UDC 621.39.1:621.378:532.57

V.M. Zemlyanskiy, DSc., M.O Gusev, A.V Ovenko (National Aviation University, Ukraine), M.R Mirza, PhD (Institute of Space Technology, Pakistan)

Laser Measurement Device for Air – Speed (LMDAS) parameters of Aircraft

A new LMDAS is proposed, in which the below-mentioned disadvantages [1] are eliminated. The LMDAS is a laser instrument of true airspeed, angles of attack and side slip, which uses the Doppler effect and a system equations for their determinations.

There is a laser instrument of true airspeed, angles of attack and side slip, which uses the Doppler effect and a system of equations for their determination [1]. Its disadvantage is the low accuracy of the measurement, due to the fact that:

- Four lasers are used that probe the airflow in four spatially different measurement zones, the speed parameters of which are not correlated and can differ significantly from each other;

- the geometry of reception of radiation in the direction of eight beams whose angular parameters depend not only on the design of the aircraft but also cannot be accurately mounted, because the four optical axes of the probing and receiving circuit are in different compartments of the aircraft at a distance from each other more than 3 - 6 m, therefor when these inaccurate angular parameters are substituted into the system of equations ([2], (4) and (5)) and their solutions, then it is found that it leads to determination of (V, α and β) with a large errors.

- In addition, it does not measure the signs of the projection of the speed Vxz, which introduces uncertainty in the solution of the system of equations ([1], (4) and (5)), as well as its operating altitude range from 10 to 35km, when spontaneous coherent radiation of molecules of air flow is observed, excited by a powerful laser beam.

At high altitudes from 0 to (3-10 km), a powerful laser probing beam [1] causes the corresponding high-power scattered radiation on the air micro particles, which greatly exceeds the power of spontaneous emission, in addition, the temperature rise in the measurement zone introduces a methodical error in air- speed parameters.

A LMDAS option is proposed, in which the above-mentioned disadvantages are eliminated (FIG. 1, FIG. 2).

The device is shown in FIG. 1 and the diagram in FIG. 2

Laser 1 emits a monochromatic beam 2 with a frequency ω0. The focusing lens 3 focuses the beam 2 (FIG. 1) at point 4 (measuring volume), through which the air flow moves at a velocity$\vec{V}$. Measurement zone 4 is located on the longitudinal axis of the aircraft OX, behind the sound barrier, that is, in the area of unexcited airflow. At altitudes of the aircraft from 0 to 10 km in the air flow there are both micro particles and molecules present, on which the laser radiation is scattered. In this range of heights, the power of the laser beam 3 is minimal and of such magnitude that it provides a signal - the noise at the output of the photo detectors is more than 10. When flying at high altitudes up to 35 km, the beam power 3 is maximal (in the beam power range from the flight altitude) to provide a mode for spontaneous coherent radiation of molecules [1] of the air medium, which is taken in the directions 9, 10, 11, 12, 42 and 43. The first 5, second 6 and third 41 optical channels are arranged identically and are designed to receive scattered radiation from the region of point 4.

The optical axis 7 of the first channel 5 and the optical axis 8 of the second channel 6 are placed in the same plane with the optical axis OX of the device (FIG. 1 and FIG. 2) and intersect it at point 4 at the same angles β. In this case, the first optical channel extracts scattered beams 9 and 10 located in the vertical plane OXZ at angles α / 2 with respect to its optical axis 7, using a reception lens 32 and an opaque screen 15 with two holes. The extracted beam 9 has a frequency $\omega_0 + \omega_{g9}$, and the beam 10 has a frequency $\omega_0 + \omega_{g10}$. Here ω_g9 and ω_g10 are the Doppler frequency shift in the scattered beams 9 and 10, which are determined by the flow rate V in the measurement volume, the beams 9, 10 are spatially aligned by a two-beam interferometer that consists of a mirror 17 constituting the combining prisms 19. Since the beam 10, when passing through the frequency offset device 37 connected to the high frequency generator 39, receives a frequency offset by value $\omega_{ml}=2\pi f_{ml}$, where f_{ml} is the frequency of the high frequency generator 39, then the combining beams 21 and 22, at the output component combining prism 19 have a frequency $\omega_0 + \omega_\partial$ and $\omega_0 + \omega_{ml} + \omega_{\partial 10}$.

At the output of the photodetector 25 as a result of optical heterodyning, a high-frequency signal is formed at a frequency:

$$\omega_1=\omega_{m1} - (\omega_{g9}-\omega_{g10}) = \omega_{m1} - 2K\sin\frac{\alpha}{2} V_{xz}\cos(\gamma - \alpha_x), \quad (1)$$

where К = 2π / λ – modulus of wave vector with wave length λ;

Vxz – projection of velocity vector of flow V on plane OXZ;

γ - is the angle between the OX axis and the direction of the difference vector $\vec{K}_1 = \vec{K}_{s11} - \vec{K}_{s12}$, the extracted beams 9, 19 α_x - is the angle between the OX axis and the direction of the *Vxz* projection of the velocity vector. On the plane OXZ (FIG. 1, FIG. 2). The second optical channel extracts scattered beams 11 and 12 located in the vertical plane OXZ also at angles α / 2 with respect to its optical axis, with the help of a receiving lens 32 and an opaque screen 16 with two apertures. The separated beams 11 and 12 are spatially aligned by a two-beam interferometer which consists of a mirror 18 and a component of the prism-combiner 29. Since the beam 12, when passing through the frequency offset device 28 connected to the high frequency generator 40, receives a frequency shift by an amount $\omega_{m2}=2\pi f_{m2}$, where f_{m2} ($f_{m2}> f_{ml}$) is the frequency of the high frequency generator 40, then the combining beams 23 and 24 at the output of the component of the prism-combiner 20 have frequencies $\omega_0+\omega_{д11}$ to $\omega_0+ \omega_{m2}+ \omega_{g12}$. At the output of the photo-detector 26, a signal is produced at the frequency:

$$\omega_2+ \omega_{m2}-(\omega_{g11}-\omega_{g12}) = \omega_{m2}- 2K\sin\frac{\alpha}{2}V_{xz}\cos(\gamma- \alpha_x), \quad (2)$$

where ω_{g11} and ω_{g12} – is the frequency shift in scattered beams 11 and 12, which determines velocity Vy in measurement volume 4; γ – angle between axis OX and direction of difference vector $\vec{K}_2=\vec{K}_{s21}-\vec{K}_{s22}$, of separated beams 11, 12. Optical circuit of dual frequency interferometer in every measurement channel provides spatial alignment of wave vector of two beams, which receives with the accuracy of seconds, whereas difference of optical path at interferometer is close to zero. High frequency signals from output of photo-detector 25 of first optical channel 5 and from output of photo-detector 26 of second optical channel 6 applies respectively at first and second input of combiner 27. Signal from the input of combiner 27 applies at inputs of first low pass filter 28 and first high pass filter 29. At the output of the first low pass filter 28; a differential frequency signal is extracted.

$$\omega_1 - \omega_2 = (\omega_{m1} - \omega_{m2})-(8\pi)/\lambda\sin\frac{\alpha}{2}V_z\cos\beta, \quad (3)$$

Where: Vz – projection of velocity vector $\vec{V}$ on axis OZ, this signal is applied at first input of second combiner 53. At the second input of combiner 53 applies signal with frequency $\omega_{m1}-\omega_{m2,}$ which is formed by feeding on first and second inputs of fifth combiner 55 signals from outputs of high frequency generator 39 and 40 respectively, and the subsequent isolation of the frequency difference signal at the output of combiner with the help of second low pass filter 61. Signal of difference frequency is:

$$\omega_x=(\frac{8\pi}{\lambda})\sin\frac{\alpha}{2}V_z\cos\beta\ , \quad (4)$$

from the output of the second combiner, through the band-pass filter, to the first input of the first Doppler frequency meter 30 whose second input through the first frequency discriminator 57 tuned to $\omega_{m1} - \omega_{m2}$ - is connected to the output of the first low-pass filter 28. With the first Doppler frequency meter 30 the value of the projection of the velocity vector Vx is measured in real time and its sign is determined.

At the output of first high pass filter 29; the sum of frequencies signal is separated:

$$\omega_1 + \omega_2 = (\omega_{m1} + \omega_{m2}) - (8\pi)/\lambda \sin\frac{\alpha}{2} V_z \sin\beta, \quad (5)$$

where Vx = is projection of vector of flow velocity V on axis OX. This signal is applied on first input of third combiner 54. On the second input of combiner 54, signal applied with frequency $\omega_{m1} + \omega_{m2,}$ which is extracted through second high pass filter 60 from out of fifth combiner 55. Signal of difference frequency will be:

$$\omega_x = (\frac{8\pi}{\lambda}) \sin\frac{\alpha}{2} V_x \cos\beta, \quad (6)$$

from the output of third combiner 54, through band filter 75, applies on first input of second Doppler frequency meter 31, second input of which through second frequency discriminator 58, tuned on frequency $\omega_{m1} + \omega_{m2}$ connected to output of first high pass filter 29 with the help of second Doppler frequency meter 31, measures real time value of projection of velocity vector Vx and determines its sign.

The third optical channel 41 separates scattered beams 42 and 43 placed in the horizontal plane OXY in fig. 1. At an angle α / 2 with respect to optical axis of device, with the help of o objective 32 and opaque screen 45 with double apertures. The separated beams 42 and 43 are spatially aligned by a two-beam interferometer, which consists of a mirror 46 and a prism component-an interferometer that consists of a mirror 46 and a prism-mixer component 49. Since the beam 42, upon passing through the frequency offset device 47 connected to the high frequency generator 48, obtains a frequency offset of $\omega_{m3} = 2\pi f_{m3}$ where $2\pi f_{m3}$ is the frequency of the high frequency generator 48, then the mixed beams 50 and 51 at the output of the prism component-mixer 49 have frequencies:

$\omega_0 + \omega_{\partial 43}$ and $\omega_0 + \omega_{m3} + \omega_{\partial 42}$;

These beams 49 and 50 pass the interference filter 71 and are further focused by the lens 72 on the point aperture of the aperture diaphragm 72 installed in front of the photo-detector 52, similarly for beams 21 and 22 directed to the photo-detector 25, as well as beams 23, 24 directed to the photo-detector 26. At the output of the photodetector 52, as a result of optical heterodyne generation, a high-frequency signal is produced at a frequency:

$$\omega_3 = \omega_{m3} - (\omega_{g42} - \omega_{g43}) = \omega_{m3} - 2K\sin\frac{\alpha}{2} V_{Y,} \quad (7)$$

where: K = 2 π / λ - modulus of the wave vector with wavelength λ; VY is the projection of the flow velocity vector V onto the OY axis. In this case, the direction of the difference vector $\vec{K}_3 = \vec{K}_{s31} - \vec{K}_{s32}$, of the extracted beams 42 and 43 coincides with the direction of the OY axis. The signal from the output of the photo-detector 52 is input to the third frequency discriminator 59 tuned to the frequency ω_{m3} and to the first input of the fourth mixer 56 whose second input receives a signal with a frequency ω_{m3} from the output of the third high frequency generator 48. From the output of the mixer 56, through band-pass filter 76, frequency difference signal:

$$\omega_y = — sin – V_{y,} \qquad (8)$$

It applies at the first input of the third Doppler frequency meter 62, the second input of which is connected to the output of the third frequency discriminator 59.

With the help of the third Doppler frequency meter, the projection of the velocity vector VY is measured in real time and its sign is determined.

Signal from outputs 30, 31 and 62 enters onboard digital processor 77, which processes through known equations with high accuracy, vector of true air speed V, angle of attack α and side slip β.

High measurement accuracy V, α, β is achieved due to the fact that the instrument uses single receive - optical unit, manufactured with high accuracy, in addition one (in place of four [1]) probing laser beam, which focuses at zone of measurement on longitudinal axis of aircraft, more over its angular position with relation to longitudinal axis of aircraft is independent of measurement accuracy.

References

1. Patent of Russian Federation RUNo.2314541 "Method and device for determining airspeed parameters of flight of aircraft" Bulletin No,200

Fig. 1.

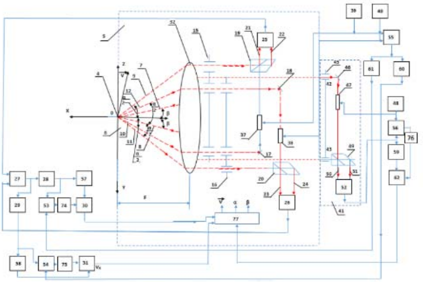

Fig. 2.