§ 15. Nonlinear MHD Simulation of Spherical Tokamak Plasma

Mizuguchi, N., Hayashi, T.

We execute nonlinear magnetohydrodynamic(MHD) simulations to study relaxation phenomena that occur in spherical tokamak(ST). Here we focus on two kinds of relaxations which are seen in relatively advanced or potential STs. One is a relaxation that develops in two steps, precursory ballooning modes and a succeeding internal n=1 mode, where n is the toroidal mode number[1]. The other is studied by using a numerical ST equilibrium at extremely high-β with the so-called ' current hole', which has a region where the toroidal current is zero and the pressure profile is flat. The simulation is done in a three-dimensional full toroidal geometry, using the fourth-order finite difference scheme. The governing equations are basically the resistive compressive MHD equations. Besides, the effect of the resistivity and the heat conduction is also examined. The fast parallel heat conduction is calculated by an explicit scheme with shorter time steps.

For the first case, the initial equilibrium is given from the experimental result of NSTX. The radial pressure, current, and safety factor profiles are somewhat broad. This equilibrium is stable under the ideal regime, that is the resistivity η and the heat conductivity κ are substantially zero. However, several unstable modes can be excited with larger η. The spectrum and the mode pattern are shown by circles in Fig.1(a) and in 1(b), respectively. Higher n modes, such as the n=12 mode, are dominant in this case. These modes are identified as the resistive ballooning mode. For larger κ, the peak mode number of the spectrum is shifted to lower n, as shown in Fig.1(a) with triangles. However, the nonlinear time evolution does not change qualitatively.

In the nonlinear time development of this case, the stability of the equilibrium is strongly affected by the precursory ballooning mode. The mode activity in the edge region destroys the flux surface and the profile is peaked at the center due to the flattening in the edge region. This induces another current driven instability inside the q=1 rational surface. The spectrum and the mode pattern is shown by the crosses in Fig.1(a) and in Fig.1(c), respectively. This secondarily induced mode is identified as the m=1/n=1 kink mode, which causes a sawtooth-like collapse.

This result shows a unique features that the internal n=1 crash is induced as a result of the spontaneous time development of higher-n ballooning modes. Such time evolution is also observed in experiment of TFTR[2].

For the second case, the initial equilibrium is obtained by numerical solution of the Grad-Shafranov equation. In this solution, it is assumed that the pressure gradient and the current goes to zero. Such situation is experimentally achieved in the large tokamak devises such as JT-60U and JET. In such confinement the pressure gradient exists only in the edge region and the plasma beta becomes very high. It is interesting to study the properties of such advanced confinement concept also for STs. In particular, we focus on the MHD stability and its nonlinear properties.

Figure 2 shows the radial profiles of pressure, toroidal current, and the safety factor of the numerical equilibrium with current hole. In this case, only the n=1 mode is unstable for ideal regime. The most dominant poloidal component is the m=3 one, and the mode is identified as the kink mode. The nonlinear time development shows a hard distortion of the overall configuration. This result is a first attempt without accurate model for parameters. More realistic modeling is our future subject, especially, the effect of plasma flows may be important.

The authors would like to thank Dr. F. Paoletti, Dr. S.Sabbagh, and Dr. S. Kaye of Princeton Plasma Physics Laboratory, who provided the experimental data, and Dr. Y. Nagayama of NIFS for fruitful discussion.

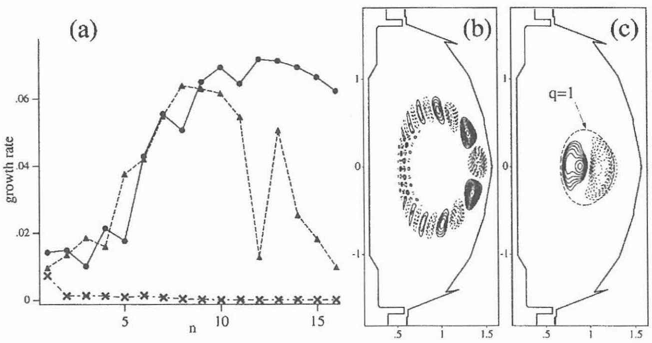

Fig.1 (a) Growth rate of the instabilities for each toroidal modes. The circles, triangles, and the crosses indicate that of the κ=0, κ=4x10^{+0} , and the secondarily induced n=1 mode, respectively. (b)Poloidal mode pattern of the linear n=12 mode for κ=0. The iso-contour of the pressure is plotted. (c)Poloidal mode pattern of the secondarily induced n=1 mode.

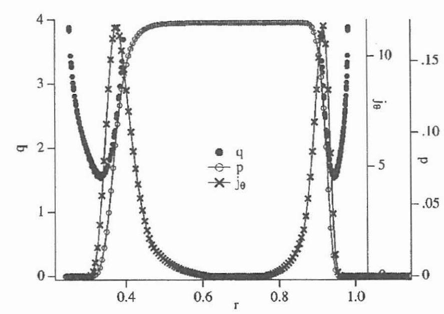

Fig.2 Radial pressure(p), toroidal current(j_θ), and safety factor(q) profiles of the equilibrium with the current hole.

Reference

[1] T.Hayashi, N.Mizuguchi, et al., IAEA-CN-94/TH/6-3, 19th IAEA-FEC, Lyon (2002).
[2] Y. Nagayama, et al., Phys. Fluids B 5, 2571 (1993).