1. ABSTRACT

The present work employs a BOUT++ three-field MHD model with an implemented impurity module to simulate the ELM triggering processes induced by lithium (Li) pellets injected from different poloidal directions under the EAST configuration. Simulations compare three poloidal geometries: the outer midplane on low-field side (LFS), the vicinity of X-point on LFS, and the inner midplane on high-field side (HFS). Linear simulations show that the local pressure perturbations introduced by Li pellet injection from all three poloidal directions are capable of destabilizing the initially stable pedestal. However, the spectrum of linear growth rates of peeling-ballooning modes (PBMs) exhibit significant differences across different injection geometries, including the spectrum width spanning over the modes with relatively big growth rates, the dominant mode number, and the evolution of the growth rate of dominant mode with pellet deposition amount. The results imply big differences in nonlinear ELM dynamics depending on poloidal injection geometry. From the linear simulation perspective, the required pellet size threshold for ELM triggering is lower for injections near the LFS X-point and from the HFS inner midplane compared to from the LFS outer midplane. Related nonlinear simulations are on the way now.

2. RESULTS

Figure 1 illustrates the schematic of Li pellet depositions from three different poloidal injection geometries compared in this work, where PDP denotes the peak deposition position and PT represents the pedestal top. The parameter R_p is defined as the ratio of the modified pressure to the unperturbed one at the peak deposition position, which represents the pellet deposition amount [1]. Our previous work [2] showed that when a Li pellet is injected from the LFS outer midplane, increasing R_p could shift the dominant mode number (n) of PBMs towards low n range, accompanied by a gradual narrowing of the spectrum width spanning over the modes with relatively big growth rates, which can be seen in Fig. 2(a). However, in the present simulations, it is found from Fig. 2(b) that when the pellet injection position deviates from the LFS outer midplane to the vicinity of LFS X-point, the spectrum width first broadens then narrows with increasing R_p. The comparison of R_p = 1.2 cases in Figs. 2(a) and 2(b) reveals that the narrower spectrum width in Fig. 2(b) is conducive to facilitating a faster growth of the dominant mode, thereby enhancing ELM triggering efficacy. Given that Li pellets failed to trigger an ELM when R_p = 1.2 in [2], the present results imply that pellet injection near the LFS X-point may reduce the pellet size threshold required for ELM triggering, compared with the injection from outer midplane. Furthermore, as R_p increases from 1.2 to 1.8 and further to 3.0, the observed trend of initial broadening followed by narrowing in the spectrum width (Fig. 2(b)) implies that the ELM-triggering capability of Li pellet injection may first weaken then strengthen with increasing pellet deposition amount. The above linear-based predictions require validation from nonlinear simulations.

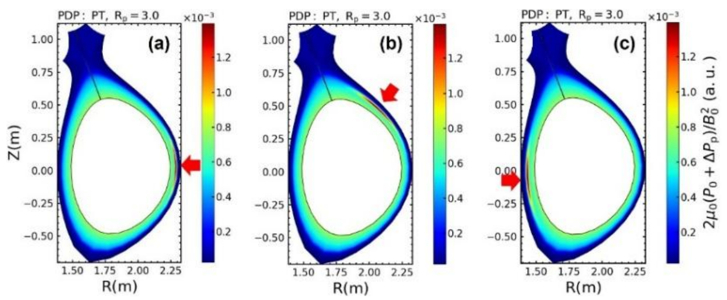

Fig. 1 Schematic of Li pellet depositions from three different poloidal injection geometries compared in this work, including LFS outer midplane, vicinity of LFS X-point, and HFS inner midplane.

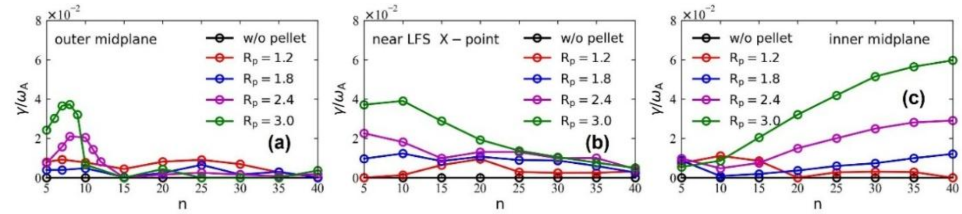

Fig. 2 Toroidal mode spectrum of linear growth rates of PBMs when Li pellets are injected from (a) LFS outer midplane, (b) vicinity of LFS X-point and (c) HFS inner midplane, respectively. The results in panel (a) were taken from [2]. The parameter R_p is the rate of the modified pressure over the unperturbed one at peak deposition position.

In contrast to the LFS injections, when a Li pellet is injected from the HFS inner midplane, the characteristics of destabilized PBMs show some differences. When R_p increases, the dominant mode number of PBMs shifts from low-n to high-n range. Similar to Fig. 2(b), when R_p = 1.2, the narrower spectrum width spanning over the modes with relatively big growth rates is also conducive to triggerring an ELM. It implies that the pellet size threshold required for ELM triggering may be lower for HFS inner midplane injection compared to LFS outer midplane injection. For cases with R_p > 1.2, the dominant mode consistently resides in the high-n region (n = 40), and the spectrum width gradually narrows as R_p increases. The results suggest a progressive enhancement in the ELM-triggering capability of Li pellet injection. However, when R_p increases from 1.2 to 1.8, whether Li pellet injection can successfully trigger an ELM or not requires further analyses based on the nonlinear simulation results.

3. IMPACT AND NOVELTY

Both EAST and DIII-D experiments have successfully achieved effective control over ELM frequency and amplitude through Li pellet injection along LFS outer midplane [3,4,5]. Recent SOLPS and BOUT++ simulations, further elucidated the physical mechanisms underlying pellet ablation, pedestal equilibrium evolution, and ELM triggering following Li pellet injection in EAST [1,2,6]. However, experimental and numerical studies have yet to investigate the physical processes of ELM triggering by Li pellets injected from different poloidal directions. Previous experimental and simulation studies on deuterium (D) pellet injection showed that Li pellets injected from LFS outer midplane could trigger ELMs with larger amplitudes, while those injected near LFS X-point and from HFS inner midplane could trigger ELMs with lower pellet size threshold [7,8]. The present linear simulation results imply that the threshold dependence of Li-pellet triggered ELM on poloidal injection geometry resembles that observed for D pellets. Nevertheless, nonlinear simulations are required to validate the linear predictions and uncover the physical mechanisms behind ELM dynamics further. The related work is on the way now. The present work aims to reveal the effect of poloidal injection geometry on Li-pellet triggered ELM, thereby providing physical insights for future experimental planning.

4. METHODOLOGY

In this work, a BOUT++ three-field MHD model with an implemented impurity module is used to simulate the physical processes of ELM triggering and its further evolution by Li pellet injection from three poloidal geometries: the LFS outer midplane, the vicinity of LFS X-point, and the HFS inner midplane. The pedestal equilibrium profile altered by pellet injection is described using the 2D Gaussian model, which is presented in [1,2]. In both linear and nonlinear simulations, the radial and poloidal deposition ranges of pellets are constrained to be identical across all poloidal injection scenarios by adjusting model parameters, which enables the investigation of dependence of ELM triggering on pellet deposition amount (R_p).

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SIMULATION OF EFFECT OF POLOIDAL INJECTION GEOMETRY ON LI-PELLET TRIGGERED ELM UNDER BOUT++ FRAMEWORK

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