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AVIATION NAVIGATION SYSTEM BASED ON POLARIMETRIC TECHNOLOGY

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Abstract**—*The paper deals with questions of developing polarimetric navigation method for determining aircraft's coordinates. This method, potentially, can increase the accuracy and sensitivity of navigation parameters determination. The paper also deals with existing methods and systems for determining aircraft's navigation parameters and proposed polarimetric method. Also offered block diagrams of the onboard and ground polarimetric device. In article were given result of the mathematical modeling of measuring channel.*

Index Terms—aircraft; Fresnel formulas; measurement device; mathematical modeling; measurement method; polarimeter; planar isotropic dielectric plate, navigation.

I. INTRODUCTION

Air navigation (Aeronavigation) is the realm of science, which studding the methods and means for driving the aircraft, as also, a set of operations to determine aircraft motion parameters and use them for navigation tasks. The process of aircraft navigating consists of sequential execution navigation tasks, the main ones are: takeoff, climb, altitude capture, obtaining the correct path, cruising flight (control and correction of deviations from course line, passing turning point), coming to point of destination, descend, landing approach and landing. To determine of navigation parameters are using different technical means, which can be divided into autonomous and non-autonomous systems. The non-autonomous navigation systems characterized by the use of information which coming on board from outside. The autonomous navigation system characterized by the use of onboard equipment for determining of navigation parameters.

Navigation parameters is some parameters and their derivatives, which describe the location, the movement, orientation in space and orientation around center of massof aircraft. There are the main navigational options: coordinates, altitude, attitude, speed, course and other

Determination and processing of navigation parameters data allows to determine the aircraft's position in space and its motion parameters. This in turn provides a safe and effective control of aircraft. Thus, piloting of modern aircraft without knowledge of navigation parameters is impossible.

Under polarimetric technology we will mean the totality of methods and devices for collection, accumulation, processing, transmission, storage and display information, which used polarimetric methods and means for obtaining primary information about the observation object.

II. PROBLEM STATEMENT

The conception of "free fly" and increased frequency of air transport traffic lead to a necessity to compacting the flow of air transport in airspace. This in turn can lead to increasing numbers of plane crash by aircraft collision at the critical density of aircraft in the air space. Increasing the number of crashes can be avoided only by increasing the accuracy of determination the coordinates of the aircraft during air traffic control. Thus there is a need to develop new or improve existing methods for determining the coordinates of the aircraft to ensure improvement of measurement accuracy.

III. REVIEW

All navigation tasks are solves through various technical means of navigation, which, depending on their physical principles of action can be divided into 5 main groups: geotechnical, inertial, radio, astronomical, lighting.

Geotechnical navigation tools are based on the different physical properties of the Earth and its atmosphere, which include the gravity force, Earth's magnetism and the earth magnetic field, terrain, pressure change with flight altitude , air velocity, thermal properties of the Earth. This group includes magnetic and gyromagnetic compasses, magnetometers, gravitometry, barometric altimeter, air speed meter, correlation-extreme navigation systems.

Radio navigation tools are based on the physical properties of artificial electromagnetic waves that propagate in space. This group of instruments are characterized by high precision work in any weather conditions, at any time of the day, and at different distances. This group includes short range radio navigation system, long range radio navigation system, VOR system, DME system, radio altimeter and others.

Astronomical navigation tools are based on use objective laws of relative position and motion of the Earth relative to the Sun, the Moon and other celestial bodies. This group includes astronomical compass, sextant and other.

Lighting and visual navigation tools are designed to provide land navigation, which include light beacons, searchlights, optoelectronic landing systems and other.

In modern aircraft commit complex use the different groups of navigational tools.

For solution of tasks for airplane en-route flight and determination coordinate of aircraft's location are most widely used short range radio navigation system and methods. Short range radio navigation system is divided into: azimuth-measurement navigation system, range-measurement navigation system, rho-theta navigation system, differential-range measurement navigation system and others, depending on the navigation parameter, which is measured.

Azimuth-measurement radio navigation system called system which provide a reception on the aircraft board or on the ground navigational information about relative angular position of the aircraft and radio sources.

Range-measurement navigation system called systems that ensure getting on board aircraft the navigational information about the distance to the radio beacon.

Rho-theta navigation system called systems that ensure getting on board aircraft the navigation information about relative angular position of the aircraft and radio sources and about the distance to the radio beacon.

Differential-range measurement navigation system called systems that ensure getting on board aircraft the navigation information about location of aircraft by used determining the difference distances to several radio navigation points.

In this case, the locating of a aircraft may be established by use information about the azimuths of two VOR beacons, about the distance to two DME beacons, about the azimuth and range to one azimuth-distance beacon, information about the three (four) independent difference distances to two (three) beacons.

IV. Problem Solution

Optical measurement methods are widely used in various fields of science and technology. Measuring polarization of light is one of the most sensitive methods of optical measurements. It allows to measure the azimuth plane polarization with accuracy 0.0005° [3]. Polarization measurement methods have very high sensitivity. Polarization measurement is a measurement to determine the parameters that characterize the polarization properties of radiation: the degree of polarization, azimuth, ellipticity and others. Currently, have begun to develop polarimetric methods for determine the direction of polarized light. These developments admit to determine the rotation angle of a moving object relative to a fixed point of reference. In article [5] it was examined the use of the method for determining the direction of polarized radiation to determine the aircraft attitude during landing and the application of polarimetric measurement methods in aircraft landing systems. One way to determine the direction of radiation is to measure the incidence angle of polarized radiation. In addition, the polarized radiation can be emitted from a moving object or irradiate the moving object. In this case, in perceiving part of the measurement system used planar isotropic dielectric plate.

Research presented in [1] and [2] show that at falling of linearly polarized light on isotropic dielectric planar plate with weakly absorbing material the reflected and refracted beams will also be linearly polarized and rotations the plane of polarization are depend from the angle of incidence. This conclusion is based on Fresnel formulas. The values of azimuth plane of polarization for the reflected and refracted beam that has passed through the two faces of the plate, can be determined by the following formulas:

$$\varphi_r = \operatorname{arctg}\left(-\frac{\cos(i-r)}{\cos(i+r)}\operatorname{tg}\varphi_e\right),$$

$$\varphi_d = \operatorname{arctg}\left(\left(\cos(i-r)\right)^2 \operatorname{tg}\varphi_e\right).$$

where φ_r is the azimuth plane of polarization reflected beam; φ_e is the azimuth plane of polarization incident beam; φ_d is the azimuth plane of polarization refracted beam; i is the angle of incidence; r is the angle of refraction.

Thus by fall of polarized radiation on the isotropic dielectric plate takes place rotates of the polarization plane azimuth for refracted, reflected beams and for beam, which pass through the two faces of the plate. Rotate of the polarization plane azimuth depends on the incidence angle of radiation and polarization plane azimuth of the incident beam.Polarimetric method for determining the coordinates of the aircraft is lie in measuring the polarization plane azimuth of the passed beam and determining the angle of incidence and polarization plane azimuth of the incident beam. Polarization plane azimuth of the incident beam directly interconnected with radio-station bearing, and the angle of radiation depends on relative radio station bearing, distance to radio station, aircraft pitch and altitude of flying.

Block diagram of the optical channel measurements shown in Fig. 1.

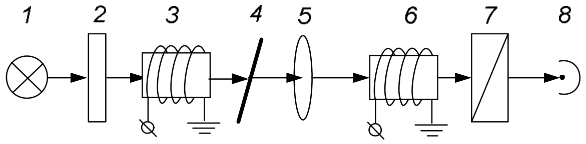

Fig. 1. Block diagram of the optical channel

Radiation source *1* is intended for radiation of unpolarized light. The optical filter *2* is designed for pass definite radiation wavelength. Faraday cell *3* is designed for polarization of light and rotation its plane of polarization. Planar dielectric plate *4* is designed to rotate the plane of polarization depending on the angle of incidence. It provides obtaining primary information about angle of incidence. Focusing lens *5* is designed for focusing the polarized beam after dielectric plate on modulator *6*. Modulator6 is designed to modulate polarized beam in an alternating magnetic field to increase the sensitivity of measurements. Analyzer *7* is designed to determine the azimuth plane polarization after the dielectric plate. Photodetector *8* is designed to convert azimuth plane of polarization into an electrical signal. The resulted electrical signal is sent to the measurement unit for determining of polarization plane azimuth and incidence angle of radiation.

Accuracy measurement is defined by the relation of a signal to noise. The relation of a signal to noise for photodetector has the following appearance [4]:

$$\frac{S}{N}=\frac{U_S^2}{U_{TH}^2+U_{SH}^2}=A_1\left(k_1+k_2\right)^2\Delta^2$$

$$\times\frac{4P^2\sin^2 2\alpha}{\dfrac{U_{TH}^2}{A_2\left(k_1+k_2\right)^2}+1-P\cos 2\alpha}.$$

where S is signal; N is noise; U_S, U_{TH}, 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; k_1, k_2 are principal transmittances of polarizing prisms; Δ is system sensitivity; P is polarization degree of the light in the optical channel; α is the angular amplitude of polarization plane vibrations, changing according to the periodic law: $\alpha=\alpha_0\Phi(t)$.

The proposed method involves the use of measurement system, which consists of two main block: radiation unit and measurement unit.Radiation unit is set on the beacon and designed to emission polarized beam with fixed value of polarization plane azimuth. Measurement unit is set on the onboard and desined to measure thepolarization plane azimuth passed beam and calculation ofstation bearing.Radiation unit providesemission of two beams, which have different wavelengths and polarization plane azimuth. Radiation unit consists of two identical channels.Block diagram of measurements unit channel shown in Fig. 2.

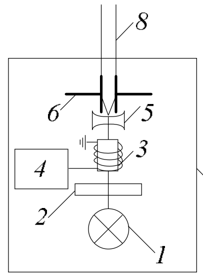

Fig. 2.Block diagram of radiation unit channel

One channel of the radiation unit involves radiation source *1*; optical filter *2*, Faradey cell *3*, sound generator *4*, scattering lens *5*, slit diaphragm *6*. Both radiation channels is placed on the platform *7*, which rotates.Monochromator *2* is designed for filtering the incidence beam and miss out the wavelength on which is tune the appropriate channel of measurement unit. Faraday cell *3* is designed for polarization of beam and rotation its plane of polarization. Sound Generator *4* is intended to form control signals to the Faraday cell *3*. Scattering lens *5* and a slit diaphragm 6 are designed for scattering plane-polarization radiation in the vertical plane with minimal divergence radiationangle in the horizontal plane.The platform *7* rotates around a vertical axis at a constant frequency and provides a change the direction of the radiation the beam *8*. Simultaneously with the platform rotation happen the rotations of the beam polarization plane. This ensures communication of polarization plane azimuth and the radiation station azimuth.Two measurement channels differ rotation frequency of the polarization plane: in the first channel it equal to the speed of platform rotation, while in the second channel it equal to the half the frequency of platform rotation.

The measuring unit consists of two identical channels, each of which is configured for measure the polarization plane azimuth of corresponding channel of radiation unit. Block diagram of a measurement unit channel shown in Fig. 3. Dependence polarization plane azimuth from radiation station azimuth in the first and second channel shown in Fig. 4.

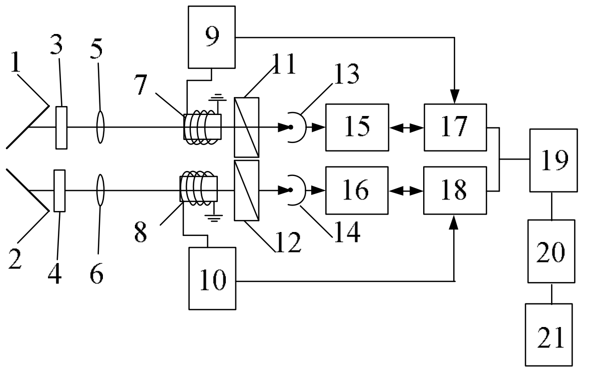

Fig. 3. Block diagram of measurements unit channel

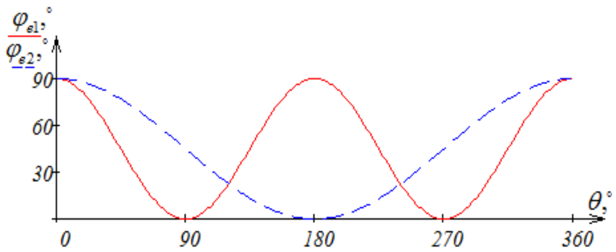

Fig. 4. Dependence polarization plane azimuth from radiation station azimuth in the first and second channel

The channel measurement unit consists of planar dielectric plates 1 and 2, which are designed to rotate the polarization plane depending on the angle of incidence and polarization plane azimuth of the incident beam, it provides getting primary information about incidence angle and polarization plane azimuth; optical filters 3 and 4, which are designed for filtering the incidence beam and miss out the wavelength on which is tune the appropriate channel of radiation unit; focusing lens 5 and 6, which are designed to focus the radiation on the Faraday cell 7 and 8; Faraday cell 7 and 8, which are designed to modulate polarized radiation in an alternating magnetic field; sound generators 9 and 10, which are designed to form the control signals which are submitted for Faraday cells 7 and 8; analyzers 11 and 12, which are designed to determine the polarization plane azimuth; photodetectors 13 and 14, which are designed to convert polarization plane azimuth into an electrical signal; narrowband amplifiers 15 and 16, which are designed to amplification of electrical signal; synchronous detectors 17 and 18, which are designed to increase the sensitivity measurement and provide measurement "on zero signal"; microcontroller 19, which is designed for the processing of measurement results; storage unit 20, which is designed for the collection and storage of measurement results; calculator 21, which is designed to perform mathematical calculations.

V. Results of Research

In paper represents the azimuth-measurement polarimetric method for determining the coordinates of the aircraft and the measuring system that implements the proposed method. The system consists of two channels. Each channel is defined the polarization plane azimuth and incidence angle of radiation. Value polarization plane azimuth of incidence radiation in two channels determines the airplane bearing. Measured values of the incidence angle may be used in determining the altitude, pitch angle and station bearing. In the process of mathematical modeling was built plot a dependence graph of the polarization plane azimuth of refracted beam from incidence angle (Fig. 5), a dependence graph of the measurement sensitivity from polarization plane azimuth of the incident beam (Fig. 6), a dependence graphs of the polarization plane azimuth of the refracted beam from polarization plane azimuth of the incident beam (Fig. 7).

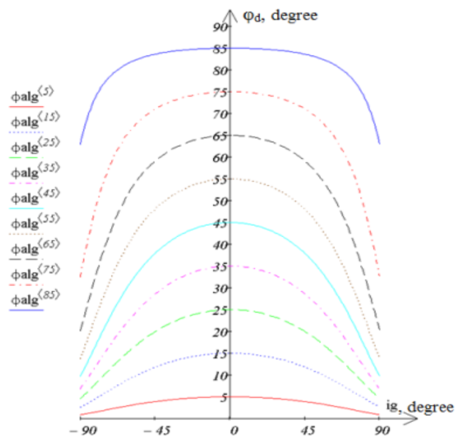

Fig. 5. Dependence graph of the polarization plane azimuth of refracted beam from incidence angle

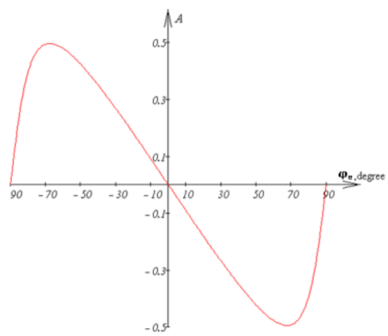

Fig. 6. Dependence graph of the measurement sensitivity from polarization plane azimuth of the incident beam

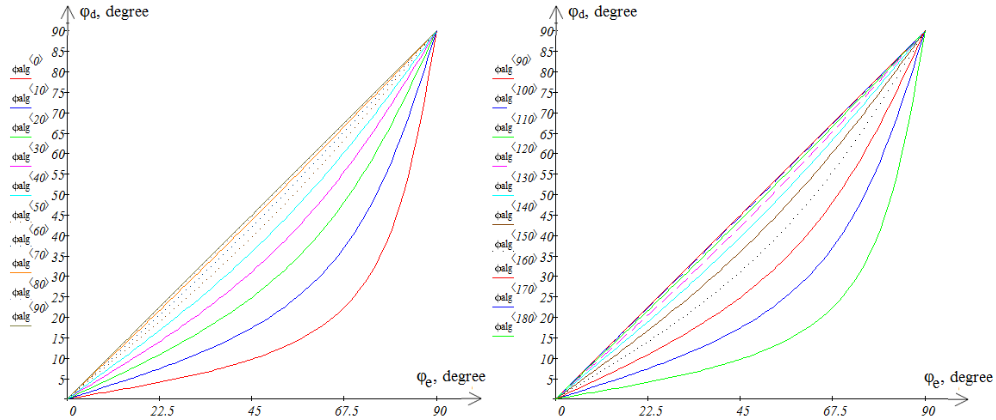

Fig. 7. Dependence graphs of the polarization plane azimuth of the refracted beam from polarization plane azimuth of the incident beam

After analyzing the dependence graph of the polarization plane azimuth of refracted beam from incidence angle (Fig. 5), we conclude that the relationship is symmetric about the y axis and depends on the polarization plane azimuth of the incident beam. After analyzing the dependence graph of the measurement sensitivity from polarization plane azimuth of the incident beam (Fig. 6), we conclude that the relationship is symmetric about zero and has extremes. The graph shows that the highest sensitivity value provides polarization plane azimuth $\varphi_e = \pm 68°$. After analyzing the dependence graph of the polarization plane azimuth of the refracted beam from polarization plane azimuth of the incident beam (Fig. 7), we conclude that the relationship is nonlinear and depends on the incidence angle. The sensitivity of the measurement increases with the increase of the incidence angle.

VI. Conclusions

The article deals with the existing methods for determining of navigation parameters and proposed azimuth-measurement polarimetric method for determining the coordinates of the aircraft. This method can potentially increase the accuracy and sensitivity of determining the navigation parameters. Also in the article is proposed the measuring system that implements this method. The proposed method and system can be used with azimuth-measurement and rho-theta navigation system for determining the aircraft's coordinates. The article also shows the results of mathematical modeling of the measurement channel.

References

[1] R. Azzam and N. Bashar. *Ellipsomeriya and Polarized Light*. Moscow: Mir, 1981. (in Russian)

[2] P. Paul. *Optics and Atomic Fizika*. Moscow: Physical and Mathematical Literature, 1966. (in Russian)

[3] A. Skripets, V. Tronko, and M. Asanov. “Transmission bearing on the distance of the object using the magneto-optical modulator”. *Electronics and control systems*. Kyiv, NAU, no. 1 (27), 2011, pp. 5–8. (in Russian)

[4] M. Asanov, V. Rogozhin, A. Skrypets, and V. Tronko. “Estimation of accuracy characteristics of onboard vertical meters based on photopolarimetric metod”. *Electronics and control systems*. Kyiv, NAU, no. 3 (34), 2012, pp. 46–50.

[5] A. Klochan, V. Romanenko, V. Tronko “Polarimetric method for UAV attitude determination during landing approach and landing”. *Proceedings 2015 IEEE 3rd International conference «Actual Problems of Unmanned Aerial Vehicles Developments (APUAVD)»*, October, 13-15, 2015, Kyiv, Ukraine. – Kyiv, 2015. pp. 202–205.

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А. Є. Клочан, А. Аль-Амморі, В. Г. Романенко, В. Д. Тронько. Авіаційна навігаційна система на основі поляриметричних технологій

Розглянуто питання розроблення поляриметричного навігаційного методу для визначення координат повітряного судна. Цей метод, потенційно, дозволяє підвищити точність та чутливість визначення навігаційних параметрів. Розглянуто існуючі методи і системи та запропоновано поляриметричний метод для визначення навігаційних параметрів літального апарату. Запропоновано блок-схему бортового і наземного поляриметричного пристрою. Приведено результати математичного моделювання вимірювального каналу.

Ключові слова: повітряне судно; формули Френеля; вимірювальний прилад; математичне моделювання; метод вимірювань; поляриметр; плоска ізотропна діелектрична пластина; навігація.

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А. Е. Клочан, А. Аль-Аммори, В. Г. Романенко, В. Д. Тронько. Авиационная навигационная система на основе поляриметрических технологий

Рассмотрен вопрос разработки поляриметрического навигационного метода для определения координат воздушного судна. Этот метод, потенциально, позволяет повысить точность и чувствительность определения навигационных параметров. Рассмотрены существующие методы и системы и предложен поляриметрический метод для определения навигационных параметров летательного аппарата. Предложена блок-схема бортового и наземного поляриметрического устройства. Приведены результаты математического моделирования измерительного канала.

Ключевые слова: воздушное судно; формулы Френеля; измерительный прибор; математическое моделирование; метод измерений; поляриметр; плоская изотропная диэлектрическая пластина; навигация.

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