Small/Grassy ELM dynamics and its impact on the SOL width scaling

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The pulsed heat load due to large ELMs is an existential problem for future devices of ITER size and FPPs because that load would produce unacceptable damage to the divertor plates. Simultaneous control of large ELMs and resulting high divertor heat loads in H-mode plasma is crucial for steady-state operation of a tokamak fusion reactor. The BOUT++ simulations for small ELMs show the SOL turbulence thermal diffusivity increases due to larger turbulent fluxes ejected from the pedestal into the SOL, leading to the SOL width broadening[1, 2]. Recent experiments, from AUG, DIII-D, EAST, JET-ILW, and TCV, show that small ELM regimes with quasi-continuous exhaust are a promising regime for a reactor with good energy confinement and significant broadening of divertor heat flux profile[3]. However, the identity of the control parameters to access small ELMs regime is still a key physics question.

Over the past decades, great efforts have been made on ELM mitigation with different active control methods. The research found that the pedestal electron collisionality is an important parameter that influences the ELM regime. Small ELMs have been achieved on different machines with different separartrix density and collisinality. Recent EAST experiments show for the first time that the small/grassy ELM regime can be achieved via controlling the pedestal density profiles by changing striking point from vertical to horizontal target plates on the new lower tungsten divertor[4]. The merely changes of the striking point position leads to significantly flattening pedestal density profiles, increased ELM frequencies and reduced ELM amplitudes. This discovery provides an alternative knob for ELM control and demonstrates that a low pedestal density gradient is a key for access to small-ELM regimes and a wide pedestal can lead to an ELM suppression. Therefore, it is very important to understand the underlying physics how pedestal density gradient and collisonality effect on ELMs dynamics and provide control knobs for the access to small ELM regime for ITER with low pedestal collisionality, low pedestal density gradient and high separatrix collisionality.

To investigate the impact of the pedestal density gradient and collisionality on the ELMs dynamics, BOUT++ turbulence simulations are conducted to capture the underlying physics of the small ELM characteristics and their impact on the SOL width scaling for EAST experimental discharges. As the separatrix density increases, pedestal density gradient decreases. BOUT ++ linear simulations show that the most unstable modes change from high-n ideal ballooning modes to the intermediate-n peeling-ballooning modes and eventually to peeling-ballooning stable plasmas in the pedestal as the pedestal density gradient decreases. Nonlinear simulations show that the fluctuation is saturated at a high level for the lowest separatrix density. The elm size decreases with increasing the separatrix density, which becomes less than 1%, leading to small ELMs. To project from the current tokamak to ITER relevant parameters, pedestal collisionality scans are performed with a fixed pedestal pressure. The ELM size increases as the collisionality decreases for type-I ELMs, which shows a good agreement with an experimental scaling. However, starting from a stable pedestal plasma at high collisionality, small ELMs can be easily triggered either by high-n ballooning modes with very weak pedestal density gradient or by low-n peeling modes with relatively large pedestal density gradient by decreasing the normalized collisionality to ~0.1. The divertor heat flux width in the small ELM regime is ~2-3 times larger than the estimates based on the HD model and the Eich's ITPA multi-tokamak scaling[5] due to the strong radial turbulence transport. The SOL width is calculated as a function of separatrix pressure fluctuation intensity flux from the pedestal to the SOL for 8 different simulations, showing positive correlations with the SOL width, which is consistent with the theory of turbulence spreading. The strong ExB shear in the SOL correlates with reduced turbulence spreading and SOL width broadening. Operating in H-mode with small ELMs will solve two critical problems: reducing the ELM size and broadening the SOL width.

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References

[1] X.Q. Xu et al., Nucl. Fusion 59 (2019)126039
[2] N.M. Li et al., AIP Advances 10 (2020) 015222
[3] X.Q. Xu et al., "Divertor Heat Flux Broadening by Grassy ELMs", 28th IAEA Fusion energy conference (FEC 2020), https://conferences.iaea.org/event/214/contributions/17601/
[4] G.S. Xu et al., "Small-ELM-regime access facilitated by new tungsten divertor on EAST", 48th EPS Conference on Plasma Physics, https://indico.fusenet.eu/event/28/contributions/264/attachments/278/635/EPSpaper2022-Xu.pdf
[5] T. Eich et al., Phys. Rev. Lett. 107 (2011) 215001