MEASURING LOCAL VELOCITIES OF SMALL-SCALE FLOWS USING A LASER

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The measurement of velocities in streams of small absolute dimensions is of great importance in the experimental study of liquid and gas flows. Quite frequently the small stream dimensions (on the order of a mm or even fractions of a mm) do not permit the use of the measurement devices which are used with success in large-scale streams (velocity tubes, hot-wire anemometers, and so on).

In these cases the application of velocity meters using lasers is effective. Such velocity meters do not introduce any disturbance into the test stream and may have high spatial resolution.

Thus, [1] showed the possibility of using the frequency method for determining liquid flow velocities. However, the spatial resolution of this method is not sufficient for measuring local velocities of very small-scale flows.

More promising for these purposes is the method utilizing the Doppler effect [2, 3] which has a measurement range from 10^{-3} to 10^{3} m/sec and a spatial resolution of less than $100 \times 10\ \mu$. Here the local velocity measurement is based on the Doppler shift of the laser radiation scattered by particles intentionally introduced into the stream. Usually polystyrene particles of dimension 0.557 μ with concentration 1:50,000 [2] are introduced into the fluid stream. Since the specific weight of polystyrene is close to that of water, we can assume that the velocity of these particles is the same as the stream velocity and their presence has practically no effect on the nature of the flow. In the usual Doppler velocity meter schemes [2, 3] the difference of the frequencies of the scattered and direct laser radiation is measured. Since this frequency difference is distinguished by the heterodyne method, it is necessary to align the two light beams in direction to within a few angular seconds. Therefore these Doppler velocity meter schemes require careful adjustment.

In the present study we use a differential Doppler velocity meter scheme in which the stream velocity is found from the difference of the Doppler frequencies. To this end two coherent light beams are directed at the test point in the stream. The observation is made in the scattered light from both beams. It can be shown easily that in this case the difference Δf_D of the Doppler frequencies is independent of the direction of observation and is defined only by the location of the incident beams and the projection of the stream velocity vector on the bisector of the angle between them, i.e.,

$$\Delta f_D = \frac{2u}{\lambda_0} \sin\frac{\alpha}{2} \tag{1}$$

Here u is the projection of the particle velocity vector on the plane in which the two incident beams lie; λ_0 is the laser radiation wavelength; and α is the angle between the two beams in vacuo. In deriving (1) it is assumed that the velocity vector u lies in the plane perpendicular to the bisector of the angle α.

In addition to the velocity, the relation (1) contains the quantities λ_0 and α, which are constants of the laser and the setup. Therefore the velocity determination reduces to measuring Δf_D and multiplying by a scale factor. We note also that in this scheme the Δf_D spectrum is independent of the aperture of the lens which gathers the scattered light.

Figure 1 shows a schematic of the setup for measuring local velocities in streams. The light beam from the LG-75 Ne – He laser 1 with wavelength 0.63 μ and power 2 mW is reflected from the pivoting

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Moscow. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, Vol. 10, No. 5, pp. 125-127, September-October, 1969. Original article submitted February 20, 1969.

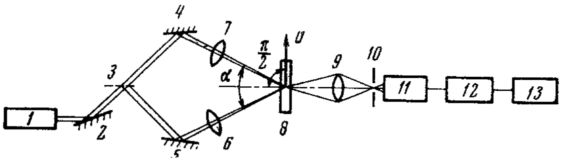

Fig. 1

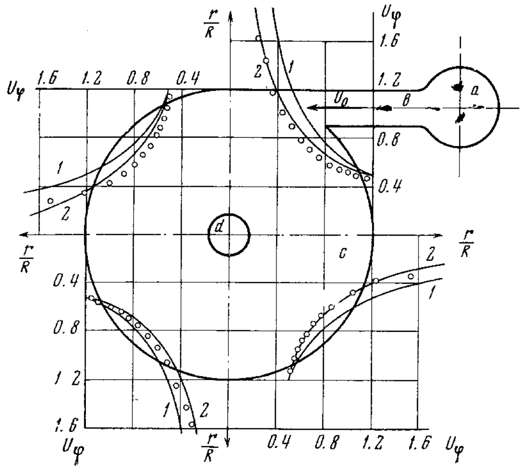

Fig. 2

mirror 2, strikes the dividing plate 3, and is split into two identical beams. With the aid of the mirrors 4 and 5, and also of the focusing lenses 6 and 7, the beams are directed to the stream test point 8.

The laser radiation scattered by the particles is gathered by the objective lens 9 and directed to the cathode of the photomultiplier 11, ahead of which there is the 100-μ-diam. shutter 10, used to increase the signal – noise ratio. The signal from the photomultiplier output passes through the wideband amplifier 12 with gain 200 to the panoramic spectrum analyzer 13. This setup made it possible to measure the local time-averaged velocities in the range from $0.5 \cdot 10^{-3}$ to $5 \cdot 10^{1}$ m sec. The upper limit of the measurable velocities is determined by the receiving apparatus used and can be extended if required.

As an example of the use of this method, Fig. 2 shows the results of measurement of the tangential velocities in a planar vortex element of a jet automatic control. The water stream enters the vortex chamber c of this element from the nozzle chamber *a* through the tangential nozzle b. The stream which has been swirled in the chamber exits through the central port d. We investigated a chamber made from plexiglass having the following dimensions: vortex chamber diameter D = 60 mm, outlet port diameter d_b = 8 mm, and height H = 18 mm. Particles of polystyrene of dimension about 0.5 micron with concentration 1: 30,000 were added to the water stream to increase the intensity of the scattered light.

The following power law [5] is usually recommended for determining the tangential velocities u_φ in vortex element chambers:

$$u_\varphi = u_{\varphi R}\,(R/r)^m \tag{2}$$

Here $u_{\varphi R}$ is the tangential velocity near the cylindrical wall, assumed equal to the velocity at the nozzle exit, R is the chamber radius, and r is the variable radius corresponding to the point, measured from the center of the chamber; m is the exponent, which depends on the fluid flow regime in the chamber and also on the chamber geometric dimensions.

However, this exponent is often assigned a value of one, i.e., that tangential velocity distribution is taken which occurs beyond the limits of the free vortex core in the fluid.

Figure 2 shows the distribution curves for the velocities in m/sec plotted using (2) for m = 1 (curve 1) and also the experimental points.

We see that the theoretical curve differs significantly from the experimental data, particularly in the central part of the chamber. The exponent m = 0.75 (curve 2), the value indicated by some authors from data of experiments performed on large-scale vortex chambers [6], agrees considerably better with experiment.

The authors wish to thank V. A. Fabrikant for helpful discussions and his continued interest in this study.

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