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DISADVANTAGES OF THE INSTRUMENTAL ERROR DETERMINING METHOD OF AIRFIELD QUASI-DOPPLER AUTOMATIC DIRECTION FINDERS

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An increase in the aircraft flights intensity leads to the need to improve the efficiency of the airfield radio equipment functioning. One of the ways to improve the accuracy of navigation equipment is to reduce the instrumental error. The article analyzes the methods of checking the instrumental error of the ADF. Is shown that the so-called “electric rotation” of the antenna system (AS) head used in the radio direction finders ADF-80K, ADF-80, ADF-85, “Platan”, DF-2000 for checking the instrumental error leads to incorrect results. The authors employed the linearity property of the Fourier transform in the simulation to prove the incorrectness of the method for determining the ADF instrumental error with the “electric rotation” of the AS head. The simulation results showed that in the ADF operating in the quasi-Doppler mode, the failure of the vibrators located along the bearing line to the radio source does not lead to the appearance of bearing error, while the failure of the vibrators located orthogonally to the bearing line can result in a bearing error reaching 3.750. The simulation results confirmed that unlike the ADF that use the AS head “electric rotation”, the ADF with mechanical rotation show reliable results of the instrumental error measurement. The paper proposes a new method for checking the instrumental bearing errors using the values of the AS phase non-identities which ensures the reliability of the measurement results.

Keywords: instrumental error, aerodrome automatic direction finders, phase non-identity, antenna system, electric rotation.

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НЕДОСТАТКИ МЕТОДИКИ ОПРЕДЕЛЕНИЯ ИНСТРУМЕНТАЛЬНОЙ ПОГРЕШНОСТИ АЭРОДРОМНЫХ КВАЗИДОПЛЕРОВСКИХ АВТОМАТИЧЕСКИХ РАДИОПЕЛЕНГАТОРОВ

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Увеличение интенсивности полетов воздушных судов приводит к необходимости повышения эффективности функционирования аэродромного радиотехнического оборудования. Одним из путей повышения точности навигационного оборудования является уменьшение инструментальной погрешности. В статье проведен анализ методик проверки инструментальной погрешности АРП. Показано, что используемое в радиопеленгаторах АРП-80К, АРП-80, АРП-85, «Платан», DF-2000 для проверки инструментальной погрешности, так называемое «электрическое вращение» головки антенной системы (АС), приводит к получению не соответствующих действительности результатов. При моделировании, для доказательства некорректности методики определения инструментальной погрешности АРП, с «электрическим вращением» головки антенной системы использовано свойство линейности преобразования Фурье. Результаты моделирования показали, что в АРП, работающем в квазидоплеровском режиме, выход из строя вибраторов, расположенных вдоль линии пеленга на источник радиоизлучения, не приводит к появлению ошибки пеленгования, а выход из строя вибраторов, расположенных ортогонально к линии пеленга, приводит к появлению ошибки пеленгования, которая может достигать 3,750. Результаты моделирования подтвердили, что в отличие от АРП, использующих «электрическое вращение» головки АС, в АРП, использующих механическое вращение, результаты замеров инструментальной погрешности являются достоверными. Предложена новая методика проверки инструментальной погрешности пеленгования с использованием значений фазовых неидентичностей АС, обеспечивающая достоверность результатов измерений.

Ключевые слова: инструментальная погрешность, аэродромные автоматические радиопеленгаторы, фазовая неидентичность, антенная система, электрическое вращение.

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Introduction

Qualitative and quantitative changes in aviation equipment lead to an increase in the intensity of flights, as a result of which there is a need to improve the efficiency of the functioning of airfield radio equipment.

One of the means of radio engineering support for flights are automatic and radio direction finders systems (ADF and RDF).

The use of radio direction finders for air traffic control raised requirements to their bearing accuracy of the ADF, which are due to economic and safety considerations [13]. This explains the appearance in recent years of a large number of publications on improving the accuracy of direction finding of RDFs [3–9, 11, 12, 14–17].

As you know, in order to prevent dangerous approaches, there should be a protective space around each aircraft (AC), within which the presence of another AC is not allowed.

A calculation confirmed that an alignment of such routes as Moscow-St. Petersburg and Moscow-Khabarovsk leads to a saving of flight time by 3-7 minutes per hour of flight, which corresponds to an annual saving of 100 to 200 hours per aircraft [1, 2, 13].

One of the ways to improve the accuracy of navigation equipment is to reduce the instrumental error.

Analysis of methods for measuring the instrumental error in airfield ADF

In the radio direction finders operated in the Air Force (ADF-11, ADF-11M2, ADF-AS), the measurement of the instrumental error of the ADF is performed using a control and test generator by rotating the head of the antenna system (AS).

However, this method is inconvenient and the testing requires a lot of effort. In this regard, such RDF as ADF-80K, ADF-80, ADF-85, “Platan”, DF-2000, operated in civil aviation, use the “electric rotation” of the AS head: instead of rotating the AS head the reference signal is discretely shifted as to display the relative bearing to the radio source.

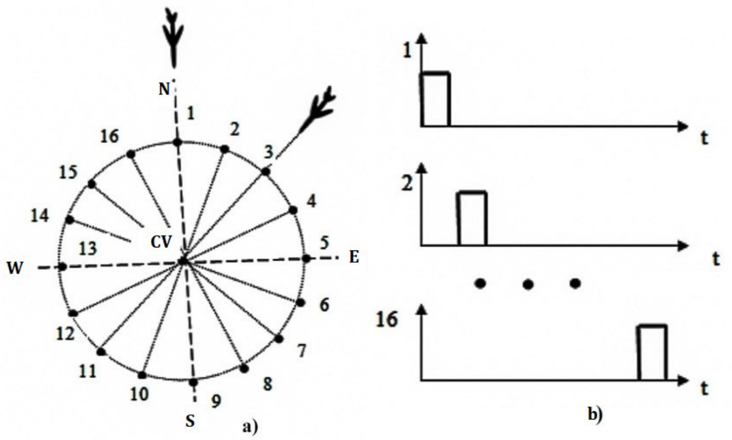

Fig. 1. Explanation of the principle of determining the instrumental error of the ADF by rotating the AS head

However, in practice, there is no “electric rotation” of the antenna head, and the measurements obtained in this way are unreliable.

To explain this, let us consider the principle of the ADF [13].

Figure 1a shows an ADF AS consisting of a central vibrator (CV) and sixteen ring vibrators (RV) arranged in a circle. AS RVs are driven by switching pulses (Fig. 1b).

The first vibrator is directed to the north and is activated by the first switching pulse. The reference signal, relative to which the bearing to the radio source is determined, is shifted 90^0 forward (to the left) relative to the first one.

In civil aviation, sixteen-vibrator wide-base antennas with a diameter of 3.2 m are used.

Figure 2 shows a sample of the phase differences between the RV and CV of the AS when the aircraft is flying towards vibrator 1, which are determined in accordance with the expression [2]:

$$\phi_i = \frac{2\pi R}{\lambda}\cos\beta\cos\left(\theta - \frac{2\pi(i-1)}{N}\right), \quad I = 1, ..., N, \tag{1}$$

where R – the AS radius; N – number of elements of the AS; λ – wavelength of the direction-finding signal; β – aircraft elevation angle; θ – bearing from the aircraft.

Figure 3 shows a sample of the phase differences between the RV and CV of the AC while taking the bearings of an on-board radio station operating at a frequency of 125 MHz, with bearing of 45^0 and elevation angle of 0^0 (the aircraft flies towards vibrator 3).

With the “electric rotation” of the AS, instead of the mechanical rotation of the antenna head, a discrete offset of the reference signal is made relative to the sample of the phase differences of the CV and RV of the AS.

However, the results obtained in this way are unreliable, since the instrumental error is checked only for one of the points, and for the remaining points, the error of forming the phase shift of the reference voltage is added to this error. This is explained in Fig. 4.

In Fig. 4a, the step curve corresponds to a sample of the phase differences of the antenna array signals, with the bearing and the angle of location equal to 0^0.

The sinusoid 1 corresponds to the first harmonic of the envelope sample of the phase differences of the vibrators of the antenna array.

Let the first vibrator be faulty in AS (i.e. the phase difference between the first and the central vibrator is zero).

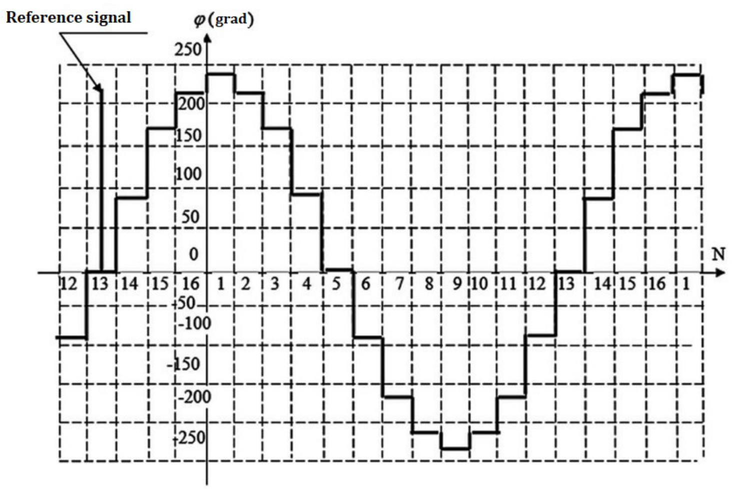

Fig. 2. Sample of phase differences between RV and CV of the AS while taking the bearings of an on-board radio station operating at a frequency of 125 MHz, with bearing of 0^0 and elevation angle of 0^0

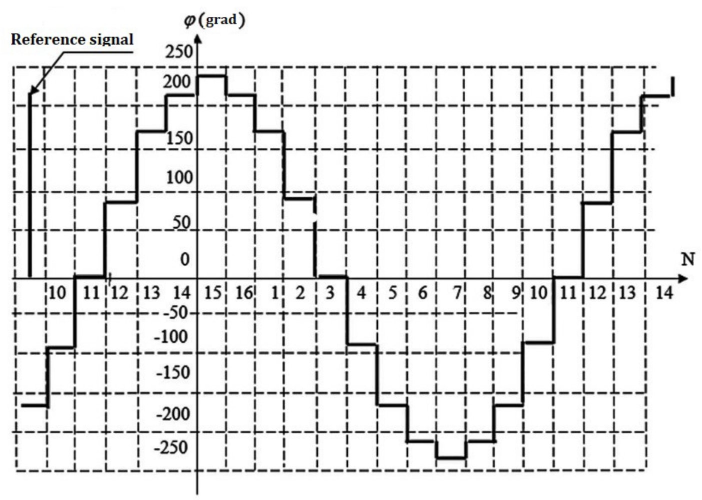

Fig. 3. Sample of the phase differences between the RV and CV of the AC while taking the bearings of an on-board radio station operating at a frequency of 125 MHz, with bearing of 45^0 and elevation angle of 0^0

This can be simulated as the appearance of a phase difference between the central and first ring vibrators of interference, opposite in phase to the signal from the onboard radio station.

Pulse 2 corresponds to the phase difference between the central and first ring vibrators in the presence of only interference.

Sinusoid 3 corresponds to the first harmonic of the phase difference of the interference component between the first and central vibrators.

As you can see from the Figure, sinusoids 1 and 2 are shifted relative to each other by 180^0. In this regard, the sum of sinusoids 1 and 2 give sinusoid 4 coinciding with sinusoid 1 in phase, but with a lower amplitude. Thus, the failure of the vibrator located on the line passing through the aircraft and the central vibrator of the antenna system does not lead to a bearing error.

This is explained by the vector diagram shown in Fig. 4c. Here, vectors 1, 3, 4 correspond to the amplitudes of sinusoids 1, 3, 4 of Fig. 4a. Vector 4 is superimposed on vector 1, so, for ease of perception, vector 4 is slightly shifted to the right.

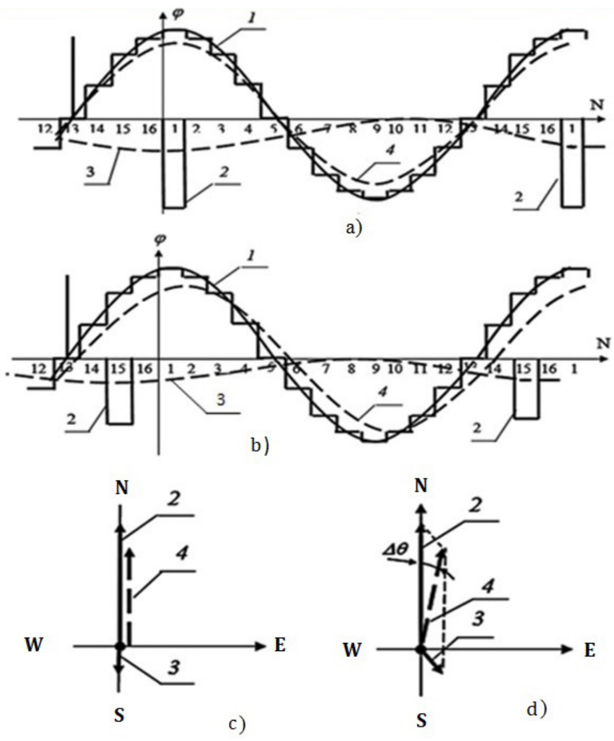

Fig. 4. Time and vector diagrams of the ADF AS operation

Figure 4b shows the case when the fifteenth vibrator of the antenna system is faulty. Here, as in Fig. 4a, sinusoid 1 corresponds to the first harmonic of the envelope of the sample of the phase differences of the antenna array vibrators.

Pulse 2 corresponds to the phase difference between the central and the fifteenth ring vibrators, if there is only interference.

Sinusoid 3 corresponds to the first harmonic of the pulse 2.

As you can see from the Figure, sinusoids 1 and 3 are shifted relative to each other by 135^0. In this regard, the sum of sinusoids 1 and 2 give sinusoid 4, which does not coincide with sinusoid 1 in phase, i.e. there is a bearing error equal to $\Delta\theta$.

This is explained by a vector diagram shown in Fig. 4d.

When the head of the antenna system is mechanically rotated, for example, when it is rotated by 315^0, vibrator 1 takes the position that vibrator 15 occupied before the rotation, which leads to a bearing error. Thus, when the antenna head is rotated mechanically, there is a complete simulation of the control and test generator (aircraft) moving around the antenna.

With the electric rotation of the antenna head, due to the fact that instead of moving the control and test generator or rotating the antenna head, the reference signal is discretely moved, relative to which the bearing is measured, the bearing error caused by the failure of the first vibrator will always be zero.

Calculation of the instrumental error caused by the failure of the AS vibrators

Let us determine the bearing error caused by the failure of the antenna system vibrator, depending on its position relative to the radio source. To do this, we use the linearity of the Fourier transform, according to which the first harmonic of the sample of the phase envelope of the antenna system is equal to the sum of the first harmonics of its components [10].

Let us assume the switching pulse duration of the antenna system vibrators equals τ (for modern domestic ADF, τ = 0.00144 s), and the scanning period of the AS is T (for domestic ADF, T = 0.023 s).

Then, the first harmonic of the Fourier series expansion of the first phase sampling pulse will be equal to:

$$S_{11} = \frac{2\phi_1}{\pi} sin\left(\frac{\pi\tau}{T}\right) cos\omega t. \tag{2}$$

The first harmonic of the i^{th} pulse is determined by the formula,

$$S_{1i} = \frac{2\phi_i}{\pi} sin\left(\frac{\pi\tau}{T}\right) cos\left(\frac{(i-1)\pi}{8}\right) cos\omega t + \frac{2\phi_i}{\pi} sin\left(\frac{\pi\tau}{T}\right) sin\left(\frac{(i-1)\pi}{8}\right) sin\omega t. \tag{3}$$

The coefficients of the Fourier series for the ith pulse are determined by the expressions:

$$a_{i1} = \frac{2\phi_i}{\pi} sin\left(\frac{\pi\tau}{T}\right) cos\left(\frac{(i-1)\pi}{8}\right), \tag{4}$$

$$в_{i1} = \frac{2\phi_i}{\pi} sin\left(\frac{\pi\tau}{T}\right) sin\left(\frac{(i-1)\pi}{8}\right). \tag{5}$$

The sum of the first harmonics that make up the samples of the phase differences of the signals will be determined by the expression:

$$S_{\Sigma} = \sum_{i=1}^{N}\left(\frac{2\phi_i}{\pi} sin\left(\frac{\pi\tau}{T}\right) cos\left(\frac{(i-1)\pi}{8}\right) cos\omega t + \frac{2\phi_i}{\pi} sin\left(\frac{\pi\tau}{T}\right) sin\left(\frac{(i-1)\pi}{8}\right) sin\omega t\right). \tag{6}$$

In order to determine the dependence of the bearing error on the relative position of the faulty vibrator and the bearing on the radio source, a computer experiment was conducted.

The simulation results showed that in quasi-Doppler ADF operating in the meter wave range, a line drawn through the faulty and central vibrators of the antenna system coinciding with the bearing to the radio source does not lead to a bearing error. The failure of the vibrator, located perpendicular to the bearing, leads to an error reaching 3.75^0.

When the ADF operates in the differential-phase mode, a malfunction of the vibrator located orthogonally to the bearing does not lead to a bearing error, but a location along the bearing leads to a maximum error.

It should be noted that the incorrect operation of the ADF due to the failure of the AS vibrator can be detected when checking the phase non-identity of the ADF AS.

Suggestions for ensuring the accuracy of ADF instrumental error measurements

One of the suggestions to ensure the accuracy of the ADF instrumental error measurements is to return to the mechanical rotation of the antenna system head, which, as noted above, is a time-consuming operation.

The instrumental error of the ADF mainly depends on the phase non-identity of the vibrators of the AS.

To determine the phase non-identity of the vibrators, an antenna monitoring generator is connected to the central vibrator of the AS, and the phase differences of the signals between the RV and CV are determined, from which the calculated values of the phase differences are subtracted.

In the ADF that have been put into operation in civil aviation in the last 20 years, the direction-finding information is processed in a channel micro-computer, which allows software to eliminate the drawback in determining the instrumental error.

For example, for a frequency of 125 MHz, for a bearing and a position angle equal to 0^0, phase samples between CV and RV are calculated (Fig. 2). The values of the phase non-identities of the vibrators of the antenna system are added to the phase samples. Based on the obtained values, the bearing is determined taking into account the instrumental error.

The ideal phase samples are calculated for another azimuth, for example, 45^0. The phase non-identity values of the corresponding vibrators are added to the new values of the phase samples. Based on the obtained sample, the bearing is calculated taking into account the instrumental error.

The differences between the specified bearing values and the calculated path found will be the instrumental errors of the ADF for the corresponding azimuths.

Results analysis

In radio direction finders operated in the Air Force (ADF-11, ADF-11M2, ADF-AS), the measurement of the instrumental error of the ADF is performed using a control and test generator by rotating the head of the antenna system. Due to the fact that this method is inconvenient and labor intensive, such RDFs as ADF-80K, ADF-80, ADF-85, “Platan”, DF-2000, intended for operation in civil aviation, use the so-called “electric rotation” of the antenna system head, according to which, instead of rotating the AS head the reference signal is discretely shifted as to display the relative bearing to the radio source. The paper shows that this method gives unreliable measurement results. With this method, the instrumental bearing error is determined by one of the points and the error of forming the reference signal is added to it.

By modeling, it is shown that the failure of any AS vibrator leads to the appearance of an instrumental error, which can reach 3.75^0.

A method for eliminating the disadvantage of determining the instrumental error by a software method using the results of measuring the phase non-identity of the vibrators of the antenna system of the radio direction finder is proposed.

Conclusion

The paper shows that the method of determining the instrumental error based on the so-called “electric rotation” of the antenna system used in the radio direction finders ADF-80K, ADF-80, ADF-85, “Platan”, DF-2000 does not give reliable results.

A method is proposed to eliminate the disadvantage by a software method using the results of measuring the phase non-identity of the antenna system of the radio direction finder.

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