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Characteristics of grassy ELMs and its impact on the divertor heat flux width

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Simultaneous control of large ELMs and divertor heat load in H-mode plasma is crucial for steady-state operation of a tokamak fusion reactor. The grassy ELM regime, one of small ELM regimes characterized by a high frequency and localized quasi-periodic collapse in the bottom of pedestal near the separatrix, can make the heat load to be continuous and the width to be broadened due to its small enough bursts and high enough frequency. The grassy ELM regime can also maintain the global confinement performance in comparison with type-I ELM H-mode as demonstrated in EAST, JT-60U, and TCV experiments. Recent DIII-D grassy ELM experiments show the divertor heat flux width can be broadened by a factor of 2-3 without RMP and the amplitude can be reduced by a factor of 10 on the inner target [1]. To understand the mechanism for the grassy ELM regime and its impact on the divertor heat flux width, linear stability and nonlinear simulations of ELM dynamics are carried out using the BOUT++ turbulence code for EAST exact grassy ELM experiments.

BOUT++ simulations indicated that the key mechanism for the grassy ELMs is the expansion of the peeling boundary due to radially localized steepening in the pedestal pressure gradient triggered by a radially localized collapse [2]. For a 60s steady-state long pulse high βp EAST grassy ELM discharge with tungsten divertor, BOUT++ linear simulations show that the unstable modes cover a range from low-n (n=10~15) with characteristics of peeling-ballooning modes (P-B) to high-n (n=40~80) modes driven by drift-Alfvén instabilities. Even though the drift-Alfvén instabilities dominate the linear growth phase with a wide n-spectrum and the fluctuation peaks on high-field side, nonlinear simulations show that the ELM crash is trigged by P-B modes on low-field side and fluctuation is radially localized near the bottom of pedestal. However, the drift-Alfvén instabilities delays the onset of the ELM and the energy loss increases with drift-Alfvén turbulence in comparison with that without it and the fluctuation extends to peak gradient region. Simulations further show that if the peeling drive is removed, the fluctuation amplitude drops by an order of magnitude and the ELM crashes disappear.

The temporal evolution of the power loading shows no obvious decay from the maximum of the ELM power pulse after the onset of the ELM power and the elm size is small (< 2%). The turbulence thermal diffusivity calculated by BOUT++ 6f-turbulence code is larger than the critical value, the threshold [3-4] between the drift dominant regime and turbulence dominant regime, indicating grassy ELM falls into the turbulence dominated regime. The divertor heat flux width given by both BOUT++ transport and turbulence simulations are about 2~3 times larger than the estimates based on the HD model and the Eich's ITPA multi-tokamak scaling by strong fluctuations in grassy ELM regimes. The heat flux width is inversely proportional to Er-shear due to the enhancement of the SOL parallel transport and suppression of radial transport.

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