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Role of edge neutrals in the low-recycling regime in achieving steady state flat temperature profiles and exciting tearing mode activity in LTX-β

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Achieving flat temperature profile in the low-recycling operation regime with lithium coated walls could be a game changer for future fusion reactors. Flat temperature profiles can eliminate temperature gradient driven instabilities and thereby increase confinement. Thus, higher confinement and bigger plasma volume for fusion to occur will be available for future fusion reactors to reduce size/cost significantly. Also, lithium walls and high edge temperatures may significantly reduce peak power flow to the divertor. Such operating regimes can offer an attractive core-edge integration solution for the future fusion reactors.

The Lithium Tokamak Experiment-Beta (LTX-β) is the first and the only tokamak in the world to demonstrate a flat radial electron temperature profile ($T_e(r)$; i.e. the core T_e is similar to the scrape off layer T_e). A transient flat $T_e(r)$ is obtained routinely in LTX-β, with a lithium coated, low-recycling first wall once the external neutral gas source is stopped [1]. In the present experiment [2], flat $T_e(r)$ is demonstrated for the first time in steady state while maintaining a moderate and constant density, n_e^{ave} ($n_e^{ave} \leq 10^{19}$ m^{-3}). If the discharge is fueled above this threshold ($n_e^{ave}{}_{th} \sim 10^{19}$ m^{-3}), $T_e(r)$ shifts from flat to peaked and a tearing mode (TM) is destabilized. Fig. 1 shows the density scan where the TM (refer magnetic spectrograms) is stabilized as the n_e^{ave} is decreased below 10^{19} m^{-3}. Low recycling enables precise control of n_e^{ave} by external fueling. Hence, a threshold of the edge neutral inventory from the external fueling, required to excite the TMs, is experimentally manifested through $n_e^{ave}{}_{th}$. The goal of this work is to investigate the role of edge neutrals in determining $T_e(r)$ and MHD stability in the unique low-recycling regime of LTX-β. Our hypothesis is that the peaking of $T_e(r)$ beyond $n_e^{ave}{}_{th}$ is due to the edge cooling by the cold neutrals beyond a critical fueling flux. At lower fueling flux, flat $T_e(r)$ results in broader pressure profile and lower resistivity (η), which in turn stabilizes the TM. This hypothesis is supported by edge neutral density estimation by DEGAS 2 code. Mode analysis by singular value decomposition confirms the TM structure to be $m/n = 2/1$. Linear tearing stability analysis with M3D-C1 predicts that plasmas with $n_e^{ave} > 10^{19}$ m^{-3} are highly susceptible to a $n = 1$ TM. M3D-C1 scans for η, q profile and pressure profile also confirm that a flatter $T_e(r)$ will provide a flatter pressure profile and/or a lower η at the mode rational surface, thus stabilizing the TM. ORBIT simulations, however, confirmed that the TMs do not affect the fast ions loss from NBI. This study shows for the first time that the edge neutral inventory could be one of the deciding factors for achieving the unique operation regime of flat $T_e(r)$ and the excitation of TM that could be disruptive for the plasmas.

References

[1] D Boyle et al., Nucl. Fusion **63** (2023) 056020

[2] S. Banerjee et al., Nucl. Fusion **64** (2024) 046026

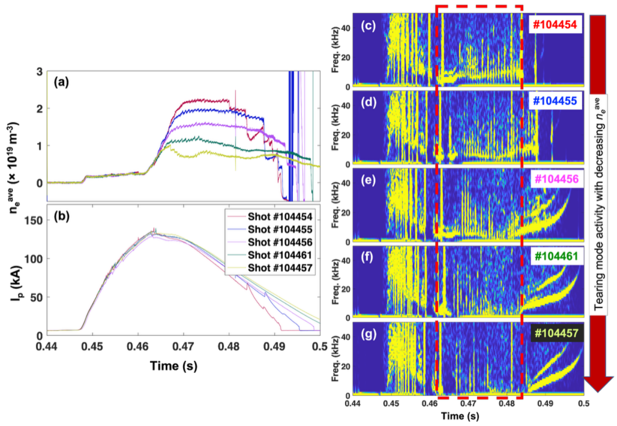

Figure 1: (a): line averaged density n_e^{ave} scan for studying the TM evolution and threshold; (b) corresponding I_p evolution for the representative shots; (c)-(g): magnetic spectrograms for the different density cases show that the TM ceases once n_e^{ave} goes below 10^{19} m^{-3}. The red broken rectangle shows the relevant portion of the discharge evolution just after the completion of I_p and n_e^{ave} ramp-up and up to the n_e^{ave} ramp-down or disruption.