Contribution ID: **110**

Type: **Poster**

ITR/P1-20: Integrated Magnetic and Kinetic Control of Advanced Tokamak Scenarios Based on Data-Driven Models

Tuesday, 9 October 2012 08:30 (4 hours)

The first real-time profile control experiments integrating magnetic and kinetic variables in tokamaks are described. Parameters such as the current, toroidal rotation and pressure profiles play a crucial role in governing plasma confinement and stability and their control is important for extrapolating advanced tokamak scenarios to future tokamaks. The integrated model-based approach presented here is being developed under the framework of the International Tokamak Physics Activity for Integrated Operation Scenarios and was initially explored on JET for current profile control. A generic method to identify device-specific, control-oriented models from experimental data was validated on JET, JT-60U and DIII-D. Such data-driven models were used to synthesize integrated magnetic and kinetic profile controllers with different levels of model integration. Closed-loop experiments were performed on DIII-D for the regulation of (a) the poloidal flux profile, psi(x), (b) the inverse of the safety factor profile, iota(x)=1/q(x), and (c) either the poloidal flux profile or the inverse of the safety factor profile together with the normalized pressure parameter, betaN. The neutral beam injection (NBI) and electron cyclotron current drive (ECCD) systems provided the heating and current drive sources for these experiments. Available beamlines and gyrotrons were grouped to form, together with the plasma surface loop voltage, Vext, or current, Ip, five independent heating and current drive actuators: (a) co-current NBI power, PCO, (b) counter-current NBI power, PCNT, (c) balanced NBI power, PBAL, (d) total ECCD power from all gyrotrons in an off-axis current drive configuration, PEC, and (e) Vext or Ip. Control of iota(x) or psi(x) and simultaneous control of iota(x) or psi(x) together with betaN were performed through a mixed-sensitivity robust control algorithm and a near-optimal proportional-plus-integral control algorithm, respectively. With the same approach, closed-loop control simulations have been performed for ITER. The nonlinear burning plasma evolution and closed-loop response to the specific ITER actuators under the controller action are modelled. Results for various control configurations and targets are discussed. Work supported by the US DOE under DE-FG02-09ER55064, DE-FG02-92ER54141, and DE-FC02-04ER54698, and by the European Fusion Development Agreement.

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Collaboration (if applicable, e.g., International Tokamak Physics Activities)

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Session Classification: Poster: P1

Track Classification: ITR - ITER Activities