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Jacobian-free Newton-Krylov methods in Production Level Magnetohydrodynamic Codes

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NIMROD is one of the key MHD simulation tools supported by the DOE's Office of Fusion Energy Sciences through the Center for Extended Magnetohydrodynamic Modeling (CEMM) SciDAC. NIMROD has successfully explained the key heat loss physics mechanisms occurring during tokamak disruptions, the onset of tearing modes during tokamak discharges, and the confinement times of spheromaks. Although NIMROD is a production-level code producing realistic physics results, improvements that would enable greater accuracy and faster execution are needed to reduce the turnaround time of a simulation.

Although, semi-implicit methods are generally successful for enabling many of the simulations that NIMROD performs, NIMROD still has a time-step limitation due to the nonlinear advection terms in the equations. Although there are implicit operators for these terms which are often comparably small for simulated cases, there still exists a CFL-like condition that depends on the flow velocities of the MHD fluid in the plasma. Simulation time constraints can arise from this condition, thus overcoming these constraints would extend the capability of NIMROD. In addition, the operator splitting introduces discretization errors in the NIMROD algorithms. Moving to an algorithm that is fully-centered would improve the accuracy of NIMROD, especially for long-time simulations.

Using the PETSc computational framework, we examine the use of fully-centered Jacobian-free Newton-Krylov (JFNK) methods in the NIMROD code via the SNES package. Previous approaches in NIMROD to incorporate nonlinear terms only considered their addition in an ad hoc manner. We report on the first fully nonlinear solve of the velocity equations and present current progress on solving the fully nonlinear system for velocity, temperature, magnetic field, and density. We will also discuss the preconditioning strategy that will be required to efficiently solve the linear systems within the JFNK iterations.