APPLICATION OF A SHADOWGRAPH METHOD TO VISUALIZE THE VELOCITY PROFILE IN FLUID FLOW

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A method of visualizing the continuous velocity profile in low-speed dielectric and conducting fluid flows is described. Examples are presented which illustrate application of the method for various kinds of flows and modes.

It is known that the measurement of low speeds by using thermoanemometers,pitot tubes, etc. results in errors due to viscosity effects and convection. In this connection, optical and visual methods have received extensive application [1-10].

A hot-wire method, which is a development and perfection of the known method of thermal markers used to visualize and measure gas flow velocities [1, 6, 8], is considered below.

The observation diagram is shown in Fig. 1 and includes the following: across the stream under investigation 1 a thin metal wire 2 is stretched (the channel 3 can be open or closed), a short electrical pulse is delivered to the wire from the working condenser 4, whereupon a uniform (along the length of the wire) temperature front is formed around the wire which appears on the screen of the shadowgraph as a white band in a dark background.

The temperature front is washed away as a result of fluid motion along the channel, to form the complete velocity profile 5 in the channel (in the diagram, 6 is the light flux of the shadowgraph, 7 are switches, and 8 is the condenser supply source).

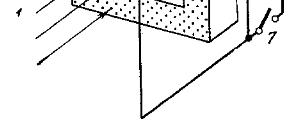

Fig. 1

The question of the suitability of the method to investigate any kind or mode of flow depends on the time and character of temperature front formation. Underlying the method is the condition of incommensurability of the time of temperature front formation in the fluid layer around the wire with the time of fluid mass displacement on the front drift section, i.e., the flow velocity. As a result of this condition, the method under consideration is applicable only to investigation of low-speed streams with a velocity range between 0.002 and 0.2 m/sec, where this range can be extended (on the high side) only by cutting down the time of temperature front formation. The lower boundary of applicability of the method is determined by the lifetime of the visible gradient in the fluid and the resolution of the shadowgraph.

In selecting the electrical R, C, U parameters governing the process of temperature formation in the fluid, it is necessary to be guided by the requirement of obtaining a clear-high contrast picture on the shadowgraph screen. An increase in the voltage U (or capacitance) on the condenser, which governs the temperature gradient in the fluid layer around the wire, is constrained by some critical value U_* whose

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rise causes the temperature front to distort and acquire rough outlines, which makes decoding the results obtained considerably more difficult. It has been detected that an increase in wire tension results in equilibrium of the temperature front. Such changes are evidently connected with the mechanical vibrations which originate during abrupt heating and cooling of the wire. The wire heating mode is selected experimentally. For example, when a 0.09-mm-diameter nichrome wire is utilized in a channel of $40 \times 40\ \mathrm{mm}^2$ area with a 50 μf capacitance condenser, the ultimately admissible voltage for which the temperature front still remains uniform is 40 V.

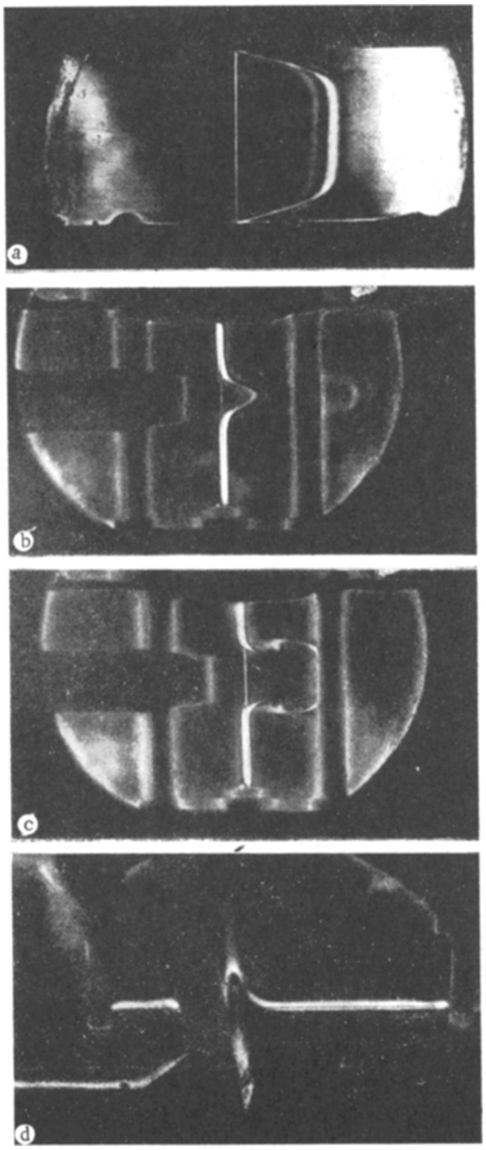

Fig. 2

On the other hand, the increase in the voltage U is constrained by the possibility of the appearance of convection of the temperature front, which can result in distortion of the velocity profile, especially for those flow types and modes when the velocity of the stream being investigated is commensurate with the velocity of temperature front emergence. In these cases it is necessary either to take account of this convection, which complicates decoding of the results obtained, or to diminish it substantially. The diminution in convection realized because of a diminution in the heating temperature of the fluid layer around the wire results in degradation of the picture quality. However, a good-quality picture, in which the influence of convection can be neglected completely, can be achieved by an appropriate selection of the voltage. Experimental investigations of the process of temperature front formation have shown that a better quality picture is already obtained successfully when heating a fluid column by $\Delta T \approx 1°\mathrm{C}$. In this case convection does not even develop for horizontal positioning of the wire.

Photographs obtained by using the IAB-451 shadowgraph (Fig. 2) illustrate certain cases of applying the hot-wire method. The velocity profile at the entrance to a rectangular hydraulic channel for $v = 0.05$ m/sec is presented in Fig. 2a. The velocity profile in a submerged jet, $v = 0.008$ m/sec, is presented in Fig. 2b. The escape occurs from the pushed forward cap, and the visualizing wire is stretched vertically. The vortex being formed at the initial instant of escape from the cap is shown in Fig. 2c. The possibility of investigating the structure of large low-frequency vortices is one of the advantages of the method. Presented in Fig. 2d is the velocity profile in a convective stream around a vertical wall (the wall is inclined). The convective jet emerges from a hole in the center of the wall (the hole is not seen in this projection). The visualizing wire is stretched horizontally. The experiments were conducted in tap water and distilled water.

In conclusion, it should be noted that the hot-wire method can be used to visualize the velocity field in open- and closed-type channels in dielectric and conducting fluid flows. However, utilization of electrolyte solutions as working fluid results in addition to a shunting effect, in the formation of a gas shroud on the wire (because of electrolyte) which will significantly degrade the condition of heat exchange between the wire and the fluid, whereupon the contrast of the shadow picture will drop sharply. In this case it is necessary to use a different kind of protective coating, of an enamel type, which has similar thermophysical properties to the wire material. It is desirable to deposit the enamel on the wire as a thin layer on the order of $1\ \mu$ thick.

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