Comparative study between MHD simulation codes for nonlinear dynamics of the ELMs in KSTAR H-mode plasma

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Introduction

Understanding of the underlying physics of the ELM is important to optimize and expand the operation window of ELM-crash free to achieve steady-state long-pulse high-performance plasmas. A validation and verification are essential approach to improve the understanding of the ELM dynamics. Nonlinear MHD simulations of the ELMs are required to interpret the observed ELM dynamics by the KSTAR ECEI systems [1-2]. The examples are the excitation of solitary perturbation just before the onset of the ELM-crash [3], the interaction of multiple modes [4] and the rapid change of dominant mode numbers [5] during the inter-ELM-crash period. Before validation of the observed results, the results from well-established MHD codes (here, BOUT++, JOREK and M3D-C1) using same plasma equilibrium are compared for verification process. The results will be helpful to understand the underlying physics of the ELM dynamics and validate a reliability among the codes.

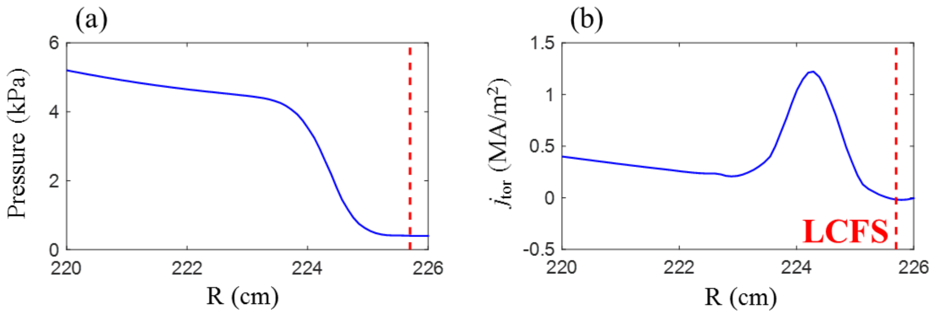

Figure 1 Equilibrium profiles mapped on LFS mid-plane: (a) pressure and (b) toroidal current density. Vertical red dotted line indicates the radial location of the last closed flux surface (LCFS).

Nonlinear simulation for study of the ELM dynamics

One of the well understood H-mode discharge (#7328) heated with the NBI power of ~3

MW in KSTAR is chosen for a numerical simulation study. Basic plasma parameters are as follow; the plasma current I_p = 750 kA, the toroidal field $B_T(R_0)$ = 2.25 T, and q_{95} ~ 5 at the time of interest. In previous simulation study [6], the edge stability is throughly investigated and edge profiles including bootstrap current driven by the steep pressure gradient are determined by scanning the profiles within the possible errors of the measurement as shown in figure 1.

Since each code has different optimized parameter windows in which the solution is numerically more stable and easily converged for the given KSTAR geometry, each code used different initial conditions (e.g., profiles of resistivity, viscosity and conductivity) for the nonlinear simulation. Since M3D-C1 is not yet sufficiently optimized for the KSTAR plasmas due to the small number of the test, the diamagnetic stabilization effect is omitted in the results shown here. In the three codes, multiple toroidal harmonics are initiated as an initial perturbation structure. The JOREK simulation includes the effect of plasma net rotation on the ELM dynamics using the plasma toroidal rotation profile measured by charge exchange spectroscopy (CES) [7].

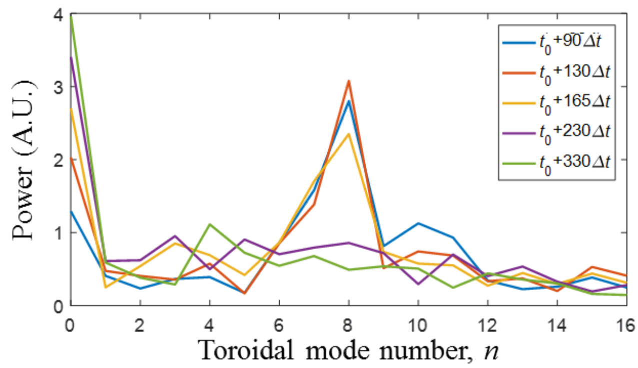

Figure 2 BOUT++ nonlinear simulation results; radially integrated toroidal mode number spectra of pressure perturbation on LFS mid-plane.

Comparative study between nonlinear simulation results

In proximity to onset of the ELM-crash, all code shows a relaxation of pedestal structure and an expulsion of mode structure across the separatrix. However, the evolution pattern of ELM structure is different in details.

Figure 2 shows radially integrated toroidal mode number spectra on the low field side (LFS) mid-plane obtained from the BOUT++ nonlinear simulation. The initial dominant mode (n = 8) in the quasi-linear period becomes weaker (at ~$166\Delta t_{bout}$) as the simulation is evolved and the broadband spectrum appears (at ~$230\Delta t_{bout}$). Finally, lower n-number (n = 4) becomes the dominant mode at ~$330\Delta t_{bout}$. The spectral power of the n = 0 component increases due to the mean value drift caused by the pedestal relaxation.

In the JOREK nonlinear simulation (see the detailed description in [8]), the n = 8 is also the dominant mode in the quasi-stable period. In the highly nonlinear stage, or near the ELM-crash time, the magnetic energy contained by the low-n modes (typically, n = 1-2) becomes comparable to that of the initial dominant mode (n = 8). In the JOREK simulation, the evolution of rotation profile can be examined owing to the included plasma toroidal rotation. Close to the onset of ELM-crash, the apparent poloidal rotation is decreased and its profile becomes strongly sheared. The strong shear induces ‘blob’ structure around the X-point.

In the M3D-C1 simulation, n = 16 is the dominant mode in the whole period of pedestal evolution as shown in figure 3. The omission of the diamagnetic stabilization effect, which suppresses mode with higher n-number, can explain the disagreement with the other two codes. In future study, the diamagnetic stabilization effect will be included for a fair comparison.

Preliminary results from comparison study with the ECEI observations

The mode evolution in the BOUT++ simulation is qualitatively in good agreement with the observations [9]. The transient disappearance of coherent mode structure and reappearance with lower mode number in the observation correspond to the broadening of mode number spectrum and the change of dominant mode number in the simulation, respectively.

The JOREK simulation provides hint for the ELM-crash triggering. In ECEI observations, the apparent poloidal rotation usually decreases and the solitary perturbation (typically, n = 1)

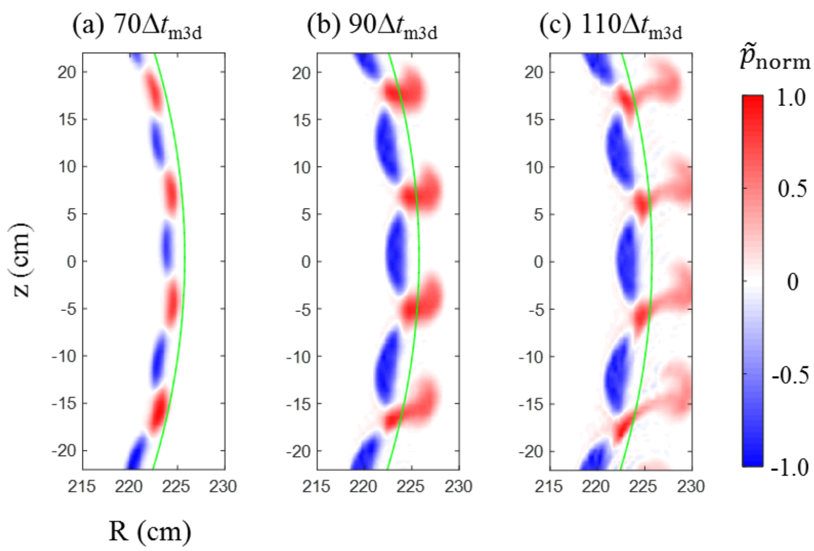

Figure 3 M3D-C1 simulation of ELM (the diamagnetic effect is omitted): pressure perturbation structures on a poloidal cross section view at the LFS edge for (a) $70\Delta t_{m3d}$ (b) $90\Delta t_{m3d}$ (c) $110\Delta t_{m3d}$. Green solid line indicates LCFS. Each frame is normalized to the absolute maximum value for each simulation time step.

is often observed [3] just before onset of the ELM-crash. Regardless of differences in details, qualitative similarities can help to understand the triggering mechanism of the ELM-crash.

The independent approaches suggest that the low-*n* mode or the lower-*n* mode is closely related to the ELM-crash triggering. To prove this hypothesis, it is necessary to investigate the connection between those modes and sudden pedestal collapse. Furthermore, it is needed to classify the conditions of two different types of crash driven by the low-*n* and lower-*n* mode, respectively.

Summary

The verification between the three different MHD simulation codes is an important process to cross-check ELM dynamics from each code prior to comparative study with the experimental observations. The simulation results from individual codes using the same plasma equilibrium are qualitatively in good agreement with the observation. The JOREK and BOUT++ simulation results suggest that the low-*n* mode and the lower-*n* mode have a connection with the triggering of ELM-crash. In future study, the initial conditions of each code will be adjusted for fair comparison and the hypothesis on the ELM-crash triggering will be validated.

Acknowledgement

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