GA–A25363

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APRIL 2006

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This is a preprint of a synopsis of a paper to be presented at the 21st IAEA Fusion Energy Conference, October 16-21, 2006, in Chengdu, China, and to be published in the *Proceedings.*

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Work supported by
the U.S. Department of Energy
under DE-FC02-04ER54698

GENERAL ATOMICS PROJECT 30200
APRIL 2006

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Prevention of the 2/1 Neoclassical Tearing Mode in DIII-D* EX-W

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The onset of the *m/n*=2/1 neoclassical tearing mode (NTM) has been prevented in DIII-D discharges at beta values up to the no-wall *n*=1 kink mode limit. Electron cyclotron current drive (ECCD) was applied pre-emptively at the *q*=2 surface, avoiding the onset of the instability. In the absence of the 2/1 NTM, beta was raised to values significantly larger than those where the mode would appear in the absence of ECCD. Maintaining alignment of the ECCD with the rational surface in the absence of the mode required the successful development of accurate real-time reconstruction of equilibria including measurements of the internal magnetic fields by the motional Stark effect diagnostic.

These experiments extend the operating space for “hybrid mode” discharges, in which a benign *m/n*=3/2 tearing mode contributes to limiting the central peaking of the current density profile. Previously the performance of such discharges with lower values of edge safety factor ($q_{95} \leq 4$) has been limited by the onset of a 2/1 NTM at $\beta_N \sim 2.7$, leading to strong degradation of confinement or to disruption [1]. In the present discharges, illustrated in Fig. 1, stabilization by ECCD allows stable operation at $\beta_N \approx 3.2$ with $q_{95} \approx 3.8$. (Here $\beta_N = \beta_T aB/I$ is the normalized beta, with B the magnetic field in Tesla, I the plasma current in MA, a the minor radius of the plasma in m, and $\beta_T = \langle P \rangle 2\mu_0/B^2$ the ratio of volume-averaged pressure to the magnetic pressure.)

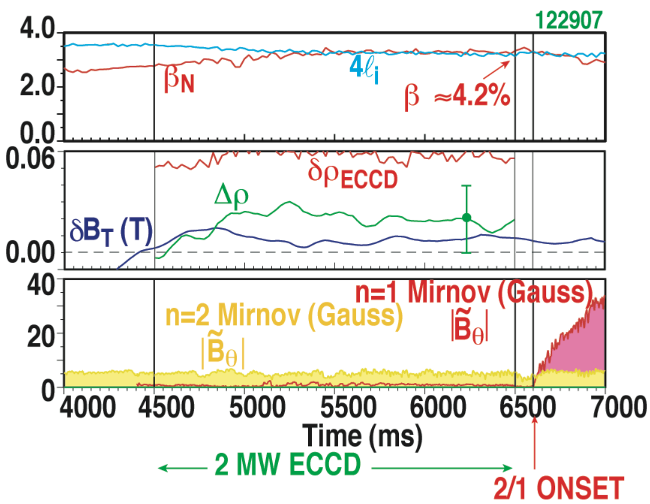

Fig. 1. Time evolution of a DIII-D hybrid discharge with preemptive stabilization of the 2/1 mode by ECCD. (a) Normalized beta (β_N) and estimated no-wall kink stability limit ($\beta_N \approx 4\,\ell_i$). (b) Full width half maximum of current drive layer ($\delta\rho_{ECCD}$) and difference ($\Delta\rho = \rho_{ECCD} - \rho_{21}$) between locations of the current drive layer and the *q*=2 surface, all in normalized minor radius ρ. Also shown is the change in toroidal field δB_T controlled by the plasma control system to maintain Δρ small. (c) Amplitudes of *n*=2 and *n*=1 tearing modes, measured at the outboard midplane wall.

*Work supported by the U.S. Department of Energy under DE-FC02-04ER54698 and W-7405-ENG-48.

An example of prevention of the 2/1 NTM is shown in Fig. 1. In this discharge, 2 MW of EC power at 110 GHz was applied at *t*=4500 ms, while beta was still rising [Fig. 1(a)]. The saturated *n*=2 mode that is characteristic of hybrid mode discharges appears earlier [Fig. 1(c)]. As beta continues to increase, the DIII-D plasma control system makes small adjustments to the toroidal field to maintain the current drive at the minor radius of the *q*=2 surface [Fig. 1(b)]. The difference between the minor radius of the current drive and the calculated *q*=2 radius was kept small compared to the radial width of the current drive layer. Good energy confinement was maintained, and normalized beta was sustained for more than one second at the no-wall kink stability limit of $\beta_T \approx 4.2\%$ and $\beta_N \approx 3.2$. (The estimate of the no-wall limit shown in Fig. 1 as $\beta_N \approx 4\ell_i$, with ℓ_i the internal inductance of the plasma, agrees with ideal stability calculations to within about 5%. Plasma rotation allows the vacuum vessel wall to stabilize the kink mode at or beyond the no-wall limit.) Finally, the ECCD is turned off at *t*=6500 ms, while beta is maintained at the same value. The onset of a 2/1 NTM about 100 ms later [Fig. 1(c)] shows that the presence of the ECCD was necessary for stability of the plasma.

Precise positioning of the current driven by ECCD is crucial to stabilization of the NTM. The effects of continuous co-ECCD at the rational q-surface are to increase the classical stability (that is, make Δ' more negative) and, if a magnetic island is present, to replace the loss of the pressure-driven bootstrap current within the island. Previous DIII-D experiments have demonstrated stabilization of a pre-existing 2/1 NTM, using feedback-controlled search techniques to find the current drive location that minimizes the mode amplitude [2]. In the present experiment, active tracking of the location of the *q*=2 surface allows the current drive to be maintained at the rational surface even in the absence of a detectable mode by controlling the toroidal field. The control algorithm is based on real-time equilibrium reconstructions using motional Stark effect data, allowing *q*-profile calculations that are updated every few ms [3]. A real-time correction of the ECCD location, taking account of refraction effects as the density varies, has recently been implemented and will be incorporated into the control of future experiments. This work provides a demonstration of potential improvement of the performance of ITER by control of neoclassical tearing modes.

[1] T.C. Luce, *et al.*, Phys. Plasmas **11**, 2627 (2004).
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