CORRECTION OF SPECTRUM OF TURBULENCE IN THE MEASUREMENT BY A CONDUCTION ANENOMETER

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UDC 532.517.4

The equivalent spectral characteristic of the sensor of a conduction anenometer with external magnetic field is determined. Its use is demonstrated for the correction of the spectrum of turbulent velocity fluctuations.

It is well known [1] that in the measurement of turbulence it is necessary to take into consideration the averaging effect of the primary transformer which affects the measurement of the mean square values of the velocity fluctuations as well as the determination of the spectral density of the signal. This is equally true for conduction-type velocity sensors.

A variable electric field appears as a result of interaction of the turbulent flow of an electrically conducting liquid with the constant magnetic field; the potential gradient of this electric field is proportional to the velocity fluctuations [2]. Using two electrodes located at a distance l, one can measure the potential difference $(\varphi_1 - \varphi_2)$ and approximately calculate the potential gradient of electric field

$$E = \frac{\varphi_1 - \varphi_2}{l}. \tag{1}$$

Formula (1) is valid if l is sufficiently small. The fulfillment of this condition depends on the spatial distribution of the electric field determined by the structure of the velocity field.

The measurement of the potential difference at a finite length l leads to a smoothing of small-scale inhomogeneities of the field and to a reduction of the measured spectral density corresponding to large wave numbers. This process is essentially the filtration of a random field with spectral density G(k) by a filter whose parameters are determined by the interelectrode distance l [1]. In this case, the transformation of the signal by the sensor is described by the following expression:

$$E(l,\ x) = \int\limits_{-\infty}^{+\infty} E(x_1)\, h(l,\ x - x_1)\, dx_1. \tag{2}$$

Applying a Fourier transform to expression (2), in the spectral region we obtain the relation

$$G(l,\ k) = G(k) H^2(l,\ k). \tag{3}$$

The equivalent spectral characteristic of the sensor $H^2(l, k)$ shows which part of the energy of the eddy with wave number k is measured. The smaller the interelectrode distance l, the smaller should be the averaging effect of the sensor. Therefore, it is natural to disregard the smoothing effect of the primary transformer with minimum dimensions compared to the averaging action of the sensor of large dimensions in a certain range of wave numbers.

For a constant spectral density G(k) and different interelectrode distances, we obtain the following relation:

$$\frac{G(l,\ k)}{G(l_0,\ k)} = \frac{H^2(l,\ k)}{H^2(l_0,\ k)}. \tag{4}$$

The ratio (4) of spectral densities of the signals of sensors with different interelectrode distances to the signal

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Donets State University. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 31, No. 2, pp. 243-247, August, 1976. Original article submitted May 20, 1975.

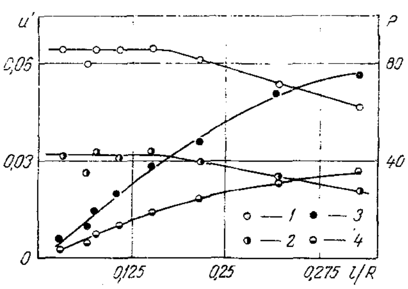

Fig. 1. Dependence of the root-mean-square value of longitudinal velocity fluctuations u', m/sec (1, 2) and signal-to-noise ratio P (3, 4) on the relative interelectrode distance l/R: 1, 3) u = 2; 2, 4) 1 m/sec.

of the sensor with $l = l_0$ is the equivalent spectral characteristic of the primary transformer of a conduction anenometer in the first approximation.

We assume that the averaging action of the sensor depends on the ratio of the interelectrode distance l to the scale of the measured perturbation L, i.e., only on the parameter l/L. Using Taylor's hypothesis about frozen-in turbulence, which is clearly satisfied at the center of a tube for a small perturbation, it is possible to represent this parameter in the form (lf/u). If the above assumption is valid, then the equivalent spectral characteristics of different sensors constructed as a function of parameter (lf/u) must coincide.

In the present investigation we determine the effect of the interelectrode distance of the primary transformer on the measurement of root-mean-square values and the spectral density of the electric field induced in turbulent flow of water in a circular tube.

The experiment was conducted on a hydraulic device of closed type described in [3]. The sensor was installed in a circular tube of diameter D = 94 mm in the section separated from the entrance by 100D. Sensors with interelectrode distances of 1.5, 3, 3.5, 5, 7, 10, 14, and 20 mm were investigated. They were installed close to the axis of the tube where the turbulence is nearly homogeneous. The average velocities at the axis of the tube were 1 and 2 m/sec and the Re numbers computed from the average velocities were $0.8 \cdot 10^5$ and $1.6 \cdot 10^5$, respectively.

The signal measured by the sensor was fed to an amplifier having a flat amplitude–frequency characteristic in the range 1-1000 Hz and was later recorded on an M-168 magnetophone. The root-mean-square value of the signal and its spectral density were determined from the reproduction of the record by the technique described in [4].

The root-mean-square values of the velocity fluctuations u' were investigated as a function of the interelectrode distance (Fig. 1). Obviously, the increase of the interelectrode distance to $l/R \leq 0.15$ has practically no effect on the measured root-mean-square values of the velocity fluctuations. The decrease of the signal for large values of l shows that the sensor begins to average eddies carrying a significant part of the energy. The magnitude of the signal-to-noise ratio shown in Fig. 1 increases with the interelectrode distance of the sensor.

The spectral density of the signals measured by sensors with different interelectrode distances is shown in Fig. 2. It may be noted that in the frequency range f < 10 Hz the curves obtained by different sensors differ very little from each other. For f > 10 Hz a noticeable decrease is observed in the values of the spectral densities with the increase of the interelectrode distance. Using the spectra shown in Fig. 2 the equivalent spectral characteristic can be determined approximately. The spectral density of signals measured by sensors with $l_0 = 1.5$ mm at a velocity of 1 m/sec and $l_0 = 3$ mm at a velocity of 2 m/sec is taken as true in the first approximation; then $H^2(l_0, k) = 1$ in expression (4). Here it becomes possible to estimate the spectral characteristic of a sensor with $l > l_0$. It is clear that the larger the difference in the values of the interelectrode distance of the sensor and the smaller the frequency, the more accurately is the following relation satisfied:

$$\frac{G(l, k)}{G(l_0, k)} = H^2\left(\frac{lf}{u}\right). \tag{5}$$

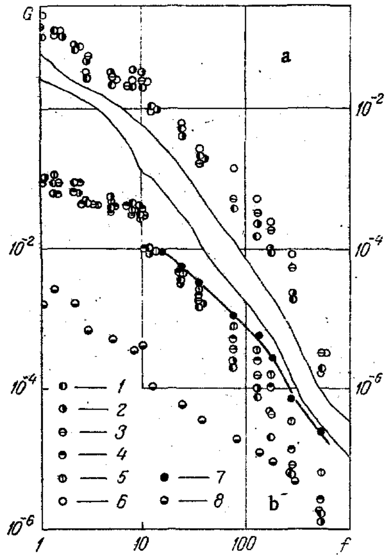

Fig. 2

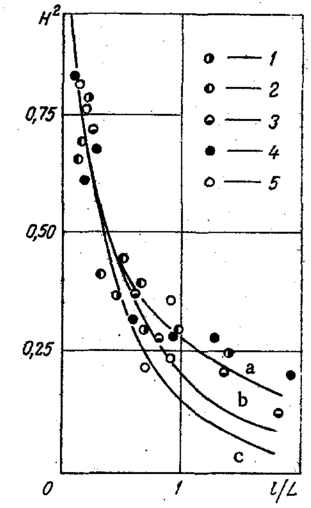

Fig. 3

Fig. 2. Dependence of the measured spectral density G, m^2/sec, on frequency f, Hz: a) u = 2 m/sec; b) u = 1 m/sec; 1) l = 10 mm; 2) 7; 3) 5; 4) 3.5; 5) 1.5; 6) 3; 7) corrected spectrum; 8) spectral density of noise.

Fig. 3. Dependence of the equivalent spectral characteristics of the sensor $H^2(lf/u)$ on parameter l/L: 1) u = 2 m/sec, l = 10 mm; 2) 2 and 7; 3) 1 and 10; 4) 1 and 7; 5) 1 m/sec and 5 mm.

The ratio of the spectral densities of the signals of sensors with different interelectrode distances to the spectral density of signals of the primary transformer with minimum dimensions is shown in Fig. 3 as a function of parameter l/L. The experimental points have a tendency to group together, which indicates the existence of a universal dependence approximated by curve 3a (see Fig. 3).

The equivalent spectral characteristic of the sensor, which is used for comparison, has an increasingly large effect on the ratio of the spectral density as l/L increases. This leads to overestimated values of the obtained equivalent spectral characteristic for large values of parameter lf/u. Using the universality of the obtained function $H^2(lf/u)$ and the fact that for small values of parameter lf/u the ratio (4) approaches (5) more closely, we can take into consideration the spectral characteristic of a sensor with interelectrode distance l_0. For this purpose it is necessary to find parameter l_0f/u and the corresponding ratio $G(l, k)/G(l_0, k)$ which is taken as the value of the characteristic of the sensor with $l = l_0$ at a given frequency f. Now multiplying (5) by the obtained value of $H^2(l_0f/u)$, according to formula (4) we obtain the second approximation of the equivalent spectral characteristic of the sensor. The feasibility of this approximation permits us to improve the values of $H^2(lf/u)$ for large values of parameter lf/u.

The effect of the spectral characteristic of a sensor with $l_0 = 1.5$ mm on ratio (5) was improved by the method indicated above. The equivalent spectral characteristic thus obtained is shown by curve 3b (Fig. 3). The theoretical curve 3c, computed for transverse orientation of the sensor under the assumption that the spectral density varies according to the "—5/3" law [1], is also shown there for comparison. The disagreement between curves 3c and 3b can be explained by the fact that the real spectrum of the velocity fluctuations somewhat deviates from the above law.

The obtained equivalent spectral characteristic of the sensor of the conduction anenometer can be described by the following expression:

$$H^2\left(\frac{lf}{u}\right) = \exp\left(-\frac{lf}{0.6u}\right). \tag{6}$$

Knowing the mean flow velocity at a point and the interelectrode distance of the sensor, we can correct the effect of primary transformer on the measured spectrum:

$$G_c(f) = G(l,\ f) \cdot \exp\left(\frac{lf}{0.6u}\right) \tag{7}$$

and increase the accuracy of measurement of the spectral density by a conduction anenometer. Thus, we corrected the spectrum of the signal of a sensor with $l_0 = 1.5$ mm (see Fig. 2).

The present study permits us to give a quantitative estimate of the optimum interelectrode distance of a sensor. In order to improve the signal-to-noise ratio, it is necessary to increase l. However, this is possible only up to a certain value of the interelectrode distance which, for the core of the flow in a circular tube, comes out to be equal to $l/R = 0.15$, since for large values of l the averaging action of the sensor begins to appear. The interelectrode distance is restricted still more by the minimum scale of turbulence, which must be measured under the conditions of the experiment. The obtained results point out the feasibility of correction of spectrum if $l/L \leq 1.5$.

NOTATION

l, interelectrode distance; φ, potential; G, spectral density; k, wave number; h(x), equipment function of the sensor; H^2, equivalent spectral characteristic of the sensor; L, eddy scale; u, mean velocity; f, frequency; D, tube diameter; u', root-mean-square value of longitudinal velocity fluctuations; R, radius of the tube; P, signal-to-noise ratio.

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INVESTIGATION OF THE EFFICIENCY OF A "JET DIFFUSER"

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UDC 532.556.4

The power characteristics of a diffuser device formed by a fine turbulent jet blown from an annular conical nozzle in the outlet section of a cylindrical channel were investigated experimentally.

In order to reduce the loss of dynamic pressure during discharge of the flow from the channel into free space, diffuser sections are usually used. Many methods are known for increasing the pressure recovery in these sections, including the method of drawing off or tangential blowing of the boundary layer. In the latter case, the jet is blown out along the surface of the expansion channel and assists stabilization or persistence of breakaway.

A scheme with direct injection of such a jet in the outlet section of a straight channel may be of independent interest. Jet devices of similar type have been suggested, for example, for increasing the thrust of propulsion systems [1]. They may be used also for reducing losses of dynamic pressure in installations with high-temperature flows or corrosive media, where the use of the normal diffusers with impermeable walls in certain cases is difficult.

Translated from Inzherno-Fizicheskii Zhurnal, Vol. 31, No. 2, pp. 248-252, August, 1976. Original article submitted May 4, 1975.