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Role of edge resonant magnetic field penetration in ELM suppression and density pump-out in the DIII-D tokamak

Q.M. Hu[1], R. Nazikian[1], B. Grierson[1], N.C. Logan[1], J.-K. Park[1], C. Paz-Soldan[2], and Q. Yu[3]

[1] Princeton Plasma Physics Laboratory, [2] General Atomics, [3] Max-Planck-Institut für Plasmaphysik

e-mail (speaker): qhu@pppl.gov

Nonlinear two-fluid MHD simulations by TM1 code reveal the role of resonant field penetration in ELM suppression and density pump-out in low-collisionality ITER-Similar-Shape (ISS) plasmas in the DIII-D tokamak. TM1 takes the measured kinetic profiles, equilibrium, transport coefficients and neoclassical resistivity from DIII-D before the resonant magnetic perturbation (RMP) is applied. TM1 uses the helical magnetic field boundary condition calculated by the toroidal ideal MHD code GPEC. Based on these inputs, TM1 predicts the RMP amplitude required for a bifurcation from screening to penetration of resonant fields at the pedestal top, and also calculates the reduction in the pedestal height and width due to collisional transport across these islands by solving the motion equation, particle and thermal energy transport. The observed density pump-out is reproduced from the MHD simulations for the penetration of resonant fields in the resistive foot of the pedestal [1]. The TM1 simulations quantitatively explain the required plasma density, rotation and RMP amplitude for the ELMs suppression by n = 2 RMPs due to the formation of magnetic islands at the top of the pedestal [2]. These MHD simulations reveal strong screening of resonant fields in the steep gradient region of the pedestal between the top and the foot of the pedestal, consistent with the preservation of the edge electron thermal barrier (ETB) during pump-out and ELM suppression as shown in Fig. 1.

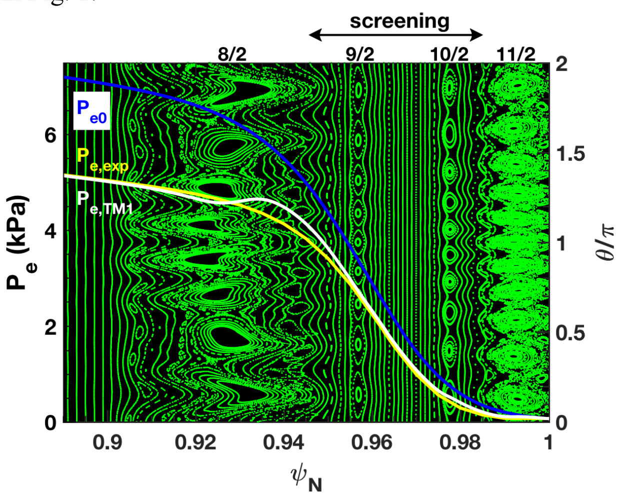

Fig. 1. Poincaré plot of the poloidal flux surfaces during pedestal-top and pedestal-foot resonant field penetration overlaid with the electron pressure from experiment (yellow) and TM1 simulation (white), the initial pressure profile is shown in blue.

The long-standing mystery of the q_{95} width of ELM suppression windows is effectively resolved based on the simulations of resonant field penetration at the pedestal top [3]. The TM1 simulations successfully predict that narrow magnetic islands form when resonant field penetration occurs at the top of pedestal, and these islands are easily screened when q_{95} moves off resonance, leading to very narrow windows of ELM suppression (typically Δq_{95}~0.1 as shown in Fig. 2a). The simulations predict that wide q_{95} windows of ELM suppression can be achieved at substantially higher pedestal pressure with less confinement degradation in DIII-D by operating at higher toroidal mode number (n = 4) RMPs as shown in Fig. 2b. This can have significant implications for the operation of the ITER ELM control coils for maintaining high confinement during ELM suppression.

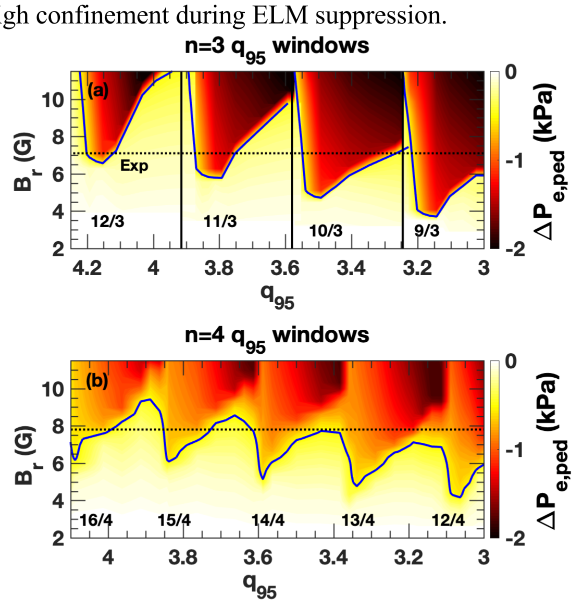

Fig. 2. TM1 simulated q_{95} windows of ELM suppression by (a) n = 3 and (b) n = 4 RMP in DIII-D presented by the reduction in the pedestal pressure versus RMP strength and q_{95}.

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Reference

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[2] Hu Q. M., *et al.*, Nucl. Fusion **60**, 076001 (2020).
[3] Hu Q.M., et al., Wide Operational Windows of Edge-Localized Mode Suppression by Resonant Magnetic Perturbations in the DIII-D Tokamak. Phys. Rev. Lett. **accepted** (2020).