of the linearly polarized infrared radiation / A. I. Vanyurihin, Yu. A. Kuznetsov, V. F. Maistrenko, V. D. Tronko // Optiko-mekhanicheskaya promyshlennost, – No 8, 1970. – P. 30–33.] (in Russian).
4. *Дерюгин И. А.* Фотоэлектрический поляриметр инфракрасного диапазона / И. А. Дерюгин, Ю. А. Кузнецов, В. Д. Тронько // Оптика и спектроскопия. Vol. 28. – No 8. – 1970. – P. 415–418.
   [*Deryugin I. A.* Infrared photoelectric polarimeter / I. A. Deryugin, Yu. A. Kuznetsov, V. D. Tronko // Optika i spectroscopiya. Vol. 28. – No 8. – 1970. – P. 415–418] (in Russian).
5. *Пат. № 92837* Украина, Спосіб реєстрації кута повороту площини поляризації світлового потоку в мутних активних середовищах / А. В. Скрипець, В. Д. Тронько, М. М. Асанов // декабрь 2010.

[*Patent No. 92837* Ukraine UA Method of polarization rotation angle registration of light beam in turbid active media / A. V. Skrypets, V. D. Tronko, M. M. Asanov // December 2010.] (in Ukrainian).

6. *Скрипец А. В.* Передача азимута объекта на расстоянии с применением магнитооптического модулятора / А. В. Скрипец, В. Д. Тронько, М. М. Асанов Електроніка та системи управління, К., – № 1(27), 2011 – С. 5–8.
   [*Skrypets A. V.* Azimuth transmission of the object at a distance using the magneto-optical modulator / A. V. Skrypets, V. D. Tronko, M. M. Asanov // Elektronica ta systemy upravlinnya, K., – No 1 (27), 2011 – P. 5–8] (in Russian).
7. *Shurkliff W. A.*, Polarized Light. Harvard University Press, Cambridge, Massachusetts, 1962.
8. *Бурачек В. Г.* / Влияние погрешности в установке поляризационных призм на точность поляризационного устройства для измерений азимутальных углов // В. Г. Бурашек, И. А. Корчин, А. И. Мороз // Оптико-механическая промышленность, №3, 1975. – С. 7–10.
   [*Burachek V. G.* The influence of errors in the installation of polarizing prisms on the accuracy of the polarization device for measuring the azimuth angles / V. G. Burachek, I. A. Korchin, A. I. Moroz // Optiko-mekhanicheskaya promyshlennost, No 3, 1975 – P. 5–8] (in Russian).

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Оцінка точнісних характеристик бортових вимірювачів вертикалі на основі фотополяриметричного методу

Розроблено та проаналізовано метод оцінювання точнісних характеристик бортових вимірювачів вертикалі на основі реєстрації кутів обертання літака навколо повздовжньої осі фотополяриметричним способом.

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Оценка точностных характеристик бортовых измерителей вертикали на основе фотополяриметрического метода

Разработан и описан метод оценки точностных характеристик бортовых измерителей вертикали, который основан на регистрации углов вращения самолета вокруг продольной оси фотополяриметрическим способом.