tance between nozzle axes; $\tau(M)$, $q(M)$, $\pi(M)$, gas-dynamic functions; δ, pressure drop at shock wave; σ, angle of slope of shock wave.

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QUESTION OF THE MOTION OF A SYSTEM OF SEQUENTIAL COAXIAL VORTEX RINGS IN A HOMOGENEOUS FLUID

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Results are presented of an experimental investigation of the singularities of the motion of a system of interacting toroidal vortices in a homogeneous fluid.

In connection with the possibility of a practical application of ring vortices to remove smoke, harmful gases, etc. in industrial plants, numerous theoretical and experimental investigations have recently been performed concerning the mechanism of ring vortex formation and the regularities of their propagation in gases and liquids [1-4]. Significantly less attention has been paid to questions of propagation of a system of coaxial vortex rings following one another. Meanwhile a number of specific properties of the motion is of interest in these cases.

It is known [5] that there is a complete analogy between the equations of vortical fluid motion and the fundamental equations of the theory of electromagnetism. Moreover, a relationship is obtained that describes toroidal vortex interaction that is analogous to the Biot-Savart law about the action of an electrical current on a magnetic pole. This would permit a general representation to be obtained about the dynamics of the motion of two coaxial vortex rings with identical direction of rotation.

Their mutual influence is that the radius of the vortex going forward increases while that of the following vortex diminishes. While the radius of the first vortex is made greater than the radius of the second, its motion is retarded and that of its follower is accelerated.

An experimental verification of the "leapfrogging" of two vortex rings was obtained in [6, 7]. We take the following notation 2,1 → 1,2 → 2,1 for convenience in describing the "leapfrogging" to two vortex rings.

Denoting by 1, 2, 3 the first, the next, and the last vortices, respectively, from the exit of a vortex generator and taking account of what was said above, we can give a basis for the following possible variants of the "leapfrogging" of three coaxial vortex rings: 1) 3,2,1 → 3,1,2 → 1,3,2 → 1,2,3 → 2,1,3 → 2,3,1 → 3,2,1; 2) 3,2,1 → 1,2,3 → 3,2,1; 3) 3,2,1 → 1,2,3 → 2,1,3 → 2,3,1 → 3,2,1; 4) 3,2,1 → 1,2,3 → 1,3,2 → 3,1,2 → 3,2,1. It is assumed here that the vortex ring of large radius does not overtake the ring of smaller radius and that two kinds of interaction, doubling (merger of two vortices) and tripling (merger of three vortices) can occur.

If the number of vortex rings is $N > 3$ then the quantity of possible interactions naturally grows. For favorable relationships between the sizes, intensity, and repetition rate

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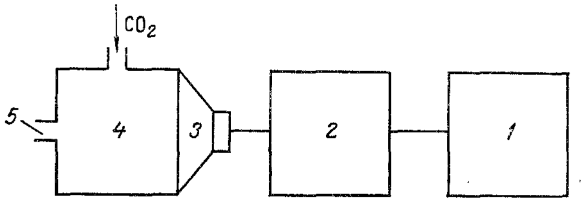

Fig. 1. Block diagram of the toroidal vortex generator.

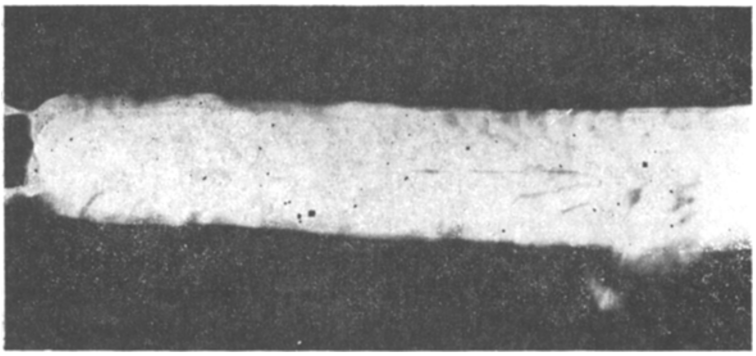

Fig. 2. Shadowgraph of the vortex column.

of the vortices, a vortex column continuous in space can be formed. The propagation of separate vortex trains is possible upon spoilage of the "leapfrogging" conditions, when the spacing between any adjacent rings grows inadmissibly, say.

On the basis of results from [8, 9], it can be assumed that interacting ring vortices are more stable as compared with singles from the viewpoint of their mixing with the environment. Then there is the possibility of obtaining channelization of the energy emitted by the generator during its propagation in fluids of gases.

The toroidal investigations were obtained in our investigation by diffraction of a pressure pulse by a circular orifice. The pressure pulses were formed in the unit used (Fig. 1) by a wideband dynamic head (2GD4) 3 within a cubic resonator 4 with 15 cm edge length. At the center of the resonator face opposite to the head was a tube 5 of diameter 15 mm and length 20 mm. The voltage pulses delivered to the dynamic head were shaped by a rectangular pulse generator 2 (G5-54) that was triggered by the master oscillator 1 (G3-118). The flow being formed was checked in an IAB-451 shadowgraph. In order to magnify the contrast of the shadow pattern, the inner space of the resonator was filled with carbon dioxide.

Stable generation of single toroidal vortices propagated in air to a distance of up to 2 m with an initial velocity of 0.2 m/sec was observed for a pulse duration of 1 msec. The system of coaxial toroidal vortices was produced for pressure pulse repetition rates in the band 10 Hz $\leq$ f $\leq$ 100 Hz. Starting with f = 10 Hz, the formation occurred of a vortex column, continuous in space, whose stability rose as the repetition rate grew and reached a maximum at f = 20 Hz. Later transverse oscillations occurred that grew as the frequency increases.

A photograph of the shadow pattern for f = 20 Hz is represented in Fig. 2, as taken with the exposure time 1/60 sec, from which it follows that the radius of the vortex formation does not change in practice, at a considerable distance from the generator. This indicates the quite low turbulent mixing with the environment. The observable length of the vortex column was 1.2 m, after which dissociation into individual toroidal vortices occurred, dissipating at different angles to the initial direction of the motion. It should be noted that in individual cases the rupture of the vortex column with an up to 50 mm spacing between individual trains of toroidal vortices was determined from a series of experiments.

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INVESTIGATION OF PRESSURE FLUCTUATIONS IN A HORIZONTAL GAS–FLUID FLOW

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A method is proposed to compute the amplitude of pressure fluctuations in a horizontal gas–liquid flow.

The fluid in a gas–liquid plug flow is distributed between the seals (plugs) and the liquid film (Fig. 1) in a gas–fluid plug flow. The rapidly moving seal captures the liquid from the film and accelerates it to the velocity of the plug. The same quantity of liquid is lost here from the rear part of the plug by forming a film with the free surface which is retarded because of the braking action of the tube walls and then is captured by the next plug.

The pressure profile along the length of the flow at a fixed time is shown in Fig. 1. The abrupt growth of the pressure in the forward part of the plug Δp_a is due to forces needed to accelerate the liquid from the film to the velocity of the plug. In the next zone the linear diminution of the pressure occurs because of friction. The pressure in the film zone is almost constant since the flow velocity is much less than in the plug.

We find the amplitude of the pressure fluctuations in the stream, equal to Δp_a, from the impulse equation

$$\Delta p_a = \frac{G_c}{F}(u_1 - u_2). \tag{1}$$

The mass flow rate of the liquid captured from the film G_c is found from the mass conservation equation

$$G_c = \rho_\ell F \varphi_{\ell 2}(c - u_2). \tag{2}$$

Analysis of the material balance equation of the liquid and gas phases showed [1] that the velocity of the liquid in the plug is quite close to the average velocity of the mixture over the tube section

$$u_1 = u_m = \frac{1}{F}\left(\frac{G_\ell}{\rho_\ell} + \frac{G_g}{\rho_g}\right). \tag{3}$$

Experimental confirmation of this situation is disclosed by the discrepancy of less than 5% between u_1 and u_c [1].

The phase velocity that equals the mean true gas velocity over the section u_g according to experimental data [1, 2] exceeds the fluid velocity in the plug by a quantity due to the influx of liquid from the film

$$c = u_g = \frac{\beta_g}{\varphi_g} u_m = u_1 + \frac{G_c}{\rho_\ell F \varphi_{\ell 1}} = u_1 + \frac{\varphi_{\ell 2}}{\varphi_{\ell 1}}(c - u_2). \tag{4}$$

The joint solution of (1)-(4) yields

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