Hartmann Boundary Layer Model In A Duct Flow

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Abstract

Magnetic confinement fusion devices make use of very intense magnetic fields, typically of the order of several teslas. Extracting the heat to eventually produce electricity is provided by liquid metals flowing in ducts, sometimes with free surface. Interaction between the magnetic field and the flow induces some current density, which interacts with the magnetic field to create Lorentz forces that change the velocity profile. Along the walls that are perpendicular to the magnetic field, a so-called Hartmann boundary layer develops with typical tiny size of the order of Ha−1, with Ha numbers of the order of several thousands, needing very large computational resources. Leboucher (1) describes a model to account for the boundary layer in the electric current density conservation equation without meshing its thickness, opening a very efficient way to solve high Hartmann number flows that are common in fusion reactors blankets. The side layer, parallel to the magnetic field, of the order of Ha−1/2, still needs a proper mesh description.
The "Electric Shielding" boundary condition of the AC/DC Module considers both the finite thickness and the electrical conductivity of the walls. A slight modification adds the contribution of current density flowing in the Hartmann boundary layer(1).

Results in FIGURE 1 illustrates the change of the horizontal velocity profile along the direction of the flow z for the case of a free surface top boundary. FIGURE 2 shows the horizontal velocity profile for the cases of wall, conductive top surface and slip, insulating free surface.
The approach, demonstrated here in a duct flow, is particularly beneficial in the context of more complex geometrical setups, where the projection of the magnetic field can be used for modeling locally varying thickness of the Hartmann boundary layers, that is crucial to allow for the conservation of current density.

Reference

1. L. Leboucher, Monotone Scheme and Boundary Conditions for Finite Volume Simulation of Magnetohydrodynamic Internal Flows at High Hartmann Number, Journal of Computational Physics, Volume 150, Issue 1, Pages 181-198, 1999.

Figures used in the abstract

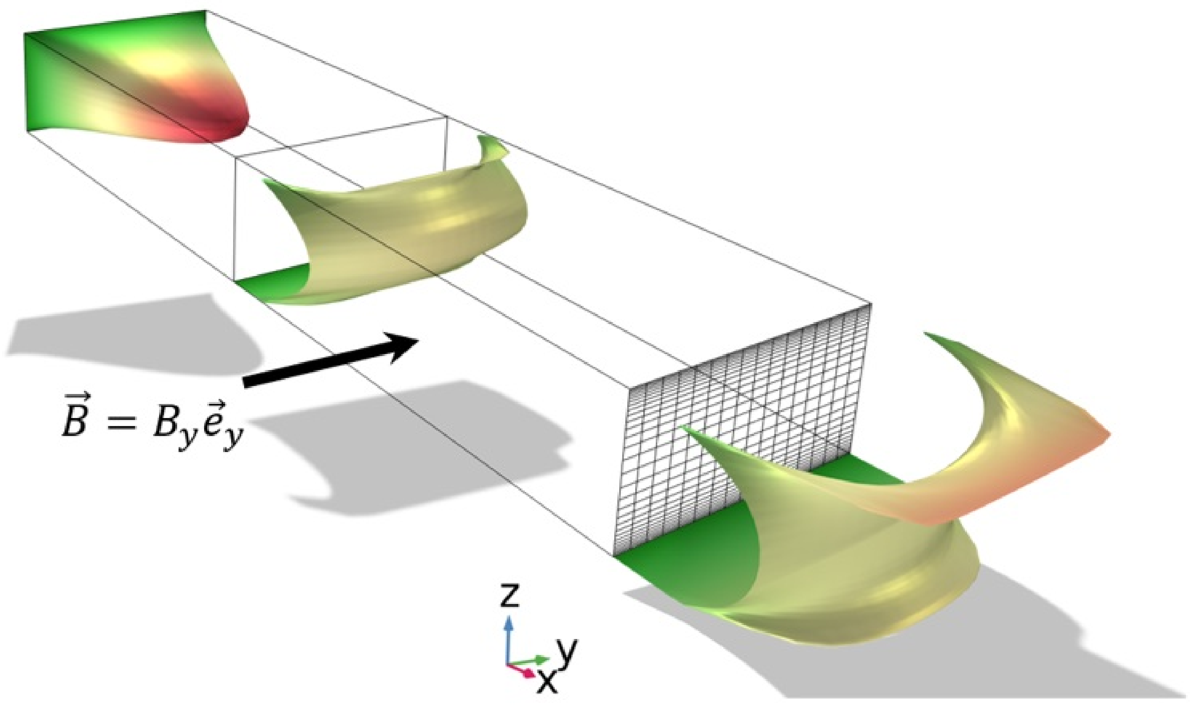

Figure 1 : FIGURE 1: The parabolic velocity profile along x at the inlet is substantially modified at the outlet by its interaction

with a transverse magnetic field. Mesh is shown at the outlet.

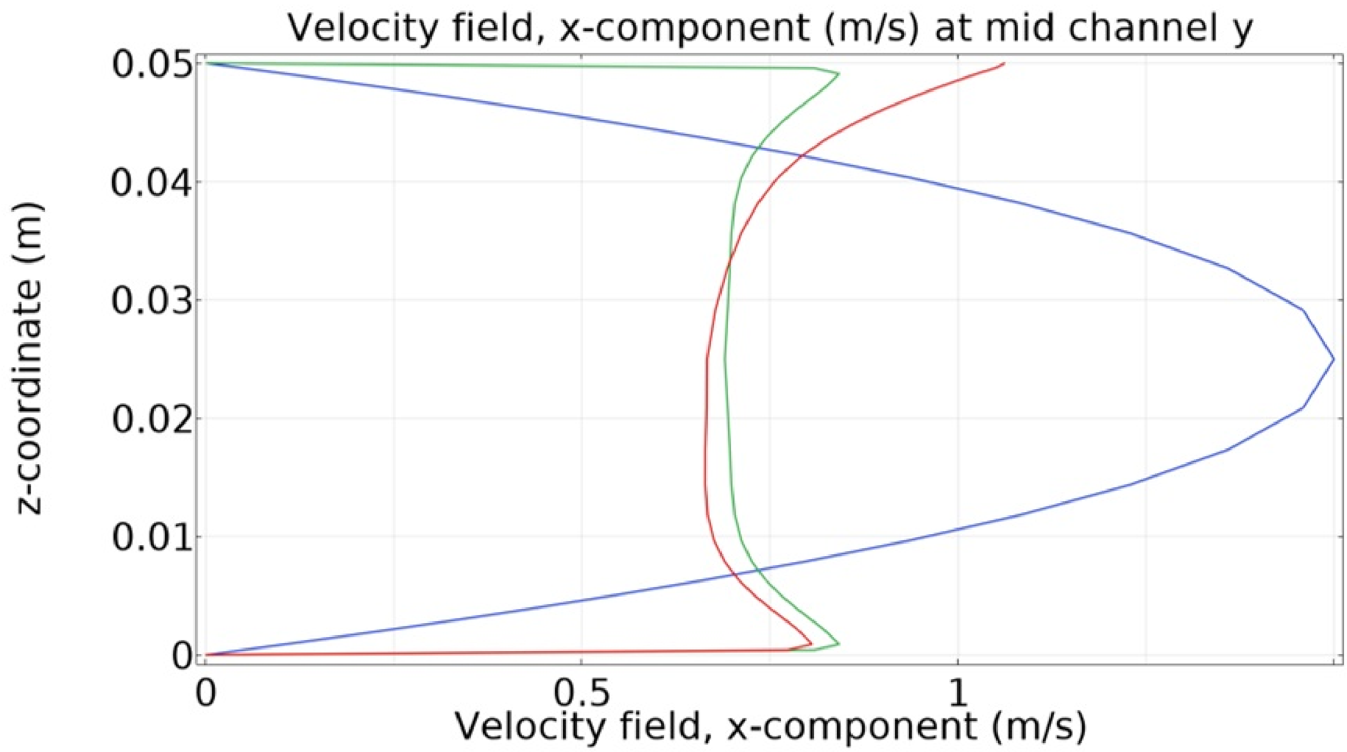

Figure 2 : FIGURE 2: horizontal velocity profile along z at the outlet with conductive top no-slip wall (green) or insulating top slip free surface (red). Inlet parabolic profile is in blue.