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Verification and Validation of Extended-Magnetohydrodynamic Modeling of Disruption Mitigation

Future tokamaks will require robust disruption-mitigation systems (DMS) to prevent damage from extreme heat loads, electromagnetic stresses, and runaway electrons. The leading-candidate DMS is shattered-pellet injection (SPI) of impurities, which is being tested experimentally on several tokamaks and will be used on ITER. Sophisticated, predictive models that have been well-validated against experiment are need to project the performance of these essential systems on future devices. We present an overview of the verification and validation of SPI simulations from three 3D, nonlinear, extended-MHD codes: M3D-C1, NIMROD, and JOREK. Each has been coupled to models for impurity ionization, radiation, and pellet ablation. First, we will look at verification benchmarks between the codes. M3D-C1 and NIMROD, both coupled to a time-dependent coronal impurity model, have found excellent agreement in 2D nonlinear simulations of core impurity deposition. JOREK simulations of the same found a twice-longer thermal quench due to the use of a coronal-equilibrium model, motivating the ongoing development of a more-sophisticated impurity model in JOREK. M3D-C1 and NIMROD have also been engaging in two 3D, nonlinear benchmarks, one with core impurity deposition and the other with an injected, ablating pellet. Initial results indicate good qualitative agreement but suggest that details of the initial non-axisymmetries can play an important role in the quantitative disruption dynamics. The conditions under which current spikes are found in each code during large MHD activity will be explored. Second, the use of several codes permits parallel efforts to validate against disruption-mitigation experiments worldwide. NIMROD modeling has found good qualitative agreement in trends with pellet composition in DIII-D. Furthermore, NIMROD has shown that reducing viscosity in these simulations decreases the damping and increases linear growth rates, shortening the thermal quench and modifying current-quench dynamics. M3D-C1 simulations with different pellet compositions have also found good qualitative agreement with NIMROD and DIII-D. Initial M3D-C1 and NIMROD simulations of JET and KSTAR will be explored as well, focusing on radiation asymmetries in JET plasmas with different stored energies. Finally, JOREK simulations of JET are also investigating the effect of pellet composition and aiming at validating with synthetic diagnostics (e.g. bolometry, interferometry, and magnetics).

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