Mathematical and Computational Assimilation for Plasma Boundary Physics and Integrated Fusion Reactor Simulations

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ABSTRACT

This work is concerned with the implementation of computational multi-physics algorithms for the whole-system simulation of nuclear fusion reactors. The objective is to account for all regions of the reactor (plasma, vacuum and confinement vessel) within the same simulation and in a Cartesian frame of reference, which represents a significant departure from current (segregated solutions on physics-driven mesh alignment) approaches on both counts [1]. A key element of this methodology is the discretisation of topologically complex rigid boundaries as well as material and state of matter interfaces. The former implies mesh generation in the conventional CFD sense, while the latter is discretisation on both sides of the material or matter interface.

A critical element for accurate tokamak simulations is the correct and physical representation of the vacuum vessel as well as the effect of the electromagnetic properties of the confinement vessel. In this presentation, we will discuss how this is achieved through the implementation of a novel diffuse interface finite volume method [2] for the solution of the MHD equations for transient case studies, involving resistive walls and regions of true vacuum. The effect of the presence of perfectly conductive and resistive boundary conditions on the flow of the plasma inside a confinement vessel is also investigated by means of a modified rigid body ghost fluid method, which takes into account the finite resistivity of an arbitrary electromagnetic rigid body. All simulations are performed using fully explicit high-order finite volume methods, whose shock-capturing characteristics are highly favourable for the simulation of violent processes, such as vertical displacement events within tokamak reactors.

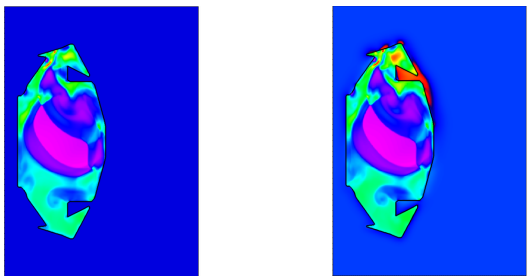

Figure 1: Magnetic field component profile for perfectly conductive wall (left) and resistive wall (right) within the ST40 fusion reactor geometry.

References

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[2] Wallis, T., Barton, P.T. and Nikiforakis, N., 2021. A Flux-enriched Godunov Method for Multi-material Problems with Interface Slide and Void Opening. Journal of Computational Physics.