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DEPENDENCE OF THE L- TO H-MODE POWER THRESHOLD ON TOROIDAL ROTATION AND THE LINK TO EDGE TURBULENCE DYNAMICS

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Dependence of the L- to H-mode Power Threshold on Toroidal Rotation and the Link to Edge Turbulence Dynamics EX-C

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The power flow required to induce a transition from L-mode to H-mode plasmas is found to depend strongly on the injected neutral beam torque and consequent toroidal plasma rotation. Edge turbulence, turbulence flows and flow shear, measured near the outboard midplane of the plasma (0.85 < *r/a* < 1.0) on DIII-D, likewise vary with rotation in a manner that can explain this rotation dependence [1]. The L-H power threshold in plasmas with the ion ∇B drift away from the X-point decreases from 4-6 MW with co-current beam injection, to 2-3 MW near zero net injected torque, and to <2 MW with counter injection, as shown in Fig. 1. Plasmas with the ion ∇B drift towards the X-point exhibit a qualitatively similar though less pronounced power threshold dependence on rotation. In related experiments, H-modes were induced via application of electron cyclotron heating (ECH) power to discharges with a 25% higher density than those shown in Fig. 1. The H-mode power threshold is found to be nearly the same for balanced neutral beam injection (NBI) and ECH-only discharges with the ion ∇B drift directed towards the X-point. At these higher densities, a larger difference in the power threshold is observed between plasmas with the ion ∇B drift towards and away from the X-point (ECH or NBI heating).

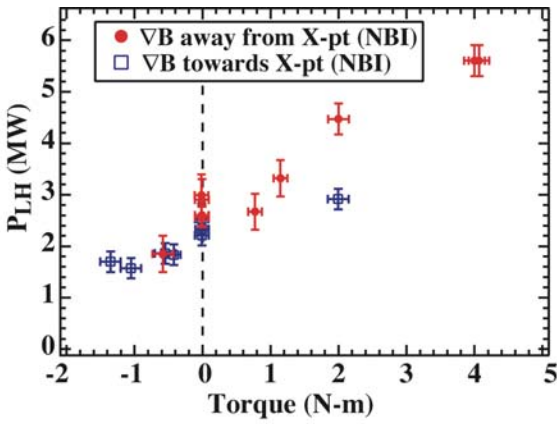

Fig. 1. L-H power threshold vs injected torque for neutral beam-heated discharges.

2D edge turbulence measurements, obtained with a high-sensitivity beam emission spectroscopy (BES) system, show an increasing poloidal flow shear as the L-H transition is approached in all conditions. As toroidal rotation is varied from co-current to balanced in L-mode plasmas, the edge turbulence changes from a uni-modal spectral character to a bi-modal structure, with the appearance of a low-frequency (*f* = 10-50 kHz) mode propagating in the electron diamagnetic direction, similar to what has been observed when the ion ∇B drift is directed towards the X-point in co-rotating plasmas [2]. As toroidal rotation is varied at constant injected power by varying the injected NBI torque from co-current to balanced, the density fluctuation spectra near the plasma edge are seen to gradually evolve from the uni-modal structure to the bi-modal character and ultimately reverse direction, as is seen in Fig. 2 that displays the power spectra [Fig. 2(a)] and the cross-phase [Fig. 2(b)] between two poloidally-adjacent BES channels. At low toroidal rotation, the poloidal turbulence flow near the edge reverses direction prior to the L-H transition. This generates a significant poloidal flow shear because radially inward locations do not reverse flow direction; the resulting flow shear rate then exceeds the measured turbulence decorrelation rate. This increased poloidal turbulence velocity shear may facilitate the L-H transition. No such reversal is observed in high toroidal rotation plasmas, though comparable poloidal velocity shear develops at higher injected power levels.

The edge radial electric fields demonstrate a consistent behavior, with larger E_r shear at lower injected power in balanced-injection plasmas, compared with highly co-current rotating plasmas. Here, the interplay of the pressure gradient and rotation terms in the ion force balance equation conspire to facilitate increased shear at lower rotation, while reducing edge shear at similar injected power in highly co-rotating discharges.

The measured zonal flow spectra evolve significantly during a torque scan at constant power. Zonal flows are manifest in the high frequency poloidal turbulence velocity spectrum measured using time-delay-estimation methods applied to poloidally displaced BES channels [3]. A transition from a coherent Geodesic Acoustic Mode (GAM) near 16 kHz to a higher-power, lower frequency zonal flow occurs as rotation varies from co-current to balanced, shown in Fig. 3. This change may also facilitate the L-H transition via increased turbulence shearing.

Simulations of these plasmas are being performed using the BOUT edge turbulence code, including the actual magnetic geometry and edge profiles. Predicted and measured characteristics of the turbulence and turbulence flows will be compared to discern how the various modes, zonal flows and radial electric fields interact.

Scaling relations for the LH power threshold do not presently include a rotational dependence, yet these results demonstrate that toroidal rotation is a critical parameter affecting the threshold. The mechanism for this effect appears to lie in the interplay of the radial electric field, turbulence flows, fluctuation spectral structure and the zonal flows. This reduced power threshold at lower toroidal rotation may benefit large low-rotation plasmas such as ITER.

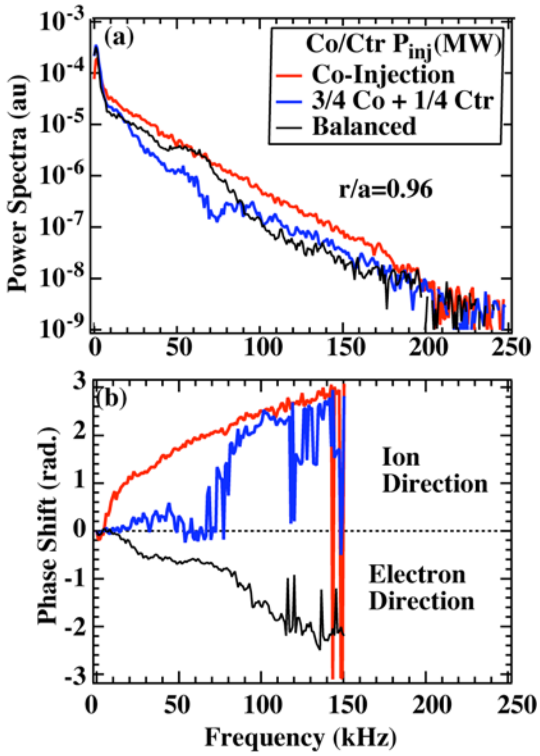

Fig. 2. Density fluctuation power spectra, and (b) poloidal cross-phase from BES at r/a=0.96 for all co-injected, partial co-injected, and balanced injection discharges (all at the same injected power).

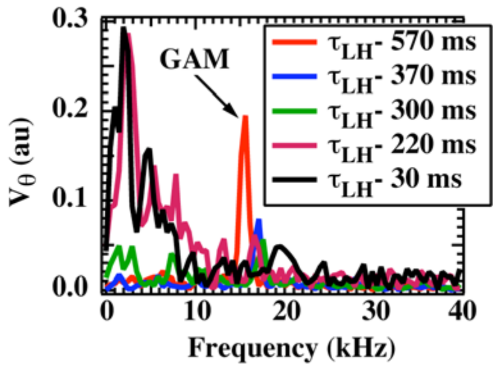

Fig. 3. Poloidal velocity spectrum evolves from a Geodesic Acoustic Mode (GAM) to zero-mean-frequency zonal flow structure as the LH transition is approached.

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