THREE-DIMENSIONAL MAGNETOHYDRODYNAMIC FLOW PAST A CYLINDER OF FINITE LENGTH

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In general hydrodynamics it is well known that a flow (e.g., in a tube of for flow past a solid-body) is almost everywhere well-described by a two-dimensional approximation (it is two-dimensional), if one of the dimensions of the flow region is considerably greater than the others.

This condition proves to be insufficient in magnetohydrodynamics, and even when it is satisfied the entire flow can remain three-dimensional. Examples of such flows in prismatic tubes are known [1-3]: when there is an inhomogeneity of the magnetic field along the flow direction, for flows in tubes with sudden expansion and contraction [4], and also in exit cones [5].

An explanation of this effect when there is an inhomogeneity in the magnetic field along the flow direction in the tube was evidently first given in [1]. This question was analyzed in greater detail in [3].

In the present communication we present results of an experiment showing that for flow past a cylinder of finite length in a transverse magnetic field, as the field increases the entire large flow region becomes three-dimensional. Before turning to a discussion of the results, we shall formulate several general considerations concerning the transition to three-dimensional flow, in addition to those expressed in [1-3].

We know that as a magnetic field increases, it tends to cancel the velocity gradient along its direction; i.e., the flow tends to become two-dimensional in a plane perpendicular to the magnetic field.* Such a transformation of the flow occurs to the extent that it allows the boundaries of the region to grow. If not all of these boundaries are planes perpendicular or parallel to the magnetic field, then as the field increases, the flow becomes three-dimensional. Precisely this situation occurs for flow past a cylinder of finite length in a transverse magnetic field. Note that the presence of nonconducting walls parallel to the field is essential here. It is also interesting to note that a transition to three-dimensional flow will also occur for flow of a nonviscous liquid. The only important factors are the presence of a velocity gradient along the direction of the unperturbed flow and the presence of the wall mentioned above.

We now proceed to a description of the methods and results of the experiment.

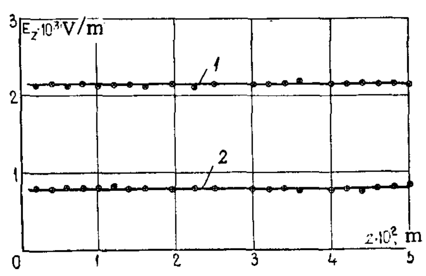

Fig. 1. Distribution of field E_z in the inward flow along the x axis: 1) 0.27 T; 2) B = 0.098 T.

The idea of the experiment is to make use of the fact that for a two-dimensional flow in a transverse magnetic field the electric field has only one vertical z component. (The x axis is directed along the principal flow, and the y axis is directed along the magnetic field.) The electric field is constant over the entire flow region. We measured the electric-potential distribution at the cylinder surface in a mercury flow for various magnetic fields.

The experiment was carried out in the device described in [4], which had a rotating ring channel 500 mm in diameter and $60 \times 30\,mm^2$

* This result (the flow approaching this state) is reasonable since such a flow is not acted on by a magnetic field in general.

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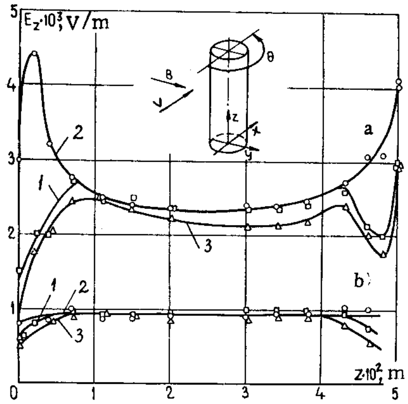

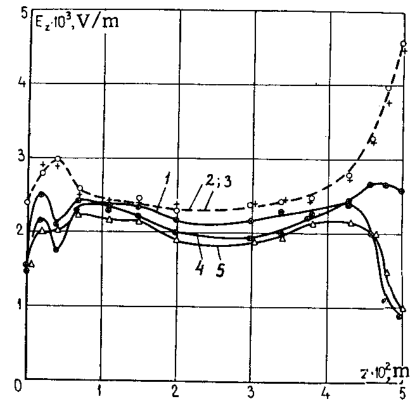

Fig. 2 Fig. 3

Fig. 2. Distribution of field E_z at the cylinder surface along the generator for various angles θ: 1) 0°; 2) 90°; 3) 180°. a) Ha = 102; b) Ha = 37. The gap between the cylinder face and the bottom of the experimental channel was 1 mm.

Fig. 3. Distribution of field E_z at the cylinder surface along the generator for Ha = 102 for various angles θ: 1) 30°, 2) 60°; 3) 90°; 4) 120°; 5) 180°. The gap between the cylinder face and the channel bottom was 5 mm.

in cross section at the open surface. The cylinder was immersed in mercury to a depth of 50 mm; two different values were used for the gap between the lower face of the cylinder and the channel bottom – in the first case the gap was 1 mm; in the second case it was 5 mm.

The cylinder, which was made of plastic, had a diameter d = 15 mm, and the copper electrodes, which were positioned along the cylinder generator, had a diameter d = 0.5 mm. The cylinder holder was constructed so that the cylinder could be rotated about its axis. In order to obtain the electric-field distribution in the inward flow, and also to take account of the velocity lag of the mercury in the channel in the presence of the cylinder, we used a two-electrode transducer with electrodes 2 mm apart. The conduction transducer was placed in the channel 300 mm from the cylinder.

All the measurements were carried out for a constant inward-flow velocity (v = 0.8 cm/sec) and two values of the magnetic field: B = 0.098 T and B = 0.27 T, which allowed us to obtain for the cylinder in one case the parameter Ha = 37, and in the other case, Ha = 102.

To measure the potential distribution at the cylinder, we remove the conduction probe from the channel. The potential difference between the electrodes of the cylinder and the transducer was recorded by the F118 instrument.

Figure 1 shows that the electric field in the inward flow remains constant in the z direction with increasing magnetic field. Hence, for the magnetic field selected, the electric-field perturbations generated by the cylinder do not distort the homogeneity of the electric-field distribution in the inward flow. It thus follows that the inward flow remains homogeneous.

For flow past a cylinder, the picture of the electric-field distribution along the generator changes significantly with increasing magnetic field.

For Ha = 37 (Fig. 2) the electric field has a constant value that is the same over the entire length of the cylinder for various θ, with the exception of boundary regions having a size of the order of two-thirds the cylinder diameter. Hence, for Ha = 37 the flow near the cylinder, except for small regions, preserves a two-dimensional structure in a plane parallel to the magnetic lines of force.

As is shown by Figs. 2 and 3, for Ha = 102 the electric field is quite inhomogeneous, and the flow has a clearly expressed three-dimensional structure. The curves deviate most strongly from a homogeneous distribution for the angles $\theta = 60°$ and $\theta = 90°$. A comparison of these curves (Fig. 3) allows us to assume that at least in the angular range $\theta = 60-90°$ at the surface of the cylinder the electric current depends only on the z coordinate

$$j/\sigma = E(z),$$

and, based on the nature of the distribution of the field E, we see that the flow has a greater velocity near the upper and lower parts of the cylinder than at the center. Thus, for Ha = 102 in the indicated range of angles θ, there is no tendency for transition of the flow to two-dimensional in a plane perpendicular to the magnetic field.

It is characteristic that a three-dimensional flow develops near the faces of the cylinder under conditions other than that in which "tongues" similar to those discovered in [4, 6] are produced. Far from the faces, i.e., in the core, we also have $E \neq$ const. Thus the flow becomes three-dimensional everywhere, which can be explained by the opposite effect of the boundary layers on the flow in the core, which is characteristic of magnetohydrodynamic flows in contrast to flows that obey the laws of general hydrodynamics [6-8].

Comparing Figs. 2 and 3 for Ha = 102, one can see a difference in the curves. The basic difference is that for the case in which the gap between the cylinder face and the channel bottom is 1 mm, the picture of the electric-field distribution is more symmetric than for the case in which the gap is 5 mm. The shift in the values of E near the face is explained by the decrease in the fluid flow in the gap between the cylinder face and the channel bottom.

In conclusion we note that the intensification of the break observed in [9] for a sufficiently strong magnetic field near the cylinder faces, produced by dissolving metals in mercury, can be explained by the formation of velocity "tongues" near the faces.

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