INVESTIGATION OF PLASMA FLUX INTERACTION WITH AN AXISYMMETRIC MAGNETIC FIELD

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The motion of the plasma flux in an axisymmetric magnetic field is examined for a magnetic Reynolds number $R_m \approx 10$, magnetohydrodynamic interaction parameter $N \approx 1$, and Hall parameter $\beta \approx 1$. Flux deceleration in a circular channel is studied at the entrance to the magnetic field because of the formation of azimuthal electrical current eddies.

The plasma flow in a channel in an axisymmetric field has been examined theoretically in [1] for a small magnetogasdynamics (MGD) interaction parameter and a small Hall parameter. The dynamics of the motion of the forward front of a plasma bunch in an axisymmetric field was studied in [2] at high velocities and it was shown that deceleration of the forward front of the bunch should occur in both the entrance zone and the exit from the magnetic system. The investigation of the plasma flow in such fields for a low plasma density ($n_e \approx 10^{13}$ cm^{-3}) has been described in [3] in order to explain the character of the flux motion in an axisymmetric magnetic field.

The aim herein is to clarify the plasma flow peculiarities in an axisymmetric field for a $n_e \approx 10^{16}$ cm^{-3} plasma density, a $R_m \approx 10$ magnetic Reynolds number, and MGD interaction parameter $N \approx 1$; to investigate the dynamics of deceleration of the forward front of a plasma bunch; to determine the azimuthal currents induced by their magnetic fields, as well as the electrical currents in the meridian plane of the channel which originate because of the Hall effect; to compare experimental results with existing theoretical data.

The plasma interaction with an axisymmetric magnetic field was studied in a pulsed electrical discharge tube with a 3.5 cm channel diameter. The parameters of the plasma bunch ahead of the entrance to the magnetic field were estimated as: temperature ≈15,000°K, electrical conductivity $\sigma \approx 100$ mho/cm, velocity of the forward front of the bunch $U = 3 \cdot 10^6$ cm/sec, Mach number $M = 5$, electron concentration $n_e \approx 10^{16}$ cm^{-3}.

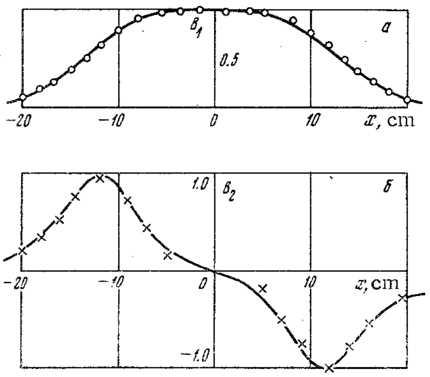

Fig. 1

Shown in Fig. 1 are the dimensionless dependences, obtained experimentally, of the axial B_1 and radial B_2 components of the applied magnetic field in a vacuum along the channel axis. As the field B_1 varies between 0.43 and 1.3 mT, the radial field component B_2 increases from 0.036 to 0.11 mT.

As the plasma flux moves along the channel in the axisymmetric magnetic field, azimuthal currents $j_\theta = \sigma U B_2$ are induced in the plasma bunch which result in the formation of a volume decelerating force $F = -j_\theta B_2$, with the same direction in both the entrance and the exit zones of the magnet since the direction of the azimuthal current also changes as the direction of the radial magnetic field component changes at the exit from the magnet. In order to simplify estimates of the order of magnitudes, the formulas are written without taking account of the Hall effect.

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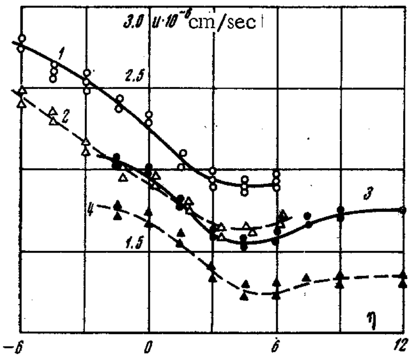

Fig. 2

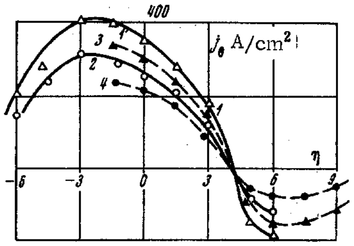

Fig. 3

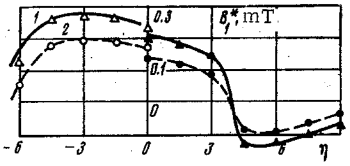

Fig. 4

The velocities of the forward front U were measured in two channel sections $x_1/2R_k = 24$ (Fig. 2, curves 1 and 2), and $x_1/2R_k = 33$ (Fig. 2, curves 3 and 4), where R_k is the channel radius) for diverse locations of the magnetic system which could advance along the channel axis. The dependences $U(\eta)$, where η is the distance between the section chosen and the center of the magnet referred to $2R_k$ (the plus and minus signs correspond to the location to the right and to the left of the center of the magnet), are presented in Fig. 2. Attention must be turned to the fact that the velocity in the channel varies because of gasdynamic friction on the channel wall as well as because of the effect of the electromagnetic forces. Thus, for $B_1 = 0$ the flux velocity drops almost 1.5-fold within a 80 cm distance. This effect explains the discontinuity in the dependence $U(\eta)$ for the same magnetic field. If just the electromagnetic effects had exerted influence on the flux, then, curves 1, 3 and 2, 4 (Fig. 2) would go continuously over into each other. Curves 1 and 3 (Fig. 2) have been obtained for $B_1 = 0.86$ mT, and 2 and 4 for $B_1 = 1.3$ mT.

A small sized Rogowski coil with an integrating coil was used to measure the azimuthal current j_θ induced in the entrance and exit zones of the magnet. One side of the belt was on the channel axis so that it enclosed all the azimuthal current on a 5 cm long section of the channel. The current j_θ was measured for the belt located on the section $-6 < \eta < 6$. Shown in Fig. 3 is the dependence of the effective azimuthal current density for different channel sections relative to the center of the magnet, obtained by dividing the current magnitudes measured by the Rogowski coil by the area enclosed by the belt. Curves 1 and 2 have been obtained for $x_1/2R_k = 24$, and 3 and 4 for $x_1/2R_k = 33$, where curves 1 and 3 correspond to $B_1 = 0.86$ mT, and 2 and 4 to $B_1 = 1.3$ mT. It turns out that the current density at the exit from the magnet is less than at the entrance.

The disturbance of j_θ in the radial direction at the center of the magnet was determined by using the Rogowski coil. Experiments showed that the current density is distributed as follows: $j_1 : j_2 : j_3 = 0.15 : 0.65 : 0.2$, where j_1, j_2, and j_3 are the currents flowing through the sections $(0, \frac{1}{3}R)$, $(\frac{1}{3}R, \frac{2}{3}R)$, and $(\frac{2}{3}R, R)$. The major part of the azimuthal current is in the middle portion of the radius $(\frac{1}{3}R < r < \frac{2}{3}R)$.

A shielded magnetic probe was used to measure the axial magnetic field component B^* in the plasma and the induced magnetic field B_1^*. Shown in Fig. 4 is the dependence of the induced magnetic field B_1^* along the channel axis for an external magnetic field $B_1 = 1.3$ mT (1) and $B_1 = 0.43$ mT (2) when the probe is $x_1/2R_k = 24$ distant from the plasma source for $\eta < 0$ and $x_1/2R_k = 33$ for $\eta > 0$. The induced magnetic field is 45-20% of the applied axial magnetic field. The greater the applied field B_1, the smaller this ratio. Both $j_\theta(\eta)$ as well as the dependence $B_1^*(\eta)$ showed that the boundary between the azimuthal current eddies is at $\eta \approx 4$.

The magnetic field B^* in the plasma is shifted to the right along the flux relative to the field B_1 in a vacuum, as is characteristic for fluxes with $R_m > 1$. The greater the field B_1, the smaller the deformation of the magnetic field in the plasma, which is associated with the nonlinear increase in the azimuthal current as the field B_1 grows.

The radial field in the plasma was computed by using the dependence $B^* = f(x)$. The deformation of the radial magnetic field in the plasma will diminish as the applied magnetic field grows.

It is known that Hall currents appear in the meridian plane in the presence of a Hall effect in a channel with an axisymmetric magnetic field and the potential difference varies along the channel length [1].

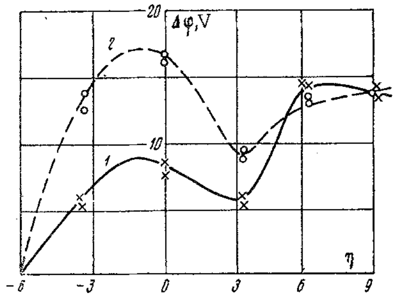

Fig. 5

To study this effect the potential difference distribution along the channel length was measured experimentally in an axisymmetric magnetic field $B_1 = 0.86$ mT by using a number of thin metal probes. The potential difference was measured on both the axis (Fig. 5, curve 1) and the walls of the channel (Fig. 5, curve 2). The distribution of the potential difference along the channel is characterized by two sections of a potential rise and one section of a potential drop, which corresponds qualitatively to the distribution of B_1'' along the x axis [1]. As follows from the theory, the potential difference between electrodes outside the magnetic field boundaries is independent of the location of the electrodes relative to the channel walls.

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