Optimal current profile control for enhanced repeatability of L-mode and H-mode discharges in DIII-D

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To collect meaningful experimental data, it is necessary to maintain consistent operating conditions in the tokamak plasma across repeated discharges. Presently, the desired plasma formation conditions, such as the shape of the plasma current profile, are achieved in a trial and error fashion, which can be a lengthy, wasteful process. In this work, model-based control techniques including optimal feedforward control and linearized feedback control are used to obtain a desired current profile at a specified time in low-confinement-mode (L-mode) as well as high-confinement-mode (H-mode) discharges. The evolution of the current profile is closely related to the evolution of the poloidal magnetic flux profile, which can be properly modeled in a first-principles manner by a nonlinear partial differential equation (PDE) referred to as the magnetic flux diffusion equation (MDE). Simplified, control-oriented formulations of the magnetic diffusion equation have already been developed for the DIII-D tokamak for both L-mode and H-mode discharges. In both cases, the control-oriented models combine the MDE with physics-based correlations for the electron temperature, plasma resistivity, and non-inductive current drive sources including neutral beam injection (NBI), electron cyclotron current drive (ECCD), and bootstrap current drive. With the use of these models, an open-loop control problem, i.e. an actuator trajectory optimization problem, is formulated to find a feasible path from the expected initial condition to the desired target. The result comprises a sequence of feedforward (open-loop) control requests and a corresponding state evolution from the initial condition to the desired target. On top of this optimal feedforward control sequence an optimal state feedback (closed-loop) controller based on a linearized model is added to track the desired state evolution. Experimental evidence of the effectiveness of the control approach in reaching the targets and facilitating repeatability between discharges is presented.

This work has been supported by the US Department of Energy under DE-SC0010661, DE-FC02-04ER54698.