§5. Nonlinear MHD Simulation of ELM in Spherical Tokamak

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The edge-localized mode(ELM) is an instability which is often observed repetitiously in the pedestal region of the H-mode operations of toroidal devices. To control the ELMs is one of the most important issues for the advanced operations of toroidal plasmas. In recent spherical tokamak(ST) experiments, as well as conventional large tokamaks, several types of the ELMs are also observed as the confinement properties and the environment of the measurement developed. Not only the most commonly observed type-I ELM, which has the largest fluctuation level of all types, but also several kinds of small ELMs has been observed. Especially, detailed filamentary structures on the plasma surface are clearly observed on the ELM crash phase. We propose a numerical modeling for the dynamics of an ELM crash in ST by means of a three-dimensional nonlinear magnetohydrodynamic(MHD) simulation.

The nonlinear resistive compressive MHD equations are solved in a full-toroidal three-dimensional ST geometry for a long time scale of several hundreds of the Alfven time. The initial condition for the reference case is given by a reconstructed equilibrium from the NSTX experiment, which has the parameters, β_0=28%, q_0=0.89, and A=1. The system includes the external open field, and a single-null X-point. A perfect conducting wall located close to the plasma surface limits the boundary condition of the simulation. The system is linearly stable for the ideal modes, but weakly unstable for the resistive ballooning mode. The simulation result shows a two-step relaxation process induced by the intermediate-*n* ballooning instability followed by the m/n=1/1 sawtooth crash. Especially, thin and elongated balloons are formed along the field lines on the plasma surface on the nonlinear phase. They eventually turn into bubbles, and are isolated from the core plasma. This behavior well agrees with the experimental observation by using fast camera images in MAST. This simulation result explains several characteristic features of the so-called type-I ELM:(1)relation to the ballooning instability (2)intermediate-*n* precursors (3)low-*n* structure on the crash (4)formation and separation of the filament (5)considerable amount of convective loss. As for the time scale, the simulation result is consistent with the experimental ELM rise times of the order of ~100 μsec.

As the linear analyses shows, the ELMs are triggered not only by the ballooning mode, but also by the combination of the peeling mode. Especially, the smaller types of ELMs may have much relation to the peeling instability. Here, we examine how the nonlinear behavior changes if the process is led by the peeling mode. To deal with the peeling modes, we use a free-boundary Grad-Shafranov code to obtain another set of the initial and the boundary conditions, where the large edge current, large triangularity, and the far-off conducting boundaries to treat the unstable external current-driven modes. This new system os unstable to the peeling modes for the ideal, and the ballooning modes for the resistive regimes, respectively. The parameters for this equilibrium are β_0=25%, q_{min}=1.27, and A=2.0.

The simulation results show that the nonlinear behavior is firstly directed by the plasma flow structures of the linear eigenfunctions. For the ballooning mode case, the filamentary structure is formed by a radial convection motion in the edge of the low-field side, whereas the radial component of the flow vortices is so small that the flow patterns turn into elongated ones along the flux surfaces for the peeling mode case. Therefore, no prominent filamentary structure can be formed for the peeling case. The outermost layer of the plasma is thinly "peeled", as shown in Fig. 1. The perturbations do not propagate into the core region, and are saturated at smaller amplitudes. This nonlinear behavior of the peeling mode may lead to a milder loss of plasma, which would be related to the smaller types of the ELM.

Thus, the simulation has partly revealed the effect of the driving source of the instability for the ELM crash types. It has turned out that the ballooning nature is essential for the formation mechanism of the observed filamentary structure. Quantitative analyses with more realistic configurations and the physics models, including the kinetic effect, the transport, and the plasma-vacuum interaction, are our future works.

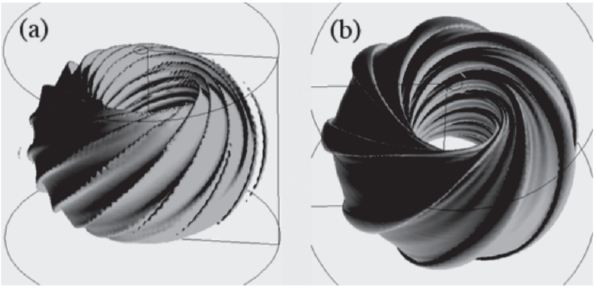

Fig.1 The nonlinear evolution of the pressure profile in three dimension for (a)the ballooning and (b)the peeling case, respectively. clear filamentary structure is seen in (a)

Reference
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2) R. Khan, et al. Phys. Plasmas (2007) (in print).