Investigating Steady-State Operating Scenarios on DIII-D Using Flexible Current Drive Actuators

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Steady-state scenario plasmas with very different current profiles have been investigated for their stability, confinement, and noninductive current drive potential at high β_N using new off-axis neutral beam injection (NBI). At one extreme, very broad current profiles characterized by low internal inductance ℓ_i=0.5–0.65 and minimum safety factor q_{min}≈2.1 at r/a≈0.6 were produced using all available off-axis NBI and electron cyclotron current drive (ECCD) power and a B-field ramp. These achieved β_N≈4 transiently with good H-mode level global confinement, but they were unstable to resistive wall modes at ℓ_i<0.6. Without a B-ramp to maximize the current profile broadness, discharges with q_{min}=2.1–2.4 at r/a=0-0.4 had poorer global energy confinement (H_{89}<2) due to apparent enhanced fast ion transport. At the opposite extreme, very peaked current profiles with ℓ_i≈1.5–1.75 and q_{min}≈1 were produced using strong on- or near-axis NBI and ECCD injection. These achieved β_N=5.3 with excellent confinement, but the first ELM usually triggered an n=1 tearing mode or fishbone mode that reduced β_N and ℓ_i. Current profiles in between these extremes have shown potential for steady-state operation in ITER or other near-term devices with β_N in the range of 3–4.5. With ℓ_i=0.73 and q_{min}≈1.5, the predicted ideal-wall kink mode β_N limit is between 4 and 5. This scenario has been shown to be stable to tearing modes for at least two current profile relaxation time scales at β_N=3.5 and ~75% noninductive fraction (Fig. 1). By mapping the landscape of possible current profiles a number of trends and trade offs are emerging that will impact future machines. These include identifying required heating and current drive upgrades for the Q=5 steady state mission on ITER, and design choices for "next step" devices, like the proposed Fusion Nuclear Science Facility in the US.

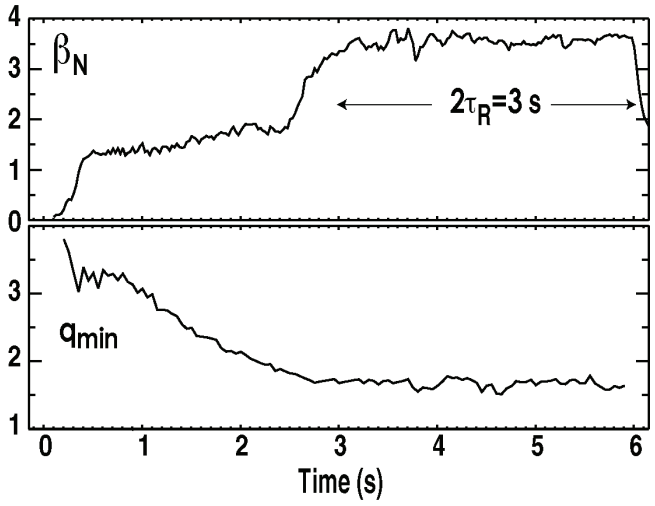

Fig. 1. Off-axis NBI helped sustain elevated q_{min} at β_N=3.5 to two resistive times until beam power was exhausted.

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