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PROBING RESISTIVE WALL MODE STABILITY USING OFF-AXIS NBI

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Probing Resistive Wall Mode Stability Using Off-axis NBI EX-S

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DIII-D experiments with off-axis neutral beam injection (NBI) yield evidence of modifications to resistive wall mode (RWM) stability. Measurements of the plasma response to slowly rotating, applied n=1 perturbations decrease in amplitude as the fractional mix of off-axis NBI power is increased at constant normalized beta. This reduction in the plasma response amplitude due to the off-axis injection is observed in repeatable plasmas over a range of plasma rotation values, and is correlated with increased pitch-alignment of the fast ion slowing-down distribution.

The impact of off-axis NBI on RWM stability is explored by reducing the level of off-axis NBI power to the minimum consistent with maintaining constant β_N. The toroidal plasma rotation is controlled by adjusting the amount of counter-I_p directed NBI power. In a typical discharge (Fig. 1), stepping the level of off-axis NBI power from 4.2 to 2.0 MW at constant β_N, l_i, and rotation coincides with a change in the radial field plasma response to an applied perturbation from $|\delta B^{plas,r}/I^{coil}| \cong 1.25$ to 2.0 G/kA, indicating a significant change in the RWM stability.

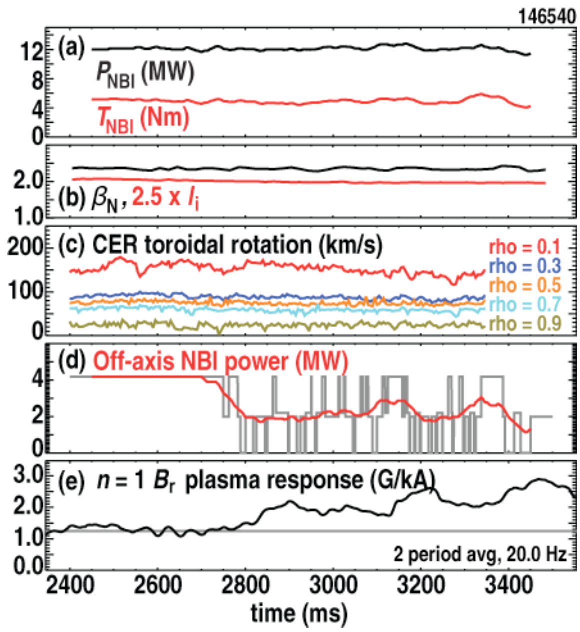

Fig 1. Evolution of RWM stability in response to modulated off-axis NBI power. The level of off-axis NBI power (d) is reduced at constant NBI power and torque (a), β_N, l_i (b), and carbon impurity rotation (c). An increase in the radial field plasma response amplitude (e) is observed coincident with the reduction in off-axis NBI power.

Present day tokamaks are able to operate above the ideal MHD no-wall beta-limit predicted for low-n external kink instabilities [1], and a theory incorporating kinetic modifications to the ideal MHD RWM dispersion relation [2] is consistent with the parametric dependencies of stability measurements in NSTX, DIII-D, and MAST [3–6]. The present theory features several mechanisms that lead to an exchange of energy between the RWM and kinetic particle populations, including resonances between trapped thermal ions and the bulk plasma rotation, a generic stabilizing influence of trapped energetic ions independent of plasma rotation, and damping due to passing ions near rational flux surfaces.

The response of a stable plasma to applied long-wavelength magnetic perturbations is a key measurement for assessing the proximity to marginal RWM stability, and provides for a direct comparison with theory [7]. Recent experiments exploited the new off-axis NBI capability on DIII-D to investigate the impact of changing the fractional off-axis NBI power on RWM stability, while maintaining conditions under which changes in proximity to the predicted ideal MHD stability limits are minimized. A 20 Hz, toroidally rotating n=1 perturbation is applied using the DIII-D in-vessel coils in high-confinement mode plasmas with constant β_N=2.2 and internal inductance l_i=0.8. The magnetic plasma response δB^{plas} is measured at the DIII-D wall using toroidally distributed arrays of pickup loops. The toroidal field and plasma current directions are chosen so that the resulting magnetic field line pitch is closely aligned with the trajectories of the off-axis beam neutrals. Transport simulations based on reconstructions of the experimental equilibria show increased pitch-alignment of the fast ion slowing-down distribution and a decreased trapped particle fraction as the off-axis NBI power is increased.

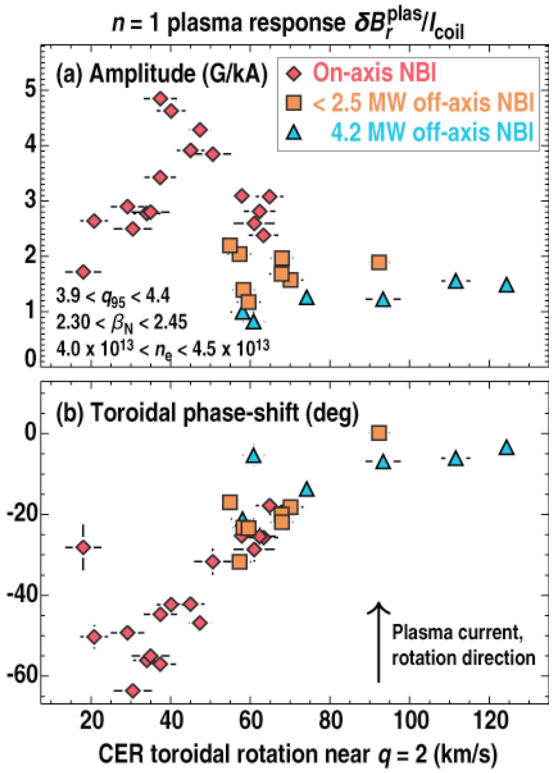

Fig 2. Comparison of the rotation dependence of the n=1 amplitude (a) and toroidal phase-shift (b) of the radial field plasma response to 20 Hz perturbations in plasmas with varying levels of off-axis NBI power.

A comparison of the rotation dependence of $\delta B^{plas,r}$ for varying levels of off-axis NBI power in similar plasmas demonstrates the increased RWM damping associated with off-axis NBI over a range in plasma rotation (Fig. 2). The fall-off in the amplitude of $\delta B^{plas,r}$ from the peak near 40 km/s is attributed to increased damping due to resonances with the precession drift frequency of trapped ions at low rotation, and harmonics of the bounce frequency of trapped ions at high rotation [4].

The observed increase in RWM damping due to off-axis NBI provides a new test for passive stability models needed to predict performance limits in ITER and future burning plasma devices. Preliminary analysis indicates that increased off-axis NBI power leads to modifications of the fast ion distribution function and may result in increased kinetic damping of the RWM.

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