NONSTATIONARY VELOCITY PULSATIONS IN TURBULENT FLOW

A. M. Kharenko and A. E. Éidel'man

UDC 532.517.4

It is experimentally established that the velocity pulsations in a developed turbulent flow in a pipe at small Reynolds numbers are statistically nonstationary

At large Reynolds numbers, small-scale perturbations of hydrophysical parameters of a flow can be assumed quasistationary, and the turbulent velocity pulsations can be modeled by a stationary random process [1]. When the Reynolds numbers are relatively small and the range of scales of perturbations is narrow, the mechanism of turbulence formation in the flow postulates an ordered change of instantaneous parameters. In this case, the application of a stationary model for the analysis and interpretation of results of measurements can lead to erroneous conclusions.

The aim of the present work is to experimentally study the nature of nonstationarity of velocity pulsations in a developed turbulent flow at small Reynolds numbers. The formation and development of turbulent flow of clay solutions in a round pipe was studied in [2]. The measurements were carried out in the region of developed turbulence at velocities when the miscibility coefficient is unity in the whole core of the flow. For the clay solution with concentration 7.5% which was studied, the beginning of this region corresponds to the smallest Reynolds number Re_{min} at flow-rate velocity u_0 = 1.1 m/sec.

The experiment was carried out on a hydraulic apparatus of the closed type with a measurement section of 98-mm diameter. The velocities were measured in the cross section at a distance of 50 diameters from the entrance for u_0 = 1.1 and 2.2 m/sec. The velocity measurements were carried out using a conduction anemometer with constant magnetic field [2]. The signal from the primary converter was registered on a magnetic recorder M-168.

The hypothesis of stationarity of the velocity pulsations was tested using the rms deviations by a method described in [3]. According to the method, we determined the character of the correlation of a sequence of samples of estimates of the rms deviation. When the hypothesis of stationarity of velocity pulsations with respect to rms deviations is valid, the following condition holds:

$$G(f_i) = \frac{G_B(f_i)}{H^2(f_i)} = G_0, \quad f_i = \frac{i}{N\Delta t}, \quad i = 1,\ 2,\ \ldots,\ \frac{N}{2}, \tag{1}$$

where $G_B(f_i)$ is the spectrum of the sample of estimates of the rms deviations with discretization time Δt, and of dimension N, $H(f_i)$ is the amplitude–frequency characteristic of the averaging device, and G_0 is a constant.

If expression (1) is taken as the test of nonstationarity, the discretization time Δt must be taken considerably longer than the maximum correlation interval of the process τ_{max}. The estimate of τ_{max} for the processes in question does not exceed $5\cdot10^{-2}$ sec, and the chosen value Δt = 1.77 sec therefore satisfies this condition. If condition (1) is not satisfied, the process is nonstationary with respect to rms deviations.

The spectral density $G_B(f_i)$ was evaluated on the computer "Dnepr-21" using the "fast Fourier transform" algorithm based on a block of 256 readings [4]. To estimate the spectral density we determined the average value of the obtained periodogram at n neighboring frequencies, and we also averaged over m realizations. The quality of averaging is in this case characterized by the number of degrees of freedom, equal to 2nm [4, 5]. The value n = 2 was chosen to decrease the error bias due to the presence of peaks in the spectrum, and the number of realizations was two and four.

Donets State University. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 42, No. 3, pp. 392-395, March, 1982. Original article submitted March 12, 1981.

 0022-0841/82/4203-0278$07.50

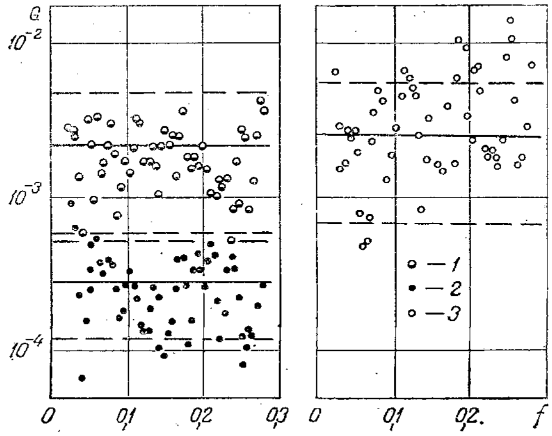

Fig. 1

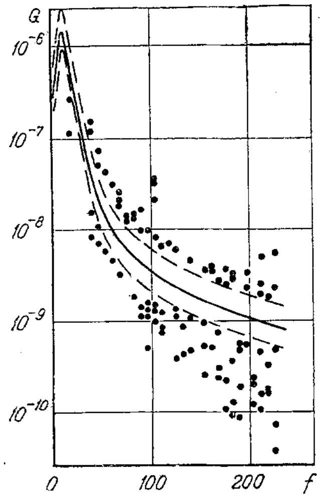

Fig. 2

Fig. 1. Spectral density G ($m^2 \cdot sec^{-1}$) of the sample of the rms deviations of the velocity pulsations as a function of frequency f (sec^{-1}). Points 1 show the transverse component in the center of the flow, and points 2 and 3 the transverse and longitudinal components near the wall of the pipe.

Fig. 2. Spectral density G ($m^2 \cdot sec^{-1}$) of the transverse velocity component as a function of frequency f (sec^{-1}). The full line shows the arithmetic mean of the estimates of the spectral density, and the dashed lines the 95% confidence interval. The points which fall within the confidence interval have been omitted.

The 95% confidence interval which characterizes the random deviation of the estimate of the spectrum from its mathematical expectation was determined by the method presented in [5], in accordance with the number of degrees of freedom (eight and six) used in the calculation. The validity of condition (1) was determined from the comparison of the magnitude of the confidence interval associated with each point, with the actual deviation of the spectral density $\frac{1}{N}\sum_{i=1}^{N} G(f_i) = G_0$ from the mean value. If the relative number of points whose deviation exceeds the confidence interval is greater than 5%, the hypothesis of stationarity of the process was abandoned.

The evaluation of expression (1) was carried out for a sample of estimates of the rms deviations measured by the voltmeter QRV-2 in the frequency range from 2 to $2 \cdot 10^4$ Hz. The results of calculation of the data obtained for Re_{min} are shown in Fig. 1, where the full lines show the mean values of the spectral density and the dashed lines limit the region of points in whose confidence interval this value falls. For the spectrum of estimates of the rms deviations of the transverse velocity component, condition (1) is satisfied in the center of the flow, as only one point out of 56 falls outside the depicted region, which is acceptable for the assumed confidence coefficient 0.95.

For the longitudinal and transverse components, condition (1) does not hold near the wall, since 24 and 20% of points fall outside the depicted regions. Thus, at Re_{min} one observes the nonstationarity of rms deviations of both longitudinal and transverse components near the wall.

For a detailed investigation of stationarity we estimated the spectral power density of the transverse component, measured at Re_{min} and $2Re_{min}$, in the center of the flow.

The spectral density was calculated for from a block of 2048 readings for each of the 11 realizations; the number of degrees of freedom was 32. Figure 2 shows the results of calculation of the spectrum at Re_{min}, and shows the points which fall outside the 95% confidence interval, which is constructed with respect to the arithmetic mean of the estimates of the spectrum, and which is shown by the full line [5]. It is clear that the hypothesis of stationarity is valid at frequencies less than 40 Hz, but not at high frequencies. The scatter of points increases at frequencies higher than 83 Hz, where more than three points from 11 at each frequency fall outside the confidence interval. The scatter increases also at frequencies higher than 170 Hz, where 4-6 points out of 11 lie outside the confidence interval. The results of calculation for the spectral density of the transverse velocity component at $2Re_{min}$ agree with the hypothesis of stationarity in the frequency region under study.

The experimental test of the statistical properties of velocity pulsations of a developed turbulent flow in a round pipe showed that in the region of developed turbulence for Re_{min}, one observes the nonstationarity of small-scale perturbations in the center of the flow. Near the wall, the nonstationarity manifests itself in the rms deviations of velocity pulsations. Thus, when considering the develped turbulence at small Reynolds numbers, one must take into account the statistical nonstationarity of pulsating velocity components.

NOTATION

$G_B(f_i)$, spectrum of the sample of estimates of the rms deviations; f, frequency; N, dimension of the sample of estimates of the rms deviations; Δt, discretization time of the process; $H(f_i)$, amplitude—frequency characteristic; τ_{max}, maximum correlation interval; U_0, flow rate velocity; n, number of neighboring frequencies; and m, number of realizations.

LITERATURE CITED

1. A. S. Monin and A. M. Yaglom, Statistical Fluid Mechanics, MIT Press (1975).
2. I. L. Povkh, N. I. Bolonov, and A. E. Éidelman, "The formation and development of turbulence in the motion of a dispersed system in a round pipe," Inzh.-Fiz. Zh., 26, No. 5, 901 (1974).
3. A. M. Kharenko, "Methods of study of the time variation of hydrodynamic fields," in: Hydrophysical Ocean Studies [in Russian], No. 2(77), Izd. MGI Akad. Nauk USSR, Sevastopol (1977), pp. 134-141.
4. R. P. Bazeeva, L. P. Borozinets, Z. G. Zuikova, S. G. Margushina, and A. M. Kharenko, "Statistical analysis of turbulent flows on the computer Dnepr-21,"State Library of Algorithms and Programs, All-Union Scientific Information Center, Inv. No. P004106.
5. G. M. Jenkins and D. G. Watts, Spectral Analysis and Its Applications, Holden-Day (1968).

CALCULATION OF TURBULENT GAS JETS

V. A. Golubev

UDC 532.517.4

A technique is proposed for calculating jets with variable density. The variations of the basic parameters of a jet are obtained and they are compared with experimental data.

In solving the problem analytically, the flow in a jet was taken as self-similar under the assumption that the external boundary and the streamlines in the main part of the jet are curvilinear and emanate from the terminal (Fig. 1). Based on experiments, it was assumed that the dimensionless profiles of excess temperatures, excess enthalpies and concentrations in the transverse cross sections of the jet coincide [1]:

$$\frac{\Delta T}{\Delta T_m} = \frac{\Delta i}{\Delta i_m} = \frac{C}{C_m}. \tag{1}$$

In the starting section of the jet, the dimensionless profiles of velocities and temperatures (enthalpies and concentrations) were determined with an accuracy useful for practical applications, from the equations

Sergo Ordzhonikidze Aviation Institute, Moscow.

Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 42, No. 3, pp. 395-402, March, 1982. Original article submitted March 23, 1981.