EFFICIENCY OF ADAPTIVE CORRECTION FOR A NONSTATIONARY WIND REFRACTION DEPENDING ON THE CONTROL BASIS

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The basis of a phase control for a light beam propagating in a moving regular medium is optimized using numerical simulations. The possibility is examined of reducing a number of controllable coordinates based on the analysis of thermal distortions of the beam and the properties of the simplex method. It is shown that an adaptive correction in the optimized basis is rather efficient in a wide range of the nonlinearity parameter.

Under nonstationary conditions one of the principal factors determining the efficiency of compensation for thermal blooming in real time is the fast response of an adaptive system. The simplest method for increasing the response rate without any additional instruments is likely to be optimization of the control basis with a beam wave front. The theoretical analysis[1–5] reveals that under stationary wind refraction the dependence of correction quality on a number of the beam wave front modes used for control is of monotonic character. When a beam propagates along extended paths the main contribution to improvement of the beam energy characteristics at the object comes from the first– and second–order modes (tilt, defocusing, and astigmatism), relative weights of these modes in the optimized wave front being approximately equal. In the dynamic regime, when the trajectory of search strongly affects the value and position of the maximum of the goal function in space of controllable coordinates, the dependence of the correction quality on the used modes becomes more complicated. Because of this fact, under nonstationary wind refraction the basis must be optimized in a different way compared to the stationary regime that can lead to somewhat different results.

In particular, instead of the criterion of focusing[6] widely used in quasistationary problems which characterizes instantaneous concentration of a light field on the object, the total light energy W incident onto an object during a given interval of time would be appropriate for use in the regime under study. Since the phase control is performed simultaneously with a "thermal lens" formation on a path, poor corrections made at the initial step of the control frequently cause a decrease of the criterion W that cannot be restored even by successful corrections. In contrast, a properly chosen control basis makes it possible to purposely affect the formed thermal lens by using its features for improving the conditions of beam propagation.

Comparative analysis of algorithms intended to compensate for thermal blooming based on cross–aperture sensing[7,8] revealed that the most efficient in stationary problems is the simplex method which ensures the highest rate of convergence of iteration process of phase optimization. Under nonstationary wind refraction it was found that a step–wise change of coordinates under control typical for the simplex method, brings about a forced beam scanning thus improving the conditions of its propagation. In this connection it is expedient to optimize the control basis using the simplex method.

The beam propagation in a moving regular medium is described by the system of dimensionless equations

$$2i\partial E/\partial z = \Delta_{\perp} E + RTE \; ; \qquad (1)$$

$$\partial T/\partial t + \partial T/\partial x = EE^* \; , \qquad (2)$$

where the standard designations and normalization are used.[6] At the medium entrance ($z = 0$) the complex amplitude of a light field is described as

$$E(x, y, 0, t) = E_0 \exp(iU(x, y, t)) \; , \qquad (3)$$

where the wave front $U(x, y, t)$ under control is a combination of basis modes. In accordance with the structure of the beam phase distortions under thermal blooming along an extended path it is reasonable to choose U in the form

$$U(x, y, t) = \vartheta(t)\, x + S_x(t)\, x^2/2 + S_y(t)\, y^2/2 \; . \qquad (4)$$

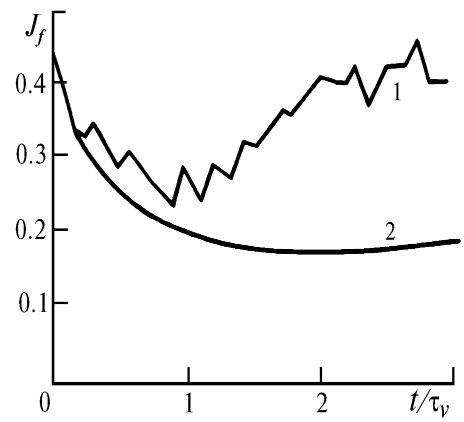

FIG. 1. Dynamic control of a beam phase using the simplex method with an optimum step (curve 1). Behavior of the criterion of focusing $J_f(t)$ without control (curve 2). Conditions of propagation: $z_0 = 0.5$, $R = -20$.

Depicted in Fig. 1 is typical dynamics of the criterion of focusing $J_f(t)$ when a beam phase is controlled in the basis (4) using the simplex method with an optimal step.[9] The coordinates ϑ, S_x, and S_y being controlled are shown in Fig. 2 as functions of time.

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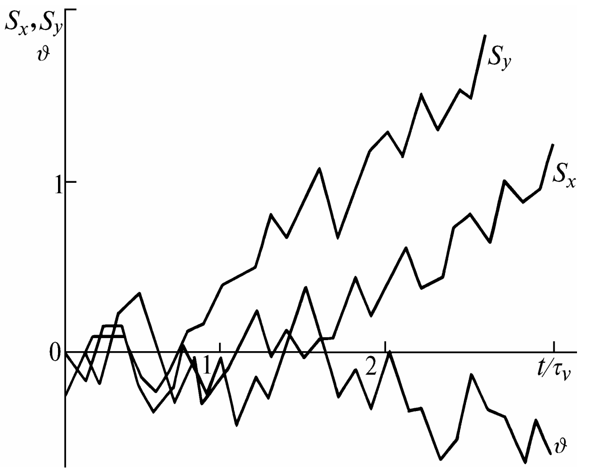

FIG. 2. Behaviors of the controllable coordinates during optimization of the criterion J_f based on the simplex method with an optimum step. Conditions of propagation: $z_0 = 0.5$, $R = -20$.

It can be seen from Fig. 2 that in the course of dynamic phase correction the variables S_x and S_y are found to be proportional to each other at each moment of time. In this connection it is reasonable to try to reduce the number of independent variables in the simplex search by introducing a combined mode $(x^2/4 + y^2/2)$, i.e., by representing the wave front as

$$U = \vartheta x + S(x^2/4 + y^2/2) . \qquad (5)$$

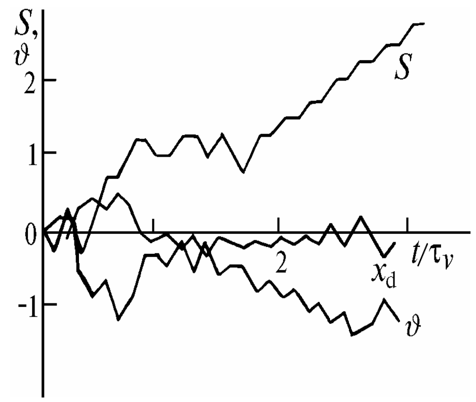

FIG. 3. Variations of the controllable coordinates S and θ and displacement of the energy center of the beam x_d during a two–dimensional control using a combined mode. Conditions of propagation: $z_0 = 0.5$, $R = -20$.

The calculations show that in this case the beam is focused better and, in spite of scanning, it is only slightly displaced from the axis of the initial propagation (Fig. 3). It should be noted that following the theory of the method the optimal length of a simplex edge depends on the dimensionality of control space, i.e., increases with its increase. Since the changes in the variables under control occurring during the search–for process are proportional to the length of the simplex edge, the two–dimensional control in the basis (5) turns out to be "smoother" than the three–dimensional one in basis (4).

The other method for reducing a number of independent variables can be proposed based on the analysis of phase distortions of a beam under the conditions of wind refraction. Taking into account the fact that a thermal lens along the path possesses a focusing action in the plane perpendicular to the velocity of the medium it is reasonable to fix S_x by putting, e.g., $S_x = 0$, i.e., to control the tilt and cylindrical focusing in the direction perpendicular to the medium movement, then

$$U = \vartheta x + S_y y^2/2 . \qquad (6)$$

It is also possible to assume that in some cases it is rather efficient to control only tilt of the wave front at S_x and $S_y = 0$, i.e.,

$$U = \vartheta x . \qquad (7)$$

The final results of modeling the above–considered algorithms within a wide range of values of the nonlinearity parameter R are given in Figs. 4*a* and *b*, where the correction efficiency is estimated based on the total light energy W incident onto the receiving aperture during the control time $T = 3\tau_v$ in a ratio to the same energy without control W_0.

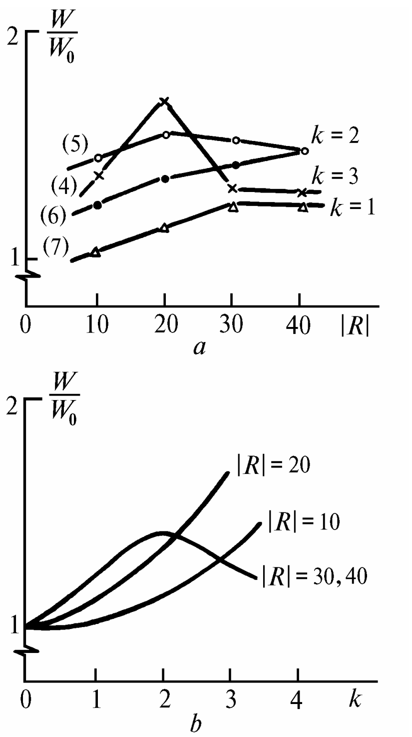

FIG. 4. Efficiency of correction during the time of control $T = 3\tau_v$ as a function of (a) the nonlinearity parameter R and (b) a number of controllable coordinates k. Figures in parentheses are the numbers of formulas describing the bases used.

As can be seen from the figure, most efficient is the control in different bases depending on the nonlinearity (radiation power) of the medium. In particular, when $|R| \le 20$ the three–dimensional basis (4) is more favourable, while for stronger nonlinearities the two–dimensional bases (5) or (6) are preferred. In a wide range of the nonlinearity parameter $0 \le |R| \le 40$ a combined mode (basis (5)) is preferable compared with a single focusing in the direction transverse to the medium movement (basis (6)). The control by tilting the wave front (7) only, at all $|R|$ is the least efficient control. On the whole it can be stated that in a two–

dimensional control in basis (5) the physical peculiarities of the problem under study and the properties of the simplex search agree best of all.

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