Amplitude-polarization method of the moving object pitch detection

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Abstract. There is discussed the amplitude-polarization method of a moving object pitch angle detection using the radio beacon horizontally polarized signals. The moving object pitch angle estimation is done using the ratio of the in-phase orthogonal horizontal linearly polarized radio beacon amplitudes of the signals received within the linearly polarized basis.

1. Introduction

The roll and the pitch angles describing the flying apparatus (FA) movement relatively its mass center are not measured now in the horizontal co-ordinate system (HCS) by the modern angle estimating systems (MAS) [1]. In the practical FA navigation there are used onboard inertial systems of orientation [2,3]. Unfortunately these systems are constantly accumulate the errors of measurement [2,3].

This investigation means to value the possibility of horizontally polarized beacon signals application for the FA pitch angles estimation.

In order to develop a new method of the FA navigation elements estimation it is necessary to present the illuminated and the received vector signals in different polarization basises and in several co-ordinate systems. The choice of the reference co-ordinate system (RCS) depending on the beacon and the FA own co-ordinate system (OCS) depending on its building axes as well as the choice of the measuring co-ordinate system (MCS) depending on the onboard receiving antenna and its UHF elements can be arbitrary and is defined by peculiarities of the problem under consideration.

2. Idea of the amplitude-polarization method

The idea of the amplitude-polarization method for a moving object pitch angle detection is as follows.

Let's suggest that the beacon is at the point (*O*) within the Cartesian co-ordinate system (zero of the immobile RCS). Axes *OX* and *OZ* are horizontal (plane *XOZ*) and the axe *OY* is vertical. The radio beacon illuminates in the direction of the axe *OZ* horizontally polarized signal as a flat simple harmonic wave (fig. 1a).

The illuminated wave within the linear polarization basis (LPB) is presented as a projection of the electric field vector $\vec{\mathbf{E}}$ on the plane *XOY* perpendicular to the propagation direction *OZ*. In such a case vector $\vec{\mathbf{E}}$, in the plane *XOZ* going along the axe *OZ* graphically present the horizontally polarized wave (fig. 1a).

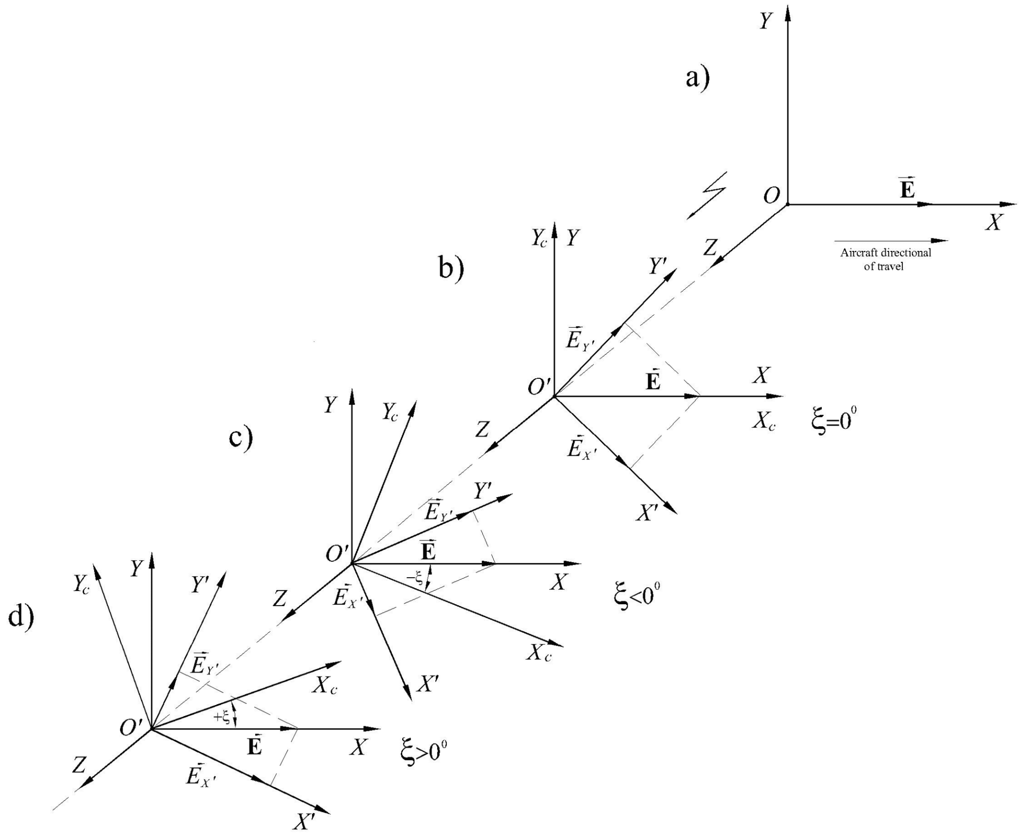

Fig.1 Illustrates the amplitude-polarization method for a moving object pitch angle detection

The FA is moving perpendicular to the axe *OZ*. Let's consider OCS connected with the FA body as a moving Cartesian system $X_cO'Y_c$, made of the length way $O'X_c$ and vertical $O'Y_c$ axes of the FA. O' is the zero point of the system coinciding the FA mass center. The axe $O'Z$ goes along the direction of the signal illumination *OZ*. Axes $O'X_c$ and $O'Y_c$ in the plane of RCS depend on the FA pitch angle ξ. If there is no pitch the axe $O'Y_c$ goes vertically up and coincides the axe *OY*, the axe $O'X_c$ coincides the FA RCS. When there is the FA pitch angle the axe $O'X_c$ changes the direction and the angle between the vector $\vec{\mathbf{E}}$ and the axes $O'X_c$ is equal the FA pitch angle ξ. This provides the physical background of the ξ measurement. If the axe $O'X_c$ is above the horizontal plane *XOZ*, the pitch angle is negative (-ξ) if the axe $O'X_c$ is below the horizontal plane *XOZ* , the pitch angle is positive (+ξ) [1,3,4]. When there is no FA pitch angle the axe $O'X_c$ and the vector $\vec{\mathbf{E}}$ coincide (fig. 1.b).

In order to measure the pitch angle ξ let's make MCS $X'O'Y'$ onboard the FA in such a way that axes $O'X'$ and $O'Y'$ make angle $\theta = \pi/4$ with the FA length way $O'X_c$ and vertical $O'Y_c$ axes (fig. 1.b).

Polarized electromagnetic waves are received by the FA onboard antenna with lobe axe is perpendicular to the FA movement. There is a linear polarized divider (LPD) in the antenna. The LPD orts coincide the co-ordinate axes $O'X'$ and $O'Y'$. Horizontally polarized waves are also received by the LPD which orts also coincide the co-ordinate axes $O'X'$ and $O'Y'$. The chosen LPD orts orientation allows to divide the received horizontally polarized wave (vector $\vec{\mathbf{E}}$) in to two in-phase orthogonally linearly polarized components $\vec{E}_{x'}$ and $\vec{E}_{y'}$. Measured amplitudes $A_{x'}$ and $A_{y'}$ of $\vec{E}_{x'}$ and $\vec{E}_{y'}$ allows to calculate the FA pitch angle ξ.

Let's find the relation of the amplitudes $A_{x'}$ and $A_{y'}$, phases $\varphi_{x'}$ and $\varphi_{y'}$ of $\vec{E}_{x'}$ and $\vec{E}_{y'}$ with the FA pitch angle ξ. The Johns vector and matrixes [5,6] can be used to describe this relation. Signals at the LPD outputs without temporary dependence can be found as follows [7]:

$$\vec{E}_{x'} = [\Pi_1]\left[R(\theta)\right]\left[R(\pm\xi)\right]\vec{E}, \tag{1}$$

$$\vec{E}_{y'} = [\Pi_2]\left[R(\theta)\right]\left[R(\pm\xi)\right]\vec{E}, \tag{2}$$

where $\vec{E} = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$ - Johns vector of the illuminated by the beacon horizontally polarized wave written in the linearly polarized basis.

$\left[R(\pm\xi)\right] = \begin{bmatrix} \cos\xi & \pm\sin\xi \\ \mp\sin\xi & \cos\xi \end{bmatrix}$ - operator of the pitch angle $\pm\xi$ turn;

$+\xi$ - the pitch is positive when the FA length way axe is above the plane *XOZ* [4];

$-\xi$ - the pitch is negative when the FA length way axe is below the plane *XOZ* [4];

$\left[R(\theta)\right] = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix}$ - operator of the $-\theta$ turn in the plane *XOY* [5,6], (θ is the angle of MCS $X'O'Y'$ orientation relatively FA OCS $X_cO'X_c$;

$[\Pi_1] = \begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix}$ - the Johns operator of the LPD first shoulder which own ort has the same direction as the vector $\vec{E}_{x'}$.

$[\Pi_2] = \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix}$ - the Johns operator of the LPD second shoulder which own ort has the same direction as the vector $\vec{E}_{y'}$.

After calculation (1) and (2)

$$\vec{E}_{x'} = \begin{bmatrix} \cos(\theta\pm\xi) \\ 0 \end{bmatrix}, \tag{3}$$

$$\vec{E}_{y'} = \begin{bmatrix} 0 \\ \sin(\theta\pm\xi) \end{bmatrix}. \tag{4}$$

So the outputs of the two-canal receiver, when (3) and (4) are taken into consideration, are

$$E_{x'} = \cos(\theta\pm\xi), \tag{5}$$

$$E_{y'} = \sin(\theta\pm\xi). \tag{6}$$

Taking into account (5) and (6), the phase $\varphi_{x'}$ and $\varphi_{y'}$, as well as the ratio of signal amplitudes $A_{x'}$ and $A_{y'}$ at the outputs of the receiver having, for example, linear amplitude characteristics and a linear detector has the form

$$\varphi_{x'} = \varphi_{y'} = 0^\circ \tag{7}$$

and

$$\frac{A_{y'}}{A_{x'}} = \left|\frac{\sin(\theta \pm \xi)}{\cos(\theta \pm \xi)}\right| = \left|tg(\theta \pm \xi)\right|. \qquad (8)$$

Putting $\theta = \pi/4$ in (8)

$$\xi[rad] = \pm\left\{\frac{\pi}{4} - \operatorname{arctg}\left(\frac{A_{y'}}{A_{x'}}\right)\right\}, \qquad (9)$$

where «+» and «-» mean positive and negative FA pitch.

Equation (9) shows that if $\frac{A_{y'}}{A_{x'}} = 1$ the FA pitch angle $\xi = 0$ (fig. 1.b), if $\frac{A_{y'}}{A_{x'}} > 1$, $\xi < 0$ (fig. 1.c), if $\frac{A_{y'}}{A_{x'}} < 1$, $\xi > 0$ (fig. 1.d).

If the two-channel receiver has logarithmic amplitude characteristics and a linear detector, then (9) is converted to the form

$$\xi[rad] = \pm\left\{\frac{\pi}{4} - \operatorname{arctg}\left(10^{\lg\frac{A_{y'}}{A_{x'}}}\right)\right\}. \qquad (10)$$

4. Conclusion

When the radio beacon illuminates horizontally polarized waves and the electric field vector $\vec{\mathbf{E}}$ lies in the horizontal plane, the FA pitch is calculated using the ratio of in-phase orthogonal linearly polarized amplitudes at the FA shoulders outputs.

The suggested method of the FA pitch angle measurement, compared with those used in practice , is based on a new physical principle and means to use electronic means of measurement utilizing vector properties of signals.

The beacon signal polarization characteristics allows first to avoid errors of measurement accumulation. On the other hand, it allows for joint complex measurements of the aircraft pitch angle using inertial and radio-technical navigation aids.

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