INTERMITTENCE OF THE FLUCTUATION PROCESSES IN THE TROPOSPHERIC CHANNELS OF LASER RADIATION PROPAGATION

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Received July 17, 1996

We present here some experimental results on the conditions of appearing and specific features of the manifestation of structural intermittence of optical beams along the near ground paths and its connection with dynamic processes in the turbulent atmosphere. We also give the results of systematic complex investigations along a horizontal path. These results enable us one to establish that over a wide range of the meteoparameters quasiperiodic alternations between two qualitatively different structural states of beam wavefront (the intermittence of the structural states of a beam) occur. One of them is characterized by the relatively small changes in the amplitude-phase profile of a laser beam. The second state has speckl-like structure of intensity distribution and strongly disturbed structure of the wavefront. Transition between the two states occurs stepwisely. Factors characterizing the dynamic state of the propagation path and stimulating the effects of the structural intermittence are analyzed.

Detailed analysis of the amplitude-phase fluctuations of radiation along the tropospheric paths[1,2] leaves the phenomenon of intermittence of fluctuation processes in the atmosphere and its manifestation in the electromagnetic beam characteristics[3-6] to be little studied. This paper is devoted to the experimental investigation of the conditions giving rise to the effects that manifest themselves in connections between the dynamic processes in the turbulent atmosphere and intermittence of the atmospheric turbulence with the structural intermittence of optical beams propagating along the ground paths.

The results presented below are obtained along a near ground horizontal path of the double passage type. The radiation emitted by a single-mode He-Ne-laser at the wavelength $\lambda_{He\text{-}Ne} = 0.63$ μm was used. The path altitude above the ground was $h = 25$ m, the one way length of the path was $L = 285$ m. Receiving-transmitting and recording equipment allowed us to estimate the intensity and phase distribution of light beam at the entrance aperture and its temporal variation. To do this we used a special device and software for entering beam images and shear interferograms into a PC. In parallel to recording of the radiation characteristics we measured meteoparameters and sounded the atmosphere along the path with a Ga-As pulse lidar at the wavelength $\lambda_{Ga\text{-}As} = 0.85$ μm.

The experiments carried out during 1994–1996 showed that for a wide range of meteoparameters the structural state intermittence characteristic of light beams occurred. The intermittence is a quasiperiodic alternation of two qualitatively different beam states. One of these states (I) is characterized by the relatively small variations in amplitude-phase profile of the laser beam. The second state (II) has a typical speckl-like intensity distribution and strongly distorted wavefront structure determined by appearance of numerous screw dislocations. The number and location of the dislocations at the wavefront are determined by the bifurcation points in the interference fringes on the shear interferograms. Qualitative illustration of the transformation of the wave beam structure and interferograms for transition from the quasiregular state I to the stochastic state II is presented in Fig. 1. An important peculiarity of the observed phenomenon is a step-wise transition between the states. This transition is accompanied by an abrupt reduction of the spatial coherence radius.

Determination of physical factors stimulating the structural intermittence effects is of special interest. The information on duration of the states I and II collected on different days is given in Table I. Analysis of the obtained data does not allow us to describe a connection between the meteoparameters and character of the structural intermittence by a simple dependence. Only an increase of the state II duration in periods of a sudden drop in temperature is clearly seen in the table (see, for example, the data on 25.11 and 26.11.1994 and 31.10 and 1.11.1995).

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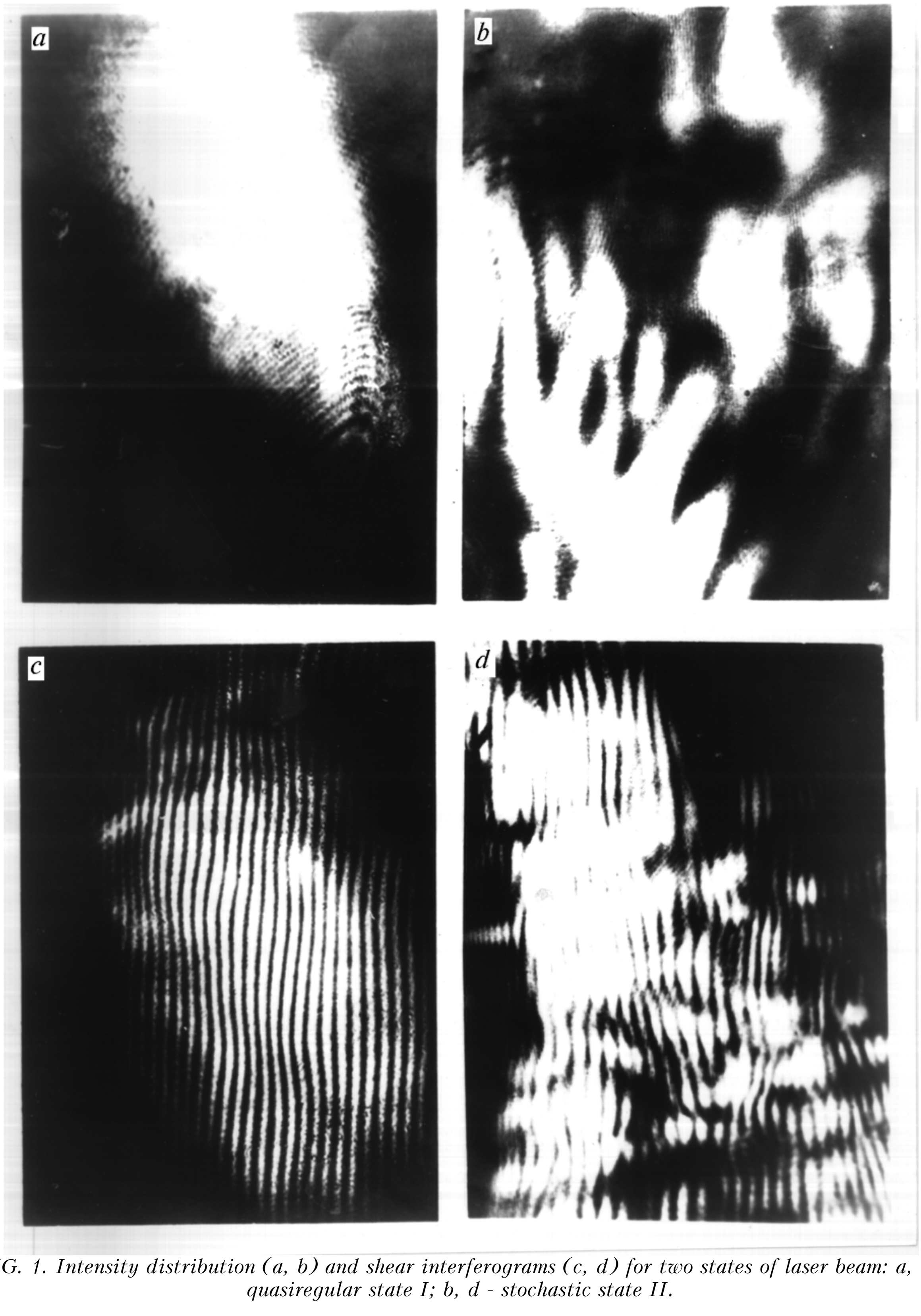

FIG. 1. Intensity distribution (a, b) and shear interferograms (c, d) for two states of laser beam: a, c - quasiregular state I; b, d - stochastic state II.

TABLE I. Durations of two beam structural states under different meteorological conditions.

Date	t, °C	V, m/s	State duration, s	
			I (quasiregular)	II (stochastic)
06.07.94	10.0	6	1–2	17
07.07.94	19.4	1	17	1–2
15.07.94	25.2	2	17	1–2
19.11.94	2.6	0	>100	1–2
21.11.94	0.6	3	12	4
22.11.94	0.8	3	25	1–2
24.11.94	4.4	5	25	1–2
25.11.94	1.2	2	>100	1–2
26.11.94	–6.8	1	1–2	25
28.11.94	–6.4	1	10	1–2
29.11.94	–1.7	1	17	1–2
30.11.94	–9.4	3	>100	5
01.12.94	–6.2	3	90	5
19.10.95	11	6	100	1–2
23.10.95	2.6	4	>100	1–2
25.10.95	7.2	4	100	2–3
	8	2	100	100
26.10.95	9	3.5	10	1–2
30.10.95	3.6	1	1–2	1–2
	2.6	1.5	>100	1–2
	2.2	1.3	>100	1–2
31.10.95	4.6	2	5–8	40
01.11.95	–4	3	1–2	100
	–3	2	5–10	20–30
02.11.95	–5	1	30–40	3–4
03.11.95	0.8	2.5	100	1–2
	1.4	0.6	100	1–2
09.11.95	–2.4	2	100	1–2
13.11.95	–5.6	3	15	30
	–6.3	2	20	20
14.11.95	1.2	1.5	1–5	30–60
	1	2	5	5
	0.4	0.5	>100	1–2

An additional analysis of the temperature profiles showed that the temperature inversion also stimulates the structural intermittence. A peculiarity of the phenomenon analyzed is that the intermittence of the quasiregular I and stochastic II states is observed in the absence of wind as well as under the conditions when the wind velocity is considerable when wind velocity essentially varies in value and direction.

In summer under high temperature the phenomenon of structural intermittence is observed only occasionally. In these conditions the state I is more probable with large displacements of centroid during day and small displacements in evening and night.

Recording of structural instabilities in the field of a cw laser radiation under different conditions was supplemented by the data on variation of lidar returns recorded along the same atmospheric path. The measurements enabled us to relate He-Ne laser beam characteristics to the backscatter parameter to be sought (Table II).

TABLE II. Relation of the beam state to the backscatter from the well formed aerosol component (5.03.1996).

Observation time	Environmental parameters	Back-scattering, $km^{-1}\cdot sr^{-1}$	Beam state
14 h 40 min	snowfall; $t = -4.0$ °C; $V \approx 1$ m/s	$4.44\cdot10^{-5}$	I prevails
14 h 50 min	snow intensified; $t = -4.0$ °C; $V \approx 0.5$ m/s	$7.09\cdot10^{-5}$	I
15 h 15 min	snowfall (large flakes); $t = -4.6$ °C; $V \approx 1$ m/s	$8.02\cdot10^{-5}$	I
16 h 10 min	snowfall stopped; $t = -4.6$ °C; $V \approx 1$ m/s	$2.66\cdot10^{-5}$	II
16 h 45 min	snowfall; $t = -4.6$ °C; $V \approx 2$ m/s	$7.27\cdot10^{-5}$	both states are probable equally
17 h 20 min	$t = -5.8$ °C; $V \approx 2$ m/s	$4.79\cdot10^{-5}$	both states are probable equally
17 h 50 min	weak snowfall; $t = -6.2$ °C; $V \approx 1$ m/s	$1.34\cdot10^{-5}$	I prevails
18 h 30 min	weak snowfall; $t = -6.2$ °C; $V \approx 1$ m/s	$1.30\cdot10^{-5}$	I prevails

Some results of synchronous measurements carried out on 5.03.96 when the weather conditions were determined by weak wind with the mean velocity $V \approx 1.5$ m/s, temperature at the height of the path $t \approx -4$–6.2°C, and occasional snow fall are presented in Table II. Recording time was about 5 min. For such conditions in the absence of snow the state II is more probable. When it snows (enhanced backscatter) the state I prevails. Note, a considerable decrease of fluctuation level in the presence of intense water aerosol (rain, fog) was observed over the ultrashort radio wave range too.[7]

Further analysis confirmed that the presence of water aerosol as a fog, rain, or snow sharply decreases the probability of the beam transition into the state II. An attempt to record the effect of beam state intermittence was undertaken along the path of the length $L = 285$ m too. The necessary receiving equipment was installed near the beam folding mirror of the basic double passage path. Along this double folded direct path the phenomenon of structural intermittence is also observed. In this case under the same propagation conditions a number of screw dislocations observed in the stochastic phase of the wavefront is approximately half as much then screw dislocation number at the receiving aperture in the case of the double passage path.

Analysis of the results obtained allows us to establish that the phenomenon of structural intermittence of laser beams ought to be uniquely connected with the intermittence of the atmospheric turbulence states at the radiation propagation path. For a more complete description of the phenomenon under study it is necessary to have information on the dimensions of the air mass volume in which the variation of the turbulence state makes the beam stochastic. To obtain this information we have modernized our experimental set up. Near the basic horizontal path we have arranged an auxiliary double passage path equipped with an independent laser source. During the experiments a geometry of the auxiliary path changed in such a way that a distance between the basic and auxiliary paths could be varied in wide limits. The experimental arrangements are presented in Fig. 2*a-d*.

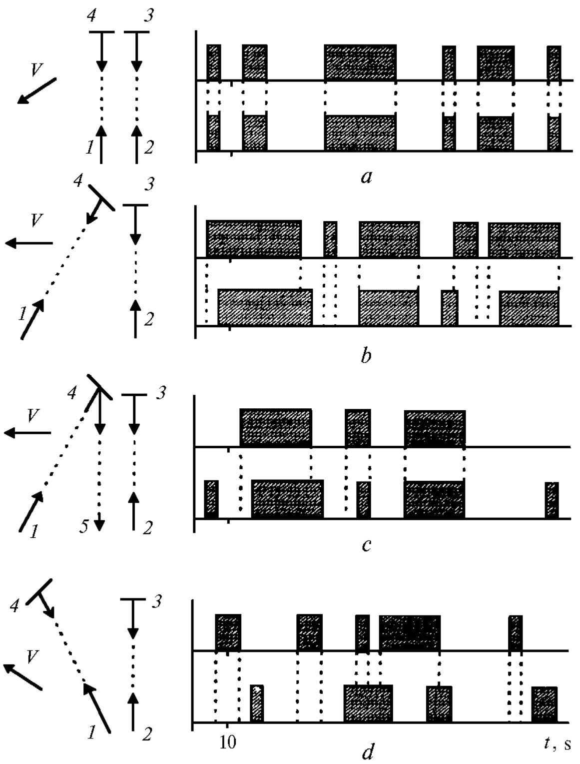

FIG. 2. Correlation of the fluctuation processes on the horizontal paths. To the left is set out the geometry of the basic and auxiliary double passage paths, to the right are shown durations of the stochastic beam state I (dashed rectangles) and quasiregular state II. Section 2–3 corresponds to the basic path, 1–4 to the auxiliary path. The upper set of the temporal intervals refers to the basic path, the lower set to the auxiliary path.

In all schemes the section *2–3* corresponds to the basic path. The sections *1–4* characterize the geometry of the auxiliary path operating under the double passage condition (in order to avoid the effects of the aberration magnification the beams at the double passage paths propagating in forward and backward directions were diverted slightly). Figure 2*c* corresponds to the geometry of the auxiliary path when its transmitting (*1*) and receiving (*5*) apertures are placed at a considerable distance from each other. The vector V in the figures determines wind direction during the measurements. The rectangles to the right from the schemes show characteristic temporal intervals corresponding to the stochastic state of a beam under conditions the measurements were carried out. The upper set characterizes the basic path and the lower set characterizes the auxiliary path. Since the rearrangement of the auxiliary path geometry requires certain time the data presented in Fig. 2 refer to different time but similar conditions.

Detailed study of the results obtained allowed the following peculiarities to be established:

The case 1 (Fig. 2*a*). The paths were parallel and distance between them was of 40 cm. The data were obtained on 12.03.1996 at 19.30–19.50. The temperature at the height of the path was $t_1 = -4$°C, temperature near the ground was $t_0 = -5$°C, mean wind velocity was $V = 2$ m/s. A specific peculiarity is the duration-independent synchronism of the existence of stochastic beam state on the main and auxiliary paths.

The case 2 (Fig. 2*b*). Rotating mirrors for two paths, as in the case 1, are at the distance of 40 cm and transmitting apertures are separated by the distance of 6.5 m. The results of measurements on 14.03.1996 at 20.00–20.30 and temperature $t_1 = 0$°C at the height of 25 m and $t_0 = -1$°C, at the ground level and mean wind velocity $V = 1.5$ m/s are presented. The synchronism of the structural intermittence is observed only on the long stages of stochastization; for a small-scale disturbance no correlation is occurs. A lag of long stages of stochastization at the auxiliary path which is wind ward relative to the basic path is observed.

The case 3 (Fig. 2*c*). The only change in the auxiliary path geometry compared to that in the case 2 is that its receiving aperture is placed near (at the distance of 40 cm) the receiving-transmitting aperture of the basic path. As compared to the previous case for the same conditions the changes in correlation between the beam structural intermittence at the two paths are not observed.

The case 4 (Fig. 2*d*). Direction of the auxiliary path is changed so that the distance between the beam folding mirrors is increased up to 35 m. The data were obtained on 22.03.1996 at 20.30–21.00 local time. Values of temperature were $t_1 = -1$°C at the height of 25 m and $t_0 = -2$°C near the Earth surface; mean wind velocity was $V = 2$ m/s. Correlation between the processes of the structural intermittence at the paths was absent completely.

The results of the above-described experiments allow us to conclude that in the process of variation of turbulence states in the ground layer of the atmosphere the zones of relatively small volume where abrupt changes of turbulence parameters take place are formed. Dimensions of these formations are limited by tens of meters and "lifetime" can be varied from fractions of a second to several tens of seconds.

Existing physical understanding of the fast processes changing near ground turbulence structure do not allow any explanation to be done using any theoretical model. But, since the rise of structural intermittence of laser beams ought to accompany an evolution of different type of instabilities in the atmosphere, it can be assumed that a transition from the states with a low fluctuation level to states characterized by the condition of "strong" fluctuations is caused by a rapid destruction of the large-scale voticies. Increase of the number of small-scale inhomogeneities with the size smaller than the Fresnel zone, $a < \sqrt{\lambda L}$, intensifies the fluctuation processes and leads to stochastization of the amplitude-phase distribution in a beam.

ACKNOWLEDGMENT

The paper was supported by the Russian Foundation of Fundamental Research (project 96-02-18609-a).

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