EFFECT OF A VORTEX WAKE ON THE FLUCTUATIONS OF SKIN FRICTION AS THE FRONTAL CRITICAL POINT OF A CYLINDER IN A TRANSVERSE STREAM

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Fluctuations of skin friction at a cylinder wall in a transverse stream and the velocity in the wake region of a vortex were measured with diffusion probes, and the results are discussed here.

It is well known that the development of a turbulent boundary layer in a shear flow is determined by the fluid zone at the wall. This zone, which is called the viscous sublayer, is where heat and mass transfer to the solid surface encounters most resistance. The size of this sublayer is so small, even at moderate values of the Reynolds number, that any measurement with probes placed in the stream is out of the question. In view of this, consideration is given to measurements with microelectrodes installed flush with the immersed body surface and operating on controllable diffusion of oxidation–reduction reactions [1, 2].

The Prandtl number corresponding to convective mass transfer in liquids ranges from 2000–5000 and the thickness of the diffusion boundary layer is extremely small. Thus, the diffusion current ties in with the flow field at the electrode. In this case the equation of the diffusion boundary layer at the electrode yields a direct relation between skin friction and mass flow [2]. By measuring the fluctuations of the diffusion current, one can evaluate the spectral density of friction fluctuations [3]:

$$S_\tau = S_q / |H(i\omega)|^2. \tag{1}$$

In order to determine the transfer function $H(\omega)$, the equation of transient convective diffusion has been solved in [4] and the results can be approximated by a relation for the modulus of the dimensionless transfer function squared:

$$\bar{H}^2 = \frac{1}{\sqrt{(9 + 0{,}54\,\bar{\omega}^2)^2 + (0{,}027\,\bar{\omega}^3)^2}}. \tag{2}$$

In dimensional form

$$|H(\omega)|^2 = \bar{H}^2 q^2 / \tau_w^2.$$

This article deals with the effect which a vortex wake has on the fluctuations of skin friction in the region of the frontal critical point of an immersed cylinder. The results shown here are based on experiments performed in a closed hydrodynamic tube with a blade 30 × 65 mm in cross section, which at a flow velocity varying from 0.03 to 0.312 m/sec provided for a variation in the Reynolds number from 250 to 1240 (referred to the cylinder diameter). The turbulence in the oncoming stream, measured with a model "Disa" thermoanemometer, did not exceed 7%.

As the specimen for our experiment we used a Textolite cylinder 4.1 mm in diameter and 65 mm long. A local probe (cathode) in the form of a 0.05 × 2.3 mm foil was installed along the generatrix flush against the cylinder surface. As the cylinder rotated about its axis, one could record the diffusion current and thus measure the distribution of the velocity gradient at the wall of the cylinder immersed in a transverse

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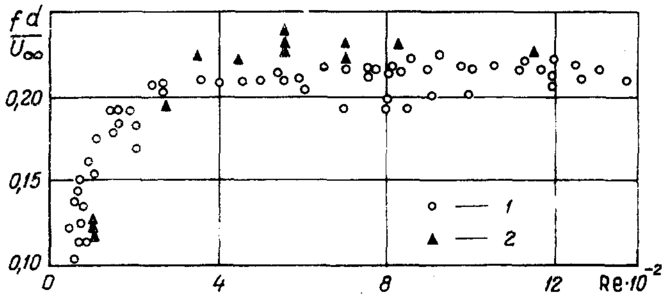

Fig. 1. Struhal number as a function of the Reynolds number: 1) according to Drescher and Roshko; 2) according to this study.

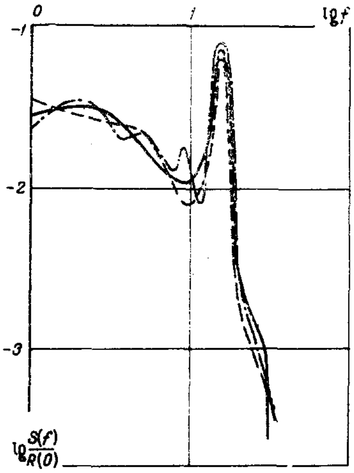

Fig. 2. Normalized spectral density of diffusion current fluctuations at the cylinder wall: $\theta = 0°$ (dash-dot line), $\theta = 45°$ (dashed line), in the wake of the cylinder (solid line). Velocity $U_\infty = 0.263$ m/sec.

stream; one could also determine the characteristics of the transition and the separation, both related to the skin-friction stresses. Simultaneously with the direct measurement of the diffusion current, fluctuations of the current were amplified and recorded on a model N-102 oscillograph for various points on the cylinder wall, i.e., as a function of the probe angle relative to the frontal critical point on the cylinder. Measurements in the nearest wake ($x/d = 5$) of the cylinder were made with an electrochemical wedge probe, a signal from which was transmitted through the second amplifier channel and also recorded on the oscillograph, together with a signal from the local probe fixed on the cylinder. The time constant of the wedge probe, calculated by the Hanratty method [2], was 0.02 sec. An analogous procedure for recording signals of probes located on the cylinder and in the wake was followed over the entire range of velocities which could be covered with this apparatus. The coordinates of curves plotted from the current oscillograms and representing the flow characteristics in the boundary layer were fed into a Minsk-22 digital computer, where the autocorrelation and the spectral function were calculated by the standard program. The periodicity of vortices formation in the wake of the cylinder – characteristic of streams with the Reynolds number in our 250-1240 range – was confirmed by the trend of the autocorrelation curve. The maximum normalized spectral density corresponded to the Struhal number $Sh = fd/U_\infty$, with the frequency f expressed in reciprocal seconds. The $Sh = f(Re)$ curve in Fig. 1 indicates a close agreement between our data and the results obtained by other authors [5, 6]. With the frequency distribution of the spectral function plotted in Fig. 2 in logarithmic coordinates for various angular positions of the local probe on the cylinder and with probes in the wake, we have a series of curves with characteristic peaks of spectral density corresponding to the Struhal frequency referred to the cylinder diameter. We conclude, then, that a transient flow in the wake of a cylinder produces fluctuations of friction in the frontal region at the cylinder in a transverse stream with a predominant frequency of vortices separation.

NOTATION

d	is the cylinder diameter;
f	is the frequency of vortices separation;
$\lvert H(i\omega)\rvert$	is the modulus of the transfer function for the system, determined from the response of a diffusion layer to harmonic velocity perturbations;
q	is the average mass flow;
Sh	is the Struhal number;
S_q	is the spectral density of mass flow fluctuations;
S_T	is the spectral density of diffusion current fluctuations;
U_∞	is the velocity of the oncoming stream.

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