DYNAMIC ADAPTIVE MIRROR IN THE ALGORITHM OF PHASE CONJUGATION

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The influence of transients processes caused by the adaptive mirror elastic oscillations on the algorithm of phase conjugation stability is considered. Using a search based on the algorithm of phase surface, providing optimal focusing in a linear medium, and thermal lens correction as an example, the possibility is shown to damp oscillations of the field parameters in the observation plane and to increase the control stability.

INTRODUCTION

When investigating adaptive compensations for atmospheric distortions of the laser radiation we have discovered that the transient processes developed in the optical system have a profound effect on the efficiency and operation speed of the beam control algorithms.[1] Using the methods of numerical experiment we have studied the two types of transient processes. The first type implies those associated with the peculiarities of radiation interaction with the atmosphere under conditions of thermal blooming. In this case the variations of amplitude and phase beam profiles as well as the variations of characteristics of the atmosphere along the path of radiation propagation result in variations of radiation parameters in the observation plane. In Ref. 1 it was shown that in spite of the variations in radiation parameters recorded we can implement the adaptive correction with the use of traditional algorithms of phase beam control, namely, multidither and phase conjugation algorithms (a detailed description of the algorithms is given in Refs. 2 and 3). A necessary condition for the correction implementation is that the period of variation of beam parameters is, in the course of control, different from the characteristic time of the transient process.

The second type of the processes developed at phase control is conditioned by the oscillations of a flexible mirror reflecting surface. The introduction of a corrector dynamic model into the multidither algorithm has made it possible to analyze the stability and quick operation of the algorithm taking into account this type of transient processes. The results of the investigations are presented in Ref. 3. As in the first case, the control is possible when the frequency of the control effects differs from the frequency of oscillations developed in the systems.

Using the problem on compensation for thermal defocusing as an example, we consider in this paper the efficiency and operation rate of the phase conjugation algorithm based on the above-described types of transient processes.

NUMERICAL MODEL OF THE ADAPTIVE SYSTEM

Propagation of a laser beam with the complex amplitude $E(x, y, z, t)$ along the OZ axis under conditions of nonstationary thermal blooming is described by the following set of equations[3]:

$$\begin{cases} 2\, i\, k \dfrac{\partial E}{\partial z} = \Delta_\perp + 2 \dfrac{k^2}{n_0} \dfrac{\partial n}{\partial T}\, T\, E\,; \\ \dfrac{\partial T}{\partial t} + V_x \dfrac{\partial T}{\partial x} = \dfrac{\alpha I}{\rho\, C_p}\,. \end{cases} \tag{1}$$

Nonlinear properties of the medium are characterized by the parameter

$$R = \frac{2k^2\, a_0^2\, \alpha\, I_0}{n_0\, \rho\, C_p\, V_x} \frac{\partial n}{\partial T}\,. \tag{2}$$

In Eqs. (1) and (2) V_x is the wind velocity (the direction coincides with the OX axis; I is the radiation intensity; a_0 is the initial beam radius; T is the medium temperature; the remaining symbols are standard. The time scale of the problem is the convective time $\tau_V = a_0 V_x$, the spatial scale in the direction of beam propagation is the diffraction wave $z_\mathrm{d} = ka_0^2$ and in the plane perpendicular to the propagation direction – the initial radius a_0.

Oscillations of the mirror reflecting surface are described by the dynamic equation[4]:

$$[M]\,\ddot{\mathbf{X}} + [G]\,\dot{\mathbf{X}} + [K]\,\mathbf{X} = \mathbf{F}\,, \tag{3}$$

where $[M]$, $[G]$, and $[K]$ are the matrices of mass, oscillation attenuation, and rigidity of the model

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mirror, **F** is the vector of external forces applied to the points of the actuators fixation, **X** is the vector of the mirror reflecting surface shifts at the nodes of the computational grid. Equation (3) and the matrices were obtained using the virtual movement method, Ref. 4.

The computer program, simulating the deformations of the mirror, was divided into two blocks. The first block (computation of $[M]$, $[G]$, and $[K]$) matrices was taken from the general model of adaptive system and it was written beforehand. The corresponding part of the program was written in two languages – Visual BASIC and FORTRAN. This enabled us to use the possibilities of the Visual BASIC when creating the graphic interface as well as the high operation rate of the FORTRAN language when making the mathematical operations. The second block, incorporated directly into the model of an adaptive system, is the subroutine for solution of the set of differential equations (3) with the initial conditions corresponding to a plane mirror.

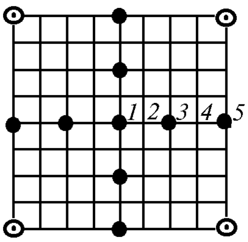

FIG. 1. Schematic representation of the mirror model: ● is for points of actuators fixation; ⊙ is for points of mirror fixation on the support.

A schematic illustration of the mirror used in the numerical experiments is given in Fig. 1. Selection of the corrector geometry is substantiated in Ref. 5, where it is shown that this mirror makes it possible to reproduce the low-order Zernike polynomials with an accuracy of 10 to 20% and provides a satisfactory efficiency of compensation for thermal blooming.

IMPLEMENTATION OF THE CONTROL BY SETTING OPTIMAL FOCUSING IN A LINEAR MEDIUM AS AN EXAMPLE

To simplify the problem, before introducing the mirror into the algorithm of beam control, we first consider reproduction of a surface U_{opt}, corresponding to optimal focusing in a linear medium at the path $z = 0.5$, by a dynamic corrector. The components F_i of the vector **F** entering into the right-hand side of Eq. (3) were determined by the least squares method. It was assumed when setting the focusing that the load on the mirror varies step by step (Fig. 2*c*):

$$\begin{cases} F_i = 0 , & t < 0 , \\ F_i = F_{i\ \text{opt}} , & t \geq 0 , \end{cases} \qquad (4)$$

where $i = 1, \dots, N$, N is the number of actuators, $F_{i\ \text{opt}}$ are the forces determined by the least squares method. The shifts of a reflecting surface of the mirror in this example are given in Fig. 2*a*, the numbers at the curves correspond to the numbers of points on the surface in Fig. 1. Oscillations of peak intensity

$$I_{\text{m}}(t) = \max_{x,\, y} I(x, y, z_0, t)$$

in the observation plane $z = z_0$ are illustrated in Fig. 2*b*. The figure shows that the mean value of I_{m} increases during the observation time, but the amplitude of the parameter oscillation is much higher than these variations.

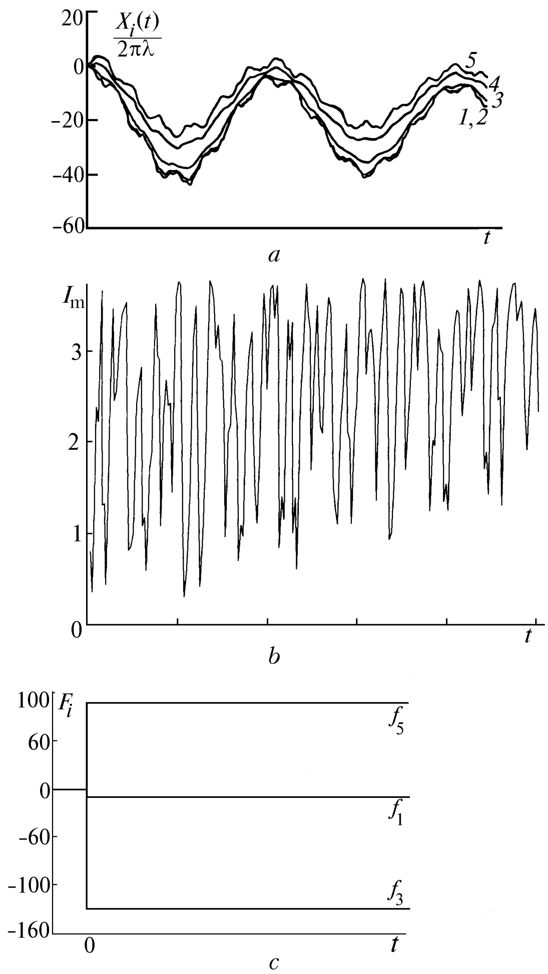

FIG. 2. Oscillations of points of the mirror reflecting surface (a) and oscillations of peak radiation intensity on the object (b) at a stepwise variation of load (c) applied to the mirror.

It is shown below that the transient processes associated with the elastic deformations result in the divergence of the phase conjugation algorithm. Therefore for the control implementation it is necessary to decrease the oscillation amplitude I_{m}. To meet this requirement, slow variation of the load on the mirror is used, i.e., the forces of F_i achieve the values of $F_{i\ \mathrm{opt}}$ not in a stepwise manner (Fig. 2*b*) but gradually as is shown in Fig. 3*b*. For this case Figs. 3*a* and *b* show the oscillations of the points of the reflecting surface and the variations of I_{m}. When comparing these figures with Figs. 2*a* and *b*, a considerable decrease of the oscillation amplitude is observed.

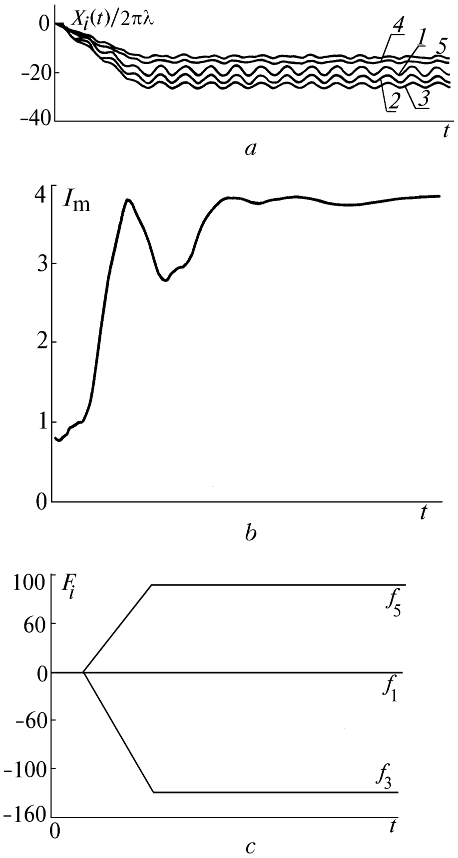

FIG. 3. Oscillations of points of the mirror reflecting surface (a) and oscillations of peak radiation intensity on the object (b) at a smooth variation of the load (c) applied to the mirror.

For the beam control we used the algorithm of a modified phase conjugation

$$U(x, y, t) = (1 - \alpha)\ U(x, y, t - \tau_d) - \alpha\varphi(x, y, t), \quad (5)$$

providing higher stability in the nonlinear medium as compared with the conventional phase conjugation method. In Eq. (5) $U(x, y, t - \tau_d)$ is the phase beam profile at the time moment $t - \tau_d$ (τ_d is the time between iteration steps); α is the factor we select empirically from the interval [0, 1]; $\varphi(x, y, t)$ is the phase of the wave reflected from an object (or a reference beam). In the nonlinear medium the algorithm allows the correction for aberrations, and in the linear medium the optimal focusing is determined. In both cases the algorithm is iterative.

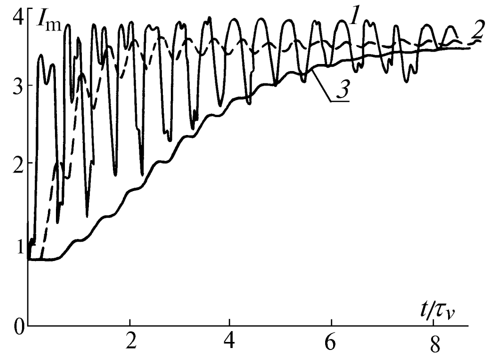

FIG. 4. Change of the convergence of the algorithm given by Eq. (5) in a linear medium when passing from stepwise variation of the load to the mirror (curve 1) to smooth variation (curves 2 and 3).

The change of peak intensity during the process of beam control based on Eq. (5) in the linear medium is illustrated in Fig. 4, curve *1*. The values of the components of the vector **F** at each iteration were found by the method of least squares; at the iteration change the components of the vector **F** varied stepwise. As the results have shown, the use of the algorithm results in the increase of the mean values of I_{m}, but in the system the high-amplitude oscillations of the parameters develop. The decrease of the oscillation amplitude and stable growth of the field concentration in the observation plane are obtained at gradual variation of the load to the mirror, as in the case with reproduction of optimal focusing (Fig. 4, curves *2* and *3*).

CORRECTION FOR THERMAL BLOOMING

The results of correction for thermal blooming based on the algorithm (5) involving the use of a flexible dynamic mirror in an adaptive system of the model and with smooth variation of the load **F** in the iteration process are presented in Fig. 5.

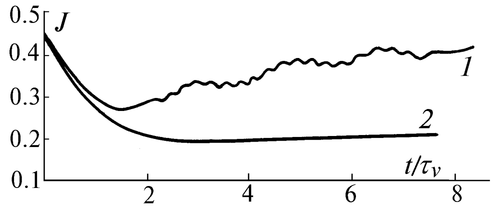

FIG. 5. Implementation of the algorithm given by Eq. (5) in a nonlinear medium ($R = -20$). Variation of the focusing criterion with (curve 1) and without (curve 2) a control.

The field concentration on the object, as usually in the problems on thermal distortion compensation, is characterized by the focusing criterion

$$J(t) = \frac{1}{P_0} \iint \rho(x, y)\, I(x, y, z_0, t)\, dx\, dy\ , \qquad (6)$$

with the meaning of the fraction of light power within the aperture of a given radius. In Eq. (6) ρ is the weighting function; P_0 is the total beam power.

According to the data of the numerical experiment performed (Fig. 5) we can conclude that at correction for thermal blooming the transient processes, connected with the elastic deformations, do not result in the loss of control stability. Adaptive focusing provides a two-fold increase of the value of J that is close to the values obtained for the ideal phase corrector.[1]

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