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[REGULAR POSTER TWIN] The simulations on the control of ELM and edge turbulence by RF waves in EAST H-mode discharges

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EAST is typically operated on the radio-frequency (RF) waves heating scenarios, which is also highly related to ITER and CFETR. For the recent experiments of EAST H-mode operations, RF waves are found to be efficient to mitigate and suppress the edge instabilities, such as ELMs [1,2]. From the simulation point of view, the RF heating and driving effects can be studied from 2 aspects: directly on the equilibrium and directly on the instabilities. For the first aspect, the heating effects by RF waves are presented as the increase of the temperatures, and the current driving as the change of the current density profile, then those profiles are considered into the reconstruction of the magnetic equilibrium. In the previous work, the equilibriums including RF effects have already been used for the studies of the ELM behaviors [3,4]. Therefore, this presentation only focuses on the physics understanding for the active control of the edge instabilities by RF waves directly.

It is considered that there are several different mechanisms which are able to achieve the suppressions and mitigations on the edge instabilities by RF waves directly. For example, the low-hybrid wave (LHWs) and ion-cyclotron wave (ICW) show different capabilities on the edge instability control due to their different physics in the plasmas. LHW can excite the forced mode, and the strong nonlinear mode coupling between the forced and spontaneous modes leads to the mitigation of the edge turbulence. For ICW, the sheath potential of the ICW antenna is essential to change the radial electric field and able to suppress the linear growing of ELMs. Therefore, the six-field two-fluid module in BOUT++ framework [5] is extended based on the requirements to simulate the interactions between edge instabilities and RF waves [6].

The LHW is considered to drive the helical filamentary current (HFC) in the SOL region which can change the boundary topology by the radial magnetic field[1]. This radial magnetic field is treated as the initial perturbation in the simulations. The nonlinear evolution of the different modes of Te fluctuations are shown in figure 1 (a) and (b). The most obvious difference is the linear growing phase of the fluctuations which are changed by HCF. Figure 1(b) shows that all the modes of Te grow much more slowly than the case without HCF. Although the radial magnetic field induced by HCF could be much smaller than the perturbed field of the edge turbulence, it is still able to excite the perturbations with n = nHCF to grow up at the start of the linear phase. As shown by the red curve in figure 1(b). This forced mode is effective to compete with the spontaneous fluctuations and changes the spectrum of the eigenmodes even in the linear growing phase. There are strong nonlinear wave–wave interactions happened between those modes, and the phase coherence time gets decreased dramatically [7]. Therefore, none of the modes can grow to its amplitude in the no-HCF case. As shown in figure 1(c), the averaged total fluctuations of all the modes for the HCF case is able to be mitigated by 35% at least. This implies the edge turbulence is able to be mitigated by HCF. The mechanism gives a potential explanation to the active control on ELMs with LHW. This mitigation mechanism by HCF from LHW is quite similar to RMP coils, and could provide the more flexible method compared to the fixed RMP coil systems.

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The ELMs are observed fully suppressed by the ICW heating during the H-mode discharge #77741 in EAST, as shown in Fig 2(a). The simulations with BOUT++ reveals that the key factor is the RF sheath on the ICW antenna. The RF sheath potential is able to increase the radial magnetic field inside the SOL and introduces a large flow shear across the separatrix [8]. The linear growth rate can be decreased to less than 0.02 with RF sheath effects in Fig. 2(b), and the ELM size is decreased from over 10% to 0.66%, which are mainly consistent with the experimental results in Fig. 2(c). The large flow shearing rate also enhances the nonlinear wave-wave interactions between the different modes, so the free energy is shared by these modes, which can decrease the energy loss and suppress the ELMs effectively. In the experiments, the probability of the ELM suppression by ICRF is low. In the simulations, it is also found that if the ELM is fully suppressed by ICRF, the requirements for the radial electric field Er is relatively high. A small sheath potential range are found for the good ELM suppression by ICRF, as shown in Fig. 2(d).

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As the conclusion, this presentation exhibits two different mechanisms on the mitigation and suppression of the edge instabilities by two different waves. LHW excites the forced mode through HCF, and the strong nonlinear mode coupling between the forced and spontaneous modes leads to the mitigation of the edge turbulence. The sheath potential of the ICW antenna is essential to change the radial electric field and suppress the linear growing of ELMs. Both mechanisms can be explained by the enhancement of the nonlinear wave-wave interactions. Therefore, both LHW and ICW show a potential to be an effective method for the active ELM control besides RMP coils and pellet injections for the future tokamaks, such as CFETR and ITER.

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