APPLICATION OF A HETERODYNE LASER SYSTEM TO DETERMINE PARAMETERS OF TURBULENT ATMOSPHERE

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The use of a heterodyne laser system in atmospheric measurements has been proposed. The continuous registration of optical phase variations of radiation propagating in the atmospheric channel has been carried out. From recorded data, the integral characteristics of a turbulence state in the radiation propagation channel are obtained.

1. Introduction

The phase dynamics of an optical field in the atmosphere is of great importance for coherent optical systems. For general purposes, one needs both the monitoring of changes of this parameter of radiation and the quantitative estimates of a state of a channel with the turbulence.

The measurement of spatial variations of the phase characterizes certain parameters of the turbulence [1]. However, in practical tasks of optical communication and remote sounding, it is often required to register the time changes of phase instant values. Such measurements impose certain requirements for a registration system since, in extensive atmospheric channels, the phase can strongly fluctuate and take great values.

By functional possibilities, the laser heterodyning allows one to build the required measuring system [2]. By automatizing the processing of recorded data, it is possible to calculate the necessary characteristic parameters of a propagation medium.

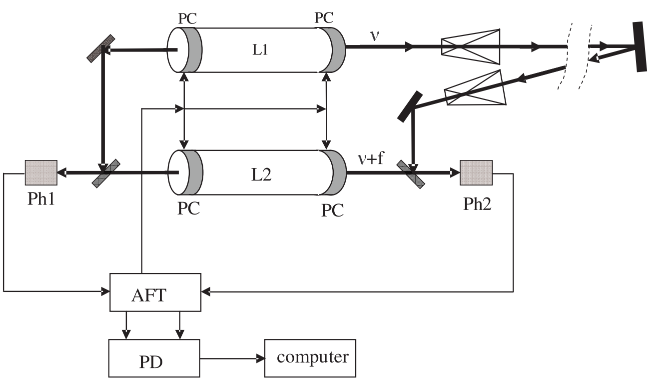

Fig. 1. Schematic view of the experimental setup

2. Experimental Setup and Results

The experimental setup is built on the base of a heterodyne laser interferometer [3] which we have constructed for deformographic measurements. It operates by the principle of the detection and the processing of a beating signal and allows one to perform phasometric measurements.

The schematic view of the setup is given in Fig. 1.

Two single-mode He-Ne laser sources L1 and L2 (each of 1-mW power) provide the sounding radiation and the reference one, respectively. Their optical frequencies differ by 800 kHz, and the stability of this difference is ensured by a system of automatic frequency tuning (AFT). The AFT analyzes the photomixing signal from photodetector Ph1 and controls piezocorrectors (PC) of laser resonators.

The sounding radiation reflected from a remote reflector is fed to photodetector Ph2, where it mixes with the reference radiation. Signals from the photodetectors through the AFT enter into a wide-range phase detector (PD) [4]. Thus, the phase disturbances of the sounding radiation are transferred into the photomixing signal at

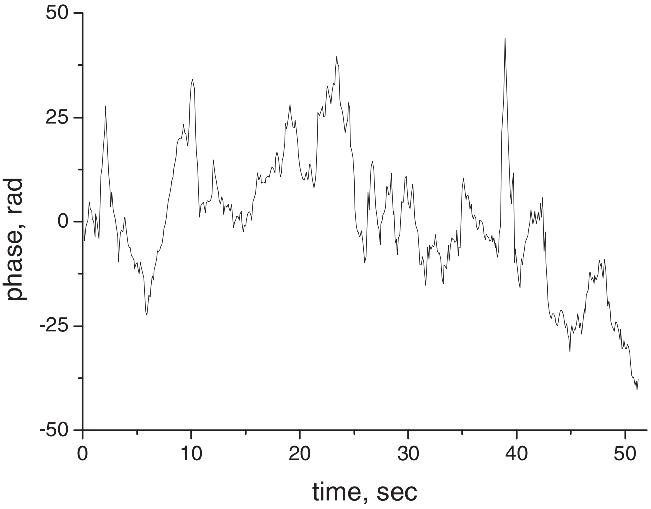

Fig. 2. Record of phase fluctuations of radiation in an atmospheric channel

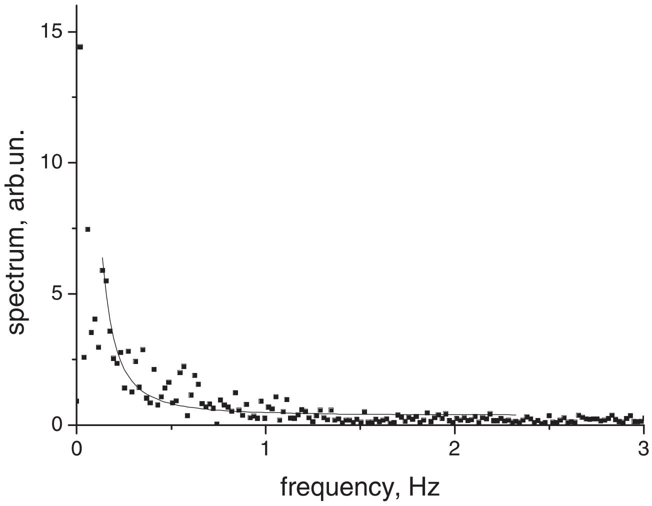

Fig. 3. Spectral distribution of phase fluctuations. Points – experimental data, solid curve - fitting by the theoretical formula

detector Ph2. Comparing this signal with the base signal, the phase detector gives out a signal which is proportional to a change of the optical phase [2]. Data are digitized and processed by a computer.

The main parameters characterizing a turbulent state of the atmosphere are the structure constant of the refraction index C_n^2 and the correlation length ρ_c of the field. The numerical value of C_n^2 can be determined by the meteorological (gradient) and optical methods. The gradient method is not capable to define C_n^2 with a high accuracy. Moreover, it gives the value of C_n^2 only at a given point of the channel. Since one has to know an effective value of C_n^2 for extensive enough paths in the tasks of the propagation of optical radiation, the more efficient way to determine C_n^2 is the method based on measurements of various optical characteristics of radiation passed through the turbulent atmosphere.

According to the theoretical model of turbulence, the characteristics of phase fluctuations for a collimated Gaussian beam will not differ from ones in the case of a direct trace [5] if the distance between the apertures of an emitter and a receiver for the back reflected beam is less than the so-called external scale parameter of turbulence L_0. In this case, the structure constant in a channel with length $2L$ can be estimated by the dispersion of phase fluctuations $\sigma_s^2(2L)$:

$$C_n^2 \approx 5\sigma_s^2(2L)(k^2 2LL_0^{5/3})^{-1},$$

where k is the wave vector.

A part of the record of phase fluctuations of a collimated laser radiation in an atmospheric channel of the length $2L = 200$ m (including the distance to the reflector and back) is depicted in Fig. 2.

The recording has been done with a frequency of 10 s^{-1}. The numerical analysis of the measured phase fluctuations (see Fig. 2) gave a dispersion of 250 rad^2. Taking the 2.5-m height of a beam over the underlying surface as L_0, we obtain the structure constant $C_n^2 = 1.4 \times 10^{-14}$ m$^{-2/3}$ (for a wavelength of 0.63 microns). The correlation length for this atmospheric channel can be estimated from the formula $\rho_c = (1.45C_n^2k^2L)^{-3/5}$ which implies the value around 4.1 cm.

The spectrum of phase fluctuations obtained by the Fourier analysis of a digitized record of phase fluctuations is presented in Fig. 3.

The plot in Fig. 3 shows that the effective components are distributed in frequency range up to 2 Hz. In our measurements, the spectral density of phase fluctuations is described by two asymptotic expressions for the increasing low-frequency and decreasing high-frequency branches [5]:

$$S(f) \approx 0.4\sigma_S^2(2L)f_1^{-1/3}f^{-2/3}, \quad \text{for} \quad f \ll f_1$$

and

$$S(f) \approx 0.08\sigma_S^2(2L)f_1^{5/3}f^{-8/3}, \quad \text{for} \quad f \gg f_1,$$

where, $f_1 = v/L_0$ is the characteristic frequency determined by the velocity of transfer v of inhomogeneities perpendicularly to a trace in terms of the external scale L_0. The fitting of the high-frequency branch of experimental spectra according to the indicated dependence gave an approximate value for $f_1 \sim 0.05$ Hz which corresponds to the motion velocity in the atmosphere $v \sim 0.13$

m/s. This estimate is in agreement with the practical absence of winds during measurements, while only convection flows are present.

It should be noted that the relative amplitude of the low-frequency part of the spectrum differs significantly from one measurement to another one. This indicates the short-time instability of this part of the spectrum even when the common state of the atmosphere remains the same. It has been found that, at the fast switching of channels, the effective width of the spectrum of phase fluctuations does not practically depend in the length of a trace. As the wind speed increases, the maximum of the spectral distribution decreases and shifts to higher frequencies.

3. Conclusion

The proposed heterodyne laser system allows one to rapidly measure the integral optical characteristics of atmospheric traces. The presented results are in good agreement with results obtained by the methods involving fluctuations of the intensity and by correlation and gradient measurements.

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ВИКОРИСТАННЯ ГЕТЕРОДИННОЇ ЛАЗЕРНОЇ СИСТЕМИ ДЛЯ ВИЗНАЧЕННЯ ПАРАМЕТРІВ ТУРБУЛЕНТНОЇ АТМОСФЕРИ

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Р е з ю м е

Описано спосіб використання гетеродинної лазерної системи для атмосферних вимірів. Проведено неперервну реєстрацію варіацій оптичної фази випромінювання, що поширюється в атмосферному каналі. За записаними даними одержано інтегральні характеристики стану турбулентності в каналі поширення випромінювання.