WIND VELOCITY MEASUREMENTS WITH A DOPPLER LIDAR BASED ON THE USE OF A SINGLE FREQUENCY TEA CO_2 LASER

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A Doppler lidar (DL) based on the use of a single frequency TEA CO_2 *laser is described. Typical results of simultaneous measurements of the wind velocity vector with the help of the Doppler lidar and standard meteorological instrumentations mounted on a high meteorological mast are shown. The experimental DL setup makes it possible to reliably determine the wind velocity under standard atmospheric conditions with the accuracy of* 2–3 m/s *at distances longer than* 2 km, *and with an additional adaptive amplifier – at distances up to* 10 km.

The problem on measuring wind velocity with the help of Doppler lidars based on the use of CO_2 lasers is a promising fundamental and applied research field. At present the Doppler lidars based on the use of cw CO_2 lasers are the most advanced instruments capable of measuring the parameters of wind flows at distances up to several hundred meters.[1]

A cw DL may be constructed following the optical arrangement of the Mach–Tsander interferometer, in which one of the mirrors is substituted by a transceiving telescope.[2] The parameters of such a DL are the following: the wavelength is 10.6 μm, the frequency shift of the local oscillator emission is 26 MHz, and the transcieving telescope diameter is 15 cm. A signal from the photodiode, whose spectrum bears the information about the wind velocity along the sounding path,[3] is applied to the spectral analyzer input via a pre–amp, and then it is processed by a computer. To obtain the necessary localization and provide the remote character of measurements, a corresponding focusing of a sounding beam is used.[1]

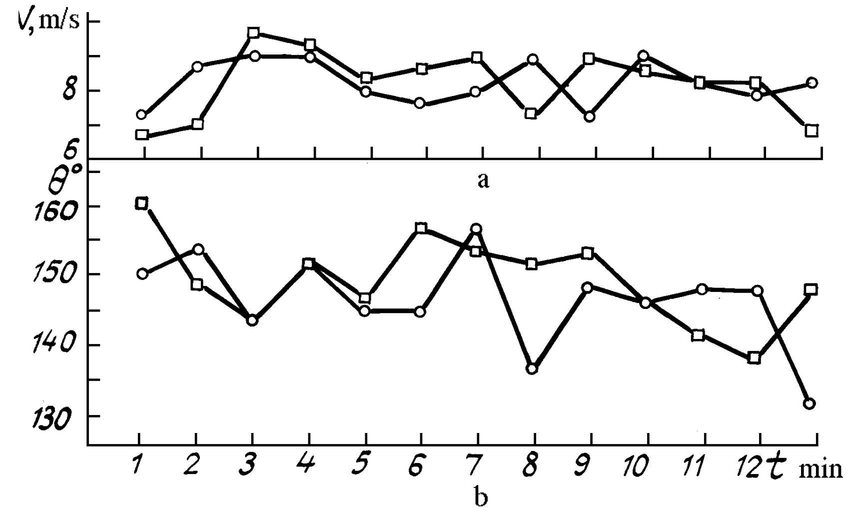

FIG. 1. Simultaneous measurements of wind velocity vector by the DL (i) and the HAMM anemometer (◊). The distance to the focusing point is 200 m, elevation angle is 68#, azimuth angles are 0, 100, and 300#; an anemometer is mounted at the 75 m height. a) wind velocity module (V) and b) azimuths (θ). Corresponding values averaged over the whole observational period are shown on the left.

Figure 1 shows typical results obtained in simultaneous measurements of the wind velocity vector, by the DL and by the standard meteorological instrumentations installed on the High–Altitude Meteorological Mast (HAMM).[4] The measurements have been conducted according to the following technique. First, three DL measurements are made at three azimuth angles while the elevation angle and the focusing distance of the telescope is fixed. The wind vector is determined by processing thus obtained three projections. Measurement range of the cw DL did not exceed 1 km.

Further increase of sounding range is possible when using a pulsed TEA CO_2 laser as a source of sounding radiation. We have developed[5] a single–frequency pulsed injection seeded TEA CO_2 laser delivering about 300 MJ energy per pulse of 2 μs duration with the emission spectrum only 0.4–0.6 MHz wide. The beam diameter is about 10 km. In the experiments on sounding the atmosphere with the DL we used a bistatic optical arrangement of measurements. In this arrangement the sounding beam emitted from a TEA CO_2 laser is directed

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into the atmosphere by a beam folding mirror 150 mm in diameter. Radiation backscattered by the atmospheric aerosol, is collected by a telescope 100 mm in diameter onto a HgCdTe photodetector. Radiation from the reference frequency–stabilized cw laser local oscillator was also directed onto the photodetector (see Fig. 2).

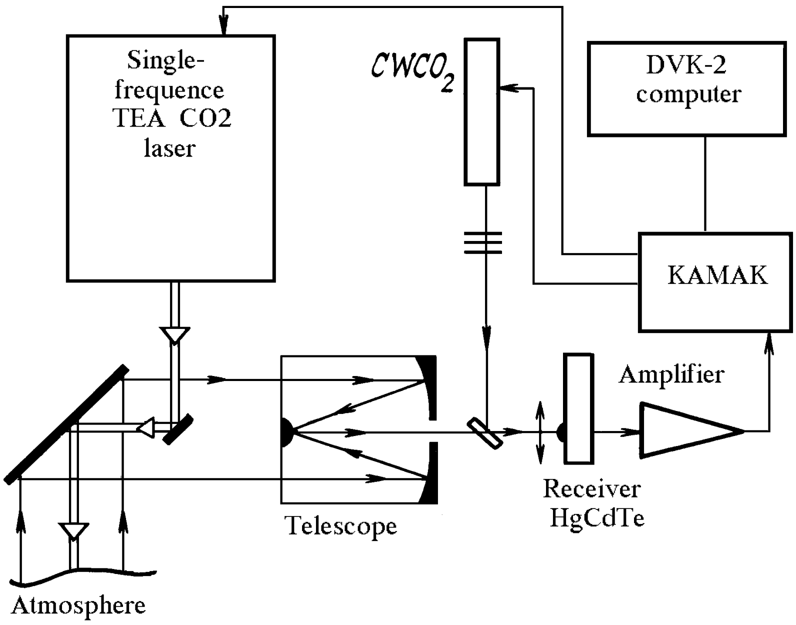

FIG. 2. Block diagram of the Doppler lidar.

The use of such a monostatic optical arrangement, in which the optical axes of the receiver and transmitter are spaced, enables one to avoid overloading of the photodetector by extraneous light from parasitic reflections in the DL transceiver.

The heterodyne frequency was selected in the optimal range from 4 to 5 MHz. The heterodyne signal was amplified by a low–noise amplifier and digitized by a fastresponse ADC, having a discretization time of 25 ns and a 2 K buffer memory of 6–bit words. The heterodyne signal was spectrally analyzed using the algorithm of fast–Fourier transform. A weighted mean frequency of the spectrum of a scattered signal was estimated using the 3σ technique. For determining this frequency in the case of motionless scatterers a model was employed for describing propagation of laser pulses that allows for actual temporal and frequency characteristics of the atmosphere. The difference between the two frequencies bears the information about the average velocity and direction of wind.

A model, similar to that used in the description of the cw DL, is based on the assumption that the positions of scattering aerosol particles in the atmosphere are mutually independent. In this case the power spectrum of the heterodyne signal describes the sum of power spectra of the heterodyne signals from individual scatterers.[1] Our model accounts for the pulse mode of probing and for finite time of detection of scattered radiation (only a fragment of a heterodyne signal is extracted from the ADC memory every time). The spectral power of the heterodyne signal coming from the distance L is described by the formula

$$S(\nu, L) = \int\limits_{\Delta L} \frac{2e^2\eta^2 P_{lo}\beta(\pi)e^{-2\sigma L}[\Phi|_{t1}^{t2}[(\sqrt{P_0}\exp(i(\omega_l-\omega_{lo}+\omega_d))t)]^2}{h^2\nu^2L^2[1+(\pi R^2/\lambda L)^2(L/F-1)^2][1+(2R/r_c)^2]}\mathrm{d}L,$$

where t_1 is the time interval between the start of the laser emission and recording; t_2 is the time interval between the laser emission start and termination of recording the scattered signal;

$$\Phi\Big|_{t1}^{t2}(\sqrt{P_0}\cdot\exp(i(\omega_l-\omega_{lo}+\omega_D)t))$$

is the Fourier transform of a portion of the laser pulse as a function of t_1, t_1, and L; $P_0(t)$ describes the temporal behavior of the detected signal; e is the electron charge; $h\nu$, λ are the energy of the quantum and the wavelength of sounding radiation, respectively; η is the quantum efficiency of the detector; $\beta(\pi)$ is the backscattering coefficient of the atmosphere; σ is the extinction coefficient of the atmosphere; R, F are the radius and the focal length of the telescope, respectively; P_{lo} is the emission power of the local oscillator; ω_l, ω_{lo}, ω_D are the frequencies of sounding radiation, radiation of the local oscillator, and of the Doppler shift, respectively; and, r_c is the radius of coherence of backscattered radiation, which depends on the atmospheric turbulence.

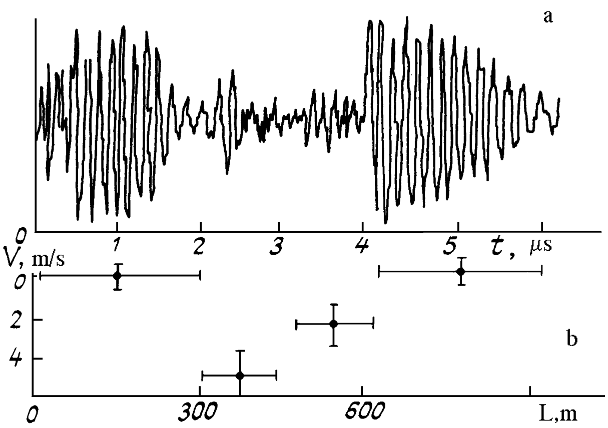

FIG. 3. Heterodyned signals of radiation backscattered by the atmosphere (a) and corresponding wind velocity values (b).

Data on both the temporal and the frequency characteristics of the sounding pulse are obtained by processing the heterodyne signal received during the first two microseconds after the emission of a sounding laser pulse. During this interval the radiation is detected, which is parasitically scattered from the surfaces of the beam folding mirrors. A heterodyned signal of radiation scattered by the atmosphere and corresponding values of wind velocity calculated using the above model are presented in Fig. 3.

When sensing the atmosphere to distance longer than 2 km, a problem arises on detection of weak signals because of decrease in its during the recording time due to the extinction losses in the atmosphere. This problem can be solved by using an adaptive amplifier with a time variable gain. An increase in the amplifier gain should compensate the fall off of the heterodyne signal with distance.

We have developed the amplifier with the synchronously switched regulated gain. The developed prototype of the Doppler lidar is capable of reliably determining wind velocity under standard atmospheric conditions with the accuracy 2–3 m/sec at a distance longer than 2 km, and a distance up to 10 km when using the regulated gain amplifier.

Sounding range can be essentially extended above 10 km when a more sophisticated monostatic optical arrangement of the DL is used. This arrangement, however, requires the use of an efficient optical shutter to lock the parasitic light due to scattering on the optical components of the transfer. Such a shutter can be made of an optoacoustic detector having a fast response (~ 100 ns) and the rejection factor better than 80%. In this case the extraneous light due to parasitic reflections on optical components occuring at the initial moment is deflected off from the photodetector. Then in about 1 μs, the scattered radiation is deflected to the photodetector.

We believe it promising to combine a cw and a pulsed Doppler lidars in wind measurements. Simultaneously operating versions of the DL can cover the whole range from the instrument to the maximum range each covering its own subrange. The cw DL measures wind velocity at the distances up to 1 km, while the pulsed one – to the distances starting from 300 m (that is a blind zone for our DL). The latter feature is important for studying wind flows in the surface atmospheric layer. The data on wind velocity, simultaneously obtained with both the cw and the pulsed DL's in the range from 300 m to 1 km may be used for mutual intercalibration of these two instruments.

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