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Integrated simulation study of ELM pacing by pellet injection with TOPICS-IB
ペレット入射によるELMペーシングに関するTOPICS-IBコードを用いた統合シミュレーション研究

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Simulations of pellet triggered ELM (edge-localized mode) have been done by the integrated code TOPICS-IB with various pellet parameters (location, timing, size and speed) to clarify optimum parameters for ELM pacing by the pellet. The pellet energy absorption effect is considered as an ELM triggering mechanism. It is found that an ELM is triggered when a pellet enters more deeply in the pedestal region for earlier pellet injection in the natural ELM cycle, smaller size or faster speed, independently of pellet injection location. The energy loss by the pellet triggered ELM just before next natural ELM onset is almost the same as the natural ELM in wide ranges of parameters, but earlier injection can reduce the energy loss depending on parameters. The energy loss by the pellet triggered ELM just after previous natural ELM becomes smaller for smaller or slower pellet. At the middle timing of pellet injection in the natural ELM cycle, the energy loss becomes smaller for larger (smaller) or slower (faster) pellet from high-field side [HFS] (low-field side [LFS]). The reduced energy loss is mainly attributed to the onset of high-n ballooning mode, while the natural ELM is triggered by intermediate-n peeling-ballooning mode.

1. Introduction

The large energy loss caused by ELM is crucial for the erosion of divertor plates in tokamak reactors. Pellet injection is considered as one of promising methods to increase the ELM frequency and to reduce the ELM energy loss. ELM pacing and mitigation by the pellet injection have been demonstrated in several experiments [1]. A few ideas have been explored in attempts to explain the ELM triggering by the pellet, but the physical mechanisms, however, are not fully understood yet. In order to study the pellet triggered ELM, we have developed an integrated core transport code TOPICS-IB [2] (1.5D core transport code TOPICS extended to the integrated simulation for burning plasmas) coupled with a linear MHD stability code MARG2D, a dynamic five-point model for SOL-divertor transport and a pellet model APLEX [3]. TOPICS-IB simulations showed that the energy absorption by a pellet in the pedestal steepens locally the pressure gradient and the ELM is destabilized. It is also found that the transport enhancement during the pellet ablation is able to steepen the local pressure gradient and to trigger the ELM as well.

For the ELM pacing by the pellet, ELMs should be reliably triggered by small pellets to minimize undesirable fuelling and impact on the target pedestal pressure/temperature. Experiments indicate the existence of trigger threshold of the pellet parameters such as the pellet size [1]. In the above TOPICS-IB simulation for a JT-60U H-mode plasma, a single pellet with a fixed radius r_p=0.6 mm (particle content ~ 5×10^{19} D) and speed v_p=120 m/s triggers an ELM at about 10 % lower pedestal pressure than that triggering a "natural" ELM. Further TOPICS-IB simulations with different parameters help to study the threshold.

In this paper, we carry out TOPICS-IB simulations with various pallet parameters of pellet location, injection timing in the natural ELM cycle, size and speed, and search for the trigger threshold and conditions satisfying the demands for ELM pacing by the pellet.

2. Simulation results

We use JT-60U parameters for simulations with TOPICS-IB whose detailed models are shown in [3]. In a simulation without the pellet injection, a series of natural ELMs by unstable modes with the toroidal mode number n~20 occurs with the period of τ_{cyc}=26 ms and their energy losses ΔW_{ELM} are about 6 % of pedestal stored energy W_{ped}~1 MJ. Three timings in the natural ELM cycle are chosen for the pellet injection only with the pellet energy absorption effect as a first step. Figure 1 shows the time evolution of profiles for those injection timings of a pellet with the same size and speed as described above. The unstable mode triggered by the pellet just before the next natural ELM onset

($\Delta t/\tau_{cyc}$=0.96) is almost the same as the natural ELM and the early injection triggers higher-n modes. As shown in Fig.2, ELM is triggered when the pellet enters more deeply in the pedestal region for earlier injection, independently of pellet injection location. The energy loss becomes smaller for earlier injection of a pellet with one set of size and speed, because of higher-n modes become unstable.

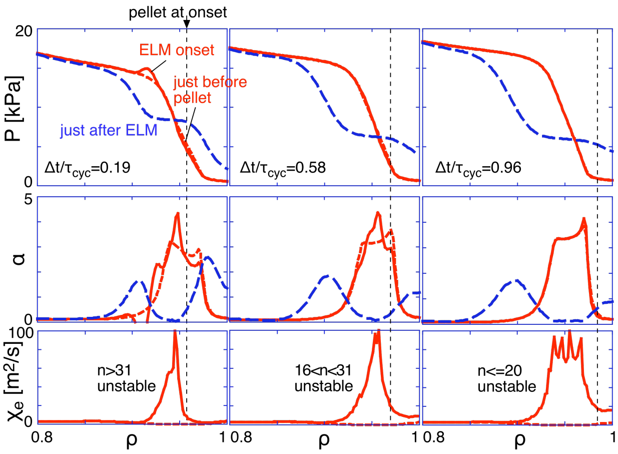

Fig.1. Time evolution of profiles of total pressure (top), normalized pressure gradient (middle) and electron diffusivity when a HFS pellet is injected at timings of $\Delta t/\tau_{cyc}$=0.19 (left), 0.58 (center) and 0.96 (right) where Δt denote time from previous natural ELM, dotted lines profiles just before pellet injection, solid ones just at ELM onset, broken ones just after ELM and vertical dotted ones pellet position at ELM onset.

We next study the dependence on the pellet size and speed at the middle injection timing ($\Delta t/\tau_{cyc}$=0.96). ELM is triggered when a pellet with size r_p>0.3 mm enters the pedestal region and smaller pellet penetrates more deeply, independently of injection location. In Fig.3, the energy loss becomes smaller for smaller pellet injected from LFS, while larger loss for smaller pellet from HFS. On the other hand, ELM is triggered when a pellet with speed v_p>5 m/s from HFS (v_p>0.5 m/s from LFS) enters the pedestal region and faster pellet penetrates more deeply, independently of injection location. The energy loss becomes smaller for slower pellet from HFS, while larger loss for slower pellet from LFS except for very low speed region in Fig.3.

At the early injection timing ($\Delta t/\tau_{cyc}$=0.19), the trigger threshold of size and speed is almost the same as the middle timing case for the HFS pellet, while larger size r_p>0.4 mm or faster speed v_p>2 m/s is necessary for triggering by the LFS pellet. The energy loss becomes smaller for smaller or slower pellet from HFS or LFS. On the other hand, at the late injection timing ($\Delta t/\tau_{cyc}$=0.96), the trigger threshold of size and speed is lower than earlier timing. The energy loss does not much change from the level of natural ELM in wide ranges of size and speed.

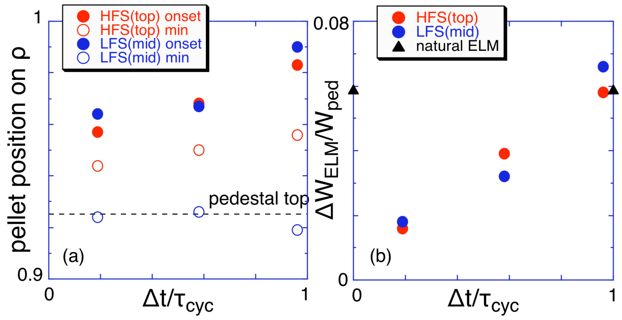

Fig.2. (a) Pellet position at ELM onset, minimum values of pellet position (i.e. penetration depth) and (b) normalized ELM energy loss as functions of $\Delta t/\tau_{cyc}$ where triangles in (b) denote energy losses by natural ELMs.

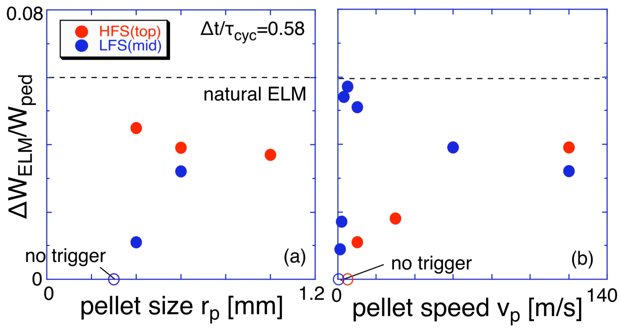

Fig.3. Normalized ELM energy loss as functions of r_p and v_p.

3. Discussions

The simulation results have potential to explain experimental observations such as variations of pellet position within the pedestal at the ELM onset and energy loss, smaller pellet enough for triggering at later injection in the natural ELM cycle [1]. The simulation results suggest that the early injection in the natural ELM cycle is desirable for the energy loss reduction if the control of pellet size and speed is difficult, but this leads to the reduction of pedestal pressure (14 % at $\Delta t/\tau_{cyc}$=0.19).

Acknowledgments

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References

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