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Model-Predictive Kinetic Control for Steady State Plasma Operation Scenarios on EAST

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Robust model-predictive control (MPC) algorithms based on extremely simple linear data-driven models have been recently developed for plasma kinetic control on EAST. This paper shows, for the first time, that MPC can be performed using a two-time-scale approximation, considering the kinetic plasma dynamics as a singular perturbation of a quasi-static magnetic equilibrium, which itself is governed by the flux diffusion equation. This technique takes advantage of the large ratio between the time scales involved in magnetic and kinetic transport, and is applied here to the simultaneous control of the safety factor profile, q(x), and of the poloidal beta parameter, beta_p, on EAST. MPC results in a much faster and more robust control than the so-called near-optimal control algorithms that were tested previously [D. Moreau, et al., Nucl. Fusion 55 (2015) 063011]. The models are state-space models identified with datasets obtained from fast nonlinear METIS simulations (METIS includes an MHD equilibrium and current diffusion solver, and combines 0-D scaling laws and ordinary differential equations). For a given operation scenario, the identified model is augmented with an output disturbance model, which is used to estimate the mismatch between measured and predicted outputs and ensures robustness to model uncertainties. An observer provides, in real time, an estimate of the system states and disturbances, and the controller predicts the behavior of the system over a prediction horizon, taking the actuator constraints into account. For plasma parameters typical of the high-beta_p steady state operation scenarios on EAST, nonlinear closed-loop simulations show that the desired q(x) profiles and beta_p can be obtained in about 2.5 s and 0.5 s, respectively, and with a monotonic approach to their target values. This is essential for avoiding MHD instabilities during the build up of the plasma equilibrium. In these control simulations, the actuators are the LHCD system at 4.6 GHz, the ICRH system, and optionally the plasma surface loop voltage. Various examples are shown, with negative shear or monotonic q-profiles, and with different beta_p target waveforms. The actuators adjust in order to reach the various beta_p targets while maintaining the q-profile in steady state, with the desired shape (or as close as possible if the q(x) and beta_p targets are not achievable).

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