Some Experimental Observations on Circulating Currents in a Crossed Field Plasma Accelerator

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Theme

IF a transverse magnetic field is applied to a plasma stream which has an electrically conducting boundary layer, current loops can circulate in the plane normal to the flow direction. The major effect of these current loops is to decelerate the stream. They can substantially lower the performance of MHD accelerators, pumps, and generators.

Contents

Voltage, current, and magnetic field as well as heat transfer to selected electrode and insulator wall regions were measured in a fully water cooled MHD channel. The channel flow discharged as an open jet into a test chamber that contained a time of flight velocity instrument and traversing probes for measuring Pitot pressure, stagnation pressure and stagnation heat transfer and a probe that gave local velocity and electrical conductivity.[1] All data were recorded as functions of time.

When used as an accelerator, velocity increases of $\Delta U/U = 2\frac{1}{2}$ could be produced for initial conditions of low velocity and electrical conductivity. In contrast to this, the velocity diminished markedly with increasing magnetic field for initial conditions of high velocity and electrical conductivity (Fig. 1) for all values of J, including $J = 0$. Paralleling the drop in velocity, the open circuit generator voltage (Fig. 1) drops from the values predicted for a parabolic velocity distribution as the magnetic field is increased. Schneider and Wilhelm[2] using a subsonic, seeded stream reported this shape of the voltage-magnetic-field curve. Both heat transfer to the insulator walls and deflection of the stream centerline, measured for the open circuit generator case, increased substantially with increase in magnetic field, paralleling the drop in open circuit voltage.

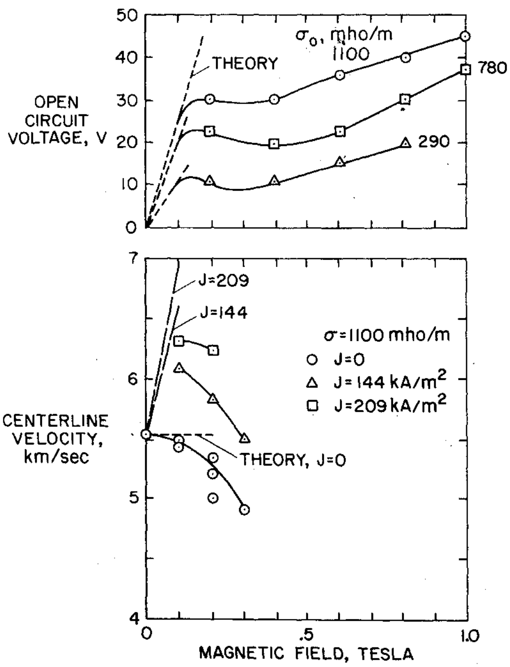

Fig. 1 The effect of magnetic field on open-circuit voltage and centerline velocity.

As pointed out in Ref. 3, prior theoretical work has largely concentrated on effects in the plane perpendicular to the magnetic field vector; whether the problem considered was electrode segmentation, velocity and thermal boundary layers on cold electrodes, Hall effects, unequal electron and gas temperatures and nonequilibrium ionization—all predict no adverse effects in the open circuit generator case. Moreover the Hall parameter was less than 2 in all tests.

Instead current loops in the plane perpendicular to the flow axis are postulated to account for the major portion of the observed adverse effects. These loops, first described and analyzed in Ref. 3, are similar to the classical Hartmann current flow except that they close completely within the fluid rather than include the electrodes as part of the electrical circuit. These currents arise from differences in velocity between the central and insulator wall regions of the channel, which interact with the imposed magnetic field to produce differences in induced voltage, the maximum difference being $U \times B$ at the stream centerline. This voltage difference results in a current flow proportional to $\sigma(U \times B)$. This current interacts with the magnetic field to produce deceleration at the stream centerline, but our experiments show the acceleration force next to the insulator

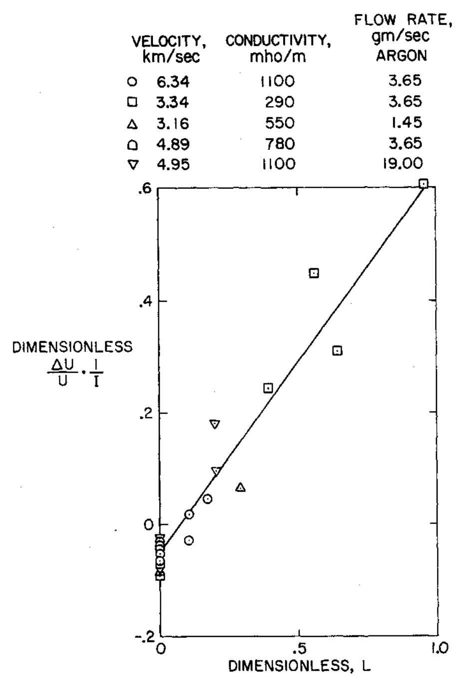

Fig. 2 Accelerator performance expressed as the product of the velocity ratio and the reciprocal of the interaction parameter plotted as a function of the Hoffman loading parameter.

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walls is dissipated in the viscous boundary layer, in contrast to the prediction of Ref. 4. Net momentum increase is determined therefore by the combination of the Lorentz force from the externally applied current and the decelerating force due to the induced current, both interacting with the magnetic field.

The gross behavior is described by the equation

$$\Delta U(\dot{m}/v) = C_2 J \times B - C_1 \sigma(U \times B) \times B \quad (1)$$

Here, ΔU is the velocity increment; $\dot{m}$ is the bulk mass flow rate; v the channel volume; and C_1 and C_2 constants. Equation (1) will predict the velocity data in Fig. 1 especially well if the tensor conductivity is used at very large values of magnetic field. The tensor conductivity is

$$\sigma = \sigma_0(1+\beta^2)^{-1} = \sigma_0(1+C_3 B^2)^{-1} \quad (2)$$

where σ_0 is the electrical conductivity in the absence of magnetic field; β the Hall parameter; and C_3, a constant. Equation (1) can be rendered dimensionless by introducing the Hoffman loading parameter, $L = J/\sigma UB$, and the interaction parameter, $I = v\sigma B^2/\dot{m}$. These parameters correlate the data over large variations of initial stream conductivity and velocity, as shown in Fig. 2. This figure leads one to the conclusion that the highest accelerator velocity ratio, $\Delta U/U$, is obtained by decreasing the interaction parameter or increasing the Hoffman loading parameter.

References

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