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AIRCRAFT INSTRUMENTS AND INSTRUMENTATION COMPUTER COMPLEXES

Vortex Sensor of Aerodynamic Angle and True Airspeed with Enhanced Functionality

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Abstract—This paper presents the design features and algorithms of processing the data of a vortex sensor of aerodynamic angle and true air speed aboard a subsonic airplane. This sensor provides measurement of the other altitude-speed flight parameters.

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Modern means of measuring the altitude and speed parameters of flight of the aircraft based on several spaced sensors and receivers of the primary information (airflow-angle sensors, air data transducers, stagnation temperature probes), installed in the incoming air stream. Then perception, transmission, conversion of the amplitude informative signals are associated with the initiation of additional instrument errors [1, 2].

The principal possibility of attaining the smaller losses of information in selecting, converting and processing the frequency-time primary informative signals as well as the natural possibility to produce output signals directly in digital form determine the availability of the combined vortex sensor of aerodynamic angle and true airspeed [3].

Figure 1 presents a functional diagram of the vortex sensor of aerodynamic angle and true airspeed [3, 4].

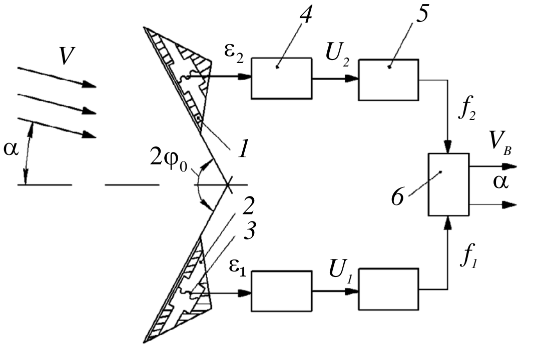

Fig. 1.

The sensor consists of two identical braking bodies *1* made in the form of wedge-shaped pyramids, on the surface of which receivers 2 are placed for intake of pressure pulsations near these bodies. In flowing the wedge-shaped pyramids by the incoming air flow, the velocity and direction of which are determined by the vector $\overline{V}$, equal in magnitude and opposite in sign to the vector $\overline{V_a}$ of the true airspeed of the aircraft, the periodic stall of vortices occurs on their surface. This generates the periodic pressure pulses near the streamlined bodies that spread far away from the body, forming the so-called Karman vortex streets. The frequency f of the periodic formation and stall of vortices depends on the speed V of the incoming air flow, the characteristic size l of the wedge-shaped body base and the angular position φ of the wedge-shaped pyramid base relative to the direction of incoming air flow. In this case, in measuring the aerodynamic angle α the wedge-shaped pyramid bases will be situated at the different angels ($\phi_1 = \phi_0 + \alpha$ and $\phi_2 = \phi_0 - \alpha$) in the incoming air stream. The frequencies f_1 and f_2 of vortex generation beyond the wedge-shaped pyramids will be also different [4].

Receivers 2 are connected with transducers of pressure or pressure differential *3*, the frequencies of output signals ε_1 and ε_2 of which are equal to the frequencies f_1 and f_2 of the corresponding Karman vortex streets. Electrical measuring circuits *4*, processing the signals ε_1 and ε_2, produce the output electrical signals U_1 and U_2. These electrical signals using Schmidt triggers *5* are converted into the sequences of pulses with the frequencies f_1 and f_2. The pulses enter processing device *6*, at the output of which the output signals α and V_a are generated with respect to the aerodynamic angle and true airspeed measured, in accordance with the equations [4]:

$$\alpha = \arctan\frac{f_2 - f_1}{f_1 + f_2},\; V_a = \frac{1}{\sqrt{2}\mathrm{Sh}}\frac{f_1 f_2}{\sqrt{f_1^2 + f_2^2}}, \tag{1}$$

where Sh is the Strouhal number of the wedge-shaped pyramid.

As shown in the paper [4], the range of operating speeds for the vortex sensor of the aerodynamic angle and true airspeed is limited by the subsonic speeds of flight (30–1200 km/h), the measurement range of the aerodynamic angle is in the interval (–15° –+35°). As shown in the analysis [5, 6], the mean square errors of the vortex sensor with respect to the true air speed channel does not exceed a value $\sigma_{\Delta V} = 3.7\ \mathrm{km/h}$, for the channel of the aerodynamic angle it does not exceed $\sigma_{\Delta\alpha} = 0.15°$.

It is proposed the wedge-shaped pyramids to be placed on the same axis one above the other. To ensure measurements in the three-dimensional incoming air flow and to eliminate the influence of the other aerodynamic angle, namely, the slip angle β of the true airspeed vector, the flow straighteners are installed perpendicular to the common axis of wedge-shaped pyramids. The straighteners are made in the form of thin flat disks that are located on the upper and lower bases of wedge-shaped pyramids. As an example we can represent the flow receiver of the vortex sensor of aerodynamic angle and true speed with the flow straightener (Fig. 2) [4].

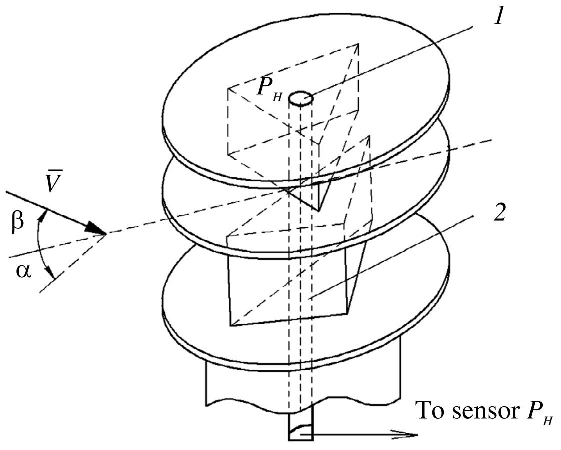

Fig. 2.

To expand the functionality of the vortex sensor of aerodynamic angle and true airspeed and obtain primary information about all the altitude and speed parameters of the aircraft using a single integrated multifunctional sensor, it is proposed hole-receiver *1* for perception of the static pressure P_H of the incoming air flow to be placed on the outer surface of the upper flow straightener (Fig. 2). This pressure in pneumatic channel *2* is registered at the input of the sensor of absolute pressure P_H, the output signal of which will be proportional to the perceived static pressure P_H at the flight altitude *H*.

Then the current absolute barometric altitude of flight is determined by the pressure P_H in accordance with the standard dependencies, for example, at –2000 m < *H* < 11000 m, according to the following formula [3]

$$H = \frac{T_0}{\tau}\left[1 - \left(\frac{P_H}{P_0}\right)^{\tau R}\right], \tag{2}$$

where $T_0 = 288.15\,\text{K}$ is the average absolute temperature at sea level; $P_0 = 101325\,\text{Pa}$ is the average absolute pressure at sea level; $\tau = 0.0065\,\text{K/m}$ is the temperature gradient that determines the change of the absolute air temperature T_H at altitude measurement; $R = 2927125\,\text{m/K}$ is the gas constant; P_H is the absolute pressure at the current altitude *H*.

The true air speed of the aircraft, measured by the vortex sensor can be represented as follows

$$V_a = \sqrt{2gRT_H\left(\frac{k}{k-1}\right)\left[\left(\frac{P_{dyn}}{P_H}+1\right)^{\frac{k-1}{k}} - 1\right]} = \sqrt{2gRT_H\left(\frac{k}{k-1}\right)\left[\left(\frac{P_t}{P_H}\right)^{\frac{k-1}{k}} - 1\right]}, \tag{3}$$

where $g = 9.80665\,\text{m/s}^2$ is the acceleration of gravity; $k = 1.4$ the adiabatic exponent of air; $P_t = P_H + P_{dyn}$ the total pressure of the incoming air flow; $P_{dyn} = \frac{\rho_H V_a^2}{2}$ is the dynamic head (dynamic pressure) of the incoming air flow; ρ_H is the air density at the flight altitude *H*, which can be presented as [7]

$$\rho_H = \rho_0 \frac{P_H T_H}{P_0 T_0}, \tag{4}$$

where $\rho_0 = 0.125\,\text{Ns/m}^4$ is the air density at altitude $H = 0$.

Using expressions (3) and (4), we can obtain the relation for calculation of the temperature T_H at the flight altitude in the implicit form

$$T_H = \frac{V_a^2}{2gR\left(\frac{k}{k-1}\right)\left[\left(1 + \frac{\rho_0}{2P_0T_0}V_a^2 T_H\right)^{\frac{k-1}{k}} - 1\right]}. \tag{5}$$

Determining from relation (5) the absolute temperature T_H according to relation (4) we can calculate the air density ρ_H at this altitude *H*.

Then the indicated speed V_{ind}, that is the true air speed, is reduced to normal ambient conditions at a level $H = 0$ can be calculated by the formula

$$V_{ind} = \sqrt{2gRT_H\left(\frac{k}{k-1}\right)\left[\left(1 + \frac{\rho_0}{2P_0}V_a^2\right)^{\frac{k-1}{k}} - 1\right]}. \tag{6}$$

At subsonic flight speeds, the equation for determining the Mach-Maevskii number is presented in the form:

$$M = \sqrt{\frac{2}{k-1}\left[\left(1+\frac{\rho_0 T_H}{2P_0 T_0}V_a^2\right)^{\frac{k-1}{k}} - 1\right]}. \tag{7}$$

Thus, the altitude and speed parameters of the aircraft flight are calculated by using the vortex sensor of aerodynamic angle and true airspeed and the additional hole-receiver of absolute pressure at the given altitude and so information is perceived by one multifunctional sensor. In this case, the absence of moving parts in the incoming air flow ensures the high reliability of the sensor operation in the real operating conditions that determines the prospects of applying the vortex system of air signals aboard subsonic aircraft of various classes and designation as well as small-sized aircraft and other objects of small aircraft.

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