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Dynamic Neutral Beam Injection as a Mechanism for Plasma Control and an Actuator for Instability Drive

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A novel capability has been added to the DIII-D neutral beam injection system, enabling in-shot variation of beam energy and current for the first time [1]. This new capability is now being explored as a tool for integrated control and optimization of equilibrium profiles and Alfvén eigenmode (AE) activity. The capability provides an alternative to the typically used pulse-width-modulation approach to controlling beam injection, and enables continuous variation of torque in the zero-torque regime. The capability also enables optimizing current drive and heating by injecting at lower energy during current ramp and at higher energy later in discharges. The first feedback algorithm making use of the new actuation approach has been experimentally tested, demonstrating stored energy and rotation control while addressing many of the challenges specific to using beam energy and current variation as an actuator. These challenges include constraints on the magnitude of beam voltage and current, slew rate limits on voltage changes, and lag between requested and achieve beam parameters. A real-time optimization-based control algorithm was developed that determines the voltage, current, and duty cycle required at steady state to maintain the optimal stored energy and rotation values, while accounting for the limits on voltage and current. The algorithm compensates the slow response of the voltage through fast adjustments of the current to more quickly track the required power and torque. The power and torque requests are augmented with a feedback term to improve energy and rotation target tracking. In a related experiment, a real-time ECE signal was used to detect AE mode activity and vary the NBI power through beam modulation based on feedback on the mode amplitude. This demonstration of AE mode control also showed that the ratio of the measured neutron rate to the classical predicted value, an indication of the effect of the AE mode on fast ion confinement, was changed through the variation of AE mode amplitude. The results of these two experiments motivate further development to integrate the new actuation and feedback approaches to control equilibrium parameters, including rotation and q, along with AE mode activity.

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[1] J. Rauch et al., Fusion Science and Technology 72, 3, (2017)

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