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Improved Reproducibility of Plasma Discharges via Physics-model-based q-profile Feedback Control in DIII-D

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Recent experiments on DIII-D demonstrate the potential of physics-model-based q-profile control to improve reproducibility of plasma discharges. A combined feedforward+feedback control scheme was employed to optimize the current ramp-up phase by consistently achieving target q profiles (Target 1: qmin=1.3, q95=4.4; Target 2: qmin=1.65, q95=5.0; Target 3: qmin=2.1, q95=6.2) at prescribed times during the plasma formation phase (Target 1: t=1.5s; Target 2: t=1.3s; Target 3: t=1.0s). At the core of the control scheme is a nonlinear, first-principles-driven, physics-based, control-oriented model of the plasma dynamics valid for low confinement (L-mode) scenarios. A partial-differential-equation model of the q-profile dynamics combines the poloidal magnetic flux diffusion equation with physics-based models of the electron density and temperature profiles, the plasma resistivity, and the noninductive current sources (auxiliary and bootstrap). Firstly, a nonlinear, constrained optimization algorithm to design feedforward actuator trajectories is developed with the objective of numerically complementing the traditional trial-and-error experimental effort of advanced scenario planning. The goal of the optimization algorithm is to design actuator trajectories that steer the plasma to the target q profile at a predefined time subject to the plasma dynamics and practical plasma state and actuator constraints, such as the minimum q value and the maximum available auxiliary heating and current-drive (H&CD) power. To prevent undesired L-H transitions, a constraint on the maximum allowable total auxiliary power is imposed in addition to the maximum powers for the individual H&CD actuators. Secondly, integrated feedback control algorithms are designed to keep the q-profile evolution on track by countering the effects of external plasma disturbances, thereby adding robustness to the control scheme. The H&CD system and the total plasma current are the actuators utilized by the feedback controllers to control the plasma dynamics. Experimental results are presented to demonstrate the effectiveness of the combined feedforward+feedback control scheme to consistently achieve the desired target profiles at the predefined times. These results also show how the addition of feedback control significantly improves upon the feedforward-only solution by reducing the matching error.

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