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On Effect of n=2 RMP to Edge Pedestal in KSTAR with Nonlinear MHD Simulation

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Edge Localized Modes (ELM) are rapid MHD events occurring at the edge region of tokamak plasmas, which can result in damages on the divertor plates. Therefore, to fully suppress ELM via resonant magnetic perturbation (RMP) [1-4] is of great help to reach and sustain high-performance H-mode plasmas. It was found that certain conditions must met for the RMP-driven ELM crash suppression [5], so understanding its mechanism is crucial for reliable ELM control using RMP. The initial understanding of its mechanism was a stabilization of linear edge instability due to the pedestal gradient degradation by RMP. However, experimental observation showed that peeling-ballooning mode (PBM)-like mode structures remained in the ELM suppression phase [6]. In addition, the bifurcation of mode rotation in the edge region was found to be closely related to mode suppression [7]. Therefore, the initial understanding may have difficulties in explaining these experimental findings and it indicates that additional physics properties should be included to understand the mechanism. For this purpose, we have carried out nonlinear MHD simulations with 3D reduced MHD code, JOREK [8] for a recent n=2 RMP-driven ELM-crash-suppression in KSTAR [7]. We successfully reproduced [9] the natural ELM without RMP (Fig.1(a)), mode mitigation with small RMP strength ($I_{RMP} = 2kA$, Fig.1(b)), and mode suppression by experimental RMP strength ($I_{RMP} = 4kA$, Fig.1(c)). Also, such ELM-crash-suppression is attributable not only to the degraded pedestal but also to direct coupling between peeling-ballooning mode (PBM) [10] and RMP-driven plasma response. The coupling between PBM and RMP can 1) enhance the size of the island at the pedestal reducing the instability source by further pedestal degradation, and 2) increase the spectral transfer between edge harmonics preventing catastrophic growth and crash of unstable mode. Because of these effects, PBMs are nonlinearly saturated, and they persist during the suppression phase without a mode crash. This outcome is consistent with the previous studies [11,12]. In addition, the locking (or rotation bifurcation) of PBMs has been numerically simulated during the suppression phase. This mode-locking is a distinguishing feature of the mode suppression as rotating mode structure remains for the natural ELM and mode mitigated case (Fig. 1(d)). PBM locking may enhance the interactions between PBMs and RMP, and therefore, it is favorable to RMP driven ELM suppression. Here, slowly rotating PBM before RMP application can be easily locked by RMP. As $V_{E\times B}$ is approximately equal to the initial PBM rotation in our case, $V_{E\times B} \approx 0$ in the pedestal will be advantageous to onset of ELM-crash-suppression. To test our hypothesis, we conduct additional RMP-ELM simulation with modified $V_{E\times B}$, and confirm that the mode suppression is not achieved with enlarged $V_{E\times B}$ on top of the pedestal, which may support the importance of $V_{E\times B} \approx 0$ on ELM-crash-suppression.

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Figure 1: (a) Time evolution of natural ELM, (b) Time evolution of ELM with $I_{RMP} = 2kA$, c) Time evolution of ELM with $I_{RMP} = 4kA$, (d) Time evolution of mode rotation velocity for natural (0kA), mitigation (2kA) and suppression case (4kA).

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