§9. Comparison between IRE and Sawtooth Activities in Spherical Tokamak

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Nonlinear magnetohydrodynamic(MHD) simulations of the relaxation phenomena in high-β spherical tokamak have been executed. We will focus on the internal reconnection event(IRE) and the sawtooth collapse. Both the IRE and the sawtooth are similar activities which are accompanied by a large scale pressure collapse in an MHD time scale. Experimentally, the main difference between IRE and sawtooth is that the pressure recovers more completely for the sawtooth, and some of the stored energy is lost in the IRE. Furthermore, there are some differences, i.e., the overall shape is deformed in IRE, a rapid increase of the total plasma current is observed in IRE, and so on. The objective of this study is to find the difference of these two activities by means of a numerical simulation. We reproduce both phenomena on a computer, and find the differences by comparing the results in detail.

The initial condition is given by numerical equilibria with tiny perturbations, and the geometry for the simulations is a realistic three dimensional torus including vacuum region. Especially, for the sawtooth case simulation, we use the real experimental data from the National Spherical Torus Experiment (NSTX) of Princeton, which is obtained by Dr. Paoletti, Dr. Sabbagh, and Dr. Kaye. The nonlinear resistive MHD equations are solved in a full toroidal geometry by the finite difference method. To model the realistic experimental configuration which has conducting materials close to the plasma, a non-rectilinear numerical grid is used for the simulation. We have developed a new high-accuracy scheme for such numerical grid, in which the spatial derivatives are evaluated by using surrounding 25 grid points. This scheme keeps the fourth-order accuracy in both the radial and the vertical direction, as well as rectilinear 5-points finite-difference scheme.

The parameters of the equilibrium used here are A=1.4, β_0=28%, and q_0=0.89 for the sawtooth case, A=1.4, β_0=44%, and q_0=0.91 for the IRE case, respectively. The radial profiles of the toroidal plasma current and the pressure is somewhat broader in the core region for the sawtooth case than for the IRE case.

We calculate the spontaneous time development from the initial equilibrium by the Runge-Kutta scheme with fourth-order accuracy in time. For the sawtooth case, the initial equilibrium is stable for ideal regime, that is, the resistivity η is small. However, it shows the system becomes unstable for larger η. We pursue the nonlinear time development of such nearly stable state, where the scaled η is set to be 4×10^{-5}. The most unstable component for this case is the middle-n modes such as n=12 and n=13. These resistive modes have the nature of the ballooning modes in that the poloidal mode structures are localized in the bad curvature region. As the instabilities grow, the amplitude of the perturbation becomes so large that the global structure is deformed to a visible scale. The plasma surface wrinkles as seen in Fig.1(a). Then, the changes in the global structure influence the global stability itself. A new linear instability is excited in the core region after the saturation of the middle-n modes. In this case, the n=1 internal mode begins to grow after t=250τ_A. The most dominant poloidal component of this instability is the m=1 component. Therefore, the plasma in the core region largely shifts toward the edge region when the amplitude of the perturbation becomes large at the following stage. This m/n=1/1 motion is well known as the precursor of a sawtooth crash in tokamak. This simulation result may show a new type of the sawteeth, which are excited by the nonlinear development of higher modes. Interestingly, the shifted plasmoid returns to the core region immediately after the crash, and finally stable axisymmetric structure emerges as shown in Fig.1(b).

On the other hand, the results for the IRE case show the loss of plasma thermal energy in part and a large distortion of the overall shape due to strong plasma flows which are induced by the magnetic reconnection between the internal and external field (see Ref.1 for more detail).

By comparing these two simulation results, we obtain a clue to know the difference in the mechanisms of these MHD activities. The large differences in the nonlinear stage, i.e., the existence of the large distortion and plasma losses, are mainly caused by the occurrence of the reconnection. The reconnection point is located near the plasma-vacuum boundary. Therefore, the reconnection is related to the linear eigenmodes. The dominant mode for the IRE case is the low-n interchange mode, and that for the sawtooth case is the middle-n resistive ballooning mode. One candidate for the reason of the difference in the linear instability is the difference of the profiles. The radial profiles of the quantities are broad for the sawtooth case compared to the IRE case.

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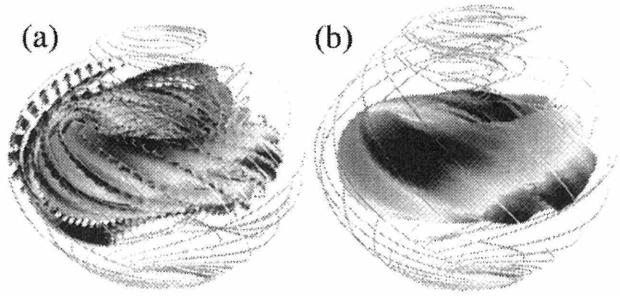

Fig.1. Iso-contour surface of plasma pressure and surrounding magnetic field lines at (a)t=270 and (b)500(τ_A).

Reference

[1] Mizuguchi, N., et al., Phys. Plasmas **7** (2000) 940.