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Combined Magnetic and Kinetic Control of Advanced Tokamak Steady State Scenarios based on Semi-Empirical Modeling

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This paper deals with combined magnetic and kinetic control for advanced tokamak (AT) operation, using the ARTAEMIS model-based approach, a method that relies on two-time-scale semi-empirical system identification and near-optimal control theory. It is applied here to the control of AT scenarios on DIII-D, in which the safety factor profile and the normalized pressure parameter, betaN, play a crucial role in governing plasma confinement and stability. A control-oriented state space model was identified from simulated data obtained using a rapidly converging plasma transport code, METIS, that includes an MHD equilibrium and current diffusion solver, and combines plasma transport non-linearity with 0-D scaling laws and 1.5-D ordinary differential equations [J. F. Artaud, et al., Nucl. Fusion 50 (2010) 04300]. A number of open-loop simulations were performed, in which four independent heating and current drive (H&CD) sources were randomly modulated around the typical values of a reference AT discharge on DIII-D: on-axis co-current neutral beam injection (NBI) power, off-axis co-current NBI power, electron cyclotron current drive power with an off-axis current deposition, and plasma surface loop voltage. Using these simulated data, a two-time-scale model was obtained for the coupled evolution of the poloidal flux profile and betaN, from which the controller was synthesized. The paper discusses the results of closed-loop nonlinear simulations, using this controller for steady state AT operation. These simulations are predictive of what would happen if DIII-D were able to run longer pulses, or in steady state devices such as EAST or Tore Supra/WEST. They were run with various sets of target profiles and controller settings, and with perturbations of the actuator values and plasma parameters. With feedforward plus feedback control the steady state target profiles and betaN parameter are satisfactorily tracked despite large disturbances applied to the feedforward powers and other plasma parameters. The effectiveness of the ARTAEMIS algorithm to simultaneously control the plasma poloidal flux profile, safety factor profile and betaN in steady state, fully non-inductive AT discharges is thus demonstrated. Its robustness with respect to disturbances of the H&CD actuators and of plasma parameters such as the H-factor, plasma density and effective charge, is also shown.

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