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HYDROMECHANICS

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Fig. 1

Figure 1: Fig. 1

Fig. 2

Figure 2: Fig. 2

Abstract

Full Text

HYDROMECHANICS

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ON ONE STABLE FORM OF THE FREE SURFACE OF A THIN LAYER OF ROTATING FLUID

(Presented by Academician V. V. Shuleikin on 8 March 1964)

Thin layers of rotating fluid were produced on the inner surface of cylindrical tubes 1 (Fig. 1) by injecting water from a centrifugal nozzle 2 into a swirling air flow. The swirling of the air flow was produced by feeding it into the tube through tangentially arranged slots 4. Drops of fluid, finding themselves in the rotating gas flow, are thrown by the centrifugal force toward the wall, forming there a layer of fluid. This layer is subsequently carried along by the swirling flow along a helical line, forming, when the slots are of sufficient length, a continuous rotating film.

Fig. 1. Diagram of the apparatus for producing a thin layer of rotating fluid.
 1 –vortex tube; 2 –nozzle;
 3 –cover of organic glass;
 4 –tangential slots for air supply

The apparatus, along with the investigation of several other questions, made it possible to observe the following interesting phenomenon. At low velocities

Fig. 2. Annular waves on the surface of a rotating thin layer of fluid

of the swirling gas flow and, consequently, of the rotating film of fluid entrained by it, the free surface of the latter, when observed through the glass cover 3 and illuminated from below by electric light, appears perfectly smooth. As the rotational speed of the flow is increased and the tube diameter is decreased, when centrifugal forces begin to play an appreciable role, annular waves appear on the surface of the film; a schematic representation of them is given in Fig.

2. The onset of the waves is, in all probability, associated with the Reynolds number reaching for

of the rotating film, $Re = uh_0/\nu$, a certain critical value.* However, at the present stage of observation, no generalization of the experimental data has been carried out, owing to the extreme difficulty of accurately determining the velocity and thickness of the rotating liquid film.

The clearest picture of the formation of regularly alternating waves can be observed at comparatively small liquid flow rates, of the order of 10–20 kg/m hr, which ensure that the film is located within the boundary layer. Otherwise, at excessively large liquid flow rates, its free surface undergoes appreciable turbulence, which leads to a disturbance of the strict arrangement of the waves characteristic of films of small thickness. The waves observed are long ones, since their length is considerably greater than their height. For example, waves arising on the surface of a film of thickness of the order of 0.1 mm, moving along the inner wall of a tube of diameter 15.6 mm, have a length of the order of 1 cm. Increasing the velocity of the rotating flow, and consequently of the liquid film carried along by it, leads to some decrease in the distance between the waves and to an increase in the velocity of their motion along the tube.

In a first approximation, neglecting the influence of gravity, surface forces, and the curvature of the tube, i.e., treating the problem as a plane one, by a method analogous to that used in the study of long gravitational waves⁽²⁾, one can obtain the following wave equation for the motion of a rotating thin layer of liquid:

$$\frac{\partial^2 \zeta}{\partial t^2} - \frac{u^2 h_0}{\zeta} \left(\frac{\partial^2 \zeta}{\partial x^2} + \frac{\partial^2 \zeta}{\partial y^2} \right) = 0, \quad (1)$$

This equation corresponds to waves propagating with velocity equal to

$$c = u \sqrt{\frac{h_0}{\zeta}} = u \sqrt{\frac{h_0}{R}}. \quad (2)$$

Here and above, u is the mean velocity of rotation of the film; h_0 is the thickness of the film corresponding to the smooth state; ζ is the z -coordinate of points on the liquid surface, measured from the axis of the tube; x and y are the coordinates of liquid points relative to a system of axes moving with the mean velocity of the film; R is the inner radius of the tube.

Visual observations show that relation (2) qualitatively correctly describes the propagation velocity of annular waves arising on the surface of a thin rotating liquid film.

It should be noted that the mechanism of origin and stable existence of the waves described differs somewhat from the case of annular waves on the surface

of a heavy rotating liquid, theoretically investigated in work ⁽³⁾, as well as from the surface oscillations of a rotating weightless liquid considered in work ⁽⁴⁾.

Further experimental and theoretical investigation of this interesting phenomenon may contribute to a deeper understanding of the complex motion of thin layers of liquid.

In conclusion, I consider it my pleasant duty to express deep gratitude to Corresponding Member of the Academy of Sciences of the USSR L. N. Sretenskii for his attention to the present work.

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CITED LITERATURE

¹ H. Schlichting, *Boundary Layer Theory*, 1956. ² L. D. Landau, E. M. Lifshitz, *Mechanics of Continuous Media*, 1954. ³ L. N. Sretenskii, *Izv. AN SSSR, OTN*, No. 1, 5 (1949). ⁴ J. W. Miles, B. A. Troesch, *Trans. ASME*, ser. E, 28, No. 4, 491 (1961).

* By analogy with a similar rotational motion of a liquid enclosed between two concentric cylinders, of which the outer one is at rest and the inner one rotates ⁽¹⁾.

Note: Figure translations are in progress. See original paper for figures.

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