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Numerical Investigation of Instability Growth and Shear Stabilization in Conducting Liquid Metal Columns

Benjamin Herfray[1*], Andrew Higgins[1], Jovan Nedić[1]

[1]Department of Mechanical Engineering, McGill University, Montréal, Canada
[*]benjamin.herfray@mail.mcgill.ca

ABSTRACT

Magnetohydrodynamic instabilities present an important challenge when employing liquid columns to drive currents in various industrial applications, such as for magnetic and inertial confinement fusion devices. In particular, the current-driven instability (CDI) resulting from a current applied axially through a conducting column can lead to the breakup or otherwise undesirable motion in the column, with the strongest instabilities usually growing in the $m = 0$ and $m = 1$ azimuthal modes. However, it has previously been suggested that non-uniform, or sheared, flow profiles in compressible, dense plasmas can help stabilize columns, although there has been little work on incompressible liquid metals. In the present work, we present numerical computations characterizing the conditions for instability and growth rates in different flow regimes. A 1.5-dimensional Chebyshev spectral code is used to solve the linearized magnetohydrodynamic equations in the radial domain for an incompressible cylindrical column with an applied axial current, allowing us to compute growth rates for different linear perturbation modes. We present results characterizing the existence of instability, growth rates, and dominant growth modes for different parametric regimes of the flow. In particular, we consider instabilities in the presence of a non-uniform (sheared) base flow in order to evaluate the effectiveness of shearing in the stabilization of incompressible liquid columns. It is found that some shearing reduces growth rates relative to those found in uniform flow, however higher shear configurations seem to be less stable, possibly due to dominant effects from a shear instability. The 1.5-dimensional linear computations are complemented with fully nonlinear simulations using the FreeMHD package. Three-dimensional simulations of liquid metal columns seeded with small initial perturbations are performed to compare their initial growth rates to our computed linear regime growth rates. We report characteristic nonlinear behaviour in the current-driven instability of the liquid column. Computational results obtained in this work will be compared to and will help inform future conducting liquid metal column experiments, as well as help provide insight into the effectiveness of various proposed shear stabilization strategies in columns. This can be useful in informing the use and design of conducting liquid columns in different industrial contexts.