EXPERIMENTAL INVESTIGATION OF THE OUTER WAVE FIELD AT THE OPEN END OF A PIPE

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The results of investigating the external wave field radiated from the open end of a tube on the linear and nonlinear resonance intervals are presented. The presence of a velocity amplitude maximum in the wall zone near the open end is detected. The limits of vortex motion of the gas within the tube are determined. The flow core in the wave field is investigated.

Almost all mass transfer processes are intensified in a wave field and depend on the wave amplitudes. The object of the present study was to investigate experimentally the wave field radiated from a tube, one end of which is open while at the other end a plane piston moves in accordance with a given periodic law with frequency ω. As the excitation frequency ω approaches the linear $\omega_n = (2n - 1)\pi a_0/2L$ and nonlinear $\omega_n^* = (2n - 1)\pi a_0/4L$ $(n = 1, 2)$ resonance frequencies the pressure and velocity grow and the diagrams are significantly deformed, which leads to the formation of periodic shock waves and high-amplitude velocity fluctuations at the open end of the tube. Here, $L = L_0 + m^2 l_0 + (m^2 + m + 1)h/3 + 0.3d$ [1, 2], $m = d_0/d$, $2l_0$ is the stroke of the piston, and 0.3d is the Rayleigh correction.

The nonlinear vibrations of a gas in an open tube were studied experimentally in [2-9]. Sharp pressure jumps were detected near nonlinear resonances [2]. It was shown that in resonance regimes the gas velocity at the open end of the tube may reach 150 m/sec or more [4, 8, 9]. Various nonlinear effects associated with wave propagation in a tube with endpieces were observed [5]. In these studies the tube diameter was equal to or less than the diameter of the piston $(m \geq 1)$.

The present experiments were performed on the apparatus described in [1, 2]. The longitudinal vibration of the gas column was produced by the piston of a motorcycle engine. Its diameter was equal to $2R_0 = 62 \cdot 10^{-3}$ m, and the stroke was $2l_0 = 66 \cdot 10^{-3}$ m. A stainless steel tube of length $L_0 = 3.2$ m with an inside diameter $2R = 0.134$ m $(m < 1)$ was connected to the

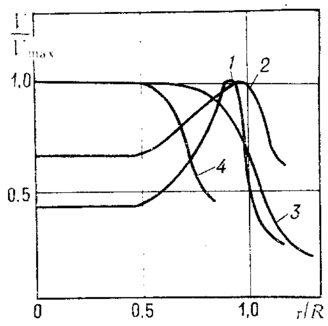

Fig. 1

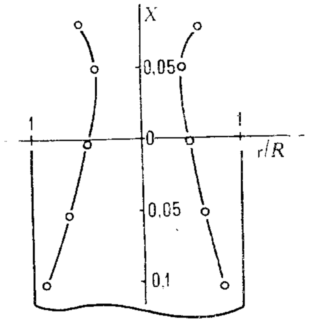

Fig. 2

Fig. 1. Velocity distribution in resonance regimes at the open end of a tube: curves 1-3 correspond to the ejection phase, curve 4 to the induction phase.

Fig. 2. Limit of vortex motion of the gas at the open end of the tube. X, m.

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engine cylinder by means of an expanding adapter $h = 9 \cdot 10^{-2}$ m high. The pressure was measured with a pressure transducer, the signal from which was fed to a S1-54 synchronizing oscillograph. The rate of revolution was determined photoelectrically correct to 0.1 Hz, and the data were recorded by a TTs-3M digital tachometer [9]. The gas velocity fluctuations were measured with the constant-temperature hot-wire anemometer of a 5600 CTA (DISA) multichannel system. The probe wire could be displaced in the axial and radial directions by means of a traverse mechanism. The oscillations of the gas velocity were recorded with a N-117 oscillograph. It is characteristic of systems of this type that during the piston oscillation period two phases of motion of the flow exist: ejection and induction. Figure 1 shows the distribution of the dimensionless peak values of the velocity in the resonance regimes at the open end of the tube. The ejection phase for linear resonance corresponds to curve 1 ($V_{max} = 32$ m/sec, $\omega_1/2\pi = 28.5$ Hz, $L_0 = 3.2$ m) and that for nonlinear resonance to curve 2 ($V_{max} = 17.5$ m/sec, $\omega_2^*/2\pi = 43.1$ Hz, $L_0 = 2.6$ m). Clearly, when $r/R < 0.5$ (r is the distance from the tube axis in the radial direction) the peak values of the velocity are constant. Then, as r/R increases, for both resonances V increases up to $r/R \approx 0.9$ and at $r/R > 0.9$ the amplitude falls. Thus, for tubes with $m < 1$ a velocity maximum is observed in the neighborhood of $r/R = 0.9$. This is an important difference from the results for tubes with $m \geq 1$, when the maximum is observed at the center of the tube [4, 9]. The corresponding experimental data are represented by curve 3 ($V_{max} = 130$ m/sec, $L_0 = 4$ m, $d = 4.4 \cdot 10^{-2}$ m, $d_0 = 0.1$ m) [9]. The formation of a maximum in the wall zone is associated with the fact that on the purely translational motion of the gas during the ejection phase there is superimposed the rotational motion of the toroidal vortex discharged from the tube. In the induction phase (curve 4, $V_{max} = 15$ m/sec, $L_0 = 3.2$ m) the peak values of the velocity are constant when $r/R < 0.5$ and as r/R increases V decreases smoothly. Velocity measurements were also made inside the tube and revealed a similar pattern of gas velocity variation. Thus, the results obtained made it possible to determine the boundary of the vortex motion of the gas inside and outside the tube (Fig. 2).

Oscillograms of the velocity fluctuations at various points in the axial direction are reproduced in Fig. 3. In the induction and ejection phases at the point $X = 5 \cdot 10^{-3}$ m the oscillation amplitudes are approxiamtely equal. Up to $X = 85 \cdot 10^{-3}$ m in the ejection phase the amplitude retains its value, while in the induction phase it decreases and at $X = 125 \cdot 10^{-3}$ m vanishes. We note that on the interval $5 \cdot 10^{-3} \leq X \leq 85 \cdot 10^{-3}$ m after the induction phase

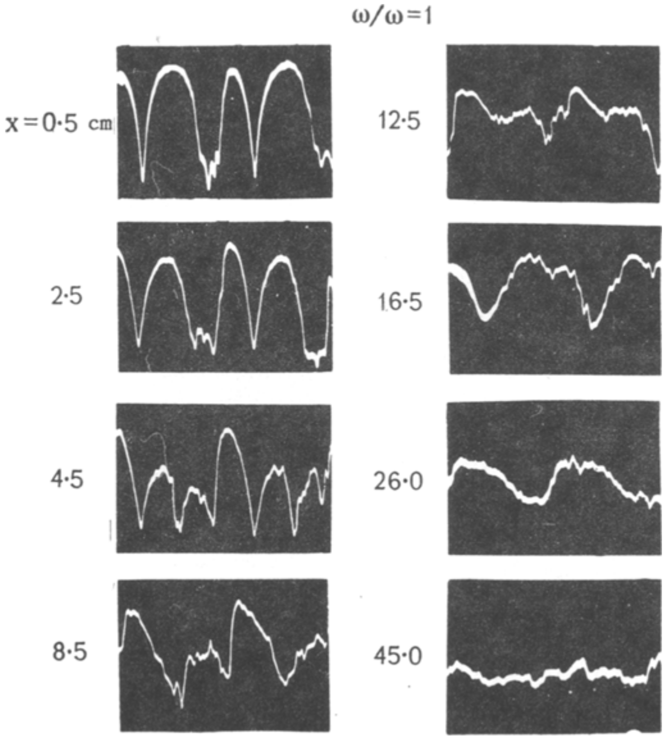

Fig. 3. Oscillograms of the velocity fluctuations at various points in the axial direction.

an additional maximum appears. As the values of X increase, the vibrational velocity component in the ejection phase also decreases and at two tube diameters (X = 0.45 m) small-amplitude random fluctuation of the gas in the core of the jet is observed. Similar behavior of the velocity fluctuations is also observed in narrow tubes ($m \geq 1$). However, the decrease in the oscillatory component in the ejection phase is observed at five diameters [9]. Thus, the experiments have revealed a number of distinctive features of the vibrations of a gas column in an open tube whose diameter is greater than the piston diameter. The results will be useful for investigating the action of an external wave field on mass-transfer processes in gas—liquid systems.

NOTATION

ω_n and ω_n^* are the linear and nonlinear resonance frequencies; a_0 is the speed of sound in the undisturbed gas; L_0 is the length of the tube; L is the reduced length of the tube; d_0 is the piston diameter; d is the tube diameter; $2\ell_0$ is the piston stroke; h is the height of the adapter; V_{max} is the maximum velocity; r is the horizontal displacement; X is the distance in the axial direction.

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HYDRODYNAMICS AND HEAT EXCHANGE IN COOLING SYSTEMS WITH INTERSECTING CHANNELS. I. HYDRODYNAMIC CHARACTERISTICS

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We present the results of visualization and measurement of hydrodynamic drag for $Re_1 = 1 \cdot 10^2 - 2.5 \cdot 10^4$ as a function of the geometry and the angle of flow about the structure.

Introduction. One of the goals of using a cooling system with intersecting channels is to increase the rate of heat transfer. There is only one attempt in the literature [1] to generalize the experimental data on the hydraulic drag for such systems. In the case closest to our area of application [2], a structure of considerable relative height ($h_c/\delta_c \sim$ 7-9) was examined, and there were no data on the hydraulic drag. However, in a number of technical objects the thickness of the heat exchanger must be limited.

In the present work we experimentally determine the structure of the flow and the hydraulic drag in cooling systems with intersecting channels of moderate height (h_c/δ_c = 1-3).

Generally the form of such a system (so called waffled structure) is obtained by forming a series of channels of uniform height h_c which intersect each other at angle φ in the material. A series of fins are formed having longitudinal spacing S_2 and transverse spacing S_1, and in the general case the channels can have different widths δ_{c1}, δ_{c2}. In practice,

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