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ADVANCED NUMERICAL SIMULATION OF MAGNETIC LIQUID SLOSHING IN MICROGRAVITY

Abstract

The term sloshing refers to the forced movement of liquids in partially filled containers. In a low-gravity environment, the liquid mixes with pressurizing gas bubbles and adopts a random position inside the vessel, resulting in unwanted perturbations and a complicated tank design. Liquid sloshing has consequently represented a major concern for Space engineers since the beginning of the Space era.

The sloshing of magnetic liquids has distinctive characteristics that suggest an alternative approach to this problem. Magnetic fields can be used to control the position, shift the natural frequencies and increase the damping ratios of a susceptible oscillating fluid. This concept may be implemented in addition to or in substitution of classical propellant management devices, reducing the inert mass of the spacecraft, enhancing the stability properties, and minimizing attitude control disturbances.

The future implementation of magnetic sloshing technologies for spacecraft control passes through the accurate understanding of basic physics and modeling capability of magnetic liquid dynamics. Quasi-analytical inviscid magnetic sloshing models have been recently introduced by the authors, but micro-gravity measurements collected at ZARM's drop tower point towards a more relevant role of magnetically-induced viscosity. Consequently, improved numerical models need to be developed to fully address this phenomenon.

This paper introduces a Computational Fluid Dynamics model for magnetic liquid sloshing analysis and simulation in low-gravity. The model implements a rigorous magneto-hydrodynamic approach and considers the magnetoviscous effects neglected in previous works. The numerical technique used in this study is a variation of that developed in Herrada & Montanero (2016) for interfacial flows. The method is fully monolitic where all the fields are solved for at the same time. Its novelty lies in the fact that the numerical Jacobian matrix required for solving the highly nonlinear system of equations through a Newton method is obtained by combining analytical functions and collocation matrices. This allows taking advantage of the sparsity of the resulting matrix to reduce the computational time on each Newton step. It is full implicit resulting in superior stability properties. In particular, arbitrarily large time steps can be used to reach stationary states. The numerical procedure can be also employed to perform a modal analysis of the system. This approach, together with the meniscus stability analysis, is key to address the magnetic sloshing control concept through numerical simulations.