Compensation for phase distortions by means of a phase-conjugation mirror with an aperture loss

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The nature of the distortions of the spatial spectrum of the conjugate beam in the far zone has been studied experimentally for the case in which there is an aperture loss at a phase-conjugation mirror.

1. The literature reveals no study of those limitations on the quality of phase conjugation which stem from the loss of information about the wavefront of the conjugate beam, even in the case of an ideal operation of the phase-conjugation mirror itself. Such a situation may occur, for example, when compensation is made for atmospheric turbulence, in operation with an optical fiber, in operation with strongly scattering liquid crystals, etc. In this letter we report an experimental study of the effect of an aperture loss on the quality of the compensation for distortions in the course of phase conjugation.

2. In the experiments we measure the far-zone distribution of the light reflected from a phase-conjugation mirror after repeated transmission through a phase plate, varying the following parameters: $K_{ap} = E_{ap} / E_{\text{tot}}$, which is the fraction of the radiant energy of the pump beam which is transmitted through aperture diaphragm 5 (Fig.

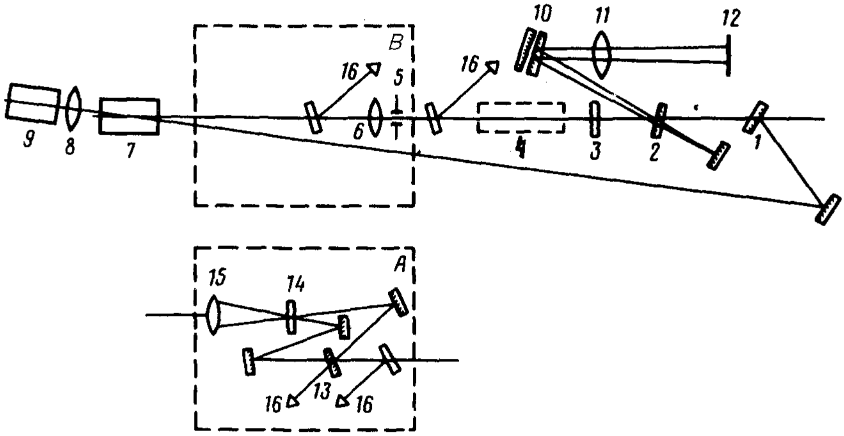

FIG. 1. The experimental layout. A: Block diagram of the testing of a phase-conjugation mirror. B: Block diagram of the simulation of an aperture loss. 1—Beam splitter, $R = 20\%$; 2, 13—splitting wedges, $R = 50\%$; 3, 14—phase plates; 4—Nd:YAG amplifier; 5—aperture diaphragm; 6, 8, 15—lenses; 7—mixing cell with CS_2; 9—generation cell with CS_2; 10—self-calibrating wedge; 12—photographic plate; 16—calorimeters.

1), and $L \lessgtr z_c = \lambda_p/\theta_p^2$, where L is the distance from the phase plate to the aperture diaphragm, z_c is the longitudinal correlation length of the pump, and θ_p is the "gray" divergence of the pump light after the light is transmitted through the phase plate. Here $\theta_s \lessgtr \theta_p$, where θ_s is the angle at which the illuminated part of the phase plate is seen from the center of the aperture diaphragm.

The pump source is a Nd:YAG laser with passive Q switching. The phase-conjugation mirror is designed on the basis of threshold-free reflection involving a Brillouin nonlinearity.[1] An interferometric procedure[2] is initially combined with measurement of directional patterns to study the way in which the quality of the phase conjugation depends on the spatial and energy characteristics of the light (Fig. 1a). The gray divergence of the signal wave is varied from $\theta_p \sim 3 \cdot 10^{-4}$ rad to $2 \cdot 10^{-2}$ rad by means of phase plates, and the angles at which the signal waves intersect the reference waves are $\sim 10^{-1}$ rad. The energy of the signal waves is varied from ~ 5 mJ to ~ 60 mJ, and that of the reference pump wave is ~ 15 mJ. As the active medium we use carbon disulfide; the mixing cell is 5 cm long, and the generation length for the reference Stokes wave is 15 cm. The length of the pump pulses is ~ 40 ns, and the spectral width is $\Delta\nu_p \sim 10^{-3}$ cm^{-1}.

Analysis of the results of calorimetric measurements of the visibility of the interference pattern[3] and of the directional patterns of the pump light and the Stokes light shows that the fraction of the conjugate wave in the reflected light depends only weakly on the energy and the gray divergence of the signal waves for this particular arrangement of the phase-conjugation mirror. This fraction is $\gtrsim 0.9$ in the region of pump parameter values specified above. To increase the dynamic range of the mirror, we used an auxiliary light amplifier, which introduced no substantial distortions in the spatial structure of the optical fields, according to a special check.

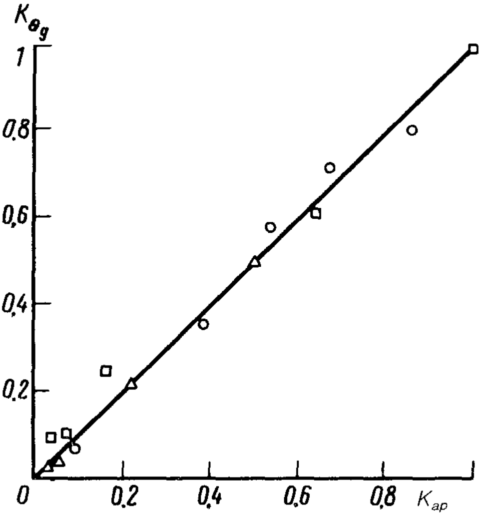

FIG. 2. K_{θ_g} versus K_{ap}. ○—$z_c \gg L$; □—$z_c \sim L$; Δ—$z_c \ll L$.

Figure 1b shows a block diagram of the final version of the experimental apparatus. The magnitude of the aperture loss is varied by varying the dimensions of aperture diaphragm 5; the ratio of the correlation length z_c to the distance (L) from the phase plate to the aperture diaphragm is varied by installing various phase plates. The far zone of the pump light and of the reflected Stokes signal is measured by a self-calibrating procedure.

3. Figure 2 shows the fraction of the energy of the reflected light, after the backward traversal of the phase plate, which arrives at an angle $\theta = 5\times 10^{-4}$ rad, normalized to the same quantity as measured for the pump light, $K_{\theta_g} = [\Delta E_{\text{ref}}(\theta = 5\times 10^{-4}\text{rad})/E_{\text{ref}}(\text{tot})]/[\Delta E_p(\theta = 5\times 10^{-4}\text{rad})/E_p(\text{tot})]$. This quantity is plotted against the value of K_{ap}, measured by the calorimeters, for various ratios of z_c and L. This dependence is clearly linear, and the fraction of the energy of the reflected light in the far zone, which is directed at the diffraction angle of the pump, is determined exclusively by the value of K_{ap}.

Figure 3 shows some typical directional patterns of the Stokes light after the backward transmission through the phase plate for various ratios of z_c and L. With $z_c \lessgtr L$ and $K_{ap} = 1$ there is complete compensation for the distortions introduced by the phase plate (Fig. 3a). In the case $z_c \ll L$, $\theta_p > \theta_s$ and $K_{ap} < 1$, the directional pattern for the Stokes light consists of a narrow core having the same parameter values as the pump, along with some wide wings (Fig. 3b). Under the conditions $z_c \sim L$, $K_{ap} < 1$ or $z_c \ll L$, $\theta_p < \theta_s$, $K_{ap} < 1$ we observe a similar pattern, but the core is broader (Fig. 3c). Finally, at $z_c > L$ (the relation $\theta_p < \theta_s$ always holds in this case) and $K_{ap} < 1$, there is a broadening of the core, and the wings are missing from the directional pattern of the reflected light (Fig. 3d).

4. The experiments show that the four cases of relations among the parameter values studied above correspond to all possible physically distinct structures of the reflected light in the far zone.

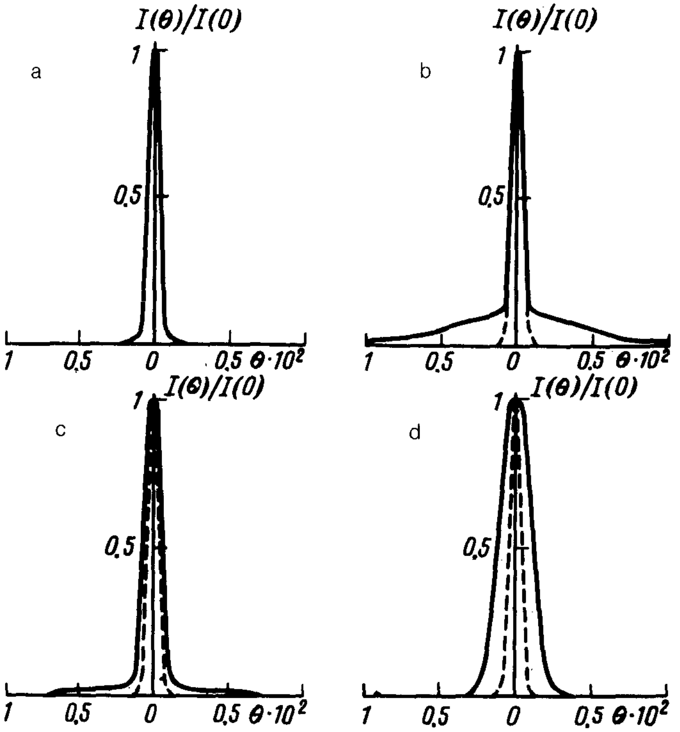

FIG. 3. Directional patterns of the pump light (dashed lines) and of the reflected light (solid lines). a—$K_{ap}=1$, $z_c \lessgtr L$; b—$K_{ap} \sim 0.1$, $z_c \ll L$, $\theta_p > \theta_s$; c—$K_{ap} \sim 0.1$, $z_c \sim L$ or $K_{ap} \sim 0.1$, $z_c \ll L$, $\theta_p < \theta_s$; d—$K_{ap} \sim 0.1$, $z_c \gg L$.

We can thus draw the following conclusions. The loss of information about the size of the illuminated part of the phase plate ($\theta_p < \theta_c$, $K_{ap} < 1$) leads to a broadening of the core of the back-reflected light. A loss of information on the size of the spot of signal light in the plane of the receiving aperture of the phase-conjugation mirror, on the other hand, i.e., a loss of information about the phase relations among the widely separated components of the spatial spectrum of the light (separated by an amount $\theta > \theta_s$), under the conditions $\theta_p > \theta_s$ and $z_c \ll L$, leads to the appearance of wide wings ($\sim \theta_p$) in the angular distribution of the reflected light. These conclusions can be used to generate *a priori* qualitative and quantitative estimates for specific situations.

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