§2. Nonlinear MHD Simulation for High Beta Plasmas in LHD

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In the recent Large Helical Device (LHD) experiments, stable high beta plasmas with about 5% of the volume averaged beta value have been obtained routinely. In MHD equilibria of LHD with a large Shafranov shift, as the β value increases, a region with a chaotic magnetic field becomes wider from peripheral to core region, where temperature gradient still remains, and the Mercier unstable region shifts from the core to peripheral region. Based on these results and the fact that the last closed flux surface does not act as a perfect conductor, full MHD simulations including the chaotic magnetic field region have been performed for the first time for analyzing characteristics of MHD stability of high β LHD plasmas appropriately and understanding why high β plasmas are stably obtained in LHD.

Nonlinear MHD simulation is carried out by using the MIPS code (MHD Infrastructure for Plasma Simulation) [2] which solves the full MHD equations in the cylindrical coordinates (r, φ, z) based on an MHD equilibrium obtained by HINT2 without assuming existence of the nested flux surfaces. The viscosity and thermal diffusion coefficients are set to be 10^{-6}. In order to identify the unstable modes, the Boozer magnetic coordinates are reconstructed inside the last closed flux surface (ρ=1) based on the MHD equilibrium obtained by HINT2, and physics quantities are Fourier decomposed in the region with $\rho < 1$ in terms of poloidal (m) and toroidal (n) mode numbers in the Boozer coordinates. The region with $\rho > 1$ corresponds to the region with a chaotic magnetic field.

Linear analyses of MHD stability have been performed for three MHD equilibria with β_0=7.5%, 9% and 11% (β_0 is a central beta value) for the magnetic Reynolds number $S=10^5$. The used pressure profiles are similar to experimentally obtained ones. The Mercier unstable region shifts from core to periphery as β increases. Figure 1 shows the β_0 dependence of structures of the dominant unstable eigenmodes. As β increases, the dominant eigenmodes change from an internal ballooning mode to modes expanding into a chaotic magnetic field. This implies a chaotic magnetic field region should be included in the analysis of the high β plasmas with unstable modes near plasma periphery.

Nonlinear simulation has been carried out for $S=10^5$ and $S=10^6$ with various β_0. Figure 2 shows time evolution of the total kinetic energy. The simulation results show that the linear growth rate decreases as the β value and/or S increase, although β dependence becomes weaker for lower S. Figure 5 shows time evolution of the pressure profile on a poloidal section for β_0=9% and $S=10^5$. Although the instabilities grow in the periphery region in the linear phase, the core region comes under the influence of the instabilities and the central pressure decreases in the nonlinear phase. However, the collapse of the central pressure strongly depends on S. As S increases, the degree of the collapse decreases, namely the saturated states strongly depends on S and the higher β plasma can be maintained for higher S. Those results are consistent with a result that high β LHD plasmas enter the second stable region of ideal ballooning modes as β increases [1], and remaining destabilized ballooning modes are considered to be resistive type, of which characteristics will be clarified soon.

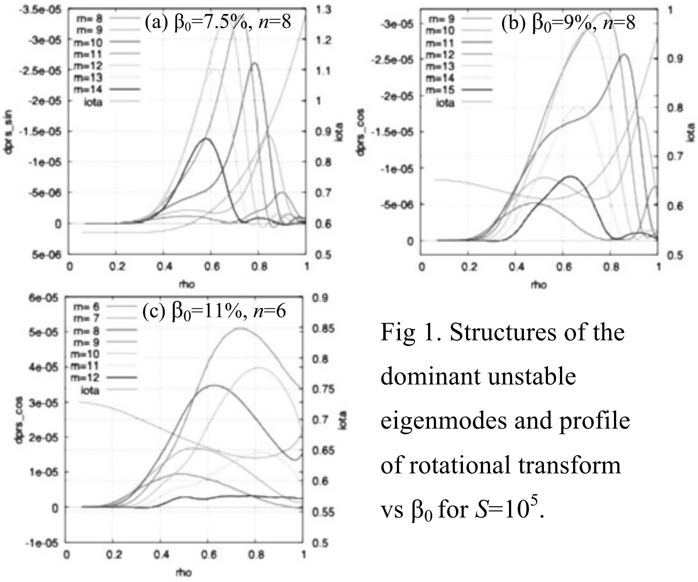

Fig 1. Structures of the dominant unstable eigenmodes and profile of rotational transform vs β_0 for $S=10^5$.

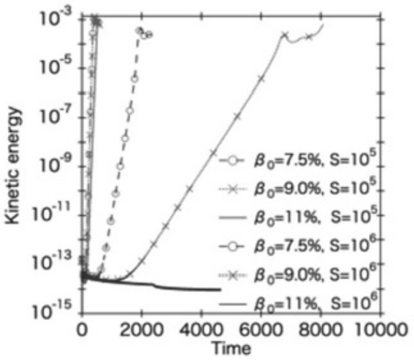

Fig. 2. Time evolution of total kinetic energy.

1) N. Nakajima, et al., Nucl. Fusion **46** (2006) 177,
N. Nakajima, et al., FS&T **51** (2007) 79.
2) Y. Todo, et al., Plasma Fusion Res.5 (2010) S2062.