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Model-Predictive Kinetic Control Experiments on EAST

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Kinetic plasma control based on extremely simple data-driven models and a two-time-scale approximation has been developed and validated on non-linear plasma simulations in recent years. Both in these models and in the associated control algorithms, the fast component (kinetic time scale) of the plasma dynamics is considered as a singular perturbation of a quasi-static magnetic and thermal equilibrium, which is governed by the flux diffusion equation (resistive time scale). Combined with classical optimal control theory, the effectiveness of this approach to simultaneously control the plasma *poloidal flux profile*, *ψ(x)*, and the normalized pressure parameter, *βN*, in non-inductive, high-*βN* discharges was demonstrated experimentally on the DIII-D tokamak [1]. Real-time control of the full *safety factor profile*, *q(x)*, and of the normalized plasma pressure is far more difficult. An advanced model-predictive control (MPC [2]) algorithm, also based on the two-time-scale approximation, was therefore developed in this aim. It was validated in closed loop nonlinear plasma transport simulations, which showed excellent performance [3]. Here, we report on *the first experiments using this new kinetic control algorithm in its simplest version to track time-dependent targets for the central safety factor, q0, and for the poloidal pressure parameter, βp* (Fig. 1a-1b-2a-2b). The experiments were performed in a steady state H-mode operation scenario on the EAST tokamak.

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It was already shown earlier on several tokamaks that the combination of extremely simple slow and fast plasma response models, identified in a given operation scenario either from experimental or simulated data [4], can satisfactorily approximate the coupled response of the plasma parameter profiles to relatively large random variations of the heating and current drive actuators. A dedicated system identification procedure has been developed and improved in recent years [3-4]. Here, the same procedure was applied to EAST experimental data in a typical H-mode scenario with electron cyclotron resonance heating (ECRH) and lower hybrid current drive (LHCD). When these experiments were performed, the only actuator available with enough real-time dynamics was the LHCD system at 4.6 GHz, with a coupled power between 1 MW and 2.5 MW. Additional LHCD power (0.5 MW) was injected at 2.45 GHz during the plasma current ramp-up, and 0.9 MW of ECRH power was injected during the 350 kA current flattop, from 2 gyrotrons at 140 GHz. The system identification data was obtained from two discharges, with chirping frequency and pseudo-random binary sequence modulations of the LHCD power, respectively. A linear state space model with 9 eigenmodes was found to reproduce satisfactorily the coupled evolution of the poloidal flux profile, *ψ(x, t)*, of the inverse of the safety factor profile, *i(x, t) = 1/q(x, t)*, and of the slow and fast components (*βp,slow* and *βp,fast*, respectively) of *βp*, with *βp(t) = βp,slow(t) + βp,fast(t)*.

The full paper will describe details of the model identification and of the MPC control algorithm including an observer estimation of the model mismatch, and discuss the results of the first control experiments performed on EAST with this algorithm. In the first discharge, the target *q0* was set at 2.4 from t = 2.7 s to t = 4.5 s and was raised to *q0* = 2.8 at t = 4.52 s (the control cycle time was 20 ms). The evolution of *q0* and the LHCD command are shown on Fig. 1a and Fig. 1b, respectively. The *q0* targets are reached in about 1 s. To cope with the nonlinear response of the LHCD actuator to the command, a proportional plus integral actuator control module was added in cascade with the MPC module. The effectively coupled LHCD power is also shown on Fig 1b (blue trace). In the second discharge, a piecewise linear βp target waveform with $1.6 < \beta p < 1.9$ was tracked. The evolution of βp was perfectly under control, as shown on Fig. 2a. The LHCD command and coupled power are shown on Fig. 2b.

Simultaneous control of the full *q(x)* profile and of βp (or any other kinetic variable or profile) was already achieved in non-linear simulations [3] and can now readily be tested experimentally with the algorithm implemented in the EAST plasma control system. For this task, more actuators will be used, such as the 2.45 GHz LHCD and the co-current and counter-current neutral beam injection systems, in addition to the 4.6 GHz LHCD system.

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