UNSTEADY SWIRLED FLOW IN A CYLINDRICAL CHANNEL

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We show the effect of the non-steady-state problem of a working medium on the evolution of the parameters of translational—rotational flow in a cylindrical channel.

The swirling of flows of working media finds wide application as an effective means for intensifying heat- and mass-transfer processes in technological apparatus of various branches of industry. In connection with this it is necessary to make a thorough study of flows in fields of mass forces. Many aspects of steady swirled flows have been studied in sufficient detail, showing the basic features in the development of translational—rotational motion [1, 2].

The nature of the operation of the technological apparatus, the necessity for changing the parameters of the regime, the features for the use of the pressure apparatus, and a number of other factors lead to the occurrence of unsteady flows of the working medium. The unsteadiness leads to a considerable deviation of many of the parameters from their quasisteady values and can abruptly change the course of the operating processes. The effect of the superimposed unsteadiness on the hydrodynamics of axial flows has been studied actively, but its effect for translational—rotational motion has not yet been studied, even though it is such an urgent problem. The basic difficulty in the study of such a type of flow is the complexity of the formulation of the physical experiment.

The study of the features of the development of turbulent flows with local swirling in long tubes and unsteady flow of the working medium were carried out on a hydrodynamic stand of closed type [3]. For the experimental section we used a tube of organic glass having inner diameter 0.056 m and length 1.6 m. As was shown by preliminary investigations in the range of variation of Reynolds number that was being measured ($4 \cdot 10^4$ to $2 \cdot 10^5$), the experimental channel is hydraulically smooth. Swirling of the flow at the input was produced by three bladed guiding devices with a central body of diameter 0.01 m. Each apparatus had 12 blades, profiled arcs of a circle, with constructive angles of output edges φ_k that were, respectively, 30, 45, and 60°. The angle of the output edge is constant over its length.

The unsteadiness of the flow was insured by a pulsator of "hydraulic resistance," established at the end of the working section. Its basic element is a disk of diameter 0.05 m, rotating about its diameter on an axis perpendicular to the flow direction. The frequency of rotation of the disk can smoothly vary from 0.2 Hz to several tens of hertz.

To carry out the experiments we measured and recorded instantaneous values of the volume flow rate Q, boundary tangential stresses $\tau_{w\Sigma}$, and local swirl angles φ_w. The flow rate of the water was determined from the measured values of the stagnation pressures and the nozzles in the prechamber that are static in the output cross section in front of the vortex. The quantities $\tau_{w\Sigma}$ were measured by the "tube-projection" method [4] in two controlled cross sections with coordinates $\overline{X} = 15$ and $\overline{X} = 25$. The pressure differentials of the systems for measurement of flow rate and friction were transformed into an electrical signal by means of differential pressure probes DMI-0.1 with standard secondary apparatus. We recorded the signals by means of a loop oscillograph K 20-21. Investigation of the amplitude and phase frequency characteristics of the hydrodynamic probes being used showed that in the frequency range 0.1-8.0 Hz, the signals are transmitted without distortion.

The swirl angles at the side of the channel were measured according to the deviation of silk threads of length 0.01 m fastened to its inner surface. Evolution of the angles in the dynamic regime in the control cross sections that were already indicated was recorded using a high-speed motion-picture camera synchronized with the oscillograph. The motion-picture filming was performed at the rate of 150 frames/sec.

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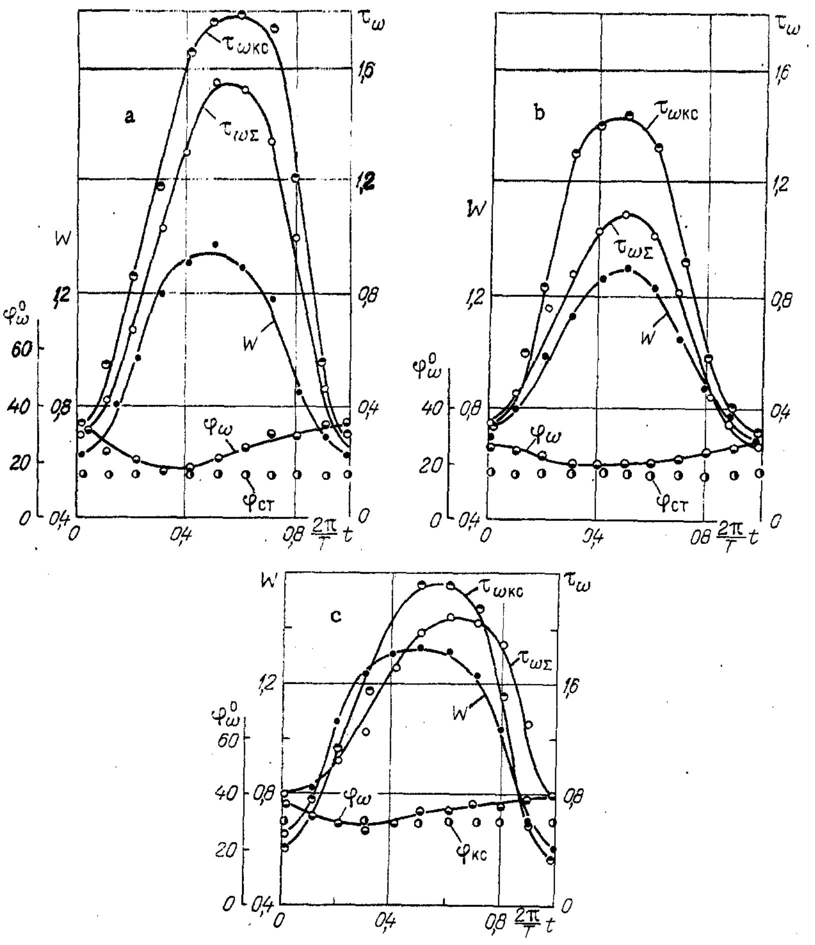

Fig. 1. Variation of parameters of the swirled flow for the guiding apparatus with $\varphi_k = 30°$ (a, c) and $\varphi_k = 60°$ (b) for frequency of superimposed pulsations 0.5 Hz (a, b) and 1 Hz (c) τ_w, N/m².

The results of the investigations of axial unsteady flows show that for that part of the vibrational period in which there occurs a positive velocity gradient, the values of the tangential stresses prove to be greater than their quasisteady analogs, i.e., the tangential stresses for the same instantaneous values of the Reynolds number. When a negative velocity gradient acts (in the slowed part of the period), the opposite picture is observed. With an increase in the vibrational frequency there is an increase in the absolute values of the velocity gradients and in accordance with this, the indicated effects have an even more pronounced character.

The appearance of a circumferential component of motion for unsteady flow considerably changes the relation between $\tau_{w\Sigma}$ and τ_{wkc}. Figure 1a shows a change in the mean-flow velocity $W = w/w_m$ of the local swirl angles at the side of the channel φ_w, the total tangential stresses $\tau_{w\Sigma}$ during a single vibrational period T in the first control cross section with swirling of the flow at the inlet of the vortex with $\varphi_k = 30°$ and frequency of superimposed pulsations 0.5 Hz. Practically, during the entire period the tangential stresses near the sided prove to be less than the quasisteady analogs, i.e., the tangential stresses occurring at a given control cross section for the same instantaneous value of the Reynolds number and local swirl angle. But in the accelerated part of the period this effect has a more pronounced character. If in the steady regime of flow the local swirl angle is practically independent of the value of the Reynolds number, and is completely determined by the intensity of swirling at the inlet to the channel and the distance up to the control cross section, then acceleration of the flow leads to a decrease, and deceleration leads to an increase, in the instantaneous values the angles. Such behavior of the parameters of translational—rotational flow is explained by the intensive rearrangement of the velocity profile, caused by the action of the acceleration or deceleration of the flow.

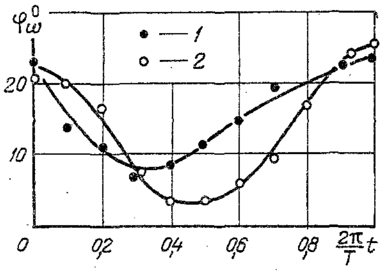

Fig. 2. Evolution of local swirl angles in control cross sections for a guiding apparatus with φ_k = 30° for frequency of 0.5 Hz: 1) X = 15; 2) 25.

Analysis of the kinematic structure of swirled flows in convergent and diffusor types of channels shows that with acceleration of the flow there is an increase in the values of the total velocity over the entire radius of the channel with simultaneous displacement of the position of its maximum in the near-axial region [5]. As a result, there is a decrease in the velocity gradient in the zone near the side and a decrease in the local swirl angles. With flow in the diffusor channels we observe the opposite picture. The indicated effects also lead to the same relation of the parameters that were shown in Fig. 1a.

An increase in the intensity of swirling leads to an increase in the boundary tangential stresses and the swirl angles during the entire period. The effect of acceleration on the boundary friction has the same character as for lower values of swirl but becomes more pronounced; this is explained by the large degree of deformation of the velocity field owing to the increase in intensity of the rotational motion. In this case there is a decrease in the amplitude of variation of the values of the local swirl angles, if in the first case it becomes 8°, then with swirling, for a guiding apparatus with φ_k = 60 it equals 4° (Fig. 1b).

A variation in the parameters of the swirled flow for a high frequency of superimposed pulsations is shown in Fig. 1c. With an increase in frequency, the amplitude of variation of the angle decreases: If for a frequency of 0.5 Hz the amplitude was 8°, then for a frequency of 1 Hz it was 4°. Analogously with an increase in the frequency, which affects the amplitude of the boundary tangential stresses, the amplitude with respect to the friction decreased for the same frequencies from 0.8 to 0.4 N/m² with a simultaneous decrease in the values of the tangential stresses averaged over the period. This indicates that the unsteadiness proves to have a substantial effect on the effects caused by the swirling of the flow. This last conclusion is confirmed by a comparison of the measurements of the boundary tangential stresses in the first and second control cross sections. If for a steady flow behind the vortex with φ_k = 45° the boundary tangential stresses decreased between the indicated control cross sections by 30%, then for a frequency of 0.5 Hz and the same initial intensity of swirling, $\tau_{w\Sigma}$ changed by 60%, which is caused by the large losses of energy of the flow owing to the multiple rearrangements of the velocity profile in the unsteady flow on the same section of the pipeline. A decrease in the intensity of the rotating motion in the second control cross section leads to an increase in the amplitude of variation of the local swirl angle (Fig. 2).

The represented results indicate that in swirled unsteady flow, both factors have a reciprocal effect on the flow parameters, where in the accelerated phase of the period the unsteadiness inhibits the appearance of effects caused by swirled flow, but in the decelerated part it promotes their appearance.

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