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INVESTIGATION OF GASEOUS LIGHT-BEAM WAVEFRONT CORRECTORS AS ADAPTIVE OPTICS ELEMENTS

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The possibility of increasing the rate of variation of the optical parameters of gaseous focusing systems by directing a light beam perpendicular to the gas flow direction is investigated experimentally. It is shown that the rate of variation of the focal length can reach considerable values close to those of adaptive optics.

Up to now, many different types of gaseous optical wavefront correctors for light beams (gaseous lenses, prisms, and mirrors) [1-3] have been developed. Their operation is based on the creation of a certain type of distribution of the refractive index in a gaseous medium using dependences of the refractive index on temperature, pressure, concentration, etc. Most gaseous correctors are designed to operate in a steady-state regime [1]. However, it is frequently necessary to use, along with the high beam stability of these elements, their ability to vary their parameters at a rather high rate, corresponding to that of adaptive optics [4], in particular, adaptive focusing elements.

The main factor that governs the rate of variation of the parameters of a gaseous focusing corrector is the gas renewal time in the working zone $\tau = l/v$, where l is the length of the working zone along the gas flow direction, and v is the mean flow rate of the gas. In most gaseous focusing correctors [1, 2] pumping is carried out along the beam axis, and the transverse gradient of the refractive index is realized by means of boundary conditions on the channel walls and is formed by various transfer processes in gases. Due to this circumstance, a constraint on the maximum flow rate exists that is governed by the shaping rate of the required distribution of the refractive index. In addition, due to the need for a rather long (≈ 1 m) optical path of the ray for the long working zone with length l, a high rate of variation of optical parameters cannot be achieved ($\tau \geq 1$ sec).

In the present work we investigate a gaseous lens with the gas flow transverse to the light beam. In this case the gas renewal time will be $\tau = 2a/v$, where a is the radius of the aperture of the beam. A diagram of the model under investigation is presented in Fig. 1. The rectangular channel 1 (500 × 300 mm) is divided into separate sections 2, which are supplied by the working medium, and it should be noted that the refractive index in each section can vary independently. At the exit of the channel a homogeneous beam 3 with a stepped refractive-index profile is formed, which, as a result of turbulent transfer processes, is transformed into profile 4. In this zone are windows 5 (200 mm in diameter) for transmission of the light beam 6. If the profile of the refractive index in the working zone can be represented in a nearly parabolic form

$$n(y) = n_0 + \Delta n \,(1 - y^2/a^2) \tag{1}$$

(where Δn is the difference in the refractive indices at the center and at the periphery of the working zone), the light beam will experience an action similar to that of a cylindrical condensing lens with focal length

$$F \approx \frac{a^2}{2l\Delta n}\,. \tag{2}$$

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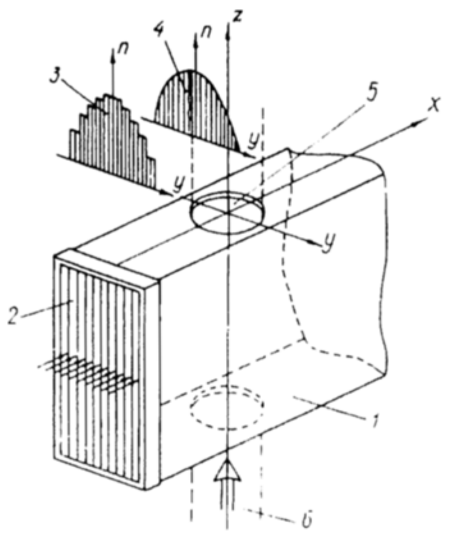

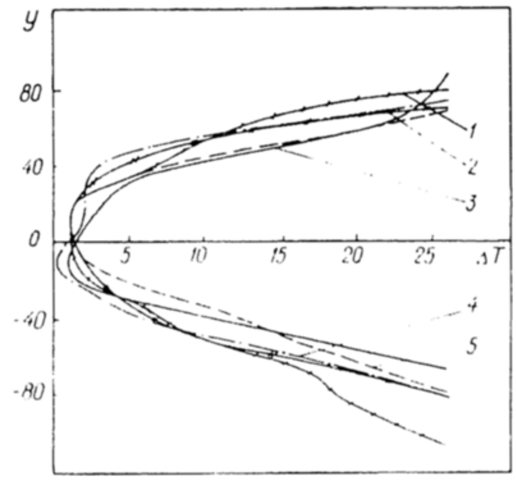

Fig. 1. Diagram of model of cylindrical gaseous lens.

Fig. 2. Temperature profiles ($\Delta T = f(y)$) in cross-sections along the z axis: 1) z = 50 mm; 2) 150; 3) 250; 4) 350; 5) 450. y, mm; ΔT, °C.

Taking into account the known temperature dependence of the refractive index of gases in terms of the Gladstone-Dale constant β

$$n(T) = 1 + \beta \frac{T_0}{T}, \tag{3}$$

we find the temperature distribution necessary to satisfy condition (1):

$$T(y) = T_0 \frac{T_0 + \Delta T}{T_0 + \Delta T(1 - y^2/a^2)}. \tag{4}$$

Finding the relationship between Δn and ΔT from (3) and substituting it into (2), we obtain

$$F \approx \frac{a^2 (T_0 + \Delta T)}{2l\beta \Delta T}. \tag{5}$$

One type of control of the refractive index can be realized by means of separate heating of the gas in each section by electric heaters. The required operation rate is reached if the condition

$$m_h < \frac{\tau P}{\Delta T_h c_h}, \tag{6}$$

is satisfied. Here P is the power of the heater, ΔT_h is the difference of temperatures of the heater and the gas flow, c_h is the specfific heat capacity of the material of the heater, and m_h is the weight of the heater. The condition can be satisfied for values of τ of the order of 0.1 sec. It should also be noted that, in addition to a high operation rate, the given type of focusing element has another advantage, namely, the ability to shape virtually any given refractive index profile and to correct by this means in a corresponding manner the wavefront of the light beam.

The heater was made from 10 quartz tubes 5 mm in diameter and 500 mm in length with Nichrome wire 0.6 mm in diameter coiled around them. Power delivered to the heaters was distributed in the following manner:

TABLE 1.

Heater number	1	2	3	4	5	6	7	8	9	10
Heater power P, W	1540	964	532	244	100	100	244	535	964	1540

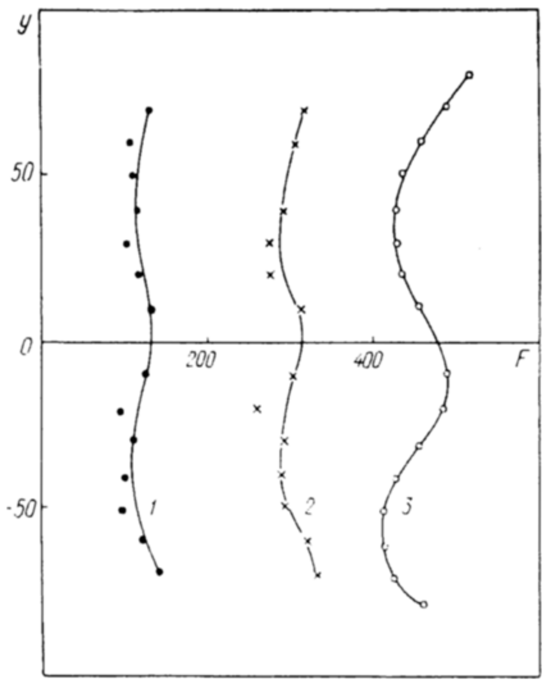

Fig. 3. Dependence of the focal length F on the y coordinate for: 1) F_{mean} = 120m; 2) 280; 3) 440. y, mm; F, m.

The model was placed in the working zone of a wind tunnel and fixed by a three-position coordinate spacer. The flow rate was measured by a Pitot tube and was maintained at a level of 2 m/sec. The temperature profiles along the cross-section of the gaseous lens were measured by a copper-constantan thermocouple, and the focal length was calculated by the formula $F_y = y/\epsilon_y$, where ϵ_y is the deviation angle of the light beam at the exit of the lens.

Several results of the investigations are presented in Figs. 2 and 3. The temperature profiles (Fig. 2) in various cross-sections along the z axis are smooth (not stepped), which indicates that the distance along the axis from the plane of the heater to the optical axis of the gaseous lens is considerable; in the given case it was equal to 1 m. The shape of the temperature profiles in different cross-sections perpendicular to the optical axis of the gaseous lens is somewhat changed but still close to parabolic, especially in the vicinity of the axis ($50 < y < 170$ mm). Inasmuch as the focusing properties are influenced by the total action over the entire thickness of the optical nonhomogeneity, these deformations of the temperature field will manifest themselves only in aberration characteristics of the gaseous lens. Their magnitude and character can be judged from the dependences of the focal length F on the entry coordinate y of the beam into the lens presented in Fig. 3. For a lens that is free of spherical aberration this dependence should be a straight line parallel to the y axis. Deviations in one direction or another indicate the presence of positive or negative spherical aberration. The results presented in Fig. 3 correspond to operation regimes of the gaseous lens with F_{mean} = 120, 280, and 440 m. Switching from one regime to another which was realized by changing the total voltage supplied to the heating device, took place in 0.08-0.1 sec. Thus, with this design, we managed to reach focal-length variation rate $\Delta F/\Delta t \simeq 200$ m/sec.

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