INVESTIGATION WITH A CONDUCTION ANEMOMETER OF THE EFFECT OF A MAGNETIC FIELD ON DISTURBANCES IN THE WAKE OF A CYLINDER

L. G. Kit, S. V. Turuntaev,
and A. B. Tsinober

UDC 538.4

Results of measurements with a conduction anemometer of electric field fluctuations in the wake of a cylinder are described. It is established that the magnetic field has a considerably different influence on disturbances from bodies situated outside a magnetic field and those placed between the poles of a magnet. It is interesting that in the latter case the intensity of disturbances may be less than the noise of the flow. Finally, it is found that the magnetic field considerably amplifies signals behind a cylinder whose generatrix is parallel to the magnetic field. The results permit the synthesis of a large group of phenomena and provide an explanation of them on the basis of a generalized hypothesis of suppression of the generation of turbulent disturbances by a magnetic field.

INTRODUCTION

In [1] a hypothesis was advanced and justified as to why a magnetic field causes a significant effect on the generation of turbulence but has a comparatively weak effect on disturbances carried from regions outside a magnetic field. Experiments on an electrolytic loop [2] showed that for attainable values of Ha/Re, for which laminarization of the flow occurs (judged by experimental data on drag coefficients), substantial velocity fluctuations, chiefly low-frequency, persist in the flow. In the same article it was shown that the level of the velocity disturbances in the wake behind a cylinder in a magnetic field is decreased, down to the complete suppression of disturbances, if the cylinder is between the poles of the magnet (special measures were undertaken to eleminate disturbances which were carried from regions outside the field). If the same cylinder was placed between the poles of the magnet, then the character of the disturbances remained practically unchanged under the influence of the magnetic field.

Furthermore, in [3], which was devoted to the measurement of the spectral density of the velocity in the turbulent wake behind a cylinder, it was found that at large magnetic fields, the magnitude of the velocity fluctuations behind the cylinder placed between the poles of a magnet was less than the corresponding value for an undisturbed flow under the same field. It should be noted, however, that the results obtained in [2, 3] are incomplete and of a qualitative nature. More detailed investigations are necessary to determine the influence of a magnetic field on the disturbances in a turbulent flow. With this aim, measurements of the electric field fluctuations were carried out with a conduction anemometer in the wakes behind cylinders of different sizes for various velocities of the oncoming flow.

EXPERIMENTAL APPARATUS AND PROCEDURES

The experiments were performed on a horizontal mercury loop similar to that described in [3]. To reduce the level of disturbances in the flow, the closed working channel had a constant cross section of 60×20 mm^2 over its whole length. Measurements of electrical signals due to velocity fluctuations in the

---

Translated from Magnitnaya Gidrodinamika, Vol. 6, No. 3, pp. 35-40, July-September, 1970. Original article submitted February 2, 1970.

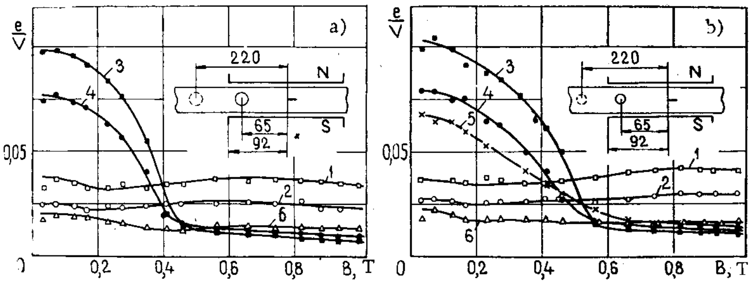

Fig. 1. Effect of magnetic field on disturbances in the wake behind a cylinder with axis perpendicular to the field. 1) d = 8 mm, 2) d = 5 mm (cylinder removed from the field-active region), 3) d = 8 mm, 4) d = 5 mm, 5) d = 2.5 mm (cylinder in the magnetic field), 6) flow noise; a) V = 20 cm/sec, b) V = 30 cm/sec.

channel were made with a conduction anemometer having a spacing of 2 mm between the electrodes of the pickup. The procedures of fabricating and mounting the pickup and the apparatus for amplifying the signal and obtaining the rms value are described in reference [1]. All experiments were carried out for that orientation of the pickup relative to the magnetic field and the mean flow for which the measured potential difference $\Delta\varphi'$ was equal to

$$\Delta\varphi' = Blu' - \sigma^{-1} j_z' l,$$

where l is the distance between the pickup electrodes, u' is the longitudinal velocity fluctuation, B is the magnetic field intensity, σ is the electrical conductivity of the medium, and j_z' is the vertical component of the current density.

Since the measurements reported in the present article are of a relative nature, let it suffice to assume that the rms potential difference $(\overline{\Delta\varphi'^2})^{1/2}$ normalized with respect to the field and the pickup interelectrode spacing will be proportional to $(\overline{u'^2})^{1/2}$, i.e., it varies in the same manner as $(\overline{u'^2})^{1/2}$. Such an assumption is physically sound, since both the electric field E' and the electric current fluctuation j' arise due to the emf Blu' induced by the velocity fluctuation u'. Hence all subsequent discussion will refer to fluctuations in electrical signals normalized in the manner described, which for the reason discussed may serve as the characteristics of the velocity fluctuation.

Measurements were made for two values of the mean flow velocity in the channel: 20 and 30 cm/sec for cylinders of diameters 2.5, 5, and 8 mm. All cylinders were made of glass. The procedure was identical for each experiment: With the velocity V kept constant, a reading of $(\overline{\Delta\varphi'^2})^{1/2}$ was taken for each setting of the magnetic field in the test section. The conduction anemometer pickup was placed along the axis of the channel at various distances from the body.

DISCUSSION OF RESULTS

Figures 1-3 and 5 show the electric field fluctuations normalized by BlV, i.e., $e/V = (\overline{\Delta\varphi'^2})^{1/2}/BlV$, as functions of B. Figures 1-3 are for the cylinder axis perpendicular to the vector B. Depending on the location of the pickup, two types of curves are obtained. Results obtained when the pickup was positioned at the beginning of the test section between the poles of the magnet are shown in Fig. 1.

First of all, we note that when the cylinder was located outside the magnetic field the field has only a slight effect on the electrical signals read from the pickup (curves 1 and 2). In contrast to this, the signals were sharply attenuated with increasing magnetic field when the cylinder was placed in the section between the poles. It was characteristic of this case that the signals were even lower than the noise of the flow (curves 3 and 4).

We should emphasize that the pickup was in both cases kept fixed. Since the cylinder placed in the magnetic field was close to the end section of the magnet, the paths traveled by disturbances from the cylinder into the magnetic field region up to the pickup were nearly identical for both positions of the cylinder. At the same time, disturbances from cylinders located outside the magnetic field were additionally damped

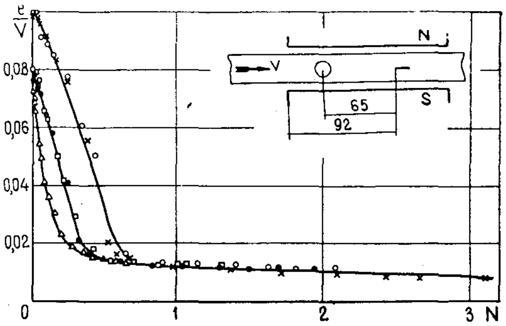

Fig. 2. Effect of magnetic field on disturbances in the wake behind a cylinder with axis perpendicular to the field. ○) V = 30 cm/sec, ×) V = 20 cm/sec (d = 8 mm); □) V = 30 cm/sec ●) V = 20 cm/sec, (d = 5 mm); Δ) V = 20 cm/sec (d = 2.5 mm).

in regions where there was no field. Therefore in weak fields, which have little effect on disturbances, the level of disturbances from a cylinder placed outside a magnetic field is less than for a cylinder located near the pickup in the test section between the magnet poles (compare curves 1, 2 and 3, 4 of Fig. 1).

For large fields ($B > 0.4$ tesla) the magnitude of the signals from the cylinder in the magnetic field is less than those from the cylinder removed from the field. This indicates that the generation of velocity disturbances behind the cylinder in the magnetic field is suppressed and agrees well with the results of [2].

The choice of the magnetic induction B as the independent variable results from the fact that the behavior of the electric field fluctuations can be placed on one figure both when bodies are in the flow and when they are absent (flow noise). It is clear from the figures that the relative positions of the curves are important. At the same time, in using any dimensionless parameter as an independent variable, the choice of a characteristic length is arbitrary. In those cases where the magnetic field has no effect on the disturbances in a flow without a body, any dimensionless parameter may be used as an independent variable.

It is of interest to calculate the Stuart number N_{cr}, at which the intensity of the disturbance is reduced to the noise level of the flow (we call this the critical condition), since this quantity is evidently close to that at which transition to a steady flow regime occurs. As shown in the table, N_{cr} increases with increasing constriction of the flow, or decreasing $W = (F_0 - F_d)/F_0$ (F_0 is the cross sectional area of the channel, F_d is the area of the midsection of the cylinder). It may be concluded from the tabulated data that the value of N_{cr} corresponding to an unconstricted flow is close to 0.3. In our experiments N_{cr} did not depend on Re. The relations depicted in Fig. 1 have a similar property. As is clear from Fig. 2, the intensity of disturbances is independent of Reynolds number and is a function only of the constriction of the flow. Note that in Fig. 2 the flow noise is not shown, for the reason mentioned earlier.

Finally, we mention one more distinctive feature: for sufficiently large values of the Stuart number the intensity of disturbances also ceases to depend on the constriction of the flow.

Figure 3 shows the results of measurements for the case in which the pickup was located at the end of the test section between the poles of the magnet. It is readily seen that the behavior is considerably different from that depicted in Fig. 1. Three characteristic regions may be distinguished in the curves of Fig. 3.

In the first region ($B \leq 0.12$ tesla for V = 20 cm/sec and $B \leq 0.18$ tesla for V = 30 cm/sec) the signal from the cylinder differs little from the flow noise. This is due to the fact that in this region generation of disturbances is still taking place in the flow and as a consequence of the intense energy transfer upwards through the spectrum (i.e., from large-scale to small-scale fluctuations), disturbances produced by the cylinder are largely dissipated on their way to the pickup. Hence the signal sensed by the pickup is practically determined by the flow noise.

The second region (B = 0.12 to 0.46 tesla for V = 20 cm/sec and B = 0.18 to 0.58 tesla for V = 30 cm/sec) is characterized by an attenuation in the signal from a cylinder in the magnetic field region, and a rather strong increase in the signal from a cylinder located outside the field. The flow noise also increases, although to a considerably lesser extent. All of these phenomena may be explained by the intense suppression of energy through the spectrum, which occurs in just that range of values of B. As a result, for disturbances carried into the magnetic field from the outside (from a cylinder lying outside the field or from flow noise) the loss of energy with increasing magnetic field is decreased owing to the cessation of its transfer through the spectrum, and the signal increases.* The rather large range in B of this second region is probably

---

*It should be noted that the cessation of generation of turbulence may be considered as a special case of a more general transfer of energy through the spectrum.

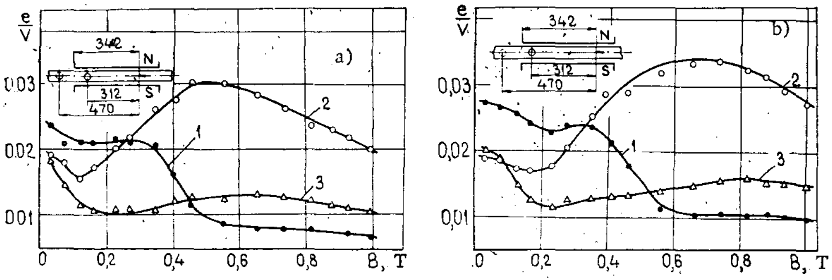

Fig. 3. Effect of magnetic field on disturbances in the wake behind a cylinder with axis perpendicular to the field. a) V = 20 cm/sec, b) V = 30 cm/sec; 1) cylinder placed in the field, 2) cylinder removed from the field, 3) flow noise.

related to the fact that energy transfer through the spectrum does not cease immediately over the whole spectrum. With increasing magnetic field energy transfer by small-scale disturbance is progressively suppressed. The attenuation of the signal from a cylinder between the magnet poles is explained as before by the cessation of turbulence generation and vortex shedding in the wake of the cylinder for certain values of B.

TABLE 1

Re	W	N_{cr}
13 900	0,600	0,63
20 800	0,600	0,63
8 700	0,750	0,40
13 000	0,750	0,40
6 500	0,875	0,30

Finally, in the third region ($B > 0.46$ tesla for $V = 20$ cm/sec and $B > 0.58$ tesla for $V = 30$ cm/sec) all three curves decrease. In this region both viscous and Joule dissipation have increasingly important roles, since turbulent transport is completely suppressed there.

The phenomena occurring in all three regions may schematically illustrated as in Fig. 4. In this figure the curve B_0 corresponds to weak magnetic fields, where the MHD-interaction parameters are very small. The curve B_I refers to the limit of the first region, within which generation of turbulence still occurs within the flow. In the second region (within the range of B_{II}) generation of turbulence does not occur, but the energy transfer through the spectrum is sharply reduced. This means that disturbances carried into the magnetic field from outside are weakly damped along the length. In the third region, characterized by the curve B_{III}, the effects of viscous and joule dissipation predominate, and the level of disturbances is again reduced there.

It is clear from Figs. 1-3 that for sufficiently high magnetic fields the fluctuations in electric field from a cylinder placed between the poles of a magnet become less than the flow noise. Attenuation of the signal behind the cylinder down to a level lower than the flow noise occurs, evidently, owing to the constriction of the flow in the section where the cylinder together the channel walls produce a nozzle. This effect is known in ordinary hydrodynamics, and the reduction in the intensity of disturbances created by the nozzle has been explained on the basis of the linear theory of turbulence [4]. On the other hand, the diffusion region does not promote growth in intensity, owing to the suppression by the magnetic field of turbulence generation and the cessation of vortex shedding.

In Fig. 5 are shown the results of measurements taken for a cylinder whose axis was parallel to B. For a cylinder located in the magnetic field (curve 1), three characteristic regions of variation of the disturbance level may be distinguished.

In the first region ($B \leq 0.6$ tesla) the magnetic field has a weak effect on disturbances. The slight increase in the signal is explainable by the fact that under the influence of the magnetic field the role of edge effects from the ends of the cylinder is reduced and the flow past the cylinder becomes two-dimensional over almost its entire length. Because of this the drag coefficient and the intensity of disturbances in the wake of the cylinder are increased.

In the second region ($B = 0.6$ to 0.8 tesla) a sharp increase of disturbances is observed, which is explained as follows. For $4 \cdot 10^2 < \mathrm{Re} < 4 \cdot 10^4$ the separated boundary layer, which becomes a Karman vortex, is very rapidly agitated, so that the motion has a structure similar to turbulence. For $B \approx 0.6$ tesla

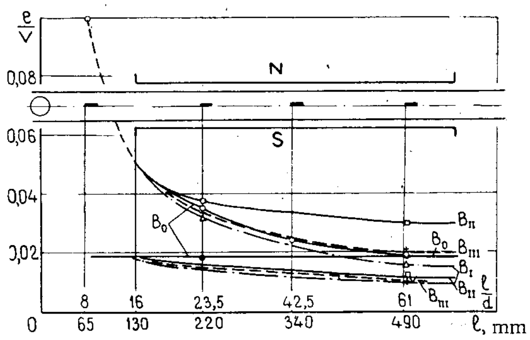

Fig. 4

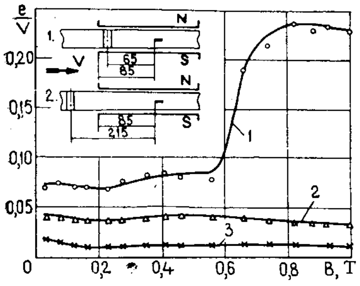

Fig. 5

Fig. 4. Effect of magnetic field on disturbances in the wake behind a cylinder with axis perpendicular to the field.

Fig. 5. Effect of magnetic field on disturbances in the wake behind a cylinder with axis parallel to the field. 1) cylinder in magnetic field, 2) cylinder removed from field, 3) flow noise. d = 5 mm

transition to laminar flow occurs in the vortices. Because of this the size of the vortices grows due to the cessation of turbulent energy dissipation in them. Probably the separation point shifts also upstream on the cylinder because turbulent energy transfer ceases between the separated boundary layer and the disturbance in the external flow. This also leads to growth in the disturbances in the wake of the cylinder.

Finally, in the third region ($B \geq 0.8$ tesla) the intensity of disturbances slowly decreases due to viscous dissipation.

Curve 2 in Fig. 5 corresponds to a cylinder removed from the magnetic field, in which case the magnetic field has the same effect on disturbances as in the case of a cylinder with axis perpendicular to **B** (cf. Fig. 1). Curve 3 corresponds to flow noise.

CONCLUSIONS

1. The results provide an explanation for a large group of diverse phenomena on the basis of a general hypothesis of suppressions of turbulence generation by a magnetic field.

2. Critical values of the Stuart number are determined for transition to steady streamline flow around a cylinder for various constrictions of the flow.

3. For sufficiently high magnetic fields the intensity of disturbances behind a cylinder whose axis is perpendicular to the magnetic field becomes lower than the flow noise.

4. The magnetic field leads to considerable intensification of disturbances produced by a cylinder with axis parallel to the magnetic field. This phenomena is evidently related to two effects. First, the magnetic field parallel to the generatrix of the cylindrical surface does not inhibit separation of the flow from the surface. Second, it suppresses turbulent transport, promoting even an intensified generation of two-dimensional disturbances with axis parallel to the magnetic field.

LITERATURE CITED

1. G. G. Branover, Yu. A. Gel'fgat, L. G. Kit, and A. B. Tsinober, Izv. AN SSSR, MZhG [Fluid Dynamics], No. 2, 35, 1970.
2. G. G. Branover, L. G. Kit, N. I. Kozlenko, and S. V. Turuntaev, Magnitnaya gidrodinamika [Magnetohydrodynamics], No. 2, 143, 1970.
3. L. G. Kit, Yu. B. Kolesnikov, A. B. Tsinober, and P. G. Shtern, Magnitnaya gidrodinamika [Magnetohydrodynamics], No. 4, 71, 1969.
4. G. Batchelor, Theory of Homogeneous Turbulence [Russian translation], IL, Moscow, 1955.