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LOCAL POLARIMETRIC SYSTEM FOR MEASURING AIRCRAFT`S NAVIGATION AND PILOTING PARAMETERS

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***Abstract*—*The paper considers questions of invention the local optical system for measuring navigation and piloting parameters on base on polarimetric technologies. Such system is aimed to increase the sensitivity and accuracy of definition the aircraft navigation and piloting parameters in a locally restricted airspace segment with high traffic density. The paper also deals with regarding existing methods and systems for measuring the aircraft's piloting and navigation parameters, as well as suggest polarimetric method and the polarimetric system, that realize it. The polarimetric method for measuring the aircraft`s piloting and navigation parameters consist in measuring the polarization plane azimuth of transmitted beam and determining the spatial and plane incident angles of the incident beam, as well as the aircraft`s attitude. Proposed local polarimetric system for measuring aircraft`s navigation and piloting parameters consist two main units: measurement block and radiation block. Radiation block emits the polarized radiation with certain polarization plane azimuth and with certain dispersion aperture. Measurement block measure the polarization plane azimuth of transmitted beam and calculate polarization plane azimuth of incident radiation and its angle of incident. The proposed system allows to measure the piloting, as well as, navigation parameters at the same time with high accuracy and sensitivity. Modeling the operation of the measurement channel shows that dependencies have linear character and match well with measuring parameters. Paper results can be applied in the process of elaboration and implementation of polarimetric navigation system, for example, and requires additional theoretical and practical research.*

Index Terms—Locally restricted airspace segment; piloting and navigation parameters; polarimetric measurement method; mathematical modeling; planar isotropic dielectric plate.

I. INTRODUCTION

The current transport industry is marked by the dynamic evolvement of air carriage. Accordant to ICAO statistics is observabled the immutable growth of extent in the regular passenger and freight carriage. The growth regular passenger carriage on 7.2% and freight carriage on 3.1% are observed in the 2017 year [1]. The principal direction for increasing the safety and efficiency in air transport industry is to provide the impactful and comprehensively navigation services [2]. Aeronavigation is the field of science about definition parameters of aircraft movement and position. Aeronavigation provide the correct implementation of the on-route flight: provide the aircraft incoming to the destination point at the fixed time and assure flight safety. The precise and well-timed definition piloting and navigation parameters of the aircraft is a essential prerequirement for providing safe and efficient air carriage. Piloting parameters describes aircraft motion and orientation around the center of attraction, that is attitude, angular acceleration, pitch angle, roll angle, yaw angle and so on. Navigation parameters describes aircraft position, motion and orientation at the space, that is speed, coordinates, height, heading and so on. Determination and processing aircraft piloting and navigation parameters permit to estimate the position and airplane trajectory parameters. This, in return, permit to assure the effective and safe aircraft control.

Concept of free flight is one of the upcoming trend to efficiency upgrading of air carriage. Free flight conception mean transmission effective decision about flight trajectory, flying speed and profile of fly to the crew [3]. Utilization such concept necessitate the accuracy increase of determination the aircraft position and relative coordinates for the purpose of avoid collision, as well as provision early warning about potential collision for the purpose of provide the appropriate margin of safety.

II. REVIEW

In order to estimate the piloting and navigation parameters use varied techniques and means. All this techniques and means in pursuance of concept of action can be classification at radio, inertial, astronomical, lighting, geotechnical. In pursuance the principle of use navigation techniques and means are divided into autonomous and nonautonomous. In pursuance the place of location means divided on ground and onboard.

Radio techniques and means are widely used in modern aircraft as the main measurement means. Their principle of action based on the measurement parameters of the artificial electromagnetic field. Radio navigation techniques refers to nonautonomous. This type of navigation means include as onboard, as well as ground means. Radio navigation techniques and means are characterized by exact accuracy of work at all times of the day, at any weather condition, at varied distances and used eminently for navigation tasks.

Inertial techniques and means are widely use in modern aircraft as one of the main measurement means in various flight stages, for implementation different tasks, as well as main measurements at unmanned planes. Their principle of action based on measuring the linear and rotation accelerations produced by action of nongravitational forces. Inertial navigation techniques refers to autonomous and inertial navigation means include only onboard means. Inertial navigation techniques and means are characterized by reasonable accuracy and sensitivity of work, error accumulation through time, relatively small weight and dimension. Inertial navigation means are used as for navigation tasks, as well as for piloting.

Astronomical techniques and means are use in modern aircraft as an additional measurement means during flight at hard-to-reach places, such as, North and South Pole, oceans and so on. The principle of action the astronomical navigation means based on measuring relative position of Earth and celestial bodies or artificial earth satellites. Astronomical navigation techniques refers to nonautonomous, but astronomical navigation means include only onboard means. Astronomical navigation techniques and means are characterized by relative high accuracy and used solely for navigation tasks.

Lighting techniques and means are generally in service in landing and takeoff flight stages. Their concept of action based on visual marking aircrafts and ground objects. Lighting navigation techniques refers to nonautonomous, but such means include only radiation means. This type of navigation means essentially using for navigation tasks to avoid collision.

Geotechnical techniques and means used in modern aircraft as the emergency measurement means. Their concept of action based on measuring the various properties of Earth and its atmosphere. This group of techniques refers to autonomous and geotechnical means include only onboard measurement means. This group of means are characterized by not-too-high sensitivity and accuracy and used only for navigation tasks.

The immediate stage of technician development is characterized by comprehensive use of means with varied principles of action. It afford to estimable lessen the measuring error and decrease setup time. The most widely used means to perform navigation during flight are inertial and radio navigation means. Any navigation means have some limitations. Radio navigation means needs existence radio source - radio beacon and inertial navigation means accumulate errors over time. Integrated utilization of navigation systems with different principles of action allow to raise the accuracy of determination the navigation parameters.

III. PROBLEM STATEMENT

There are main factors that lead to need for densification the air transport flow in airspace and bring about eventual safety decrease due to increasing aircraft collision at increasing density of aircraft in airspace: airborne traffic volume growth, actualization air traffic control concept "Free Flight", intensive development of air transport sector. Enhancement the accuracy and sensitivity of measuring the piloting and navigation parameters, as well as, prognosticating aircraft motion trajectory give the opportunity to improve fly safety in the event of increasing the density of air transport flow. Consequently, there exists need for elaboration or perfection existing measuring methods of piloting and navigation parameters for the purpose of measurement accuracy increase. The prime importance have increase accuracy of measuring the aircraft position at locally bounded space.

IV. PROBLEM SOLUTION

This paper is an extension of work originally presented in IEEE 5th International conference "Methods and Systems of Navigation and Motion Control (MSNMC)" [7]. This article continues studying the issue of using polarimetry in aircraft piloting and navigation systems and is aimed at a wider and more detailed examination of the polarimetric technology possibility to solve aircraft navigation and piloting tasks. Polarimetric techniques are understood to mean the totality processes of collection, accumulation, processing, transmission, storage and display of information. They use polarimetric methods and devices to obtain basic information about the object.

One of the way to increase the accuracy of aircraft's piloting and navigation parameters measurement is to use polarimetric measurement methods (PMM). Application of PMM to solve air-navigation tasks is possible through using dielectric isotropic plane-parallel plate in the optic measurement channel. Using the dielectric plate in measurement channel allow rotate the polarization plane of incidence beam according to its angle of incidence and polarization plane azimuth (PPA). The questions of increasing accuracy and sensitivity of determaination the aircraft's coordinates and attitude with use of polarimetric technologies are considered in [4], [5] and [6]. In papers [4] and [6] considered application polarimetric technologies in landing system, and in [5] – in aviation navigation systems.

The polarimetric method for measuring aircraft`s navigation and piloting parameters and system, which implements this method, are proposed in this article. The operation principle of the method is based on Fresnel's formulas. The principle of use the polarimetric navigation method based on the measurement parameters of the artificial electromagnetic field in the visual range. In accordance with the principle of action the proposed system is a nonautonomous and, accordingly, to the classification given above, it can be related to the radio navigation of the optical range.

Solving the aeronavigation tasks with the use of polarimetric technologies is as follow. Polarimetric navigation system (PNS) consist of two main units: measurement block and radiation block. Radiation block emits the polarized radiation with certain PPA and with certain dispersion aperture. At that, the PPA depends directly on the direction of radiation. Measurement block measure the PPA of transmitted beam and calculate PPA of incident radiation and angle of incident. In addition to the above, the PPA of the incident beam is directly connected with bearing angle of radiation and incident angle depends on altitude, aircraft attitude and distance to emitter. Radiation block can located on the navigation beacon, at airport zone or on aircraft and measurement block located on aircraft. The simplify block diagram of optical measurement channel of polarimetric principle for determining air-navigation parameters is shown in Fig. 1.

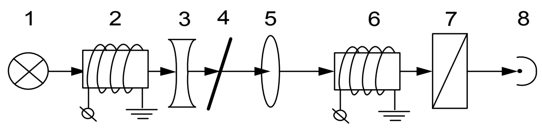

Fig. 1. Simplify block diagram of the optical measuring channel

Radiation source 1 and Faraday cell 2 provide emit polarized light and rotation its plane of polarization. The scattering lens 3 provide dissipate polarized radiation with certain aperture. The dielectric plate 4 provide rotation the polarization plane of transmitted beam depending on PPA of the incident beam and angle of incident. The focusing lens 5 and modulator 6 provide determination PPA of transmitted beam with high sensitivity. Analyzer 7 and photodetector 8 provide measure the PPA and convert measured signal into electrical. Measured electrical signal is received to calculated unit to provide calculation the PPA and incidence angle of radiation.

The radiation unit include two blocks. The first block include two channels and provides scattering of two plane-polarized beams in the vertical plane, which differ in polarization azimuth plane and wavelength. The second block include one channel and provides scattering plane-polarized beam in the horizontal plane. The dependence of polarization azimuth plane (φ_{e1}, φ_{e2}) on the direction of the radiation (θ) in first unit and on the direction of radiation (α) in the second unit are shown in Fig. 2.

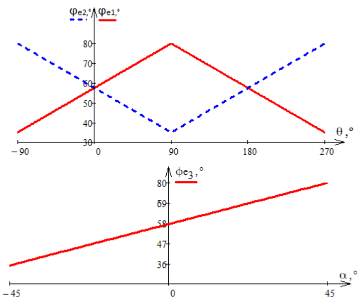

Fig. 2. Dependence PPA of radiation on the direction of radiation in the first and second unit of radiation block

The block diagram of radiation unit channel is shown in Fig. 3.

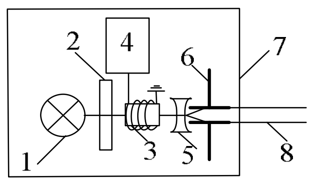

Fig. 3. Block diagram of radiation unit channel

Radiation source 1 and monochromator 2 provide radiating the plane-polarized beam with certain wavelength. Faraday cell 3 and sound generator 4 provide rotation the beam polarization plane by certain rotation law. Scattering lens 5 and a slit diaphragm 6 provide scattering the plane-polarization radiation with a definite divergence angle in the vertical and horizontal planes. The platform 7 provide changing the radiation direction of the beam 8 by certain rotation law. PPA of beam 8 and direction of radiation rotates simultaneously, this ensures communication of radiation direction and PPA.

The measurement unit include three blocks, each of which measure the polarization plane azimuth of the corresponding beam of radiation unit. The first and second block includes two measurement channels, and the third block has one measuring channel. Thus, the measurement block include five measuring channels. The block diagram of measuring unit channel is shown in Fig. 4.

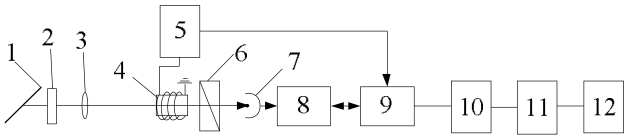

Fig. 4. Block diagram of measuring unit channel

Planar dielectric plate 1 provide rotation the polarization azimuth plane depending on the PPA of the incident beam and its angle of incidence. Optical filter 2 and focusing lens 3 provide focus the radiation with certain wavelength on the Faraday cell 4. Faraday cell 4 and sound generator 5 provide modulation the polarized radiation by way of increase the measurement sensitivity. Analyzer 6 and photodetector 7 provide getting electric signal that is compliant with PPA of transmitted beam. Narrow-band amplifier 8, synchronous detector 9 and microcontroller 10 provide processing measured signal. Storage unit 11 and calculator 12 perform mathematical calculations and store measurement results.

The local polarimetric system for measuring aircraft's piloting and navigation parameters include five channels and provide measuring the five PPA φd, which are governed by the following formula:

$$\varphi_{d_n} = \operatorname{arctg}\left(\cos^2\left(id_n - \arcsin\left(\frac{\sin(i_{d_n})}{n}\right)\right)\operatorname{tg}(\varphi_e)\right) \quad (1)$$

where φ_{d_n} is the PPA of the transmitted beams in nth measuring channel; φ_e is the PPA of the incident beam in appropriate measuring channels; i_{d_n} is the angle of incidence in nth measuring channel; n is the refraction index of dielectric plate material.

Spatial incidence angle as a function of the inclination angle of dielectric plates and planar incidence angles of radiation are governed by the following formula:

$$i_n = \operatorname{arctg}\sqrt{\operatorname{tg}^2\left(i_\alpha + \alpha_{pl_n}\right) + \operatorname{tg}^2\left(i_\theta + \theta_{pl_n}\right)}, \quad (2)$$

where i_n is the spatial incidence angle of radiation in nth measuring channel; i_a is the planar incidence angle of radiation in horizontal plane; i_θ is the planar incidence angle of radiation in vertical plane; α_{pl_n} is the horizontal inclination angle of dielectric plates in nth measuring channel; θ_{pl_n} is the vertical inclination angle of dielectric plates in nth measuring channel.

Substitute equations (2) in the equations (1) and solve the formed system of equations we will find the planar incidence angle of radiation in horizontal and vertical planes i_α, i_θ and the polarization azimuth planes φ_{e1}, φ_{e2}, φ_{e3}.

The PPA of the beam (radiation direction) relative to the horizontal plane α_φ and the vertical plane θ_φ, which registered on board the aircraft and governed by the following formulas:

$$\begin{aligned}\theta_\varphi &= 2(\varphi_{e1} - \varphi_{e2} - \varphi_0 + \varphi_1),\\ \alpha_\varphi &= 2(2\varphi_{e3} - \varphi_{e1} - \varphi_{e2} - \varphi_0 + \varphi_1).\end{aligned} \quad (3)$$

Angles of aircraft deviation from the "zero" direction of radiation can be found by the following formulas:

$$\Delta\theta = \theta_\varphi + i_\theta, \qquad \Delta\alpha = \alpha_\varphi + i_\alpha. \quad (4)$$

The aircraft attitude can be found by the following formulas:

$$\begin{aligned}\gamma &= \frac{\varphi_{e1} + \varphi_{e2} - \varphi_0 - \varphi_1}{2},\\ \psi &= \Delta\theta + \theta_0, \qquad \vartheta = \Delta\alpha + \alpha_0,\end{aligned} \quad (5)$$

where φ_0 is the minimum PPA of the radiation; φ_1 is the maximum PPA of the radiation; θ_0 is the course of zero radiation direction of the radiation unit in the first unit; α_0 is the inclination angle of the radiation direction of the radiation unit in the second block.

V. Results of Research

The paper considers existing methods and means for determination the piloting and navigation parameters and proposed using PMM, which unlike existing methods, allows simultaneous determinate the navigation and piloting parameters. Also, the local navigation polarimetric system, which realize the offer method, is proposed in the paper.

In the course of mathematical modeling was built the dependences graph of the PPA on the radiation azimuth in the horizontal (α) and vertical (θ) planes at the constant values of incidence angles (i_θ and i_α). Figure 5 shows the dependency graph at i_θ = 15° and i_α = 5°. Also was built the dependence graph of the PPA on the incidence angles at the constant values of the incident beam PPA. Figure 6 shows the dependency graph at $\varphi_{e1} = 45; \varphi_{e2} = 70; \varphi_{e3} = 60$.

After analyzing the graphs, we can make the following conclusions. The dependence graph of the PPA from the radiation azimuth has a similar character with the dependence of the PPA on the azimuth of radiation. That is, the unambiguous determination of radiation azimuth is provided. The dependence of the PPA on the incidence angles have almost linear type, which allows unambiguously and precisely to determine the incidence angles.

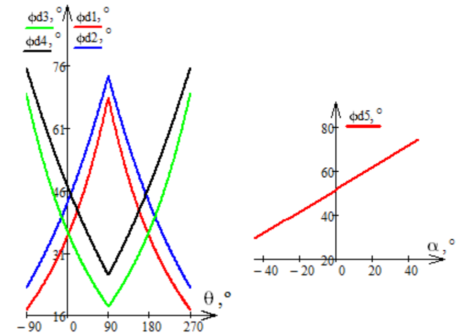

Fig. 5. The dependence graph of the PPA on the radiation azimuth

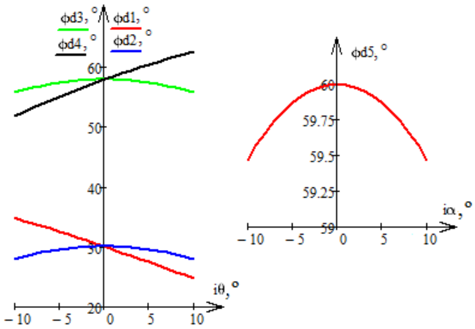

Fig. 6. The dependence graph of the PPA of the transmitted beam

Thus, the proposed aviation local polarimetric system for measuring aircrafts piloting and navigation parameters provides the determination of the incidence angles and PPA of radiation, which allows to calculate aircrafts navigation and piloting parameters with high accuracy

VI. CONCLUSIONS

The paper get a lift problem of increase accuracy of measurement the aircraft's piloting and navigation parameters at locally bounded space by the way of invention the local aviation PNS. The proposed system allows to measure the piloting, as well as, navigation parameters at the same time with high accuracy and sensitivity. Modeling the operation of the measurement channel shows that dependencies have linear character and match well with measuring parameters. Paper results can be applied in the process of elaboration and implementation of PNS. The main practical realization of the offered method is to create a PNS and requires supplementary theoretical and practical investigation. This paper presents results of one theoretical investigation stage of the possibility to usage polarimetric technology for permitting airnavigation tasks.

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А. Є. Клочан, А. Аль-Амморі, В. К. Суботіна, О. П. Пальчик, М. М. Дехтяр. Локальна поляриметрична система вимірювання пілотажно-навігаційних параметрів повітряного судна

У статті розглянуто питання розробки локальної оптичної системи для вимірювання пілотажно-навігаційних параметрів повітряного судна з використанням поляриметричних технологій. Така система спрямована на підвищення чутливості та точності визначення пілотажно-навігаційних параметрів повітряного судна у локально обмеженому сегменті повітряного простору з високою щільністю руху. У роботі розглядаються існуючі методи та системи для вимірювання пілотажно-навігаційних параметрів повітряного судна, а також запропоновано поляриметричний метод та поляриметричну систему, які їх реалізують. Поляриметричний метод вимірювання пілотажно-навігаційних параметрів повітряного судна полягає в вимірюванні азимута площини поляризації заломленого променя та визначенні просторового і плоских кутів падіння випромінювання, а також просторового положення літального апарату. Запропонована локальна поляриметрична система для вимірювання пілотажно-навігаційних параметрів складається з двох основних вузлів: блоку вимірювання та блоку випромінювання. Блок випромінювання випромінює поляризований промінь з визначеним азимутом площиною поляризації та з певним кутом розсіювання. Блок вимірювання вимірює азимут площини поляризації заломленого променю та обчислює азимут площини поляризації падаючого випромінювання та його кут падіння. Запропонована система дозволяє одночасно вимірювати як пілотажні, так і навігаційні параметри з високою точністю та чутливістю. Моделювання роботи вимірювального каналу показує, що залежності мають лінійний характер і добре узгоджуються з вимірювальними параметрами. Результати роботи можуть бути застосовані в процесі розробки та впровадження, наприклад, поляриметричної навігаційної системи і вимагають додаткових теоретичних та практичних досліджень.

Ключові слова: локально обмежений сегмент повітряного простору; пілотажно-навігаційні параметри; поляриметричний метод вимірювання; математичне моделювання; плоскопаралельна ізотропна діелектрична пластина.

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А. Е. Клочан, А. Аль-Аммори, В. К. Субботина, О. П. Пальчик, М. М. Дехтяр. Локальная поляриметрические система измерения пилотажно-навигационных параметров воздушного судна

В статье рассмотрены вопросы разработки локальной оптической системы для измерения пилотажно-навигационных параметров воздушного судна с использованием поляриметрических технологий. Такая система направлена на повышение чувствительности и точности определения пилотажно-навигационных параметров воздушного судна в локально ограниченном сегменте воздушного пространства с высокой плотностью движения. В работе рассматриваются существующие методы и системы для измерения пилотажно-навигационных параметров воздушного судна, а также предложен поляриметрический метод и поляриметрическая система, которые их реализуют. Поляриметрический метод измерения пилотажно-навигационных параметров воздушного судна состоит в измерении азимута плоскости поляризации преломленного луча и определении пространственного и плоских углов падения излучения, а также пространственного положения летательного аппарата. Предложенная локальная поляриметрическая система для измерения пилотажно-навигационных параметров состоит из двух основных узлов: блока измерения и блока излучения. Блок излучения излучает поляризованный луч с определенным азимутом плоскости поляризации и с определенным углом рассеивания. Блок измерения измеряет азимут плоскости поляризации преломленного луча и вычисляет азимут плоскости поляризации падающего излучения и его угол падения. Предложенная система позволяет одновременно измерять как пилотажные, так и навигационные параметры с высокой точностью и чувствительностью. Моделирование работы измерительного канала показывает, что зависимости имеют линейный характер и хорошо согласуются с измерительными параметрами. Результаты работы могут быть применены в процессе разработки и внедрения, например, поляриметрической навигационной системы и требуют дополнительных теоретических и практических исследований.

Ключевые слова: локально ограниченный сегмент воздушного пространства; пилотажно-навигационные параметры; поляриметрический метод измерения; математическое моделирование; плоскопараллельная изотропная диэлектрическая пластина.

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