Contribution ID: **371** Type: **Poster**

Feedback Control Design for Non-inductively Sustained Scenarios in NSTX-U Using TRANSP

Wednesday, 19 October 2016 14:00 (4h 45m)

Spherical torus based designs for fusion nuclear science facilities [1] and pilot plants [2] have little to no room for a central solenoid, and require the plasma current to be generated non-inductively. Recently completed upgrades to NSTX-U will enable the study of non-inductive scenarios, including start-up, ramp-up, and flat-top current sustainment. This paper examines active control of such scenarios using TRANSP simulations. TRANSP is a time-dependent integrated modeling code for prediction and interpretive analysis of tokamak experimental data. Its predictive mode has been used for scenario development on NSTX-U, including fully non-inductive scenarios [3], and exploration of approaches to non-inductive ramp-up [4]. Recently, the ability to include feedback control algorithms in TRANSP has been developed [5]. The actuators considered for control in this work are the six neutral beam sources and the plasma boundary shape. The neutral beam sources allow the current drive deposition and heating to be tailored in real-time. The primary plasma boundary shape parameter that is considered is the mid-plane outer gap. Increasing this gap leads to increased bootstrap current and moves the neutral beam deposition off axis, tending to increase the central safety factor. To understand the response of the plasma current, stored energy, and central safety factor to these actuators and to enable systematic design of control algorithms, simulations were run in which the actuators were modulated and a linearized dynamic response model was generated. The simplified model was used to design several PID control laws using different combinations of actuators and measurements. Closed loop simulations show that modest changes in the outer gap and heating power can improve the response time of the system, reject perturbations, and track target values of the controlled values. Strong coupling between the controlled quantities is observed, making multi-variable control design an important next step.

Work supported by US Department of Energy Contract No. DE-AC02-09CH11466.

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Paper Number

EX/P4-43

Country or International Organization

United States of America

Primary author: Dr BOYER, Mark (Princeton Plasma Physics Laboratory)

Co-authors: Dr GATES, David (PPPL); Dr POLI, Francesca (PPPL); Dr MENARD, Jonathan (Princeton Plasma Physics Laboratory); Dr ANDRE, Robert (Princeton Plasma Physics Laboratory); Dr GERHARDT, Stefan (Princeton

Plasma Physics Laboratory)

Presenter: Dr BOYER, Mark (Princeton Plasma Physics Laboratory)

Session Classification: Poster 4

Track Classification: EXW - Magnetic Confinement Experiments: Wave–plasma interactions; current drive; heating; energetic particles