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ADVANCES TOWARD QH-MODE VIABILITY FOR ELM-FREE OPERATION IN ITER

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The application of static, non-axisymmetric, nonresonant magnetic fields (NRMFs) to high β DIII-D plasmas has allowed sustained operation with a quiescent H-mode (QH-mode) edge and zero-net both toroidal rotation and neutral beam injected torque. Previous studies have shown that QH-mode operation can be accessed only if sufficient radial shear in the plasma flow is produced near the plasma edge [1]. In past experiments, this flow shear was produced using neutral beam injection (NBI) to provide toroidal torque. In recent experiments, this torque was completely replaced by the torque from applied NRMFs [2]. These results open a path toward QH-mode utilization as an edge localized mode (ELM)-free H-mode in the self-heated burning plasma scenario, where toroidal momentum input from NBI may be small or absent.

Recent theoretical and experimental work has brought significant advances in the understanding of the interaction of static non-axisymmetric fields with a rotating high beta plasma. When a non-axisymmetric nonresonant magnetic field is applied to a near-stationary plasma, the toroidal rotation is accelerated toward a neoclassical “offset” rotation rate, which is in the direction opposite to the plasma current (counter-I_p) [3,4]. This magnetically driven torque provides a new knob to control the plasma rotation, and can be utilized to provide a counter-rotation profile that is suitable for QH-mode operation with no net NBI torque, as will likely be the case in a self-heating fusion reactor. Figure 1 shows a comparison of two similar QH-mode discharges with and without NRMF, where the NBI torque is slowly ramped towards zero from a large counter-I_p value. Both discharges have ITER-similar cross-section shape, reactor-relevant low pedestal collisionality, $\nu_\mathrm{e}^* \sim 0.1$, and monotonic safety-factor profile with $q \sim 1.1$ on axis. In the discharge without the NRMF, the quiescent regime is lost and ELMs appear below a counter-I_p NBI torque magnitude $|T_\mathrm{NBI}| \sim 2.5$ Nm. In contrast, in the discharge with NRMF applied, the ELM-free regime is maintained as the NBI torque is reduced down to $|T_\mathrm{NBI}| \sim 0$. Note that with the applied NRMF, a larger edge counter-rotation is obtained without NBI counter-torque. In addition, measurements indicate that the shear in the edge rotation driven by the radial electric field is the important quantity in maintaining the QH-mode edge.

The application of the NRMFs does not degrade the global energy confinement of the plasma. Conversely, it increases plasma resilience to locked modes and allows plasma operation

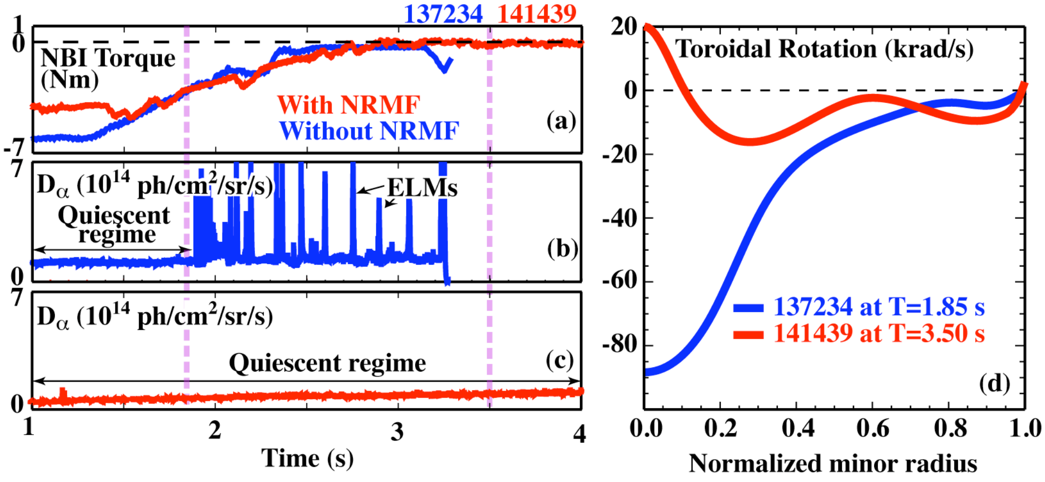

Fig. 1. Comparison of NBI torque rampdown discharges with an n=3 NRMF applied (red traces) and with no NRMF (blue traces). (a) NBI torque; (b,c) D_α light, showing QH-mode regime when bursting behavior (from ELMs) is absent; (d) radial profiles of the toroidal rotation at the time indicated by the vertical dashed line in (a-c).

at very low NBI torque and plasma rotation. According to theory, at this low rotation the NRMF torque is amplified by entering a regime where the radial electric field vanishes, leading to "superbanana" particles with enhanced radial fluxes, which in turn exert a larger toroidal torque on the plasma. Measurements of the dependence of this torque on the plasma velocity have shown that a peak in the torque exists at very low plasma rotation, as shown in Fig. 2, and that this peak is found to occur where the radial electric field is small, as predicted by theory [5]. Experimental results also show that surprisingly, the energy confinement quality increases at low plasma rotation. Furthermore, the beneficial effects of the applied NRMF are enhanced as the energy content of the plasma increases, likely because of plasma amplification of the applied NRMF. All these results project favorably toward the realization of an ELM-free "quiescent" self-heated burning plasmas in ITER, where the torque from NBI is expected to be small.

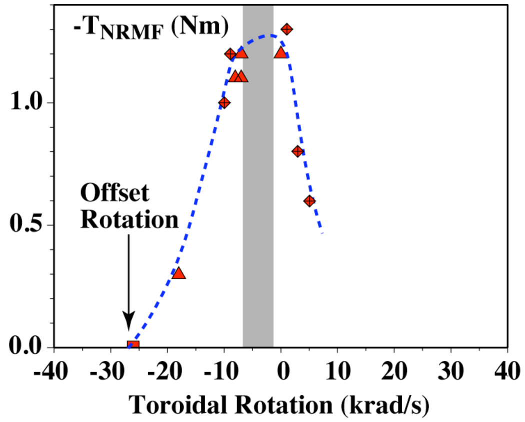

Fig. 2. Measurements of the counter-torque from non-axisymmetric nonresonant magnetic fields, as a function of plasma toroidal rotation rate. The location of the theoretically-predicted torque peak, indicated by the gray band, is in good agreement with the measurements.

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