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EFFICIENT AND ACCURATE APPROXIMATION OF INDUCTIONLESS MAGNETOHYDRODYNAMIC FLOWS IN FUSION PROBLEMS

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Abstract. We describe the numerical approximation of the incompressible inductionless magnetohydrodynamic (MHD) equations for the simulation of flow problems in fusion technologies. MHD is a multiphysics problem which consists of the coupling of the incompressible Navier-Stokes and a simplified form of the Maxwell equations through the Lorentz force. The traditional approach to solve this problem is to reduce the set of equations using divergence constraints to obtain Poisson equations for the pressure and the electric potential in combination with operator splitting techniques to advance in time. Whereas this permits to reduce the complexity of each time step, a severe restriction is introduced which results in a scheme that is not efficient for steady problems typical of fusion technologies. This approximation also makes difficult to exactly satisfy charge conservation at the discrete level, which pollutes the numerical solution, sometimes corrected partially with divergence cleaning techniques. Apart from discussing this issue we describe a monolithic formulation where all variables are approximated in the appropriate function spaces, which permits to prove exact charge conservation at the discrete level. This is an important feature from a physical point of view and we present some illustrative examples. However, the monolithic formulation results in a large algebraic system whose solution is a challenge. We address this challenge using an iterative Krylov procedure with an algebraic block preconditioner in which uncoupled problems for each variable are solved. The resulting algorithm is implemented in GridapMHD.jl a parallel code written in the Julia programming language which exploits Gridap.jl, an open source software eco-system that permits the numerical solution of partial differential equation. We also present a validation comparing computational with experiment results and a some performance tests illustrating the efficiency of the formulation, specially parallel scalability.

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