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Abstract

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EXPERIMENTAL INVESTIGATION OF TURBULENT FLOW OF AN ELECTRICALLY CONDUCTING FLUID IN A PIPE IN A LONGITUDINAL MAGNETIC FIELD

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In hydrodynamics, the calculation of near-wall turbulent flows is based mainly on semiempirical theories of turbulence, which is explained by the absence of a complete rigorous theory of inhomogeneous turbulent flows. The construction and development of semiempirical theories of turbulence is based on analysis of numerous experimental data relating to the characteristics of the mean and pulsation flow.

From the standpoint of investigating turbulence with transverse shear in a conducting fluid in a magnetic field, at values of the magnetic Reynolds number $R_m \ll 1$, it appears of interest to study a flow in a magnetic field whose induction vector is parallel to the mean velocity, since in this case mean currents are absent and the mean, in any volume element, value of the body forces arising from the interaction of pulsation-induced currents with the external magnetic field is zero. The magnetic field causes dissipation of the kinetic energy of the pulsation motion into Joule heat, which leads to a rearrangement of the mean-velocity profile and to a change in the characteristics of the pulsation motion (1).

A characteristic example of such a flow is flow in a pipe in a longitudinal magnetic field. Its simplest characteristic from the point of view of experimental determination may be the coefficient of hydraulic resistance. In the experimental work of Globe (2), the influence of a longitudinal magnetic field on hydraulic resistance during the flow of mercury in conducting and nonconducting pipes was investigated at values of the Hartmann number $\left(\mathrm{H} = Bd\sqrt{\sigma/\nu\rho}\right)$ up to 80. At such values of H, the influence of the magnetic field on the coefficient of hydraulic resistance proves to be noticeable up to Reynolds numbers ($\mathrm{R} = Ud/\nu$) of the order of 10^4. The use of these data in the analysis of turbulent flow is made difficult by the fact that the characteristic laws of turbulent flows appear at considerably larger Reynolds numbers. In view of this, it is highly desirable to extend the range of investigation toward higher values of the Hartmann and Reynolds numbers, which constituted the aim of the experimental study set

Figure 1

Figure 1: Figure 1

Figure 2

Figure 2: Figure 2

forth here.

To carry out the experiments, a liquid-metal gallium loop was used, described in (^{3}). The loop contained a direct-current electromagnetic conduction pump, a Venturi flowmeter, a cooler, and a working section. Pipes of stainless nonmagnetic steel with internal diameters of 9.8 and 5.2 mm were used as the working sections. The conductivity of the steel was about 1/3 of the conductivity of gallium. Along a pipe length of 1 m, 6 static-pressure taps were arranged.

The working sections were located in a solenoid 1 m long, on whose axis it was possible to obtain a field induction of up to 0.75 Wb/m^2. The field induction on the solenoid axis remained constant to within 1% over a length of 0.75 m.

Fig. 1. 1 —$\lambda = 0.3164\,\mathrm{R}^{-0.25}$; 2 —$\lambda = 64\,\mathrm{R}^{-1}$; 3 —according to formula (2), $H = 64$; 4 —according to formula (2), $H = 84$; 5 —according to formula (2), $H = 110$; 6 —according to formula (2), $H = 144$; 7 —according to formula (2), $H = 164$; 8 —according to data of work (2), $H = 61.2$; 9 —according to data of work (2), $H = 78.8$. Open points correspond to regimes without a field, obtained in the intervals between regimes with a field.

Before entering the magnetic field, the working sections had a stabilization length of about 0.3 m. The length of the flow-stabilization section in the magnetic field, in the investigated range of Reynolds and Hartmann numbers, did not exceed 0.3 m (including the region of magnetic-field growth, which was about 0.2 m). Such a stabilization length was estimated from measurement of the pressure drop of static pressure in the first three taps, located at a distance of 0.125 m from one another. The pressure drop between the taps was measured by means of a piezometric board with two-liquid piezometers.

Fig. 2. 1 —$\lambda = 0.3164\,R^{-0.25}$; 2 —according to formula (2), $H = 150$; 3 —according to formula (2), $H = 20$; 4 —according to formula (2), $H = 260$; 5 —according to formula (2), $H = 300$

The hydraulic resistance coefficient was determined by the formula

$$\lambda = -2d\frac{dP}{dx}\Big/\rho U_{\mathrm{av}}^2. \quad (1)$$

The pressure gradient dP/dx was determined over a section 0.5 m long.

Fig. 3

Figure 3: Fig. 3

Figures 1 and 2 show the experimental dependence of the hydraulic resistance coefficient on the Hartmann and Reynolds numbers, on

Fig. 3—the influence of the Hartmann number on the ratio of the coefficient of hydraulic resistance for flow in a magnetic field to its value in the absence of a field, for various values of the Reynolds number. The satisfactory agreement of our experimental data, obtained in work with gallium, and the data of work (2), obtained in work with mercury, makes it possible to conclude that there is no influence, in the investigated range, of the magnetic Prandtl number ($\mathrm{Pr}_m = \nu/\nu_m$; for mercury $\mathrm{Pr}_m \approx 1.5 \cdot 10^{-7}$, for gallium $\mathrm{Pr}_m \approx 1.3 \cdot 10^{-6}$).

Fig. 3. *a*—$R = 3500$; *b*—4500; *v*—4700, *g*—5500; *d*—6500; *e*—8000; *zh*—9800; *z*—12500; *i*—16750; *k*—21000; *l*—26500; *m*—33500; *n*—42500; *o*—51000; *p*—3500 (data of work (2)); *r*—4500 (data of work (2)); *s*—5500 (data of work (2))

It is seen that the imposition of a longitudinal magnetic field can substantially reduce the coefficient of hydraulic resistance for the flow of an electrically conducting liquid and, at a sufficiently large field induction, transform turbulent flow into laminar flow (in our experiments such a transition was observed for $H = 164$ at $R \approx 5000$). For each value of the Hartmann number there is a certain maximum value of the coefficient of hydraulic resistance; moreover, as the field induction increases, the Reynolds number corresponding to this maximum increases. It should be noted that, in flow regimes close to laminar, the reproducibility of the experimental data deteriorates, i.e., for each value of the Hartmann number, apparently, there is a certain transition region in Reynolds number where the flow is unstable in character.

The experimental data obtained for the dependence of the coefficient of hydraulic resistance on the Reynolds and Hartmann numbers in the investigated range of stable turbulent flow regimes are satisfactorily approximated by the empirical relation

$$\lambda = 0.3164 R^{-0.25} \left(1 - 37.7 H^{1.65} / R^{1.45}\right). \tag{2}$$

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