USE OF LASER DOPPLER ANEMOMETER FOR THE INVESTIGATION OF TURBULENT FLOW OF POLYMER SOLUTIONS

N. A. Pokryvailo, D. A. Prokopchuk, and Z. P. Shul'man

The results of measurements of the mean velocity, the intensity of the longitudinal and the transverse components of the fluctuation velocity, and Reynolds stresses in the wake of a disk with polyoxyethylene solution injected in the aft zone are presented. The measurements were made by a laser anemometer.

The drawbacks of the contact methods of measuring the averaged and fluctuation velocities of fluids, in particular, of polymer solutions, are due to the necessity of introducing the measuring devices into the flow that gets distorted thereby. These drawbacks led to the miniaturization of the measuring elements, on the one hand, and to the development of noncontact methods of measurement, on the other. One of the most promising measuring devices is the laser Doppler anemometer.

The method of measuring turbulent fluctuations with the use of laser technology utilizing the Doppler effect has been well substantiated by Goldstein and Hagen [1]. They demonstrated for the first time the possibility of computing the characteristics of a turbulent flow using the spectral analysis of the Doppler signal. The broadening of the Doppler signal is considered as a function of the probability density distribution of the values of the velocity in the flow. This method was further developed in [2-6].

At present, the most widely used laser Doppler systems are the "intersecting reference beam" system proposed by Goldstein [7] (one beam is used as the local oscillator), the "dual scattering" system developed by Brayton [8] (only the scattered light is detected from both beams), and the "Doppler meter" system introduced by Rudd [9] (all the forward propagating radiation, both scattered and nonscattered, is detected).

The "dual scattering" (differential) system is used in the present work. In principle, all these systems are equivalent and the use of each of these systems is dictated by the specific situation.

Let us consider the theoretical basis of the laser Doppler technique and the interpretation of the obtained output signals. The radiation scattered from the point of intersection of two coherent beams emitted by a single laser source is mixed in a photodetector to obtain beats of the Doppler frequency proportional to the initial flow velocity at this point, which is given by the following expression:

\[ f_D = \left( \frac{n \bar{w}}{\lambda_0} \right) (\bar{v}_1 - \bar{v}_2). \]
Only one velocity component is measured—that which lies in the plane of the two intersecting beams and perpendicular to their bisector. In our scheme the Doppler signal is analyzed by an S4-8 spectrum analyzer. For a sufficiently large averaging time and small width of the passband of the spectrum analyzer the spectrum of the Doppler signal may be identical to the probability density distribution of the velocity values. The standard procedure of determining the velocity and the mean square value of the fluctuation can then be applied to the obtained signal representing the probability density distribution of the velocity values.

The spectrum of the Doppler signal usually has a Gaussian form and the mean velocity can be found from the maximum of the distribution curve. The vector of the instantaneous fluctuation of the velocity can be expressed in the form \( \vec{W} = \vec{u}^e \times \vec{v}^e \). For a turbulent flow it follows from Eq. (1) that

\[
\Delta f_D = \left( \frac{n}{\lambda_0} \right)^2 \left( \frac{m}{\lambda_0} \right)^2 \left( \frac{1}{\lambda_0} \right)^2 
\]

Then, if \( \alpha \) is the angle between the plane of the intersecting beams and the \( x \) axis, Eq. (2) is written in the form

\[
\Delta f_D = 4 \left( \frac{n}{\lambda_0} \right)^2 \sin^2 \theta \left[ \mu^2 \cos^2 \alpha + 2 \mu^2 \cos \alpha \sin \alpha + \nu^2 \sin^2 \alpha \right] 
\]

Thus it follows from Eq. (4) that in order to obtain the basic characteristics of the turbulent flow it is sufficient to carry out three measurements at each point, rotating the plane of the probing beams by three fixed values of angle \( \alpha \). Let \( \Delta f_D/\Delta f_3 = \sigma^2 \) be the square of the variance of the Doppler signal. Then for the cases \( \alpha = 0, +45^\circ, -45^\circ \) we have, respectively

\[
\sigma^2_0 = \mu^2_0, \quad \sigma^2_{45^\circ} = \left[ \mu^2 + \nu^2 + 2 \mu \nu \cos \alpha \right]/2 \mu_0^2, \quad \sigma^2_{-45^\circ} = \left[ \mu^2 + \nu^2 - 2 \mu \nu \cos \alpha \right]/2 \mu_0^2. 
\]

Thus, in order to find the basic characteristics of turbulence we have the following expressions:

\[
\frac{\mu^2}{\mu_0^2} = \sigma^2_0, \quad \frac{\nu^2}{\mu_0^2} = \sigma^2_{45^\circ} + \sigma^2_{-45^\circ} - \sigma^2_0, \quad \frac{\mu^2 \nu^2}{\mu_0^2} = \left( \sigma^2_{45^\circ} - \sigma^2_{-45^\circ} \right)/2. 
\]

A helium-neon laser LG-36 and the optical scheme shown in Fig. 1 were used for the measurement of the mean velocities and also the intensities of the longitudinal and transverse components of the velocity fluctuation and the turbulent tangential stresses.

The light beam from the monochromatic source of the helium-neon laser 1 is split into two beams by the divider 2 and lens system 3 and is focused at a given point of the flow. It should be noted that the divider, the mirror, and the lens system were made in the form of a single block which could be rotated about the axis of the laser beam. Thus the plane of the probing beams could be rotated by any angle relative to the flow in the channel. The position of the point could be changed in the longitudinal direction by moving the entire optical system along a rigid guide. The change of the position of the point of measurement in the transverse direction was accomplished by the displacement of the hydrochannel. The light beam reflected from the particles in the flow gets Doppler shifted in frequency and passes through objective 4, diaphragm 5, and falls on a PM-84 photomultiplier 6. The voltage taken from PM-84 is amplified by a wideband VZ-14 amplifier and fed to the S4-8 spectrum analyzer.

The spectrum of the Doppler signal averaged over 5 sec was recorded. The spectral half-width of the Doppler signal for a given position of the plane of the probing beams was determined from the spectrum and then the basic characteristics of the turbulence were computed from formulas (5)–(7).

The mean and the fluctuation characteristics of the turbulent flow were investigated on a continuous-action hydrodynamic tube (Fig. 2). A 4.5-kW electric motor sets an impeller pump into rotation through a clutch 2; the pump can ensure a discharge up to 2 liters/sec and a pressure up to 15 atm. The rotor of the pump 4 has rifling in the form of a multiple thread. A similar rifling but of opposite direction is made in the frame 3. The flow rate is regulated by the bypass segment with throttle 5. From the pump the liquid goes into a diffuser 6.