Three-Dimensional Numerical Study of the Flow Past a Magnetic Obstacle

M. Rivero[1], O. Andreev[2], A. Thess[3], S. Cuevas[4], T. Fröhlich[1]

[1]Institute of Process Measurement and Sensor Technology, Ilmenau University of Technology, Ilmenau, Germany

[2]Helmholtz-Zentrum Dresden-Rossendorf e. V., Institut für Sicherheitsforschung Abteilung Magnetohydrodynamik, Dresden, Germany

[3]Institute of Thermodynamics and Fluid Mechanics, Ilmenau University of Technology, Ilmenau, Germany

[4]Instituto de Energías Renovables, Universidad Nacional Autónoma de México, Temixco, Morelos, México

Abstract

Flows of electrically conducting liquids in external magnetic fields are present in several practical applications. In particular, the flow of a conducting fluid past a localized magnetic field, usually known as a magnetic obstacle [1], is of interest for a developing velocimetry technique [2]. In this kind of flow, the inhomogeneous magnetic field creates a breaking force on the conducting fluid that depends on the magnetic field strength, the electrical conductivity of the fluid and the flow velocity. As a result, a stagnant or low-velocity zone is formed in the zone affected by the localized field so that the fluid flows around it, in a similar way as the flow around a solid body, and a wake is created. Wakes in magnetohydrodynamic (MHD) flows present interesting challenges since they offer a wider dynamical behavior if compared with the flow past a solid body and so far have been very poorly explored. As a matter of fact, only a few experimental studies have been performed in order to discern the behavior of these flows [3].

In this work, a numerical simulation in COMSOL Multiphysics® is compared with experimental results of the flow past a magnetic obstacle in a rectangular duct. In the experiment, a liquid metal alloy (GaInSn) flows in a 20 mm high, 100 mm wide and 500 mm long non-conducting channel in the presence of a non-homogeneous magnetic field produced by two NdFeB permanent magnets (20 mm high, 40 mm wide and 30 mm long) coupled by a steel yoke and located 120 mm far from the channel entrance, as shown in Figure 1. An electromagnetic pump based on rotating permanent magnets drives the liquid metal in a horizontal loop, with a flow rate up to 2 liters per second. Laminar and turbulent regimes were obtained in the experiment [3, 4] and stationary patterns were observed.

For this magnetohydrodynamic problem, the Navier-Stokes equations and the electromagnetic equations are solved using the COMSOL finite element solver through a coupling between

physics interfaces from the AC/DC and CFD Modules. For the fluid dynamic simulations the laminar and k-epsilon turbulent models are used, where the Lorentz force is included in the momentum equation. In addition, the heat transfer problem is investigated since the Joule heating is also computed.

Although attempts to describe the scenario for the flow past a magnetic obstacle have been made, due to the enlarged parameter space only a restricted scenario has been explored so far. The main goal of this paper is the numerical calculation of the velocity and electric current density fields of the MHD flow. These results will be validated with available experimental data [3] and thus will help in understanding the dynamics of liquid metal flows exposed to inhomogeneous magnetic fields.

Reference

1. S. Cuevas et al., On the flow past a magnetic obstacle. Journal of Fluid Mechanics, 553,227–252 (2006)
2. A. Thess et al., Lorentz Force Velocimetry, Physical Review Letters 96,164601(2006)
3. O. Andreev et al., Application of the ultrasonic velocity profile method to the mapping of liquid metal flows under the influence of a non-uniform magnetic field. Experiments in Fluids, 46,77–83 (2009)
4. M. Rivero et al., Experimental study of flows past a magnetic obstacle. Proceedings of the 8th PAMIR International Conference on Fundamental and Applied MHD, Vol 1, 347-351 (2011)

Figures used in the abstract

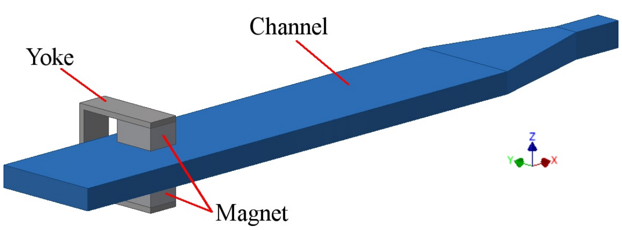

Figure 1: Scheme of the studied problem.