INFLUENCE OF THE OPTICAL ABERRATION TYPE ON THE ACCURACY OF WAVE FRONT INVERSION AT STIMULATED BRILLOUIN SCATTERING OF A XeCl-LASER BEAM

N.G. Ivanov, V.F. Losev, and Yu.N. Panchenko

Institute of High–Current Electronics,
Siberian Branch of the Russian Academy of Sciences, Tomsk
Received February 10, 1997

This paper presents some experimental results of investigations into the wave front (WF) distortion and possibility of wave front reconstruction at wave front inversion of a XeCl-*laser beam. The divergence of a beam with the diameter of 150* mm *at propagation to* 25 m *distance increases up to* 20 θ_d *due to the air turbulence aberration. The WF inversion of a beam distorted due to aberrations of an optical element* ($\theta \le 15\ \theta_d$)*, may result in their complete compensation. If the aberrations are caused mainly by the air turbulence, then the accuracy of the wave front inversion decreases.*

1. INTRODUCTION

At present the excimer laser systems are most promising for achieving high radiation density, due to the proportional dependence of the limiting brightness on the squared D/λ ratio, where D is the diameter of the laser beam, λ is the emission wavelength. This is first because the excimer lasers emit at short wavelengths and with a high intensity of the radiation. Second, there are no principal restrictions on the increase of the cross size of their active medium. However, in practice many difficulties on preservation of the diffraction divergence of the radiation arise with the growth of the beam cross section due to the aberrations both in active medium, and in other elements of the optical channel.

It is known, that the use the WF inversion phenomenon at Brillouin stimulated scattering allows one to eliminate the aberrations in the optical system. Thereby the accuracy of the WF reconstruction depends on the WF shape and the degree of the WF distortion.[1–4] However, in majority of cases, both theoretical and practical, the WF distortion is set by a phase plate. Thus, in the focal caustic area there exists a statistically uniform distribution of the radiation intensity. In these conditions, when the quality of the WF inversion is highest, the divergence of the pumping radiation is limited by the range $10^2 < \theta/\theta_d < 10^3$, here θ_d is the diffraction angle. The case of weakly distorted beams, when $\theta/\theta_d < 10^2$, is considered as less favorable for the WF inversion due to the distortions of various types, for example "serpentineB At the same time in Refs. 5–8 they say about the WF inversion of the excimer laser radiation, usually about double–pass electric-discharge amplifiers with Brillouin's mirror. However, these reports mostly dealt with the case when insignificant aberrations, arising on the inhomogeneities of the laser pump are eliminated. At the same time, if the divergence of the pump beam is only slightly in excess of the diffraction limit (the 1.5–3 times), the observed improvement of the divergence of the reflected and again amplified laser beam may be a result of its spatial filtration.[13,14] For the beams with large cross section (the diameter of the beam is equal to 75 mm), as we considered in Ref. 9, the aberrations in the optical channel without an active medium, become essential, exceeding the aberrations due to the inhomogeneities of the pump, and the contribution from the WF inversion will be more noticeable.

In this paper we deal with the determination of the distortion degree of the XeCl-laser beam WF with the diameter up to 150 mm at its transportation and also with the investigation of possibilities of compensating them for the WF inversion.

2. EXPERIMENT

The laser system used consists of three electric-discharge XeCl-lasers. The optical arrangement of the experiment is shown in Fig. 1. The formation of a low divergence powerful beam of a narrow-band radiation was performed in the unstable resonator of the control laser *CL*, operated in the injection synchronization mode, Ref.10. The polarized radiation of the master oscillator *MO* with the line width $\Delta\nu \le 0.01$ cm^{-1} and energy $E \le 1$ mJ was injected into the resonator of the *CL* through a semitransparent spherical mirror *4*. The output mirror of the *CL* resonator was the plane mirror with the variable reflectivity. The *CL* output beam with the energy $E \le 80$ mJ and pulse duration $\tau_{0.5} \le 100$ ns was collimated with the lenses *6* and *7* and passed the polarization decoupling block *8*, *9*. Then it was expanded with a telescope *10*. The

0235-6880/97/09 646-04 $02.00

path of the expanded beam was 2×12 m. The laser beam, coming back at a small angle to the counter flux, was again compressed up to the diameter about 2 cm. Then the laser beam, after additional amplification in the optical amplifier *OA* up to the energy not greater than 50 mJ was focused in the chamber with a nonlinear medium using lens *12*.

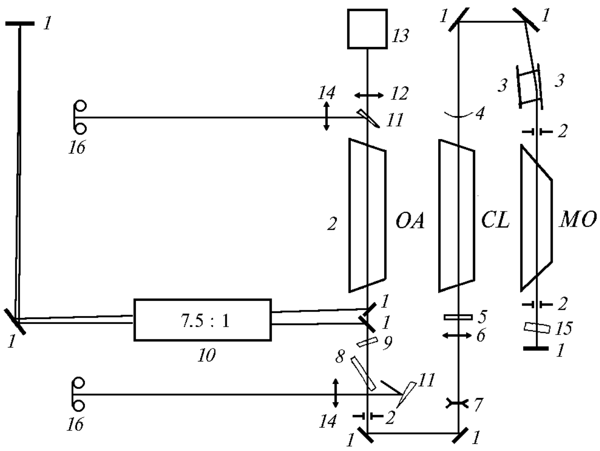

*FIG. 1. The optical arrangement of the experiment: 1 is the total reflector; 2 is the diaphragm; 3 is the diffraction grating (*2400 groove/mm*); 4 is the convex mirror with f* = – 634 mm*; 5 is the mirror with a variable reflectivity; 6 is the lens with f* = 550 mm*; 7 is the lens with f* = – 200 mm*; 8 is the polarizer; 9 is the quarter wave plate; 10 is the telescope (the lenses with f* = 1500, – 200, *and* – 460 mm*); 11 is the wedge; 12 are the lenses with f* = 0.5, 1, *and* 2 m*; 13 is the chamber with* SF_6 *at a pressure of* 10 atm*; 14 is the lens with f* = 3 m*; 15 is the Fabry–Perot etalon; 16 is the film. Here f is the focal length.*

The control of the divergence of the pump radiation was performed photographically at the focus of the lens *14* and by directly measuring the power distribution with the help of a calibrated diaphragm and IMO–2N calorimeter. The power distribution of the reflected radiation, that passed the optical channel, was calculated from the densitograms with the account of the film nonlinearity.

3. DISCUSSION OF THE EXPERIMENTAL RESULTS

Figure 2*a* depicts the angular distribution of the radiation energy, incident on the nonlinear medium with the diameters of the collimated beam of 75 and 150 mm. The larger divergence of the beam in the second case is mainly due to the turbulence of the air as one may see from the photographs of the focal spots (Fig. 3). Thus, as we can see, the focal spot disintegrates on separate randomly located clusters (Fig.3*d*). In the case when some extra turbulence is introduced into the channel of the beam transportation (∅ = 75) by heating its separate parts, the focal spots of both beams have identical structure.

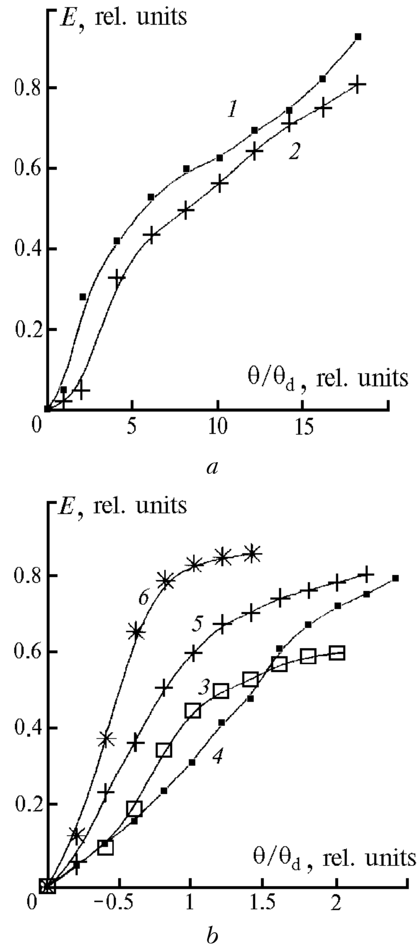

FIG. 2. The angular distribution of the radiation energy, incident on the nonlinear medium (curves 1, 2), (a); the output control laser beam (curve 3), reflected and passed again through the optical channel (curves 4–6), (b); the diameter of the beam is equal to 150 mm *(curves 2, 4) and* 75 mm *(curves 1, 5, and 6); the curve 5 was obtained at heating separate areas of the optical channel.*

In Fig. 4 are shown the photographs of the focal spots and the densitograms for the radiation, reflected from the nonlinear medium and again passed through the optical channel. Dashed line on the densitograms shows the size of the diffraction core. As one can see, the degree of the compensation of the distortion at different diameters of the beam is different. Its quantitative estimate can be obtained from the calculated distributions of the radiation energy, shown in Fig. 2*b*. For the beam with the diameter of 75 mm, the inverted radiation has practically the diffraction limited divergence, i.e., the divergence narrower, than the divergence of the initial radiation in Fig. 2*b*, curve *3*. That is caused by the spatial filtration in the optical channel. For the laser beam with the diameter

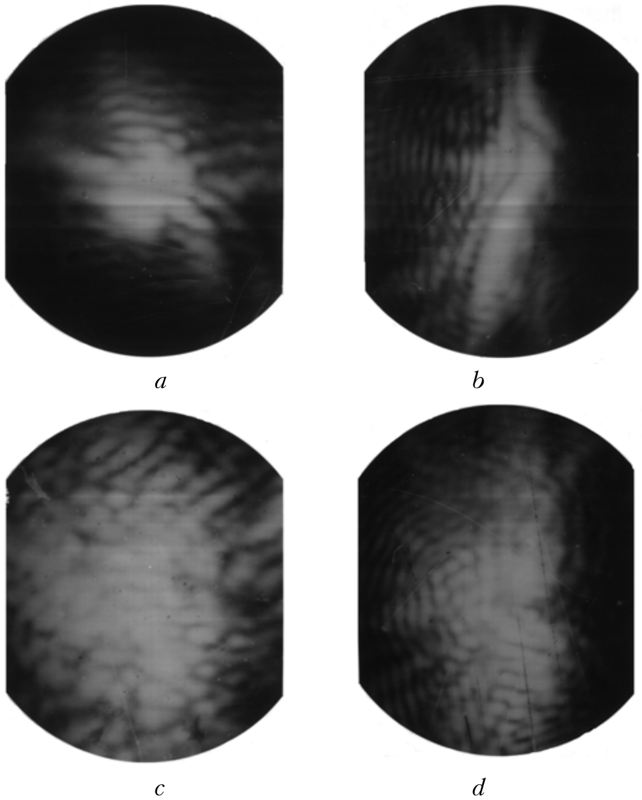

FIG. 3. The photographs of the focal spots of the beam radiation with ∅ = 75 mm, *(a, b) and* 150 mm, *(c, d) with the thermal heating of the separate area of the optical channel, (b) at the* 4 m *shortened transportation channel, (c) and the* 24 m *complete one, (d). The photographs are in about the same scale relative to the diffraction angle.*

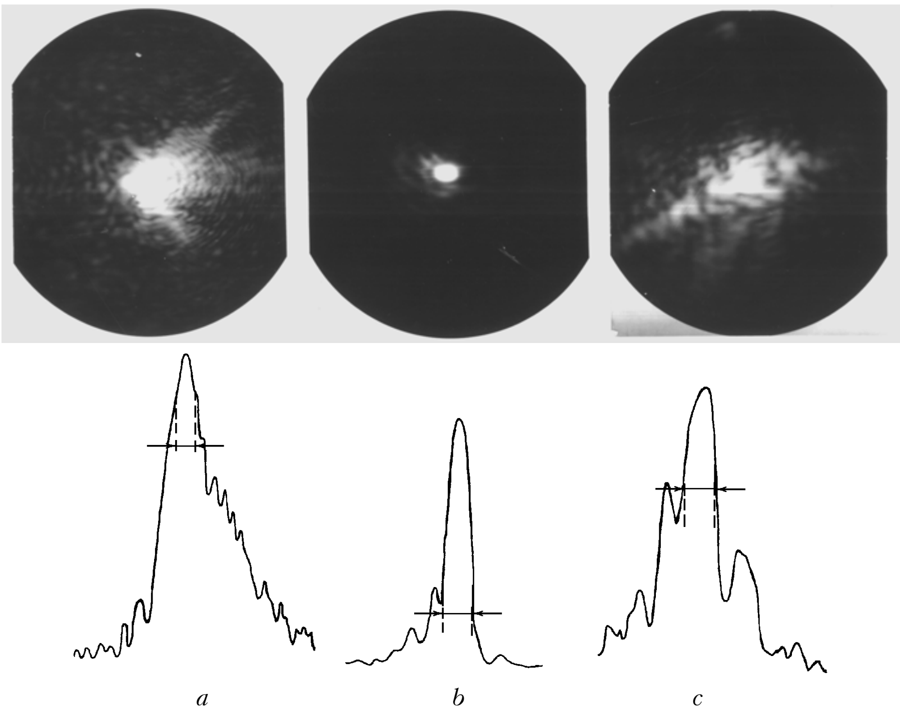

FIG. 4. The photographs of the focal spots and the densitograms of the radiation, reflected from the nonlinear medium and passed again through the optical channel. The diameter of the extended beam is equal to 150 mm, *(a) and* 75 mm, *(b, c). The wave front on the last photographs was distorted additively by the heating of the area of the optical channel.*

of 150 mm the partial compensation takes place because of the speckle structure around the diffraction core. This speckle structure contains a significant fraction of the total energy. The change of the focal length of the lens *12* did not practically change the quality of the wave front inversion. Similar picture was observed in the case, when the additional wave front distortions of the beam with the diameter of 75 mm were introduced by heating separate areas of the optical channel (Fig. 2*d* and 4*b*). In our mind, such a behavior can be due to two reasons.

The first one is connected with the essentially different intensity of the radiation clusters in the caustic such, that no due increment in its separate areas is reached amplification, and the part of information about the phase in the reflected beam is lost. Besides, with the increasing capacity of the pump radiation the degree of the distortions grows as a result of the component intensification, uncorrelated with the incident wave in the areas of enhanced intensity.

Second, the complete restoration of the WF is possible only for certain structure of the cluster distributions because of the infringement of the mechanism of the four-wave mixing, Ref. 11.

Thus, the analysis of experimental results shows, that at transportation of a beam with ∅ = 150 mm at a distance of the order of 25 m its divergence can grow as the result of the air turbulence up to about 20 θ_d. The high accuracy of the wave front reconstruction at Brillouin stimulated scattering of a focused radiation of the XeCl-laser is reached at a significant (about 15 θ_d) excess of the divergence of the pump beam above the diffraction limit in the case when the wave front distortions occur in the optical elements. At a further increase of aberrations, due to the air turbulence, the accuracy of the WF inversion is reduced. Probably for conserving the accuracy it is necessary to use the phase plate,[1] or the four-wave mixing.[11,12]

REFERENCES

1. V.I. Bespalov, ed., *Wave Front Inversion of the Radiation in the Nonlinear Media* (Applied Physics Institute, USSR Academy of Sciences, Gor'kij, 1982), 247 pp.

2. V.I. Bespalov, A.A. Betin, and G.A. Pasmanik, Radiofizika **20**, 791 (1977).

3. B.Ya. Zel'dovich, N.F. Pilipetskii, and V.V. Schkunov, *Wave Front Inversion* (Nauka, Moscow, 1985), 252 pp.

4. V.N. Belousov, Yu.K. Nizienko, N.F. Pilipetskii, and V.V. Ragul'skii, Dokl. Akad. Nauk SSSR **71**, 261 (1981).

5. R.G. Caro and M.C. Gower, Optics Letters **6**, No. 11, 557–559 (1981).

6. M.R. Osborne, W.A. Schroeder, M.J. Damzes, and M.H.R. Hutchinson, Appl. Phys. **B48**, 351–356 (1989).

7. Yu.I. Bychkov, V.F. Losev, and Yu.N. Panchenko, Kvant. Electron. **19**, 688 (1992).

8. M. Sugii, M. Okare, A. Watanabe, and K. Sasaki, IEEE J. Quant. Electron. **24**, 2264 (1988).

9. Yu.I. Bychkov, N.G. Ivanov, et al., in: *Abstracts of Reports at the Conference on Laser Optics*, State Optical Institute, St.-Petersburg (1993), p. 177.

10. N.G. Ivanov, S.E. Kovalenko, V.F. Losev, and Yu.N. Panchenko, Atmos. Oceanic Opt. **8**, No. 11, 873–875 (1995).

11. G.M. Davis and M.C. Gower, IEEE J. Quant. Electron. **27**, No. 3, 496–501 (1991).

12. R.H. Moyer, M. Valley, and C. Cimolino, J. Opt. Soc. Amer. **B5**, 2743 (1988).

13. D.A. Glazkov, A.A. Gordeev, I.G. Zubarev, and S.I. Michailov, Kvant. Electron. **19**, 286 (1992).

14. V.E. Yashin and V.I. Kryzhanovskii, in: *Abstracts of Reports at the Third All–Union Conference on Laser Optics*, S.I. Vavilov State Optical Institute, Leningrad (1981), p. 310.