ACOUSTIC STABILIZATION OF THE WAVEFRONT OF A LASER BEAM IN A NONUNIFORM GASEOUS MEDIUM

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The action of an acoustic field on a nonisothermal gaseous medium for the purpose of improving the optical characteristics of the medium is studied. Restoration of optical uniformity of the gas and stabilization of the wavefront of a laser beam were modelled in experiments with acoustic flows.

As a light beam propagates in a nonisothermal medium the wavefront of the beam is distorted [1, 2]. In many cases the problem of phase distortion can be solved not only by correcting the wavefront but also by reducing the nonuniformities in the path of the beam. In a gaseous medium such stabilization of the wavefront can be achieved by the action of a poweful acoustic field on the region of nonuniform gas and acoustic flows arising in the gas on absorption of sound. Acoustic flows can be employed, first of all, to remove nonuniformities from the path of the light beam and, second, to reduce the scale of the nonuniformity.

The main advantages of acoustic flows over other types of convection are their low inertia and the fact that the dimensions of the region of interaction are controllable [3].

We shall study the following model of the action of acoustic flows on a nonisothermal medium (Fig. 1). The sound emitter 1 generates an ultrasonic beam 2 in the direction toward the nonuniformtiy 3. Owing to the absorption of sound secondary acoustic flows 4, propagating in the same direction as the sound, develop in the gas. As a result the nonuniform gas is blown out of the region of the light beam 5 and the front of the light beam remains undistorted.

The stabilizing action of the acoustic field is characterized by the size of the region S from which the nonuniformity must be removed and the time T_k from the start of the emission of sound to restoration of the phase front or intensity of the light flux. The distance over which effective action on the optical nonuniformity is possible is determined by the power of the transmitter and the sound absorption coefficient. There are several possible cases of ratios of the sound absorption coefficients α_0 in the medium regarded as a uniform medium and the absorption coefficient α_n in the irradiated nonuniform medium:

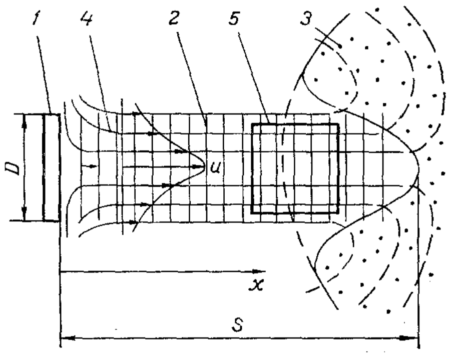

Fig. 1. Acoustic flows in a nonuniform medium: 1) sound emitter, 2) sound waves, 3) nonuniformity, 4) streamlines of acoustic flows, 5) light beam.

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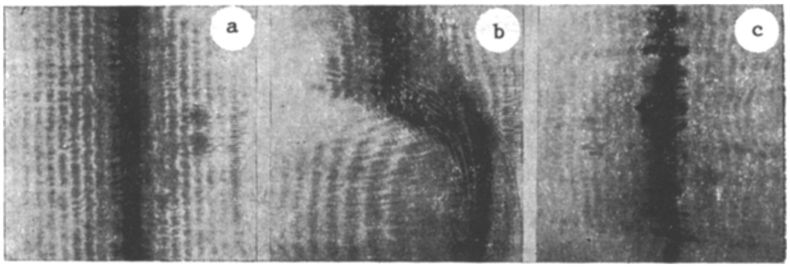

Fig. 2. Undistorted laser beam (a), laser beam with a distorted wavefront (b), and beam with the wavefront restored in an acoustic field (c).

a) $\alpha_n \ll \alpha_0$ – the nonuniformity is removed by the flow arising in a uniform region and S is determined by the properties of the uniform medium;

b) $\alpha_n \gg \alpha_0$ – acoustic flows arise primarily in the nonuniform region and S is actually determined by the size of the removed nonuniformity; and,

c) $\alpha_n \sim \alpha_0$ – the flows arise both outside and inside the region of the nonuniformity.

In the general case we shall assume that S is characterized by a large absorption coefficient:

$$S = A\alpha^{-1}, \tag{1}$$

where the constant A = 1.5-3.

At this distance the absorption of the starting energy of the acoustic field is of the order of 99%.

In the case of linear propagation and absorption of acoustic waves, when the acoustic Reynolds number $Re_a < 1$, α = const [4] and the optimal frequency of the sound can be determined for a given region of action of the flows. Since [5]

$$\alpha = \frac{A}{S} = \frac{2\pi b f^2}{\rho_0 c_0^3},$$

the frequency of the sound will be determined by the expression

$$f \simeq \sqrt{\frac{\rho_0 c_0^3 A}{2\pi b S}}. \tag{2}$$

For $Re_a \gg 1$ (intense sound in a weakly absorbing medium) the absorption owing to nonlinear distortion of the acoustic wave will occur much more rapidly, especially after the formation of rupture in the waves [4]. Starting from the same conditions we shall estimate the optimum frequency of the sound. To simplify the calculations we shall assume that the sound propagates in the ideal medium ($Re_a \to \infty$). The decay of the amplitude of the wave after the formation of rupture is described by the formula [4]

$$\frac{\Delta v(S)}{\Delta v(0)} = \frac{\pi}{1 + S/x_r}, \tag{3}$$

where x_r is the distance from the sound emitter to the region of rupture formation in the wave.

In accordance with the definition adopted for S

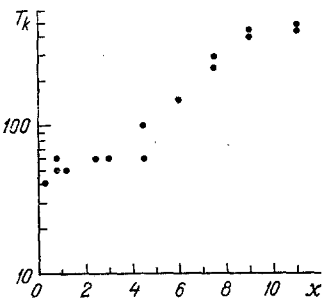

Fig. 3. The restoration time as a function of the distance to the sound emitter. T_k, msec; x, cm.

$$\frac{\Delta v(S)}{\Delta v(0)} = \frac{1}{eA}. \quad (4)$$

From here we obtain an expression for the frequency of the sound

$$f \simeq \frac{1{,}2\, c_0^2 A}{\Delta v \varepsilon S}, \quad S \geqslant \frac{\pi}{2} x_r. \quad (5)$$

The formulas (2) and (5) make it possible to estimate the frequency and the intensity of the sound, which give rise to effective action on the nonuniformity, and conversely the size of the region in which efficient generation of secondary flows is possible can be determined from the known frequency and intensity of the sound. The action of acoustic flows on a nonuniform medium for the purpose of reducing the phase distortions of the light beam was studied experimentally as follows. Gas, whose refractive index was different from that of air (xenon or carbon dioxide), was injected through a nozzle into the uniform medium (air) along the path of the initially undistorted laser beam (Fig. 2a). This created in the medium a distribution of the refractive index of the form n = n (x, y). As the light propagated through such a medium the wavefront became distorted with the phase changing up to 10π, which resulted in significant redistribution of intensity of the laser beam in space (Fig. 2b). Under the action of an acoustic pulse with a sound frequency of 1 MHz and intensity 130-140 dB, which generated secondary flows, the nonuniformity was blown away from the path of the laser beam, and as the density of the medium was restored the wavefront and the intensity distribution were restored (Fig. 2c). In this manner phase stabilization was achieved.

To determine the speed of this method for stabilizing the light beam we studied the change in the intensity of the light on the axis of the laser beam with an acoustic pulse emitted into a nonuniform medium. Analysis of the dependence $I_0(t)$, where t is the time at which the sound emission starts and I_0 is the intensity of light on the axis of the beam, shows that the restoration time T_k, defined as the time from the start of sound emission to restoration of the light intensity to the initial intensity, corresponding to the undistorted beam, practically equals the formation time of acoustic flows in the medium [3]. This result is valid, at least, in the zone of active acoustic flows. Away from the emitter at a distance x > S the time T_k increases appreciably (Fig. 3). At these distances the acoustic flows are significantly attenuated. It follows from here that, first of all, in the zone S of generation of intense acoustic flows the characteristic times T_k are determined by the flow development times and, second, in the far zone, where the second intensity is much lower and the acoustic flows are much weaker, T_k is determined primarily by the velocity of the acoustic flows and can exceed the corresponding time near the emitter even by an order of magnitude (Fig. 3). For this reason, in choosing the frequency and intensity of the sound in accordance with the model described it is necessary to take into account the fact that phase stabilization is best done at distances not exceeding $S = A\alpha^{-1}$.

It follows from the experimental results that the acoustic method of phase stabilization of a light beam makes it possible to reduce (prevent) significant phase distortions ($\gg \pi$) over times of the order of tens of milliseconds by acting on the nonuniform medium. The region and time of action are determined by the frequency and intensity of the acoustic pulse.

NOTATION

f, sound frequency; ρ_0, density of the medium; c_0, sound velocity; α, sound absorption coefficient; b, absorption constant; A, coefficient of proportionality; S, size of the region of stabilization; T_k, wavefront restoration time; Re_a, acoustic Reynolds number; Δv, amplitude of the particle velocity in the ultrasonic wave; I_0, intensity of the light; n, optical refractive index,; and, ε, nonlinear parameter of the medium.

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MULTIPLICITY OF HYDRODYNAMIC STATES OF THE FLOW OF A REACTING GAS THROUGH A LAYER OF CATALYST

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It is shown numerically for the example of a two-temperature quasistationary model of the processes occurring in a layer of catalyst that in a reactor operating with a fixed pressure differential a set of stationary states can in principle exist.

The pressure drop in a layer of catalyst through which a reacting gas flows is a quite important technological characteristic, determining the intensity of transport processes and the energy required to produce the layer. For most cases of practical interest there exists a single-valued relationship between the pressure drop and the flow rate; this relationship is most often expressed by the formula of Ergun [1].

A chemical reaction accompanied by intense heat release in the layer of catalyst can destroy the single-valued relationship between ΔP and G. This fact has already been investigated in [2, 3], where it was established that several stationary states exist for a fixed pressure drop over the layer of catalyst. In these works the single-temperature model of the ideal flow was employed and in the analysis of the model, in our opinion, quite strong assumptions that could affect the final quantitative results were made. Thus in the analysis of multiplicity in [2] the equation of state of the gas mixture was not taken into account, and in [3] the quadratic term in Ergun's equation [1] as well as the effect of heating of the layer of catalyst on the pressure drop were neglected.

In this work we analyze the multiplicity of hydrodynamic states based on a two-temperature model, usually employed to analyze the processes occurring in the layer, without making the assumptions described above.

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