Stabilization of Neoclassical Tearing Modes in Tokamaks by RF Current Drive

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Resistive neoclassical tearing modes (NTMs) will be the principal limit on stability and performance in the ITER standard scenario as the resulting islands break up the magnetic surfaces that confine the plasma. Drag from rotating island-induced eddy current in the resistive wall can also slow the plasma rotation, produce locking to the wall, and cause loss of high confinement H-mode and disruption. The NTMs are maintained by helical perturbations to the pressure-gradient driven "bootstrap" current. Thus this is a high beta instability even at the modest beta for ITER. A major line of research on NTM stabilization is the use of rf current drive at the island rational surface. While large, broad current drive from lower hybrid waves (LHCD) has been shown to be stabilizing (COMPASS-D), most research is directed to small, narrow current drive from electron cyclotron waves (ECCD); ECCD stabilization and/or preemptive prevention is successful in ASDEX Upgrade, DIII-D and JT-60U, for example, with as little as a few percent of the total plasma current if the ECCD is kept sufficiently narrow so that the peak off-axis ECCD is comparable to the local bootstrap current.

NTM island control in ITER is predicted to be challenging both because of the relatively narrower marginal island widths and the relatively broader electron cyclotron current drive. Experiments in ASDEX Upgrade, DIII-D, JET, and JT-60U with either beta ramp down without ECCD, or at constant beta with ECCD, show that the marginal island width for NTM stabilization is about twice the ion banana width [1]. This is only 1~2 cm in ITER and is much less than the 5~6 cm width 2/1 island that is expected to wall lock with the low rotation in ITER [1,2]. Locking sets a practical limit to which control must be successful.

Most rf experimental work to date uses narrow, cw ECCD; the relatively wide ECCD in ITER will be less effective if cw; the stabilization on the island O-point will be nearly cancelled by the destabilization on the X-point if the ECCD is broad. However, modulating the ECCD to be absorbed only on the rotating island O-point is proving successful in recovering the effectiveness in ASDEX Upgrade when the ECCD is configured for wider deposition. A recent change in the ECCD launcher scheme in ITER from "remote" to "front" steering has narrowed the expected ECCD considerably, making the stabilization-- with or without modulation-- much more certain [2]. Improved understanding of both NTM physics and rf current drive stabilization strategies (width, alignment, cw or modulation) builds confidence that the available EC power will be adequate for the task in ITER.

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[1] R.J. La Haye, et al., "Cross-machine Benchmarking for ITER of Neoclassical Tearing Mode Stabilization by Electron Cyclotron Current Drive," Nucl. Fusion **46**, 451 (2006).

[2] R.J. La Haye, et al., "Evaluating Electron Cyclotron Current Drive Stabilization of Neoclassical Tearing Modes in ITER: Implications of Experiments in ASDEX Upgrade, DIII-D, JET and JT-60U," Proc. 21st IAEA Fusion Energy Conference, Chengdu, China, 2006, Paper EX/P8-12.