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EX/P2-01: Access and Sustained High Performance in Advanced Inductive Discharges with ITER-Relevant Low Torque

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Recent experiments on DIII-D have demonstrated that advanced inductive discharges with high normalized fusion gain approaching levels consistent with ITER Q=10 operation can be accessed and sustained with very low amounts (˜1 Nm) of externally driven torque. This level of torque is anticipated to drive a similar amount of rotation as the beams on ITER, via simple consideration of the scaling of the moment of inertia and confinement time. These discharges have achieved beta_N˜3.1 with H_98˜1 at q_95˜4, and have been sustained for the maximum duration of the counter neutral beams (NBs). In addition, plasmas using zero net neutral beam torque from the startup all the way through to the high beta phase have also been created. Advanced inductive discharges are found to become increasingly susceptible to 2/1 neoclassical tearing modes as the torque is decreased, which if left unmitigated, generally slow and lock, terminating the high performance phase of the discharge. Access is not notably different whether one ramps the torque down at high beta_N, or ramps the beta_N up at low torque. The use of electron cyclotron heating (ECH) has proven to be an effective method of avoiding such modes, allowing stable operation at high beta and low torque, a portion of phase space that has otherwise been inaccessible. In many cases, the ECH has been aimed to drive current near the q=2 surface, although this does not appear to be a critical element in order to gain the benefits of the ECH. Indeed, high beta_N˜3 discharges at low torque have been sustained using ECH without current drive, and deposited significantly inside of the q=2 surface. The insensitivity to the deposition position, together with the lack of need for current drive, suggests that the EC assists stability in a different way than the simply replacing the bootstrap current caused by the flattening of the pressure profile in the island. These advanced inductive discharges are measured to have significant levels of intrinsic torque at the edge, consistent with a previously determined empirical scaling considering the role of the turbulent Reynolds stress and thermal ion orbit loss.
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