CORRECTION OF THE THERMAL SELF-ACTION OF LASER RADIATION ON ATMOSPHERIC PATHS WITH THE HELP OF A "SLOW" PHASE CONJUGATE ADAPTIVE SYSTEM

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The power dependence of the dynamics of the change in the on-axis intensity of a laser beam with adaptive ''slow" phase conjugate correction of the distortions on an extended nonuniform, propagation path was studied. A variant that gives stable correction by limiting the minimum scale of nonuniformity of the phase of the correcting phase distribution is proposed and checked by means of numerical modeling.

Phase conjugate adaptive optical systems, employed for correcting distortions caused by thermal self-apt ion of the radiation, are divided into fast and slow.[1] The compensation regime is slow if over the time of the refreshment of the correcting phase distribution t_c the distortions associated with the thermal self-action of the radiation become stationary, i. e., $t_c \gg \tau_{rel}$. In the case when the opposite equality is satisfied, the correction regime is fast. The distortions are' established within a time estimated by the relation[1]

$$\tau_{rel} \approx 2a/v_{eff}, \qquad (1)$$

where $2a$ is the diameter of the laser beam and v_{eff} is the effective relative velocity of the beam and the air masses.

The slow correction regime presupposes that a phase-distribution control loop with a narrower band of processed frequencies than in the case of the fast regime is employed. It is also possible to use a correcting optical element with a narrower band; this can be important for technical implementation. However the use of the slow regime of the phase-conjugation method has only been justified heuristically. In this case the repetition of correction cycles is not an iterative procedure seeking the maximum of the integral criterion, reaching which ensures that the intensity of the laser radiation on the object will be maximum.[2]

The possibility of instabi1ity of the correction owing to development of large-scale nonuniformities of the beam structure was demonstrated previously on model problems.[3,4] For the short-pulse regime it was found numerically that the laser beam breaks up into filaments.[5] In addition, in Refs. 6 and 7 it was noted that small-scale perturbations of the structure of the laser beam develop along the optical axis along the propagation path.

In this paper we investigate the stability of the correction of thermal self-action of laser radiation on nonuniform atmospheric paths in the case of the slow correction regime under conditions of wind-induced refraction. The details of the mathematical model and the propagation path of the radiation are described in Ref. 8. A slow phase conjugate adaptive system was modeled numerically. It was assumed that the laser operated in the repetitive pulse mode.

The values of the normalized on-axis intensity of the laser radiation D with repetition of the correction cycles are presented in Fig. 1.

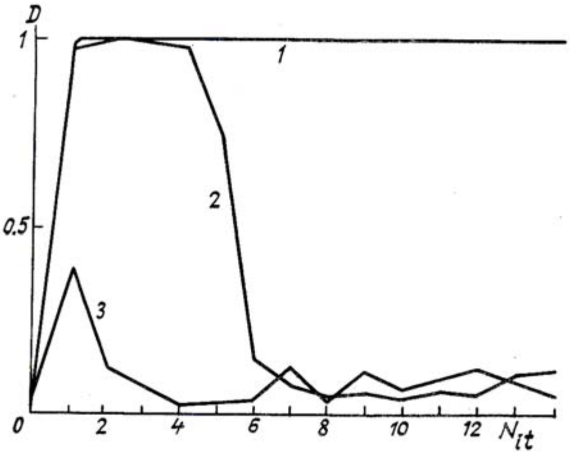

FIG. 1. The normalized on-axis intensity versus the number of correction iteration cycles N_{it} (curves 1, 2, and 3 correspond to per unit length power of 2, 5, and 10 relative units).

The curves 1, 2, and 3 correspond to radiation with a power of 2, 5, and 10 relative units. The calculations showed that as the radiation power increases when the correction cycles are repeated the normalized on-axis intensity decreases (curves 2 and 3 in Fig. 1), i.e., correction becomes unstable. At the same time, it is observed that low-scale modulation of the intensity

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and phase of the laser beam develop at the point of exit from the dense layers of the atmosphere; this is indicated by the results of calculations of the width of the spatial spectrum of the complex amplitude of the laser beam, as shown in Fig. 2. The curves 1, 2, and 3 in Fig. 2 represent the behavior of the energy spectrum of the complex amplitude of the laser beam at the point of exit from the path[8] for radiation with power equal to 10^{-4}, 5, and 10 relative units, respectively.

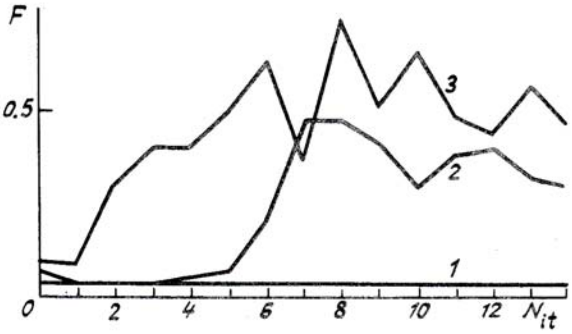

FIG. 2. The width of the energy spectrum of the complex amplitude at the point of exit from the distorting layer of the atmosphere as a function of the number of correction cycles N_{it} (the curves 1, 2, and 3 correspond to per unit length power of 10^{-4}, 5, *and* 10 *relative units).*

Under the conditions of unstable correction, the correcting phase also exhibits small-scale irregularity. Figure 3 shows the correcting phase φ_c in the first correction cycle with a power of 10 relative units.

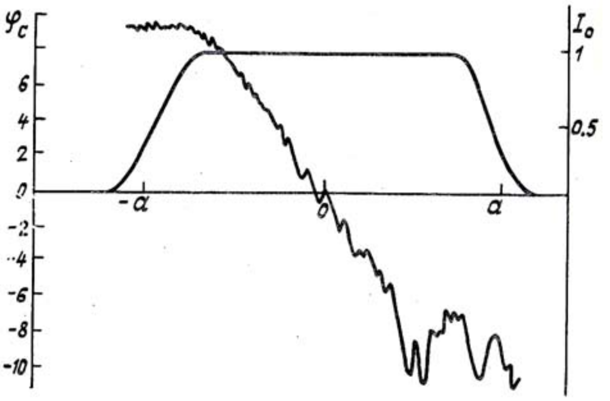

FIG. 3. The distribution of the correcting phase front after the first correction cycle with a power of 10 *relative units.*

Consider now the effect of limiting the minimum scale of the nonuniformity of the correcting phase distribution on the stability of phase conjugate correction. For this, a segmented phased mirror was modeled. The slit aperture was divided into a number of segments. Figure 4 shows the dependence of the normalized on-axis intensity with repetition of the correction cycles for radiation with a power of 5 relative units (curves 1, 2, and 3, respectively), with the aperture divided into four and eight segments, and with conjugation of the phase at each point of the aperture. We obtain the distribution of the correcting phase on each segment from the complex conjugate phase front of the reference beam by approximating with the closest (in the mean square sense) segment.

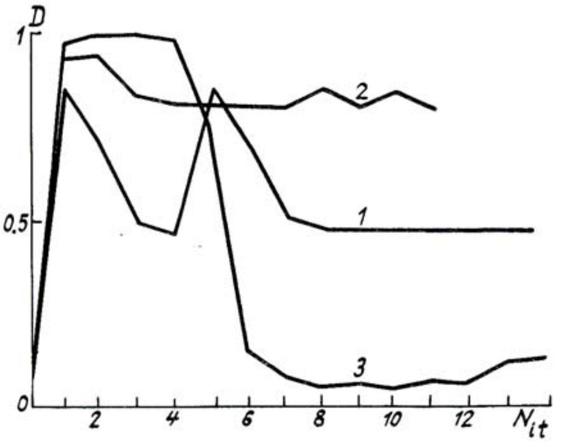

FIG. 4. The normalized on-axis intensity versus the number of correction cycles N_{it} when the slit aperture is divided into four and eight segments and when the phases at each point of the aperture are conjugate (curves 1, 2, and 3).

The above-studied variants of limitation of the minimum size of the nonuniformity of the correcting phase distribution give stable correction, and in addition as the number of elements into which the aperture is divided is increased the attainable on-axis intensity increases. We note that conjugation at each point of the computational grid can be interpreted as correction with the help of a segmented phased mirror, the size of whose elements is equal to one grid step. Then, from the results presented in Fig. 4 (curve 3), it follows that further increasing the number of mirror elements results in instability. Therefore there exists for each radiation power level an optimal size of an element of the segmented phased mirror for which the correction is stable and maximum on-axis intensity is obtained.

CONCLUSIONS

1) The instability of correction of distortions with the help of a slow phase conjugate system with the laser operating in the repetitive pulse mode is connected with the development of small-scale irregularity of the amplitude-phase distribution of the laser radiation.

2) Stable correction of the distortions caused by thermal self-action of radiation in the atmosphere can be obtained by minimizing the size of the nonuniformity of the correcting phase distribution, by using, for example, a segmented phased mirror as the controlled optical element.

REFERENCES

1. V.P. Lukin, *Atmospheric Adaptive Optics* (Nauka, Novosibirsk, 1986), 248 pp.

2. M.A. Vorontsov and V.I. Shmal'gauzen, *Principles of Adaptive Optics* (Nauka, Moscow, 1985), 336 pp.
6. K.S. Gochelashvili, I.V. Chashei, and V.I. Shishov, Kvant. Elektron. **8**, No. 7, 1551–1555 (1981).
7. K.S.Gochelashvili, A.M. Prokhorov, and A.N. Starodumov, Izv. Akad. Nauk SSSR, Ser. Fiz. **52**, No. 2, 403 (1988).
8. V.L. Dmitriev, V.B. Kasperskii, V.P. Lukin, and V.V. Sychev, Opt. Atm. **3**, No. 12, 1304–1306 (1990).
3. J. Herrmann, J. Opt. Soc. Am. **67**, 290 (1977).
4. V.V. Vorob'ev, Radiotekhn. Elektron., No. 11, 2334 (1981).
5. V.A. Vysloukh, V.P. Kandidov, S.S. Chesnokov, and S.A. Shlenov, Izv. Vyssh. Uchebn. Zaved. Ser. Fiz., No. 11, 30 (1985).