Accuracy and scalability of incompressible inductionless MHD codes applied to fusion technologies

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It is well known that magnetohydrodynamics (MHD) is going to dominate the dynamic of the liquid metal flows inside the breeding blankets (BB) of future nuclear fusion plants by magnetic confinement. MHD is a multiphysics phenomenon involving both electromagnetism and incompressible fluid mechanics.

From the computational point of view, the simulation of MHD flows entails a significant challenge. Indeed, due to the shape of the induced electrical currents inside the bulk of the fluid, high spatial resolutions are needed next to the boundary layers and the 3-dimensional elements of the domain. Besides, solving the equations accurately typically requires very small time steps for the transient algorithms. The amount of computational resources needed for solving the MHD problems increases geometrically with the intensity of the magnetic field. Therefore, realistic simulations of liquid metal flows in the nuclear fusion environment are usually very costly and requires of scalable codes.

Over the past few decades, some parallelizable MHD codes have been developed with success to simulate complex flows in increasingly realistic geometries. Among them, the MHD tools of commercial CFD platforms have attracted attention due to their relatively soft learning curve. Most of these codes are based on the so called φ-formulation which, by applying the divergence free condition of the current density to the Ohms law, reduces the electromagnetic part of the problem to a single Poisson equation. As a downside, the charge conservation is not guaranteed at a discrete level which in practice establishes strong limits to the time-step needed to obtain accurate and stable solutions. In this work, these limits are explored for the commercial platform ANSYS-Fluent using test geometries under different conditions.

As an alternative to commercial platforms, a new code based on Finite Element Methods (FEM) is introduced as well. This open-source code, called GridapMHD (https://github.com/gridapapps/GridapMHD.jl), aims at solving the full set of MHD equations using a monolithic approach. GridapMHD is still in early stages of development but it has shown promising results of accuracy and scalability.