§3. A Hall MHD Simulation in the Large Helical Device

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Nonlinear evolutions of short-wave unstable modes have been studied to clarify the saturation mechanisms of pressure-driven instabilities in LHD.

Our fully 3D MHD simulations of LHD reveal that the unstable modes can be saturated mainly through both linear and nonlinear contributions of the parallel heat conductivity, and the saturated profile of the pressure should be studied more correctly by an extended-MHD model. [1)]

Fully 3D MHD simulations of LHD are carried out by the use of the MINOS code[2)], in which the compressible magnetohydrodynamic equations are described in the helical-toroidal coordinate system. Spatial derivatives are approximated by the use of the 8th-order compact scheme The initial equilibrium of the inward-shifted magnetic axis position (3.6m) and the $\beta_0 = 3.7\%$ is perturbed randomly for $n \le 15$. The growth of the ballooning modes over the toroidal modes $n \le 15$ and their nonlinear saturation are resolved sharply.

In Fig.1, the mean pressure profiles in the simulations are shown. The initial state (thin solid line), an intermediate state similar to that in an experiment[3)](dotted), the saturated state with a large parallel heat conductivity $\kappa_{//} = 10^{-2}$ (thick dotted line), and the saturated profile with a small parallel heat conductivity $\kappa_{//} = 10^{-6}$ are shown. The saturated pressure profile is improved significantly by the large parallel heat conductivity. It can be also shown that the parallel heat conductivity contributes to the saturation not only in the linear stage but also in the nonlinear stage, mainly through suppressing the parallel pressure gradient. [1)] Though the instability is saturated by a large $\kappa_{//}$, the pressure deformation is still large in comparison to the experiment[1)]. We can find in Fig.1 that the pressure is flattened locally in a course of time evolution but it turns out that neither the local pressure flattening nor the parallel heat conductivity provides sufficient stabilization of the unstable ballooning modes.

Expecting further stabilization by two-fluid effects, we plan to carry out extended MHD simulations in LHD. As the first step of this approach, we have carried out Hall MHD simulation for the same geometry, the same initial equilibrium in the above. We do not expect a stabilization by the Hall effect, since we have not carried out any linear stability analysis. However, as we can see in Ref.[4], the Hall term can stabilize the Rayleigh-Taylor-type instability with a moderate wave number. In Fig.2, the pressure profile at the time of nonlinear saturation in our Hall MHD simulation is shown. The mean pressure profile is flattened at the center of the core region, becoming almost hollow. It makes a sharp contrast with the saturated pressure profile in Fig.1, in which the pressure profile in the simulation with the large parallel heat conductivity keeps relatively large beta. It shows that the introduction of the Hall term does not necessarily bring about stabilization of the ballooning modes and can bring about further deterioration of the pressure profile. These numerical results will be taken into account in our future numerical simulations. These numerical results have been presented in the IAEA Fusion Energy Conference at Daejeon, Korea, 2010.[5)]

1) Miura, H., and Nakajima, N.: Nuclear Fusion **50** (2010) 054006.
2) Miura, H. et al.: Fusion Science and Technology **51** (2007) pp.8-19.
3) Sakakibara, S. et al.: Plasma Fusion Res. 1 (2006) pp. 177-185.
4) Huba, J.D.: Phys. Plasmas **3** (1996) 2523-2532.
5) Miura, H. and Nakajima, N.: IAEA 23rd FEC (Oct. 11-16 2010, Daejeon, Korea) TH/P9-16.

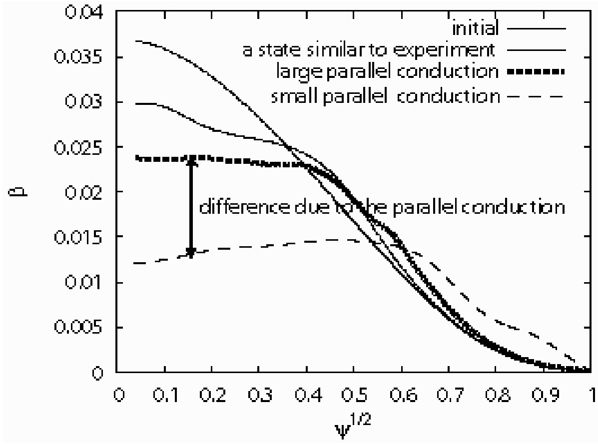

Fig.1: Mean pressure profiles in some nonlinear simulations.

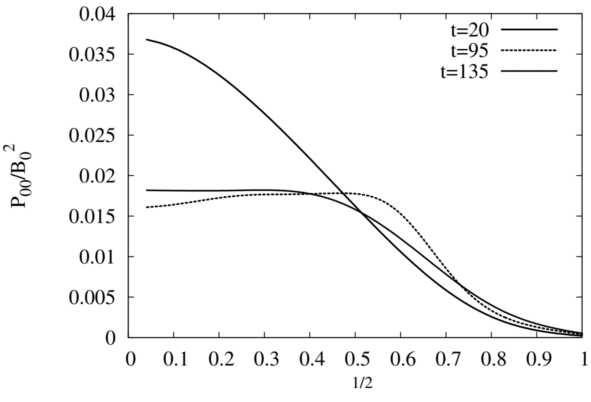

Fig.2: Mean pressure profiles in Hall MHD simulations. The growth of ballooning modes are saturated at t=135 (in toroidal Alfven unit time).