§5. n = 1 Activity in High-β Spherical Tokamak

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Nonlinear analysis of the relaxation phenomena in high-β spherical tokamak has been done by means of a magnetohydrodynamic(MHD) simulation. The initial condition and the geometry for the simulations are modeled by using the realistic experimental data of the National Spherical Torus Experiment (NSTX)[1] of Princeton. The simulation result shows a delayed excitation of a sawtooth-like internal n=1 activity at the high-β regime.

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[2], in which the spatial derivatives are evaluated by using surrounding 25 grid points, keeping fourth-order accuracy in both the radial and the vertical direction.

The initial conditions for the simulations are the reconstructed numerical equilibria, which are calculated by using the EFIT code[3] by Dr. Paoletti, Dr. Sabbagh, and Dr. Kaye of Princeton. The parameters of the equilibrium used here are A=1.4, β_0=28%, and q_0=0.89. The radial pressure profile is somewhat broad in the core region (see t=0 of Fig.1).

We calculate the spontaneous time development from the initial equilibrium by the Runge-Kutta scheme with fourth-order accuracy in time. The initial equilibrium is stable for ideal regime, that is, the resistivity η is small. However, it shows instability for large η. The most unstable component is the middle-n modes such as n=12 and n=13 in this case, where the scaled η is set to be 4×10^{-5}. These resistive modes have the nature of the ballooning modes in that the poloidal mode structures are localized in the bad curvature region. On the other hand, the low-n modes are much more stable than the middle-n modes at this stage.

As the linear unstable modes grow, the amplitude of the perturbation becomes so large that the distortion in global structure becomes visible scale. The plasma surface wrinkles (see Fig.2(b)), and the pressure profile becomes flat around the related rational surfaces (see R=0.3-0.7 and 1.3-1.5 at t=250 of Fig.1). Moreover, the nonlinear couplings among such middle-n modes make rapid excitation of other modes, especially, the low-n modes including the n=1 mode. These low-n activities are also seen in the outer region, corresponding to the parent modes.

The changes in the global structure due to the nonlinear growth of the instabilities influence the stability itself. A new linear instability is excited after the saturation of the middle-n modes. In this case, the n=1 internal mode begins to grow after t=250τ_A. It should be noted that there is an obvious difference in the poloidal mode structures between the nonlinear n=1 mode by couplings and the latter n=1 mode . The most dominant poloidal component of the latter n=1 mode is the internal m=1 mode. 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 (see Fig.2(c)). This m/n=1/1 motion is well known as that of the 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(Fig.2(d)). Finally, the broad radial pressure profile, which has similarity with the initial state, emerges at t=500τ_A (Fig.1 and Fig.2(e)). Though the calculation has not been executed after t=500τ_A, the broad pressure profile at the final state would imply the repetitious excitation of similar events after that.

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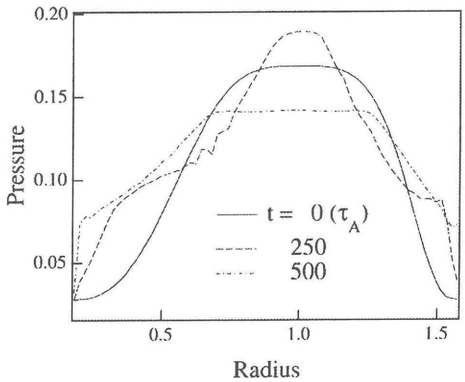

Fig.1. Temporal change in radial pressure profile.

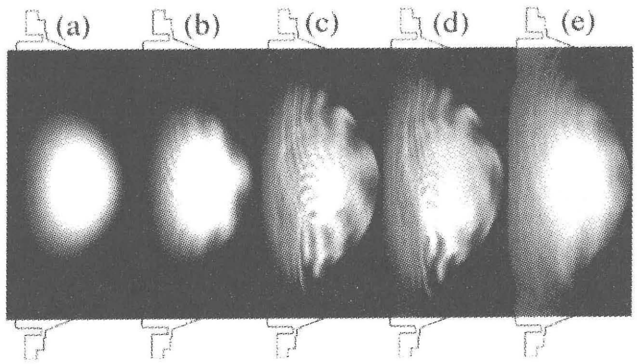

Fig.2. Poloidal pressure profile at (a)t=0, (b)180, (c)270, (d)300, and (e)500(τ_A).

Reference
[1] Ono, M., et al., Nucl. Fus. **40** (2000) 557.
[2] Mizuguchi, N., et al, J. Plasma Fus. Res. **77**(2001)309 (in Japanese).
[3] Sabbagh, S., et al., in Proceedings of the 18th IAEA-