Nonlinear NIMROD modeling of DIII-D QH-mode discharges with broadband-MHD turbulence§

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It is desirable to have an ITER H-mode regime that is quiescent to edge-localized modes (ELMs). ELMs deposit large, localized and impulsive heat loads that can damage the divertor. A quiescent regime with edge harmonic oscillations (EHO) or broadband MHD activity is observed in some DIII-D, JET, JT-60U, and ASDEX-U discharge scenarios [Garofalo et al, PoP (2015); Burrell et al., PoP (2012); Garofalo et al, NF (2011) and refs. within]. These ELM-free discharges have the pedestal-plasma confinement necessary for burning-plasma operation on ITER. The mode activity associated with the EHO or broadband MHD is characterized by small toroidal-mode numbers (n≈1-5) and is thus suitable for simulation with global MHD codes. The particle transport is enhanced during QH-mode, leading to essentially steady-state profiles in the pedestal region. Relative to QH-mode operation with EHO, operation with broadband MHD tends to occur at higher densities and lower rotation and thus may be more relevant to ITER. Nonlinear NIMROD simulations initialized from a reconstruction of a DIII-D QH-mode discharge with broadband MHD saturate into a turbulent state.

High quality equilibria are essential for extended-MHD modeling with initial-value codes such as NIMROD [Sovinec et al., JCP 195, 355 (2004); Sovinec and King, JCP 229, 5803 (2010)]. We include profiles outside the LCFS which generate associated currents when we solve the Grad-Shafranov equation with open-flux regions using the NIMEQ solver [Howell and Sovinec, CPC 185, 1415 (2014)]. The new solution is an equilibrium that closely resembles the original reconstruction (which does not contain open-flux currents). This regenerated equilibrium is consistent with the profiles that are measured by the high quality diagnostics on DIII-D.

Results from a nonlinear NIMROD simulation of DIII-D QH-mode shot 145098 at 4250ms with broadband MHD are presented. The measured toroidal and poloidal rotation profiles are included in the simulation as experimental observations indicate that the QH-mode operational regime is dependent on the rotation profile. The simulation develops into a saturated turbulent state and the n=1 and 2 modes become dominant through an inverse cascade. Each toroidal mode in the range of n=1-5 is dominant at a different time. The perturbations are advected and sheared apart in the counter-clockwise direction consistent with the direction of the poloidal flow inside the LCFS. Work towards validation through comparison to ECE, BES and Doppler reflectometry measurements is presented. Consistent with experimental observations during QH-mode, the simulated state leads to large particle transport relative to the thermal transport. A discussion of the transport assumptions built into our MHD modeling concludes that future QH-mode simulation studying the induced transport should run as a turbulence calculation where profiles are fixed and needs to include first-order FLR drift effects that stabilize high-n modes.

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