BACKSCATTERING EFFECT AT RADIATION REFLECTED FROM OBJECTS OF FINITE SIZE

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Experimental results on the influence of a diffraction size of a reflector on the mean intensity of a beam in its axis when propagating along correlated and uncorrelated paths through an inhomogeneous medium are presented. The mean intensity on the correlated path, as compared with uncorrelated one, is shown to increase when the reflector dimensions are multiple of even number of Fresnel zones and to decrease when dimensions are multiple of odd number of zones. At the increase of the reflector dimensions and turbulence strengthening, the mean intensity on the axis of beams propagating along both correlated and uncorrelated path approaches magnitude of the intensity of a spherical wave.

Use of reference beacons[1] in the systems of adaptive optics to generate control signals causes the necessity to study backscattering effects for reflectors of finite size with constant reflection coefficient over the surface. The influence of correlation between waves propagated to the beacon and back along the same path is quantitatively estimated, as a rule, using the "amplification" factor of the mean intensity [2]:

$$N(\rho) = \langle I^R_{\rm c}(x_0, \rho)\rangle / \langle I^R_{\rm uc}(x_0, \rho)\rangle ,$$

where $\langle I^R_{\rm c}(x_0, \rho)\rangle$ is the mean intensity of radiation propagating along the path with a reflection, $\langle I^R_{\rm uc}(x_0, \rho)\rangle$ is the mean intensity of radiation for the uncorrelated path of $2L$ length, L is the distance to the beacon.

Calculations from Ref. 3 for the mirror and the corner reflector show that under conditions of weak intensity fluctuations, when the diffraction pattern being formed by the reflector in the receiving plane is sufficiently sharp, dependence of the amplification factor on the Fresnel number of the reflector $\Omega_{\rm r} = \kappa a_{\rm r}^2/L$ is of oscillating character (where $\kappa = 2\pi/\lambda$, $a_{\rm r}$ is the reflector radius). In this case, for the corner reflector the amplification factor is more than unity for all values of $\Omega_{\rm r}$, the mean intensity of radiation reflected backward decreases for the mirror when $\Omega_{\rm r} < 5$. The calculations from Ref. 4 are in qualitative agreement with those made for two sizes of the reflector: of one and two Fresnel zones.

Experimental study of the backscattering effect at radiation reflection from a mirror of size $\Omega_{\rm r} = 1$–16 was carried out in a randomly inhomogeneous medium with the use of a setup modeling the conditions of developed convective turbulence. Previous investigations[4] of turbulence structure modeled over the heated surface showed that fluctuation spectrum of the refractive index of the medium was satisfactorily approximated by Karman model in the range of scales 0.5–15 cm.

The experimental scheme is shown in Fig. 1. A frequency stabilized LGN–302 laser *1* was used as a radiation source. The lens *2* formed a quasispherical wave with uniform distribution of intensity at the reflector *4* which was the front side of a cube. The removable diaphragms *5* were set closely to the cube. For the isolation of an incident and reflected waves in this channel the optical wedge *3* was used.

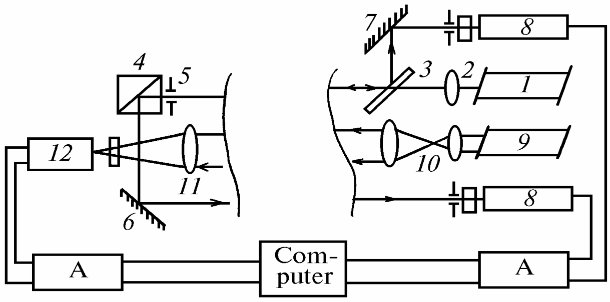

FIG. 1.

Radiation reflected from the diagonal of the cube was turned by the mirror *6* parallel to the backscattering beam and it passed at such a distance that eliminated the possibility for these beams to propagate through the correlated inhomogeneities in the forward and backward directions. The radiation in both channels was detected with PMTs *8*. Similar diaphragms (~120 μm) and interference filters selecting the radiation from sources used were set in front of the PMTs. Distances from the diaphragm *5* to the detectors were equal to 265 cm.

Turbulence in the medium was monitored by the variance of fluctuations in angles of plane waves arrival. For this purpose the additional path was arranged with the laser *9*, collimating optics *10*, receiving lens *11* with the focal length of 1 m and a servo system based on the dissector *12* providing a possibility to measure a source image shift by a pair of perpendicular coordinates $\sigma^2_\rho = \sigma^2_x + \sigma^2_y$. Radiation of lasers on the main and additional paths propagated over the heater at one and the same height.

Signals from the shift detector and both PMTs were transferred to a computer through the four-channel amplifier of direct current. The scheme of the experiment and the equipment used made it possible to measure the mean intensity and intensity fluctuations in both beams at the same time and the variance of fluctuations in source

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image shift σ_ρ^2. The structure constant of fluctuations in the refractive index of medium C_n^2 and turbulence parameter

$$\beta_0^2 = 1.23\, C_n^2\, \kappa^{7/6}\, L^{11/6}$$

were calculated using the values of σ_ρ^2.

Changing the power applied to the heaters and height of radiation propagation over the heated surface it was possible to obtain stable states of turbulence in the medium for a long time sufficient for making measurements. For each diaphragm 10–15 realizations of 50 s duration were recorded at the sampling rate of 100 Hz at practically the same values of β_0^2. Besides, at the same value of β_0^2 the signals from the infinite reflector (spherical wave) were recorded on the correlated and uncorrelated paths. During the measurements the accuracy of alignment of forward and backward propagation of radiation along the correlated path and accuracy of position of receiving diaphragms of the PMTs on the axis of beams were constantly monitored.

Influence of diffraction effects on a reflector edge results in the change in the shape of a backscattering beam. The mean intensity on the axis of a beam is determined by the intensity distribution in the receiving plane and swinging of the beam as a whole relative to the receiving aperture. For the experiment eight diaphragms were chosen (diameters of the diaphragms were equal to 1, 2, 3, 4, and 5 diameters of Fresnel zones) which corresponded to extreme values of the amplification factor N for the turbulence parameter $\beta_0^2 < 1$ and intermediate values of N ($2\,a_{\rm r}$ = 0.56; 1.56; 2.6 Fresnel zones) in accordance with Ref. 3.

The mean intensity for correlated $\langle I_{\rm c}^R(0)\rangle$ and uncorrelated $\langle I_{\rm uc}^R(0)\rangle$ propagation paths for two boundary cases of beam intensity distribution on the receiving plane is shown in Fig. 2 as an example. Here the mean intensity of a spherical wave is also shown.

Analysis of the results obtained for the reflectors with the sizes multiple of even numbers of Fresnel zones showed that in the turbulent medium the mean intensity on the axis of the beam on the correlated path increased faster than for the beams on the uncorrelated path. For the reflector of two Fresnel zones the mean intensity saturated when $\beta_0^2 \sim 0.6$–0.7, and for the reflector of four Fresnel zones the mean intensity saturated at lower level when $\beta_0^2 \sim 0.2$–0.3. The saturation values of the intensity tend to the level of the mean intensity of a spherical wave reflected from an infinite reflector.

For the reflectors with the size of odd number of Fresnel zones the intensity decreases with increasing β_0^2. The largest rate of intensity decrease is observed for the beams propagating along the correlated path when the beam is reflected by an object with $n = 1$. In this case the intensity decreases linearly with β_0^2 increasing from 0 to 0.8, and for $\beta_0^2 = 0.8$ this magnitude is only 40% of the intensity in a homogeneous medium. With the increase of the reflector size ($n = 3$, $n = 5$) the intensity falls off rapidly and practically linearly when changing β_0^2 from 0 to 0.3, then the falloff rate is moderate, and for $\beta_0^2 > 0.6$ the mean intensity keeps a constant value for correlated and uncorrelated paths. But always a remainder value of the mean intensity is higher for the uncorrelated path.

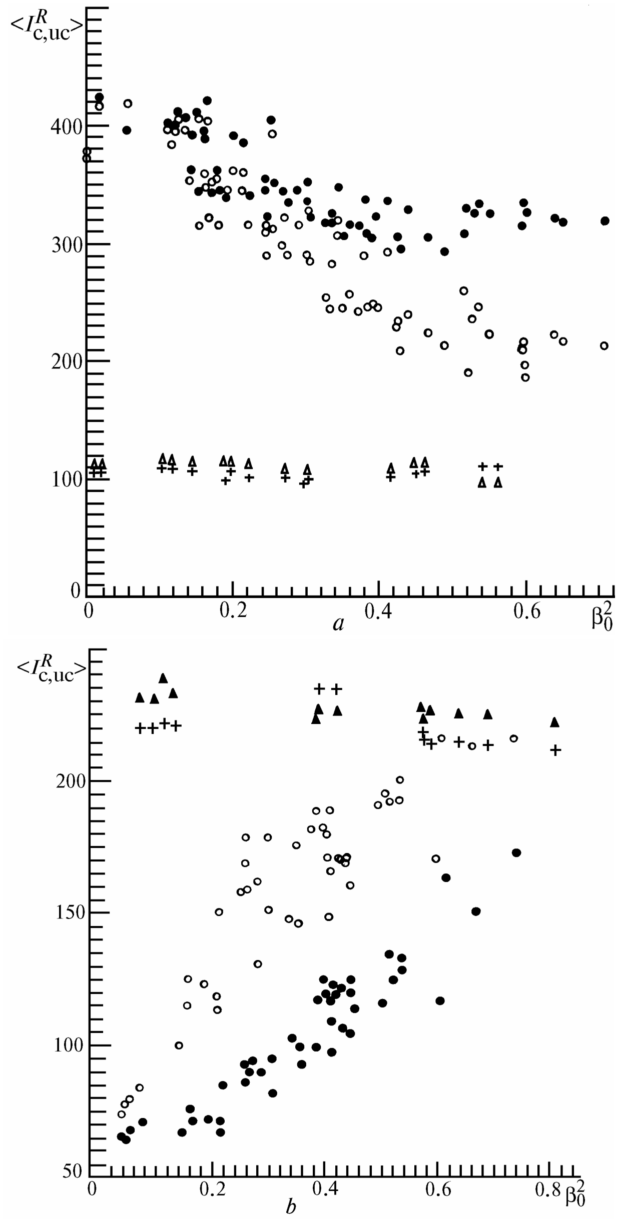

FIG. 2. The mean intensity for the correlated (○, △) and uncorrelated (●, +) paths as a function of the turbulence parameter (○, ● – finite reflector; ▲, + – spherical wave): a) reflector size equals one Fresnel zone $n = 1$ *and b) reflector size equals two Fresnel zones* $n = 2$.

All the above said is illustrated in Fig. 3 where the mean intensity averaged over 10–15 realizations and normalized to the mean intensity in a spherical wave. The intensity refers to the axes of beams propagated along the correlated path (solid curves) and uncorrelated one (dashed curves) for different size of the reflector as a function of the turbulence parameter. As is seen from Fig. 3, the value of intensity on the axes of beams tends to the mean intensity of a spherical wave with increasing size of the reflector and strengthening of turbulence along the path.

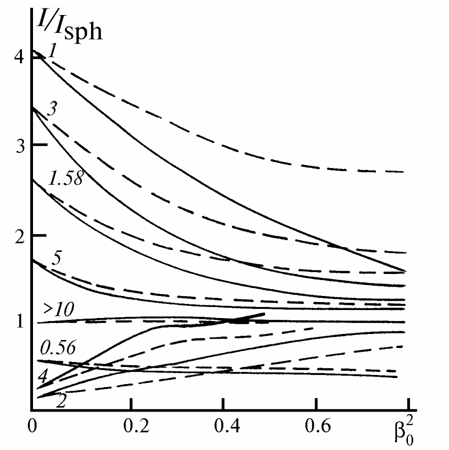

FIG. 3. The averaged values of the mean intensity on the beam axes of correlated (solid curves) and uncorrelated (dashed curves) paths. Digits show the reflector size in units of the Fresnel zone size.

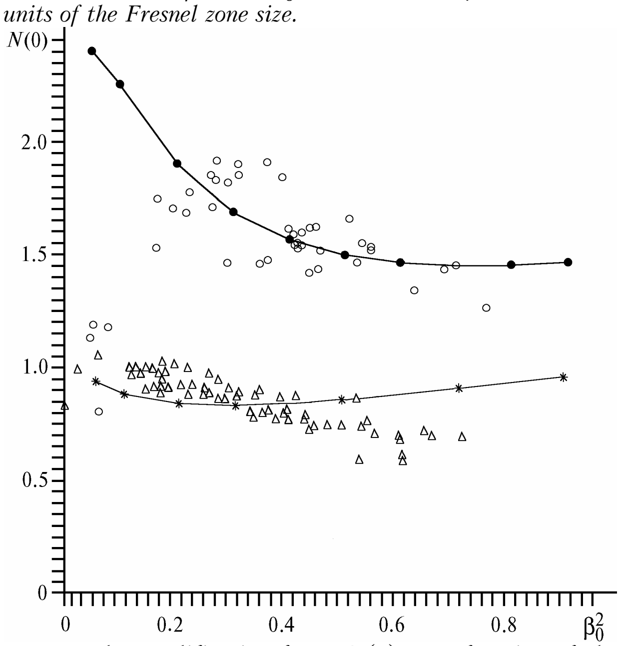

FIG. 4. The amplification factor $N(0)$ as a function of the turbulence parameter along the path: (△) – the reflector size equals to one Fresnel zone, (○) – the reflector size equals to two Fresnel zones, solid curves correspond to the theoretical calculations from Ref. 3.

Figure 4 presents the value of the amplification factor $N(0) = \langle I^R_c(0)\rangle / \langle I^R_{uc}(0)\rangle$ obtained in the experiment for the reflectors of one and two Fresnel zone. Solid curves correspond to the calculations taken from Ref. 3 As is seen from Fig. 4, for the reflector with $n = 2$ (the same dependence is observed for $n = 4$) $N(0)$ exceeds unity, and the theoretical dependence is satisfactorily confirmed by the experimental data at the turbulence parameter $\beta_0^2 > 0.2$. The maximum value of the amplification factor $N(0) \le 2$ is for $\beta_0^2 \sim 0.2$–0.3. For the reflector with size multiple of odd number of Fresnel zones the amplification factor $N(0)$ is less than unity. The theoretical and experimental results coincide at small values of β_0^2, but at $\beta_0^2 > 0.4$ the theoretical calculation assumes an increase of the amplification factor what is not observed in the experiment.

A number of measurements carried out with the reflectors of size $n = 0.56$, 1.6, 2.6 confirms the theoretical relations for $N(0)$ in the range of β_0^2 change between 0.2 and 0.6. Out of this range the theoretical and experimental results do not coincide.

Thus, the intensity of radiation on a beam axis reflected from a reflector of the size multiple to even number of the Fresnel zone size is higher than that of radiation reflected from a reflector of size multiple to odd number of the Fresnel zone size and propagated along a correlated path compared to the case of an uncorrelated path. Mean intensity of a beam at its axis tends to that of a spherical wave both for correlated and uncorrelated paths with increasing size of a reflector and strengthening of the atmospheric turbulence.

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