Simulation of magnetohydrodynamic (MHD) flows by using an electric potential formulation

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Abstract

The study of magnetohydrodynamic (MHD) flows in presence of intense magnetic fields is of fundamental importance for the development of nuclear fusion reactors. Here, in the so called blanket, liquid metals are used for producing tritium that feeds the fusion reaction, for removing the generated heat and for shielding the neutron and radiation fluxes. The interaction of the moving electrically conducting fluid with the magnetic field that confines the fusion plasma modifies stream patterns, flow features and pressure distribution in the blanket compared to those expected in hydrodynamic flows. Hence there is the need of simulating coupled magneto-hydrodynamic and heat-mass transport problems in complex geometries in order to optimize the blanket design.

For low magnetic Reynolds numbers, typical of such liquid metal systems, the induced magnetic field can be neglected compared to the imposed one and the electric field can be defined as the gradient of an electric potential. MHD flows are then mathematically described by a momentum equation, where electromagnetic forces appear as source term, and by Ohm's law that expresses the electric current density in terms of the electric potential gradient and an induced electric field. Conservation of mass and charge has also to be satisfied. These equations have been implemented in OpenFOAM according to a second order projection method [1]. Special care has been taken to realize a consistent and conservative formulation for calculating the current density to be used to evaluate the Lorentz force [1, 2]. This type of scheme is required to reach high accuracy for simulations of flows in very strong magnetic fields.

The obtained code has been validated against available analytical solutions. For instance fully developed MHD flows in ducts with highly electrically conducting [3] or insulating walls have been simulated and the results show a perfect agreement with the analytical solutions. Tests have been also carried out to understand the effects of various discretization methods on the accuracy of the employed numerical algorithm.

The ongoing work focuses on the implementation of strategies that allow simulating MHD flows in geometries with walls of arbitrary electrical conductivity. Possible procedures to achieve this goal and to broaden the present code are outlined.

Key words: Magnetohydrodynamics (MHD), liquid metals, magnetic field, electric currents

References

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