Reducing the L-H Transition Power Threshold in ITER-Similar-Shape DIII-D Hydrogen Plasmas

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Recent experiments in electron-heat-dominated, low-torque, ITER-similar-shape (ISS) hydrogen plasmas (q_{95} ~3.6) show that the L-H transition power threshold P_{LH} can be reduced substantially (~25-30%) with moderate Helium trace injection (helium ion fraction $n_{He}/n_H \leq$ 25% during the ensuing H-mode). Without mitigation, the power threshold was increased by a factor of ~3 compared to reference deuterium ISS plasmas due to the significant edge electron heat flux [$Q_e(\rho=0.95)/Q_i(\rho=0.95)$=1.2-2]. Hydrogen ISS plasmas with increased edge safety factor q_{95} ~5 exhibited a significantly lower power threshold, an observation not accounted for by the commonly used multi-machine threshold scaling [1] (a dependence of P_{LH} on q_{95} was observed in deuterium ISS plasmas only at mid-density [2]). In co-injected plasmas, P_{LH} increased with neutral beam torque as previously observed in DIII-D deuterium plasmas.

Techniques for reducing P_{LH} are very important for ITER, in particular for hydrogen plasma operations during the PFPO-1 campaign with marginal auxiliary heating (20-30 MW of ECH). We report here also new observations that P_{LH} can be effectively reduced at low ion edge collisionality via applied n=3 Non-Resonant Magnetic Perturbations (NRMF), producing local edge counter-current torque via the Neoclassical Toroidal Viscosity (NTV) at the plasma edge, consistent with linear plasma response simulations. CER measurements show a substantial increase in toroidal (Carbon) edge rotation shear with applied NTV before the L-H transition. Initial evidence indicates that $\boldsymbol{E}\times\boldsymbol{B}$ flow shear inside the LCFS increases due to increased radial shear in the $v_\phi B_\theta$ term in the radial ion momentum balance, reducing the L-H transition power threshold. These results contrast with the increased L-H power threshold observed with applied n=3 *Resonant* Magnetic Perturbations (RMP) in DIII-D, ascribed to edge stochastization due to island overlap, and reduced Reynolds stress [3,4].

Control of L-mode $\boldsymbol{E}\times\boldsymbol{B}$ shear via Helium seeding, or applied NRMF/NTV can open up a path for reducing P_{LH} in burning plasma experiments. For example, the ITER 3-D internal coil set can be used to generate large NTV in the edge plasma layer, favored by the relatively low collisionality expected in the ITER L-mode edge.

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