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Prospects for Stabilization of Neoclassical Tearing Modes by Electron Cyclotron Current Drive in ITER **IT**

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Analysis of experiments worldwide indicates that the system planned for electron cyclotron current drive (ECCD) in ITER can mitigate the deleterious effects of neoclassical tearing modes (NTMs) provided that: either adequate alignment of the ECCD to the rational surface is maintained, or a misalignment is corrected on a time scale shorter than the plasma response to “large” islands. Resistive NTMs maintained by helical perturbations to the pressure-gradient driven “bootstrap” current will be the principal limit on stability and performance in the ITER standard scenario. A major line of research on NTM stabilization is the use of ECCD localized at the island rational surface. ECCD stabilization and/or preemption of NTMs is successful in ASDEX Upgrade, DIII-D and JT-60U, for example, with driven current as little as a few percent of the total plasma current if the ECCD current density is: (1) radially well-aligned to the island or rational surface, (2) comparable to the local bootstrap current density, and (3) either sufficiently narrow with respect to the marginal island width, or modulated on the island O-point if substantially wider.

NTM island control in ITER with ECCD 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 show that the marginal island width for NTM stabilization is about twice the ion banana width [1] which is only 1 to 2 cm in ITER. A change in the ECCD launcher scheme in ITER from “remote” to “front” steering has narrowed the expected ECCD considerably [2]. Evaluation of the required EC power for either the m/n=3/2 or 2/1 modes in ITER, assuming perfect alignment of the peak ECCD on the rational surface in question, indicates that the proposed 20 MW of ECCD is adequate. However, the narrower ECCD makes accurate alignment more critical.

Most experimental work to date uses narrow, continuous wave (cw) ECCD. In ITER cw ECCD may be less effective because the ECCD deposition width is still relatively broad and the stabilization effect of replacing the “missing” bootstrap current in the island O-point will be more nearly canceled by the destabilization on the X-point. However, modulating the ECCD so that it is absorbed only on the m/n=3/2 rotating island O-point is proving successful in recovering effectiveness in ASDEX Upgrade when the ECCD is configured for wider deposition [3]. Preliminary work in DIII-D directing the broader ECCD at the m/n=2/1 mode suggests that cw and modulated control are equally effective because the cw ECCD also makes classical tearing more stable; more experiments are planned.

Various techniques are used to achieve alignment. ASDEX Upgrade has used a feed-forward sweep of the toroidal field to get ECCD alignment on the island [3]. Improved methods of real-time alignment are planned. JT-60U has used feed-forward sweeps of the launching mirror to get alignment of the ECCD on the island. This was followed by real-time adjustment of the mirror using the electron cyclotron emission (ECE) diagnostic to locate the island rational surface [4]. Preemptive avoidance of the m/n=3/2 mode has also been demonstrated by repeating with fixed alignment at the best condition for removing the mode.

In DIII-D, ECCD alignment techniques have used real-time equilibrium reconstructions with measurements of the magnetic field pitch to accurately locate the rational surface and to correct the current-drive location for refraction. The latter method allowed, DIII-D to run higher stable beta without any occurrence of either a 3/2 or a 2/1 mode [5].

Avoiding wall-locking with loss of H-mode and subsequent disruption sets a practical limit on m/n=2/1 island width for successful control. It is expected that wall-locking will occur at about 5 cm island width owing to the low rotation in ITER [1]. This places strict requirements on ECCD alignment with the expected ECCD effectiveness of 5 MW peak power dropping to zero (at a 10-cm island width) for misalignments as small as 1.7 cm for cw (Fig. 1) and 2.5 cm for modulation (Fig. 2). The system response time for islands transiently exceeding the critical value for locking will also be provided for the plasma system controller to be developed; modeling for ITER based on DIII-D mode locking predicts that an m/n=2/1 island 50% larger than critical (w=7.5 cm) would take "only" a few seconds to lock in ITER. An alignment resolution error of no more than 1 cm and realignment rate of at least 1 cm/s are required. Thus with the 20 MW available injected power and narrower ECCD from front steering, and good control of alignment, ITER should be able to manage potentially deleterious m/n=2/1 NTMs, with power to spare for other modes such as m/n=3/2.

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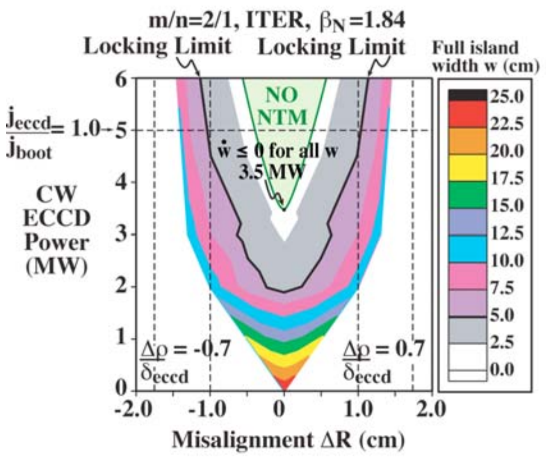

Fig. 1. Necessary cw power larger with increasing misalignment. Too large misalignment and "large" m/n=2/1 NTM locks.

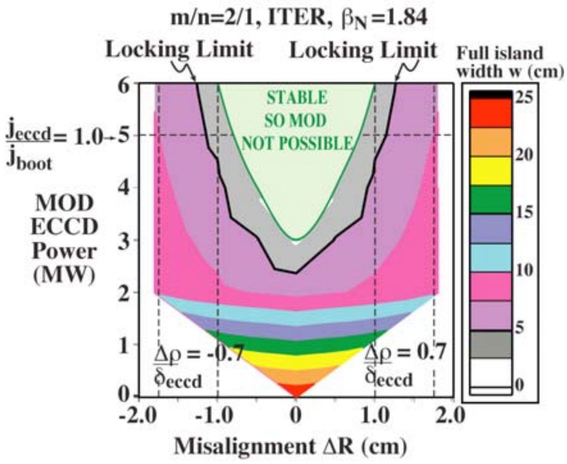

Fig. 2. Necessary modulated power slightly less sensitive to ΔR than cw.

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