AUTOMATIC CONTROL SYSTEMS

UDC 629.735.051.83:629.7.014-519 (045)

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DUAL-CHANNEL POLARIMETRIC DEVICE FOR FIXED-WING UAV ATTITUDE DETERMINATION DURING LANDING APPROACH

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Abstract—*This paper deals with existing methods and devices for determining the UAV's attitude and offered polarimetric method for determining the UAV attitude during landing approach. This method provides increased accuracy of measurements and determining the UAV's attitude relative to the plane of boarding, which is not horizontal. Also offered block diagram of the dual-channel polarimetric device with modulator in the block of radiation. This device provides simultaneous measurement of roll, yaw and pitch angles.*

Index Terms—Attitude; Fresnel formulas; measurement device; measurement method; pitch angle; planar isotropic dielectric plate; plane of boarding; polarimeter; roll angle; yaw angle.

I. INTRODUCTION

Unmanned aerial vehicles (UAV) is aerial vehicle of reusable or conditional-reusable use which do not have onboard crew and which capable independently and purposefully to move in air for performance various functions in automatic mode or by means of remote control. Depending on a flight principle unmanned aerial vehicles divide on 5 groups: UAV of plane type (fixed-wing UAV), UAV with flexible wing, UAV of helicopter type (rotorcraft UAV, rotary-wing UAV), flapping-wing UAV, UAV of aerostatic type (blimps) [2]. UAV of plane type differ long range, high cruising speed and flight autonomy [7]. Parachute, runways, special catchers (cables, grids, extensions) are used for landing of fixed-wing UAV. It’s depending on their size.

Depending on weight and duration of flight UAV are divided into [1]:

– mikro- and mini-UAV with near radius of action (take-off weight to 5 kg, range of action to 25…40 km);

– light UAV with small radius of action (take-off weight to 5…50 kg, range of action to 10…70 km);

– light UAV with average radius of action (take-off weight to 50…100 kg, range of action to 70…150 km);

– average UAV (take-off weight to 100…300 kg, range of action to 150…1000 km);

– average-heavy UAV (take-off weight to 300…500 kg, range of action to 70…300 km);

– heavy UAV with average radius of action (take-off weight more than 500 kg, range of action 70 … 300 km);

– heavy UAV with long duration of flight (take-off weight more than 1500 kg, range of action about 1500 km);

– unmanned warplanes (take-off weight more than 500 kg, range of action about 1500 km).

Parachute and special catchers are used for light and small UAV of plane type. For landing of average and heavy fixed-wing UAV are used runways.

Landing approach and landing of aircraft are one of the most critical phases of flight. Statistical analysis of aircraft accidents shows that about 40% of disasters occurs on phase landing approach and landing of aircraft. Safety and effectiveness landing approach and landing of airplane depends on several factors. One of the most important parameters is to determine the aircraft`s attitude relative to the horizon. The aircraft`s attitude in space is determined by yaw angle, pitch angle and roll angle. Accurate and continuous determination of the aircraft`s attitude during landing approach and landing can improve the accuracy, safety and efficiency of the landing approach and avoids collision of the aircraft with the ground of separate structures: the wing during landing with roll, nose or tail during landing with pitch.

II. PROBLEM STATEMENT

Unmanned aerial vehicles are used in different areas of activity and have different applications. In general, provides for the possibility of landing not on a specially prepared landing surface. In this regard, the UAV automatic landing systems are required to improve the accuracy and sensitivity of attitude measuring and measure UAV attitude relative to landing plane, ship deck, for example. Avail-

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ability of landing system that meets these requirements will allow to landing on any surface in automatic mode.

The mathematical description of UAV attitude is as follows: $F = f(\vartheta,\psi,\gamma)$, where ϑ is the pitch angle, ψ is the yaw angle, γ is the roll angle. This function is implemented through measuring of parameters ϑ, ψ, γ by onboard tools. As a result of measurements get the measured parameters ϑ_m, ψ_m, γ_m. Measured parameters ϑ_m, ψ_m, γ_m can be determined by the following equations:

$$\vartheta_m = \vartheta + \xi_\vartheta,$$

$$\psi_m = \psi + \xi_\psi,$$

$$\gamma_m = \gamma + \xi_\gamma,$$

where ϑ_m, ψ_m, γ_m are measured angles of pitch, yaw and roll, respectively; ϑ, ψ, γ are true values of pitch, yaw and roll angles, respectively; $\xi_\vartheta, \xi_\psi, \xi_\gamma$ are errors of measurement pitch, yaw and roll angles, respectively. The value of measurement errors ξ_ϑ, ξ_ψ, ξ_γ are reduced through signal processing by means of optimal filtration, such as optimal Kalman filter. It is necessary to estimate measurement accuracy of UAV attitude.

III. Review

To determine the UAV attitude during landing is use the same devices used in flight: the inertial system, micromechanical gyroscopes and accelerometers, etc. [8]. Accuracy of UAV attitude determination by using these devices is 0.2–3° depending on the flight mode [9]. At the same time, gyroscope are inherent “gyro wander” and linear acceleration introduce error into measuring of accelerometers. Therefore, the measurement accuracy may vary for different modes of flight. Thus the existing devices and systems provide sufficiently and relatively accurate definition of aircraft's attitude relative to the horizon plane. Therefore is proposed to develop polarimetric method and device for measuring the UAV attitude during landing. Polarimetric method potentially allows measure the UAV attitude relative to plane of boarding and improve the accuracy and sensitivity of measurement.

IV. Polarimetric Method for Determining Attitude

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 potentially allows to measure the azimuth plane polarization with accuracy to 0,03′ [5]. Polarization optical methods characterized by the fact that they can solve the problem that cannot be resolved by other methods or solve them nontrivial and simpler ways. 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. Parameters which are determined in each case determined depending on the research methodology and the device that is used.

Currently, have begun to develop polarimetric methods for determining the rotation`s angle of a moving object relative to a fixed plane of reference. One method is determining the incidence angle of polarized radiation. In addition, the polarized beam 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.

In [1] stated that for optically isotropic environments, if the incident wave linearly polarized so that the electric vector oscillates parallel to (p) (perpendicularly (s)) plane of incidence, then reflected and refracted waves also be linearly polarized, and their electric vectors will fluctuate in parallel (perpendicular) plane of incidence. In case if incident wave linearly polarized and electric vector are not in the p - or s - condition, the polarization of the reflected and refracted waves will be different from the polarization of the incident beam. This explained by difference transmission coefficients (gain) of Fresnel for *p*- and *s*-components of radiation in reflection and refraction. In [3] is shown the research, which shows the influence the incidence angle on reflection of linearly polarized light from flat surface. As a result of the experiment it was shown that for plates with weakly absorbing material in transition from air to plate polarization of the reflected beam remains linear and occurs rotates the plane of polarization depending on the incidence angle, and in the transition from plate to air the polarization of the reflected beam at angles of incidence less than the full reflection angle remains linear and occurs changes the azimuth of the plane of polarization, and for angles of incidence, that more complete reflection angle polarization changes to elliptical. This research and conclusions presented in [1] and [3] based on Fresnel formulas. Thus the conclusion made regarding the reflected beam is right for refracted beam. So 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 incidence angle.

To calculate the amplitudes of the reflected and refracted rays of light beam (electric vector or vector of polarization) decompose on two mutually perpendicular. E_s is the amplitude of the light beam that is perpendicular to the plane of incidence. E_p is the amplitude of the light beam, which is parallel to the plane of incidence. Given that the countdown polarization azimuth is carried from the plane of falling, then the ratio *s*-component beam to *p*-component will determine tg(φ), where φ is the azimuth plane of polarization. Scheme for decomposition the electric vector on *s*- and *p*-component shown in Fig. 1.

While passing beam through the dielectric isotropic plate is happens refraction, reflection, absorption and scattering of radiation. The absorption and scattering of radiation associated with surface roughness and defects of plate. The intensity of the reflected and refracted radiation depends on the material of the plate and the incidence angle of radiation and are defined using Fresnel formulas [6]. Fresnel formulas determine the coefficient of gain (principal value of bandwidth) *s*- and *p*-component of incident beam for the reflected and refracted beam.

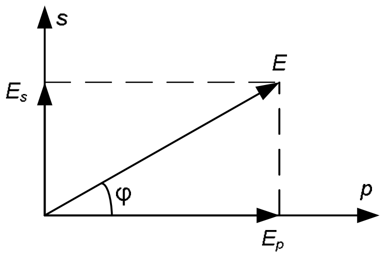

Fig. 1. Scheme decomposition of electric vector on *s*- and *p*-components

For the reflected beam Fresnel formula will look like:

$$\frac{E_{r,s}}{E_{e,s}} = -\frac{\sin(i-r)}{\sin(i+r)}, \quad \frac{E_{r,p}}{E_{e,p}} = \frac{n\cos i - \cos r}{n\cos i + \cos r} = \frac{\mathrm{tg}(i-r)}{\mathrm{tg}(i+r)},$$

where $E_{r,s}$ and $E_{r,p}$ is the amplitude of the *s*- and *p*-component of the reflected beam; $E_{e,s}$ and $E_{e,p}$ is the amplitude of the *s*- and *p*-component of the incident beam; *i* is the incidence angle; *r* is the refraction angle; *n* is the refractive index.

For beam that has passed through limit between two environments (refracted beam) Fresnel formula will look like:

$$\frac{E_{d,s}}{E_{e,s}} = \frac{2\sin r \cdot \cos i}{\sin(i+r)}, \quad \frac{E_{d,s}}{E_{e,s}} = \frac{2\sin r \cdot \cos i}{\sin(i+r)\cdot\cos(i-r)},$$

where $E_{d,s}$ and $E_{d,p}$ is the amplitude of the *s*- and *p*-component of refracted beam, $E_{e,s}$ and $E_{e,p}$ is the amplitude of the *s*- and *p*-component of the incident beam.

The ratio of the gain *s*- and *p*-component of the incident beam to the reflected beam will look like:

$$\frac{E_{r,s}}{E_{e,s}} \Big/ \frac{E_{r,p}}{E_{e,p}} = -\frac{\cos(i-r)}{\cos(i+r)} = \frac{E_{r,s}E_{e,p}}{E_{r,p}E_{e,s}} = \frac{E_{r,s}}{E_{r,p}} \cdot \frac{E_{e,p}}{E_{e,s}}, \quad (1)$$

The ratio of the gain *s*- and *p*-component of the incident beam to the beam that has passed through limit between two environments (refracted beam) will look like:

$$\frac{E_{d,s}}{E_{e,s}} \Big/ \frac{E_{d,p}}{E_{e,p}} = \cos(i-r) = \frac{E_{d,s}E_{e,p}}{E_{d,p}E_{e,s}} = \frac{E_{d,s}}{E_{d,p}} \cdot \frac{E_{e,p}}{E_{e,s}}, \quad (2)$$

Taking into account the scheme decomposition of electric vector on *s*- and *p*-components the equations (1) and (2) will look like:

$$\mathrm{tg}\varphi_r \frac{1}{\mathrm{tg}\varphi_e} = -\frac{\cos(i-r)}{\cos(i+r)}, \quad \mathrm{tg}\varphi_d \frac{1}{\mathrm{tg}\varphi_e} = -\cos(i-r),$$

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.

For refracted beam passing through the first facet of plate $\tan\varphi_d = \cos(i-r)\tan\varphi_e$, this beam will be incident while passing through the second facet of the plate. For refracted beam passing through the two faces of the plat $\tan\varphi_d = \left(\cos(i-r)\right)^2$. Then the values azimuth plane of polarization to the reflected and refracted beam that has passed through the two faces of the plate, can be determined by the following equations:

$$\varphi_r = \mathrm{arctg}\left(-\frac{\cos(i-r)}{\cos(i+r)}\mathrm{tg}\varphi_e\right), \quad \varphi_d = \mathrm{arctg}\left(\left(\cos(i-r)\right)^2 \mathrm{tg}\varphi_e\right). \quad (3)$$

Since for the plate with weakly absorbing material intensity of the incident beam is divided between the reflected and refracted beams so that the majority of intensity is transmitted to refracted beam, then this method is proposed to measure the azimuth plane of polarization for the refracted beam.

Mueller matrix (scattering matrix, the polarization matrix phase or matrix) – a mathematical operator in the theory of light scattering developed by the American physicist Hans Muller. And introduced to describe the interaction of randomly polarized electromagnetic radiation, given Stokes vector with the scattering object, surface or environment element.

Mueller Matrix for transparent isotropic plate has the following form:

$$P_{pl,id} = \frac{1}{2}\begin{bmatrix} k_1+k_2 & k_1-k_2 & 0 & 0 \\ k_1-k_2 & k_1+k_2 & 0 & 0 \\ 0 & 0 & 2\sqrt{k_1k_2} & 0 \\ 0 & 0 & 0 & 2\sqrt{k_1k_2} \end{bmatrix},$$

where k_1 is the principal value of s-component incident radiation bandwidth; k_2 is the principal value of p-component incident radiation bandwidth.

Block diagram of the optical channel measurements shown in Fig. 2. Polarizer *1* is intended for polarization of light, it provides a certain value of azimuth plane of polarization of incident beam. Planar dielectric plate *2* is designed to rotate the plane of polarization depending on the incidence angle. It provides obtaining primary information about incidence angle. Focusing lens *3* is designed to focus polarized beam after dielectric plate on Faraday cell *4*. Faraday cell *4* is designed to modulate polarized beam in an alternating magnetic field. Analyzer *5* is designed to determine the azimuth plane polarization after the dielectric plate. Photodetector *6* is designed to convert azimuth plane of polarization into an electrical signal.

Measurement device consists of two main blocks: block of radiation and block of measurement. One of the blocks is placed at the point of reference, the other is placed on a moving object. The block of radiation is designed to radiate polarized beam with certain value of azimuth plane of polarization. In the simplest case the block of radiation include a laser and polarizer. Block of measurement designed to measure the azimuth plane of radiation polarization that has passed through the dielectric plate. In the simplest case block of measuring include a dielectric plate, focusing lens, Faraday cell, analyzer, photodetector.

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]:

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

where S is power signal; N is power noise; U_S, U_{TH}, U_{SH} are, signals amplitude 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; Δf is passband; θ is the angular amplitude of polarization plane vibrations, changing according to the periodic law: $\theta = \theta_0\Phi(t)$. According to this formula accuracy of measurement will be defined by quality of the optical channel. Accuracy of measurement depending on a solved target problem and can vary in a wide range with the greatest value of accuracy 0.0005°.

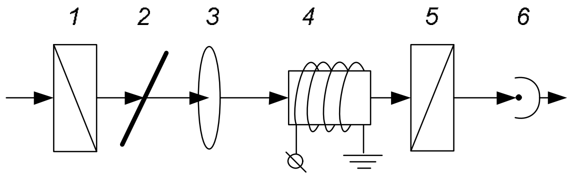

Fig. 2. Block diagram of the optical channel

Equation (3) shows dependence the azimuth plane of radiation polarization after passing through the dielectric plate from the incidence angle and azimuth plane of polarization of incident radiation. One channel of measurement enables to measure the rotation angle of a moving object only around one of the axis. And it is necessary that the object was unmovable around other axes. In this case we can measure the incidence angle or roll angle (rotation plane of incidence radiation polarization). Using two channel of measurements and calculator enables to measure the incidence angle and roll angle. The incidence angle depends on the pitch angle and yaw angle. In this case to measure roll, course and pitch is necessary use three channel of measurement and calculator. Scheme decomposition incidence angle in pitch and yaw angles shown in Fig. 3. The dependence incidence angle from yaw and pitch angles has the following form:

$$i = \operatorname{arctg}\sqrt{\operatorname{tg}^2\vartheta + \operatorname{tg}^2\psi},$$

where i is the incidence angle; ϑ is the pitch angle; ψ is the yaw angle.

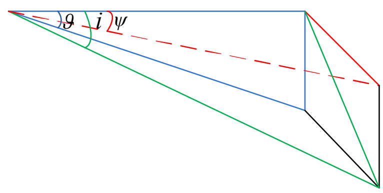

Fig. 3. Scheme decomposition incidence angle in pitch and yaw angles

Using the modulator in block of radiation and calculator in measurement block allows measuring the incidence angle and rotation azimuth of radiation plane polarization (the roll angle in this case) by using one channel. The algorithm of the measurement is as follows.

1. Measure the azimuth of radiation plane polarization after passing through the dielectric plate (φ_{d0}).
2. Rotate the polarization plane of incident radiation to angle δ;
3. Measure the azimuth of radiation plane polarization after passing through the dielectric plate (φ_{d1}).
4. Calculate the difference between azimuths of radiation plane polarization after passing through the dielectric plate Δ: $\Delta = \varphi_{d1} - \varphi_{d0}$.
5. Calculate the coefficient A:

$$A = \frac{1 + \dfrac{\mathrm{tg}\Delta}{\mathrm{tg}\varphi_{d0}}}{1 - \mathrm{tg}\varphi_{d0}\mathrm{tg}\Delta}.$$

6. Calculate the azimuth plane polarization of incident radiation (φ_e):

$$\varphi_e = \mathrm{arctg}\left(\frac{-(1-A) \pm \sqrt{(1-\mathrm{A})^2 - 4A\mathrm{tg}^2\delta}}{2A\mathrm{tg}\delta}\right).$$

7. Calculate the roll angle γ ($\gamma = \varphi_e - \varphi_{e0}$).
8. Calculate the incidence angle (i), solve the equality for this:

$$i \cdot n - \sin i = \sqrt{\arccos\frac{2A\,\mathrm{tg}\varphi_{d0}\mathrm{tg}\delta}{-(1-A) \pm \sqrt{(1-A)^2 - 4A\,\mathrm{tg}^2\delta}}}.$$

To determine the UAV`s attitude (measuring roll, pitch and yaw angles) by using the device with the modulator in radiation channel is necessary use only two channels of measurement and calculator. To determine the UAV`s attitude relative to the horizon or to the plane of boarding is enough to establish ground unit in the horizontal plane or on the plane of boarding and make measurements.

V. Polarimetric Device for Determining UAV Attitude

For proposed method is needed optimum trajectory of landing (glide slope). Deviations from the glide slope of landing approach are measured using the proposed method. Therefore, method most approaches for UAV of plane type. Consider the block diagram of dual-channel polarimetric device for UAV attitude determination during landing approach, which is shown in Fig. 4.

Measurement device consists of two main units: unit of radiation 28 and unit of measurements 27.

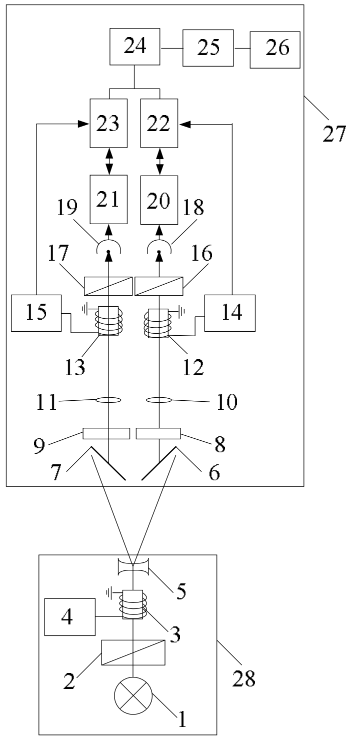

Fig. 4. Block diagram of dual-channel polarimetric device for UAV attitude determination relative to the plane of boarding during landing approach

The unit of radiation 28 included radiation source 1; polarizer 2, which is designed for polarization of radiation; modulator 3, which is designed to rotate the polarization plane of incident on dielectric plates 6 and 7 radiation to angle δ; sound generator 4, which is designed to form the control signals which are submitted for modulator 3; scattering lens 5 which is designed for scattering of polarized radiation for cover plane-parallel dielectric plates 6 and 7 by polarized light. The unit of measuring 27 consists of planar dielectric plates 6 and 7 which are designed to rotate the plane of polarization depending on the incidence angle and azimuth plane of polarization of the incident radiation, they provide obtain primary information about incidence angle and azimuth polarization plane of radiation; optical filters 8 and 9, which are designed to pass definite radiation wavelength; focusing lenses 10 and 11, which are designed to focus the radiation after optical filter 8 and 9 on the Faraday cells 12 and 13; sound generators 14 and 15, which are designed to form the control signals which are submitted for Faraday cells 12 and 13; Faraday cells 12 and 13, which are designed to modulate polarized light in an alternating magnetic field; analyzers 16 and 17 which are designed to determine the azimuth plane of polarization of radiation after dielectric plates 6 and 7; photodetectors 18 and 19, which are designed to definition of azimuth polarization plane; narrowband amplifiers 20 and 21 which are designed to amplification of electrical signal; synchronous detectors 22 and 23, which are designed to increase the sensitivity of measurement by ensuring measuring a minimum signal; microcontroller 24 is designed for the processing of the measurement results obtained in dynamic mode in two measurement channels; the storage unit 25, which is designed to collect information; calculator 26 is designed for computing, provides calculate the difference between azimuths of radiation plane polarization, the coefficient A, the azimuth plane polarization of incident radiation, the angles of roll, yaw and pitch, the incidence angle.

Radiation unit is set on the ground, and the propagation direction of radiation forms a glideslope line. Measuring unit is set on board the UAV in the bow.

VI. RESULTS OF RESEARCH

In paper is represent the principle of operation and block diagram of dual-channel polarimetric device for UAV attitude determination relative to the plane of boarding during landing approach. Two measurement channels are different in that dielectric plates have different installing angle. It provides different incidence angles. As the plane-parallel dielectric plates used diamond plate. The device principle is as follows: via the modulation of incident radiation each measuring channel measures the incidence angle and rotation polarization plane of the incident radiation (roll angle), yaw and pitch angles determined in calculators. The yaw and pitch angles are determined as a result of solving the following system of equations:

$$\begin{cases} i_1 = \operatorname{arctg}\sqrt{\operatorname{tg}^2(\vartheta + \theta_{pl1,v}) + \operatorname{tg}^2(\psi + \theta_{pl1,g})} \\ i_2 = \operatorname{arctg}\sqrt{\operatorname{tg}^2(\vartheta + \theta_{pl2,v}) + \operatorname{tg}^2(\psi + \theta_{pl2,g})} \end{cases},$$

where i_1 is the incidence angle in the 1st channel; i_2 is the incidence angle in the 2nd channel; ϑ is the pitch angle; ψ is the yaw angle; $\theta_{pl1,v}$ is the angle of installing plate in the vertical plane in the 1st channel; $\theta_{pl2,v}$ is the angle of installing plate in the vertical plane in the 2nd channel; $\theta_{pl1,g}$ is the angle of installing plate in the horizontal plane in the 1st channel; $\theta_{pl2,g}$ is the angle of installing plate in the horizontal plane in the 2st channel.

The dependence graph of the azimuth polarization plane of refracted beam from incidence angle at different values of azimuth polarization plane of incident beam is shown in Fig. 5.

Analyzed the dependence graph of the azimuth polarization plane of refracted beam from incidence angle (Fig. 6) we conclude that the dependence is symmetric about the y axis and is depend from azimuth polarization plane of incident beam.

To find optimum azimuth polarization plane of incident beam is need to construct dependence graph of the measurement sensitivity from the azimuth polarization plane of the incident beam for positive and negative incidence angles. Graph is shown in Fig. 6.

Analyzed the dependence graph of the measurement sensitivity from the azimuth polarization plane of the incident beam (Fig. 6) we conclude that the dependence is symmetric relative to zero and has a extremes. The graph shows that the highest sensitivity provides a value azimuth polarization plane $\varphi_e = \pm 68°$. Consequently, polarizer 3 and modulator 4 provides alternately azimuth polarization plane incidence beam of $\varphi_e = +68° / \varphi_e = -68°$.

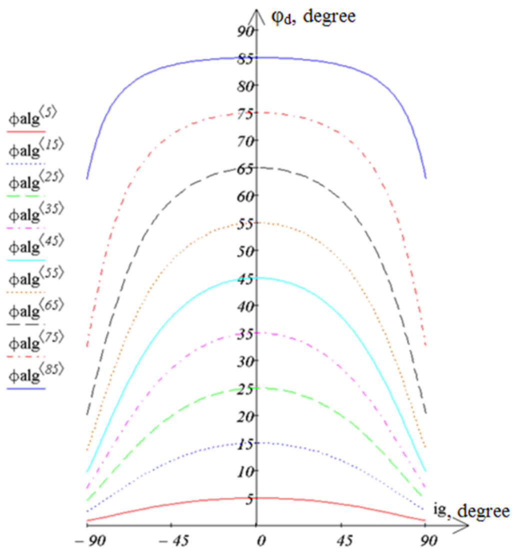

Fig. 5. Dependence graph of the azimuth polarization plane of refracted beam from incidence angle

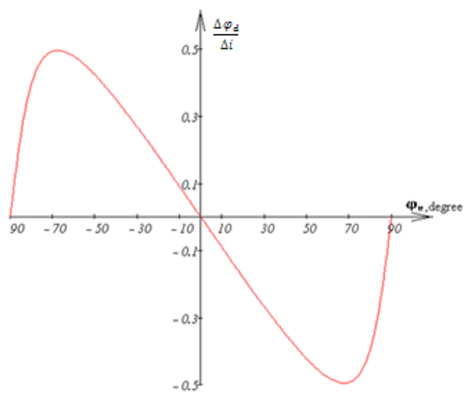

Fig. 6. Dependence graph of the measurement sensitivity from the azimuth polarization plane of the incident beam

To find optimum incidence angle is need to construct dependence graphs of the measurement sensitivity and dependence graphs refracted beam intensity from incidence angle on one graph. The value of the incidence angle point of intersection graphs is optimal incidence angle. It is shown in Fig. 7.

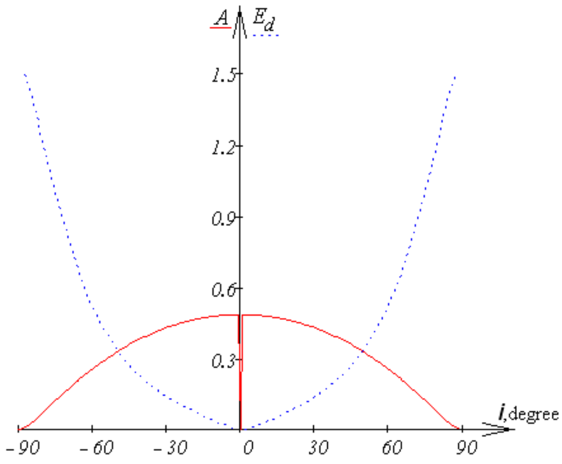

Fig. 7. Dependence graph of measurement sensitivity and refracted beam intensity from incidence angle

Analyzed the dependence graph of measurement sensitivity and refracted beam intensity from incidence angle (Fig. 7) we conclude that the optimum incidence angle (i) is ±52,5°. The optimal installation angle is provided by installation the dielectric plate at an angle to the horizontal plane. Due to the fact that device have two measuring channels it is proposed to install a plate in first channel at an angle 52.5 to the vertical plane and in second channel at an angle 52.5 to horizontal plane. In this case the system of equations (1) will have the following form:

$$\begin{cases} i_1 = \operatorname{arctg}\sqrt{\operatorname{tg}^2(\vartheta + 52,5) + \operatorname{tg}^2(\psi)}, \\ i_2 = \operatorname{arctg}\sqrt{\operatorname{tg}^2(\vartheta) + \operatorname{tg}^2(\psi + 52,5)}. \end{cases}$$

VII. CONCLUSIONS

The paper offers the polarimetric method and device for fixed-wing UAV attitude determination during landing approach. Offers device, unlike other device for attitude determination provides increased accuracy and sensitivity of measurements, determining the attitude relative to the plane of boarding, which is not horizontal and provides simultaneous measurement of roll, yaw and pitch angles. Offers device most approaches for unmanned aerial vehicles of plane type. And the use modulator in channel of radiation reduces the number of required measurement channels. Also in paper is defined the optimal azimuth polarization plane of incident radiation and the optimal incidence angle.

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Received July 17, 2015

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А. Є. Клочан, В. Г. Романенко, В. Д. Тронько, А. В. Скрипець. Двоканальний поляриметричний пристрій для визначення просторового положення БПЛА літакового типу під час заходу на посадку

Розглянуто існуючі методи і пристрої для визначення просторового положення БПЛА і запропоновано поляриметричний метод для визначення просторового положення БПЛА під час заходу на посадку. Цей метод забезпечує підвищення точності вимірювань і визначення просторового положення БПЛА відносно площини посадки, яка не є горизонтальною. Запропоновано блок-схему двоканального поляриметричного пристрої з модулятором в блоці випромінювання. Цей пристрій забезпечує одночасне вимірювання кутів курсу, тангажу та рискання.

Ключові слова: просторове положення; формули Френеля; вимірювальний прилад; метод вимірювань; кут тангажу; плоска ізотропна діелектрична пластина; площина посадки; поляриметр; кут курсу, кут рискання.

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А. Е. Клочан, В. Г. Романенко, В. Д. Тронько, А. В. Скрипец. Двухканальное поляриметрическое устройство для определения пространственного положения БПЛА самолетного типа при заходе на посадку

Рассмотрены существующие методы и устройства для определения пространственного положения БПЛА и предложен поляриметрический метод для определения пространственного положения БПЛА при заходе на посадку. Этот метод обеспечивает повышение точности измерений и определения пространственного положения БПЛА относительно плоскости посадки, которая не является горизонтальной. Предложена блок-схема двухканального поляриметрического устройства с модулятором в блоке излучения. Это устройство обеспечивает одновременное измерение углов курса, тангажа и рыскания.

Ключевые слова: пространственное положение; формулы Френеля; измерительный прибор; метод измерения; угол тангажа; плоская изотропная диэлектрическая пластина; плоскость посадки; поляриметр; угол курса, угол рыскания.

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