and by (5). It is clear from Fig. 4 that the values calculated by (5), which takes account of heat transfer at the gas—fiber boundary, are in better agreement with experiment than values calculated by (28).

NOTATION

λ_g^*, λ_g, molecular thermal conductivity of gas inside a dispersed material and in a free volume; Kn, Knudsen number; $\bar{l}$, $\bar{l}^*$, mean free path of gas molecules in a free volume and inside a dispersed material; λ_1, thermal conductivity of fiber; λ_r, radiative heat-transfer coefficient; α, heat-transfer coefficient of gas—fiber boundary in a layer of thickness $\bar{l}^*$; λ_{eff}, effective thermal conductivity of dispersed material; D, fiber diameter; Δ, L, elementary cell parameters; C_p, ρ_g, specific heat and density of gas filler, respectively; $\bar{v}$, average velocity of thermal motion of gas molecules; M, molecular weight of gas; F_{sp}, specific surface of solid phase per unit volume of dispersed material; m, porosity; k, Boltzmann constant, $1.38 \cdot 10^{-23}$ J/deg; n_0, Loschmidt number, $2.69 \cdot 10^{25}$ m^{-3}; T_i, temperature of gas at a distance $\bar{l}^*$ from fiber surface; T_s, temperature of fiber surface; a, accommodation coefficient; γ, ratio of specific heat of gas at constant pressure to specific heat at constant volume.

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USE OF A DIAMETRAL BLOWER IN A FLOW-THROUGH LASER WITH A CLOSED GAS-CIRCULATION SYSTEM

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The choice of a dimetral blower in a closed laser gasdynamic loop is justified and its operation is investigated.

It is known [1] that the specific energy applied to the active medium of electric-discharge gas lasers is limited by two factors — heating and instability of the gaseous plasma. The main method for overcoming them in application to continuously operating lasers is the rapid pumping of gas through the discharge in a time less than the relaxation time of the internal degrees of freedom and the time of development of instabilities [2]. The stability of the discharge essentially depends on the uniformity of the stream. In [3], e.g., upon a decrease in the velocity scatter from 10 to 3% the maximum energy applied in the stable mode grew more than twofold. The reason for this phenomenon is that nonuniformity of the stream leads to superheating of those of its parts which move with a lower velocity. This leads to transverse stratification of the discharge [4]. The zones with increased current density arising in this case are most dangerous from the point of view of contraction of the discharge [5] and considerably reduce the attainable threshold for the total energy input. Local superheats also lead to optical nonuniformity of the medium associated with density gradients. Optical nonuniformities cause radiation losses to scattering in the active medium, as well

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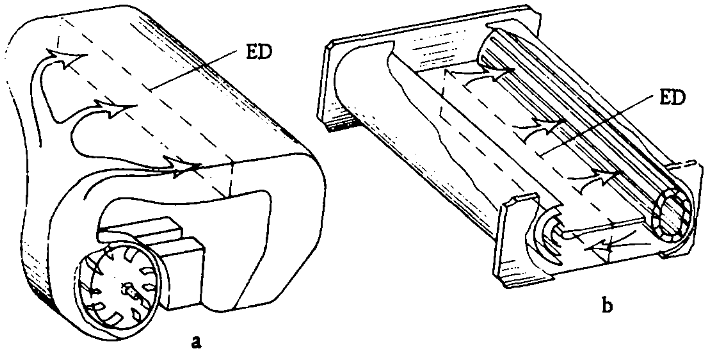

Fig. 1. Geometry of a closed gasdynamic laser loop using a) a centrifugal blower; b) a diametral blower; ED) electric-discharge chamber.

as degradation of the quality of the generated optical beam owing to deformation of the wave front [6] and power transfer from the principal mode to higher-order modes [7].

Rapid pumping is associated with high rates of gas consumption, which can be avoided only in systems with closed circulation [3, 8]. The geometry of such systems is determined by the ratio of the cross sections, transverse to the flow, of the active zone and of the device producing the gas motion. Blowers are used to produce subsonic streams while compressors are used for near-sonic and supersonic streams. Both of them usually belong either to the axial or the centrifugal type [9]. Continuous gas lasers are characterized by relatively low amplification factors. Therefore, to create sufficient amplification on one pass one must use active zones which are long along the optical axis (on the order of a meter). The second dimension of the active zone across the flow is determined by the interelectrode distance (usually less than 10 cm). Thus, the cross section of the active zone is a greatly elongated rectangle. As is known, the cross sections of axial and centrifugal blowers (compressors) have nothing in common with this geometry. So when such ventilators are used in closed gasdynamic loops one must introduce adapters for the gradual narrowing and widening of the stream in different planes (Fig. 1a). This leads to large hydraulic losses and a considerable increase in the overall size of the installations. It has an especially ruinous effect on the stream quality. It is known that separation of the stream from the walls and the formation of large-scale vortices already occur in diffusors having an expansion angle of more than 10° [10]. In order not to pass beyond the limits of allowable expansion angles the length of the diffusors must not be less than several meters. Usually one uses another means of improving the stream uniformity — the installation of grills [2], baffles [3], and honeycombs [11]. One more source of large hydraulic losses appears in this case, however. Moreover, the optimum parameters of the smoothing devices only correspond to fully determined gasdynamic modes.

The use of the so-called diametral blower in a flow-through laser with closed gas circulation is described in the present report. The operating principle of this relatively little-known type of blower consists in the use of the asymmetry of the vortex field produced by an impeller of the centrifugal type with blades bent slightly forward, lying partly inside a knee-shaped housing [12]. In this case the gas stream moves in the direction of the diameter of the impeller and passes twice through the rotating grill. Because of the absence in principle of limits on the axial dimension, these blowers have a considerably higher output than other types, while they have a considerably higher pressure owing to the twofold impulse obtained from the vanes. Korovkin [13] has made a major contribution to the development and investigation of diametral blowers.

In choosing the diameter and width of the blower one can make its cross section identical to the cross section of the discharge chamber, thus avoiding the need for narrowings and widenings of the gasdynamic loop. The latter can therefore be made simple and compact (Fig. 1b).

A number of specific new problems arise when diametral blowers are used in laser gasdynamic loops. Blowers operating in the mode of several thousand revolutions per minute are required for the creation of high-velocity streams of a laser mixture of gases (30-150 m/sec). The diametral blowers described earlier [13] operate in the range of 400-600 rpm. Vacuum-

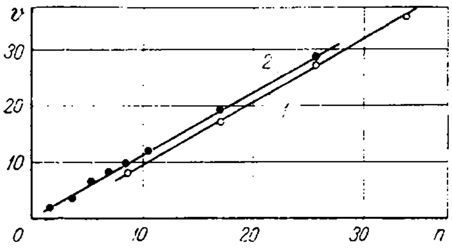

Fig. 2. Dependence of stream velocity on rotation speed of blower (v, m/sec; n, rpm): 1) helium; 2) $CO_2 + N_2 + He$ mixture (1:3:5).

tight rotating leads are required to prevent air leakage into the laser space, which is a rather complex engineering problem at the indicated rotation speeds. The question of the operation of a diametral blower in a closed loop whose geometry differs considerably from those studied earlier [13], on gas mixtures containing the light gas helium, and at a pressure considerably less than atmospheric requires clarification. Finally, to assure stability of the laser operation it is necessary to minimize the level of vibrations produced in the operation of the blower.

The results of kinematic measurements made at a distance of 10 cm from a diametral blower 1 m long, whichsatisfies the indicated conditions and operates in the gasdyamic loop shown in Fig. 1b, are described below. Turning vanes were mounted on the opposite side of the gasdynamic loop from the blower to reduce hydraulic losses.

The measurements at atmospheric pressure were conducted with a Pitot—Prandtl tube and a thermoanemometer. Calibration was performed in a low-turbulence wind tunnel. The problem of measurements at a considerably lower pressure requires a special discussion. It is known [14] that the interpretation of the readings of these instruments is a very complicated task in this case. Unfortunately, the methods of laser anemometry can also not be used, since they require the introduction into the stream of suspended particles, and besides, these are poorly entrained by the stream at a reduced pressure. As seen from the foregoing, it seems most reliable to us to rest on the dependence between the rotation speed of the blower and the stream velocity obtained at atmospheric pressure (Fig. 2). In fact, in converting to the peripheral velocity of the blower blades we obtain the dimensionless velocity ratio v/u, which should be a function only of the Reynolds number for Knudsen numbers $Kn \ll 1$ (relative to the characteristic dimensions of the gasdynamic loop). As seen from Fig. 2, this ratio is constant in a wide range of velocities and depends weakly on the kind of gas, with experiments with air and a triple laser mixture giving practically identical values. The ranges of variation of the product, entering into the Reynolds number, of the density and velocity of the gas entrained by the blades partially overlapped in the measurements at atmospheric and reduced pressures. Calibration of the thermoanemometer was performed in the section of overlap.

To construct the relative velocity profile it is sufficient to determine the character of the dependence of the signal taken from the thermoanemometer on the stream velocity. It is known [15] that at atmospheric pressure the voltage on the filament of a constant-resistance thermoanemometer depends in the following way on the stream velocity:

$$E^2 - E_0^2 = A\sqrt{v}, \tag{1}$$

where the left side is proportional to the power applied, and hence lost to heat removal from the thermoanemometer filament. The latter is inversely proportional to the thickness $\delta \approx d/\sqrt{Re}$ of the boundary layer. Therefore, at atmospheric pressure the Nusselt number Nu, characterizing the heat transfer due to forced convection, is proportional to $\sqrt{v}$. At reduced pressures, corresponding to $Re \approx 1$ (relative to the filament), the boundary layer ceases to be the characteristic dimension. It follows from theory and experiment [16] that in the transition from the continuous to the free-molecule (relative to the filament) mode there is a smooth transition from the dependence $Nu \sim \sqrt{Re}$ to $Nu \sim Re$. Since $Kn \approx 1$ in the present work (P = 10–30 mm Hg), we set up an additional experiment to refine the dependence of Nu on Re. It was found that in the indicated range the dependence of $Nu \sim (E^2 - E_0^2)$ on the gas pressure is practically linear. Since $Re \sim pv$ in this range, this is an argument in favor of the linear dependence

$$E^2 - E_0^2 = Bv. \tag{2}$$

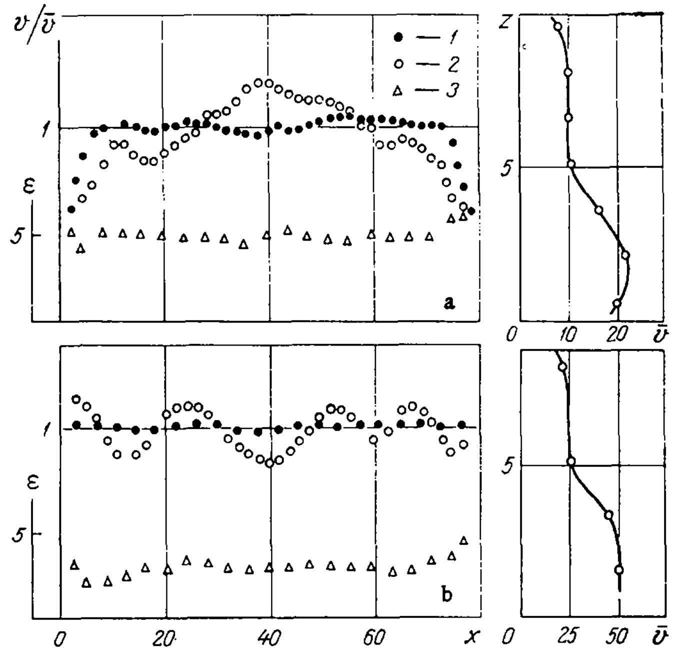

Fig. 3. Velocity profiles at p = 1 atm (a) and p = 20 mm Hg (b) (x, cm; z, cm): 1) with turning vanes; 2) without them; 3) mean level of pulsations (ε, %).

Equations for determining the velocity variation relative to the mean level were obtained from (1) and (2) under the assumption that $\Delta E \ll E$:

$$\frac{\Delta v(x)}{v} = \alpha \frac{E\Delta E}{E^2 - E_0^2}. \tag{3}$$

The coefficients α following from (1) and (2) equal four and two, respectively. It is obvious that slight departures from the linearity (2) cannot significantly affect measurements of the velocity profile.

The results of typical measurements of velocity profiles in the direction parallel to the blower axis at atmospheric and reduced pressures are presented in Fig. 3a,b. It is seen from the figure that when a diametral blower and turning vanes are used one obtains sufficiently high stream uniformity in the immediate vicinity of the blower without the use of any smoothing devices. The rms departure from the mean velocity comprises 2.9% at p = 1 atm and 1.4% at p = 20 mm Hg. In the absence of turning vanes the velocity profile is sharply degraded while the scatter reaches 16 and 11%, respectively. The improvement of the velocity profile at the reduced pressure is connected with a decrease in Re, i.e., with an increase in the role of the viscous interaction.

Measurements were also made of the projection parallel to the stream of the mean level $\varepsilon = \sqrt{\overline{\Delta v^2}(t)}/v$ of transient velocity pulsations. This quantity has a value of about 5% at atmospheric pressure and varies little over the width of the channel. It is known [17] that fine-scale pulsations promote "dissipation" of the nuclei of plasma instabilities and thus are useful for the given problem. The fundamental pulsation frequency is determined by the product of the number of blades (25) times the number of revolutions per second (50-100), and it is several kilohertz. Since the time of development of "molecular" instabilities in steady discharges [5] is on the order of 10^{-3} sec, these pulsations are suitable for their suppression.

The velocity profile over the height of the channel (Fig. 3a,b) proved to be nonuniform. The maximum velocity is reached near the outer wall of the loop. The axial velocity profiles are taken at this height. The velocity near the inner diaphragm proves to be about 1.5 times lower. Since the glow discharges used in flow-through lasers possess sharply expressed asymmetry in the anode-cathode direction [18], nonuniformity in this direction only can prove useful for selective action on individual zones of the discharge [19].

An important feature of a diametral blower is the high ratio of the stream velocity to the peripheral velocity of the blades. It is known [9] that this ratio is less than unity for axial and centrifugal blowers. In our experiments the stream velocity near the outer wall proved to be 2.1 times higher than the peripheral velocity at the outer diameter of the blower. This fact is extremely important, since it allows one to obtain higher stream velocities at relatively low ventilator speeds (2-3 times higher than for centrifugal and axial blowers). Thus, problems associated with dynamic balancing, the vacuum seal of the rotating shaft of the blower, and the strength of the latter against breakage and vibrations are considerably simplified.

The absolute values of the velocity at a reduced pressure can be calculated in the following way. In the present work it was established experimentally that the dependence of Nu on the peripheral velocity u of the blower at $p = 20$ mm Hg is linear. In combination with the relation Nu ~ Re this leads to the proportionality $v \sim u$. These considerations correspond well to the dependence between the blower speed and the stream velocity obtained at atmospheric pressure (Fig. 2). All the foregoing, in conjunction with the similarity with respect to Re, allows one to extrapolate the dependence of v on n (Fig. 2) into the region of pressures on the order of 10-30 mm Hg. At the maximum velocities at the reduced pressure, when the Reynolds number has the same value as at low velocities at atmospheric pressure, the similarity with respect to Re is sufficient for extrapolation. The absolute value of the velocity was also monitored by the deflection of a flag placed in the stream. The maximum stream velocity was 130 m/sec. It is interesting to compare the outputs of centrifugal and diametral blowers in the same gasdynamic loop. At equal rotation speeds and blade outer diameters the output of the diametral blower was as many times higher as the width of the discharge chamber was larger than the axial dimension of the centrifugal blower. This amount should be multiplied by two (double impulse). Thus, there is a matter of an order of magnitude even without allowance for the hydraulic losses in a loop of variable cross section.

In conclusion, we point out the connection between the stream velocity and the power expended on the rotation of the blower. The latter (under the assumption that the stream compression is adiabatic) is equal to the change in the enthalpy of the system per unit time, i.e., it is proportional to $v\Delta p$. When a blower operates in an open space Δp is the total pressure drop produced by the blower. Since $\Delta p \sim v^2$, the useful power expended is proportional to the cube of the velocity. When operating in a closed cycle the blower only compensates for the pressure losses in the loop. The latter, as is known, are proportional to the stream velocity for the frictional drag and to the square of the velocity for the so-called local resistances [12].

The experimental data were approximated by the dependence v^m. It was found that $m \approx 1$ at low velocities while $m \approx 2$ at high velocities, which corresponds to frictional drag. When various obstacles were installed in the loop the dependence became steeper ($m > 2$). On the whole, the dependence of the total power required by the blower on the stream velocity is weakened in comparison with the estimates given above. This is explained by hydraulic losses in the blower itself and by other kinds of losses.

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NOTATION

v, stream velocity; u, peripheral velocity at outer diameter of blower; n, number of blower revolutions per unit time; Kn, Knudsen number; Re, Reynolds number; Nu, Nusselt number; E, voltage on thermoanemometer filament; E_0, the same at $v = 0$; d, filament diameter; δ, thickness of boundary layer; p, pressure; Δv, velocity variation; ΔE, voltage variation; x, z, present coordinates along width and height of gasdynamic loop, respectively; ε, mean level of pulsations.

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EXPERIMENTAL INVESTIGATION OF THE TURBULENCE FLOW CHARACTERISTICS BEHIND A SYSTEM OF FLAME STABILIZERS

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Measurements are carried out of the intensity and scale of turbulence in the flow behind a system of flame stabilizers. A comparison is made between the results obtained and the known data for flows behind grills and single stabilizers.

The front assembly of modern straight-through type combustion chambers is a system of flame stabilizers arranged, in practice, in a single plane. The degree of blocking of the flow by the stabilizers may reach 50%. The flow turbulence characteristics behind the front assembly, which mainly determine the fuel combustion intensity and consequently also the length of the combustion chamber, in these conditions should depend in a significant way on the energy of the pulsation motion generated by the flow around the flame stabilizers and by its dissipation mechanism.

Data are available in the literature concerning the turbulence characteristics of the flow behind single stabilizers [1-3] and behind grills of different types [4-7]. There are almost no similar data in the literature for a system of stabilizers. The question concerning what type of flow is closest to the flow behind a system of stabilizers along the fuel combustion zone, to the flow behind a system of single stabilizers or to the flow behind a grill, still remains open.

In this present paper, therefore, measurements have been carried out of the flow turbulence characteristics behind systems of stabilizers, an attempt is made to find a relation between these characteristics and the geometrical dimensions of the system, and also a comparison is carried out between the measured quantities and the similar data for single stabilizers and grills.

The experiments were conducted in models of a combustion chamber of rectangular cross section 170 × 230 mm and 250 × 300 mm, in which two or four plane V-shaped flame stabilizers were installed, with a vertex angle of 45°. The stabilizers were arranged in one plane of

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