THE DEPENDENCE OF THE EFFICIENCY OF CORRECTION FOR THE THERMAL LENS EFFECT ON THE CONTROLLING COORDINATE BASIS

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The efficiency of the phase control of a laser beam in a nonlinear medium is determined as a function of the number of the wavefront aberrations, reproduced by the corrector. This investigation is performed for a wide range of the parameters of the medium and the beam.

A flexible mirror, whose design is determined by the corrected distortions, as a rule, serves as a controlling element in the adaptive system of phase control of a beam. In order to compensate for the lowest–order aberrations, viz., tilts, defocusing, and astigmatisms, mirrors with 4–6 degrees of freedom are used,[1,2] while to compensate for the higher–order distortions, the number of the degrees of freedom increases and may amount to 37–58 (Refs. 3 and 4).

In this paper we determine an optimal basis for control by mirror, intended for compensation for the thermal blooming. Results of the analogous investigations in the class of Zernike polynomials have been published in Refs. 5-7. In accordance with the data of Ref. 5, the correction of the lowest–order aberrations provides the control efficiency of the order of 80% of the value obtained with the use of an ideal corrector (a corrector which does not impose any restrictions on a given phase shape). According to Ref. 6 the correction of tilts, defocusing, and astigmatism ensures an efficiency of ˜40% of the attainable maximum. Since the authors of Refs. 5–7 examined the compensation for thermal blooming under conditions of different parameters of the beam and the medium one can assume that the choice of the optimal control basis depends on the conditions of beam propagation. In order to teslify the above assumption as well as to determine an optimal basis for different conditions, in this paper we examine the compensation for self–action for a wide range of the thermal lens parameters.

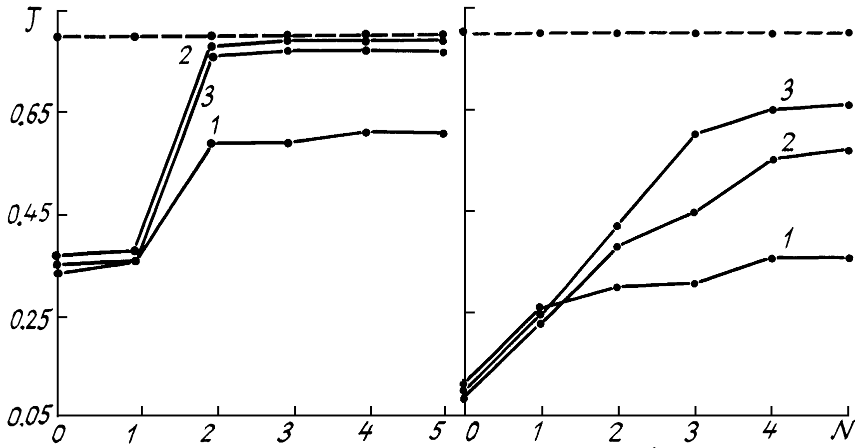

FIG. 1. The resulting values of the focusing criterion J as functions of the number of aberrations, reproduced by the corrector: N = 0 (without correction), N = 1 (tilt), N = 2 (tilt and defocusing), N = 3 (tilt, defocusing, and astigmatism), N = 4 (tilt, defocusing, astigmatism, and coma), and N = 5 (tilt, defocusing, astigmatism, coma, and spherical aberration). The parameters: a) $R_v = -10$ *and* $Z_{nl} = 0.5\,Z_d$ *(curve 1),* $R_v = -20$ *and* $Z_{nl} = 0.1\,Z_d$ *(curve 2), and* $R_v = -250$ *and* $Z_{nl} = 0.01\,Z_d$ *(curve 3); b)* $R_v = -30$ *and* $Z_{nl} = 0.5\,Z_d$ *(curve 1),* $R_v = -90$ *and* $Z_{nl} = 0.1\,Z_d$ *(curve 2), and* $R_v = -700$ *and* $Z_{nl} = 0.01\,Z_d$.

The control of the beam is implemented based on an algorithm of cross–aperture sounding. As a goal function of control we employ the focusing criterion

$$J = \frac{1}{P_0} \int\int \rho(\mathbf{x}, y)\, I(\mathbf{x}, y, \mathbf{z}_0)\, \mathrm{d}\mathbf{x}\mathrm{d}y) , \qquad (1)$$

which has the meaning of the relative portion of light power, which falls within an aperture of radius S_t. In the above equation P_0 is the total beam power, ρ is the aperture function, and $\rho(x, y) = \exp(-(x^2 + y^2)/S_t^2)$. We consider the interaction between the radiation and the medium in the approximation of the stationary wind refraction.[2] We have chosen the following geometry of the problem. The beam propagates along the OZ axis. The wind velocity direction coincides with the OX axis (the thermal lens is symmetric about the XOZ plane). The wind velocity is constant, and the medium nonlinearity is described by the parameter

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$$R_v = \frac{2k^2 a_0^3 \alpha I_0}{n_0 \rho C_p V} (\partial n/\partial T) , \qquad (2)$$

where a_0 is the initial beam radius, I_0 is the axial power density in the plane $Z = 0$, V is the wind velocity, and k is the wave number. The rest of the designations are standard and correspond to those used in Ref. 2. The diffraction length $Z_d = ka_0^2$ is the spatial scale of the problem along the axis of beam–propagation. The correction is considered on the path $Z_0 = 0.5\, Z_d$, and the thickness of the nonlinear layer is varied from $Z_{nl} = 0.01\, Z_d$ to $Z_{nl} = 0.5\, Z_d$.

The dependence of the resulting values of the criterion J on the number of Zernike polynomials reproduced by the corrector is shown in Fig. 1. The data were divided into two groups. Fig. 1*a* a corresponds to the control of small distortions (small values of the parameter R_v or a small thickness of the nonlinear layer Z_{nl}) and Fig. 1*b* corresponds to the control of great nonlinear distortions. In both figures the broken line stands for the diffraction limited values of the criterion obtained for the path length under consideration. Table I gives the data which characterize the relative contribution of the individual aberrations. Here those values are accepted as 100%, which have been obtained under condition of complete reproduction by the corrector of all polynomials under consideration (up to the spherical aberration, inclusively). One can see that under conditions of small distortions ($Z_{nl} = 0.5\, Z_d$ and $|R_v| \le 10$; $Z_{nl} = 0.1\, Z_d$ and $|R_v| \le 20$; $Z_{nl} = 0.01\, Z_d$ and $|R_v| \le 250$) the compensation for the lowest–order aberrations, i.e., tilts and defocusing, provides a high quality of correction of the thermal lens effect. At the same time, the correction of the higher–order aberrations makes it possible to increase the control efficiency by not more than 5%.

TABLE I. The relative control efficiency (%) as a function of the number of aberrations reproduced by the corrector.

Corrected aberrations	Thermal lens parameters				
	$R_v = -10$ $Z_{nl} = 0.5\, Z_d$	$R_v = -20$ $Z_{nl} = 0.1\, Z_d$	$R_v = -250$ $Z_{nl} = 0.01\, Z_d$	$R_v = -30$ $Z_{nl} = 0.5\, Z_d$	$R_v = -90$ $Z_{nl} = 0.1\, Z_d$
Without correction	56	47	49	27	16
Tilt	58	50	47	70	40
Tilt and defocusing	95	99	97	81	68
Tilt, defocusing, and astigmatism	95	99	99	81	77
Tilt, defocusing, astigmatism, and coma	100	100	100	100	98
Tilt, defocusing, astigmatism, coma, and spherical aberration	100	100	100	100	100

TABLE II. The resulting values of the focusing criterion J, obtained when there exist predistortions of the phase (Eq. (2)).

Phase predistortions	–	(2)	–	(2)	–	(2)
Corrected aberrations	Thermal lens parameters					
	$R_v = -20$ $Z_{nl} = 0.5\, Z_d$		$R_v = -30$ $Z_{nl} = 0.5\, Z_d$		$R_v = -90$ $Z_{nl} = 0.01\, Z_d$	
Without correction	0.19	–	0.10	–	0.09	–
Tilt	0.30	–	0.26	–	0.23	–
Tilt and defocusing	0.40	0.45	0.30	0.33	0.39	0.40
Tilt, defocusing, and astigmatism	0.41	0.45	0.30	0.33	0.44	0.45
Tilt, defocusing, astigmatism, and coma	0.46	0.46	0.37	0.38	0.56	0.57
Tilt, defocusing, astigmatism, coma, and spherical aberration	0.46	–	0.37	–	0.57	–

As the nonlinear distortions becomes greater and the thickness of the thermal lens becomes smaller the contribution of the higher–order polynomials increases. Thus, for $Z_{nl} = 0.5\, Z_d$ and $|R_v| = 30$, the compensation for the astigmatism, coma, and spherical aberration enables us to increase the control efficiency by 19%, and for $Z_{nl} = 0.1$ and $|R_v| = 90$ it is increased by 32%.

Note that the contribution of the spherical aberration is very insignificant in the above–indicated range of the parameters. Let us consider the employment of this polynomial in ample detail. In so doing we conventionally divide the formed phase surface into two regions, i.e., a defocusing region at the center described by the equation $\varphi_c(x, y) = -\alpha(x^2 + y^2)$, and the focusing region $\varphi_f(x, y) = \alpha(x^2 + y^2)^2$, the coefficient α being varied in the process of control. It was found out in the numerical experiments that the effect of the region φ_f on the compensation for the thermal lens is analogous to the effect of focusing. For this reason, the variations of the shape of the defocusing region φ_c are of interest in order to determine φ_c for which a maximum efficiency of the adaptive control is attained. We have examined the defocusing regions

$$\varphi_c(x, y) = \alpha\, (\exp(-x) + \exp(-y)) , \qquad (3)$$

$$\varphi_c(x, y) = \alpha\left(\exp(-x^2) + \exp(-y^2)\right). \quad (4)$$

We have found out that, when φ_c is given *a priori* in form (4), the control efficiency for the lowest–order aberrations increases (Table II). In this case the resulting values, obtained with the use of all polynomials considered, remain without changes. An assignment of φ_c in form (3) does not lead to any improvement of the correction quality.

In conclusion let us emphasize once more that for small thermal distortions of the beams it is quite sufficient to use for the adaptive control the corrector, which would reproduce only the lowest–order aberrations, i.e., tilt and defocusing. As the nonlinear distortions became greater it is necessary to employ the controlling element with the larger number of degrees of freedom.

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