§11. MHD Equilibrium and Stability of Spherical Tokamak with Current Hole

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It is known that broader pressure and more hollow current profiles are suitable to improve the high-β stability of tokamak. The current hole, in which the current goes to zero in the core region, is placed as an extreme of such improved profile of tokamak. This study has been done to investigate the potential characteristics of spherical tokamak(ST) configurations with current hole by means of a magnetohydrodynamics(MHD) simulation[1].

The two-dimensional axisymmetric MHD equilibrium of ST with current hole is obtained numerically by solving the Grad-Shafranov equation with an appropriate assumption for the current and pressure profiles. Moreover, we introduce an equilibrium model with stational toroidal shear flows. This equilibrium is obtained by solving the following set of modified Grad-Shafranov equations:

$$\begin{aligned} \Delta^*\psi &= -r^2\frac{p_r}{\psi_r} - FF' - \frac{r^3 f^2}{\psi_r}, \\ \Delta^*\psi &= -r^2\frac{p_z}{\psi_z} - FF', \end{aligned} \qquad (1)$$

where ψ is the poloidal flux, $F(=rB_\theta)$ and $f(=v_\theta/r)$ are the arbitrary functions of ψ for the toroidal field and flows, respectively. These two equations are solved simultaneously by using a newly developed iterative scheme. We have obtained solutions of current hole ST configurations with and without toroidal shear flows, in which the maximum Mach number is about 0.1.

We have executed the linear and nonlinear resistive compressive MHD simulations to investigate the stability and the nonlinear scenario of the growth of instabilities. The linear analysis showed that low-n kink mode and high-n ballooning mode is unstable for an example case. The growth rate for each toroidal mode number is plotted in Fig.1. The results for both cases with and without the flows are shown together. The result shows that the existence of the shear flow tends to make the higher-n modes more unstable. This seems to be caused by the steepening of pressure profile due to the centrifugal force of toroidal flows. However another recent simulation results for different initial equilibria show that the growth rate for the ballooning modes becomes smaller if the toroidal flows exist. It is our future work to reveal the factors that determine the stability under the existence of flows.

The nonlinear behavior of the above-mentioned instabilities is also our interest. Especially, it is important whether the system is disruptive, saturated, or resilient on the highly nonlinear state. The nonlinear simulations for the current hole ST plasma without toroidal shear flow show that the system is highly destructive. Figure 2 show the temporal change of pressure profile in a poloidal cross section. The simulations are executed with two kinds of initial conditions: the random white noise where the n=6 mode glows dominantly[Figs.2(d) and (e)], and only the n=1 mode noise where the low-n kink behavior is extracted[Figs.2(b) and (c)]. So far as we can see from the result, there are no indications that the system recovers after the event, which can be seen in our previous simulations of MHD relaxation phenomena. One of the reasons for such nature is the existence of the current hole, in which there is no MHD force balance to restore the torus configuration. It might be important to suppress these instabilities for making use of such improved configurations.

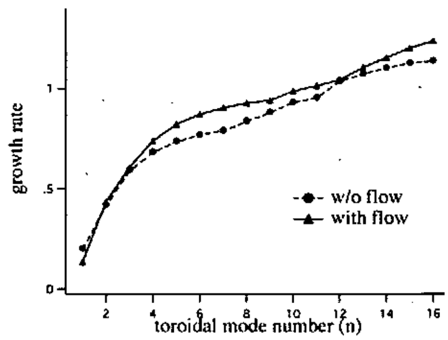

Fig. 1. Linear growth rate of the instabilities for each toroidal mode numbers(n).

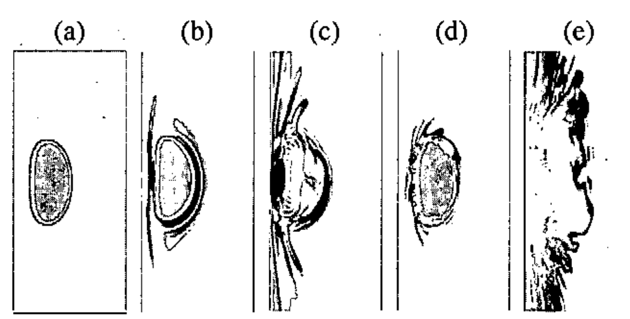

Fig. 2. Nonlinear time development of pressure profile. (a)t=0(τA),(b)500,(c)620(n=1),(d)60,(e)320(n=6).

Reference

1) Mizuguchi,N., and Hayashi,T. ; J. Plasma and Fusion Res. SERIES **6** (2004), to be published.