§19. Study of MHD Stability Beta Limit in LHD by Hierarchy Integrated Simulation Code

Sato, M., Watanabe, K.Y.,
Nakamura, Y. (Kyoto Univ.), Fukuyama, A. (Kyoto Univ.), Murakami, S. (Kyoto Univ.), Toda, S., Yokoyama, M., Funaba, H., Sakakibara, S., Ohdachi, S., Yamada, H., Nakajima, N.

In this study, the beta limit by the ideal MHD instabilities (so-called "MHD stability beta limit") for helical plasmas has been studied in order to explore the capability of the LHD configuration from the perspective of the MHD stability and a guideline for the design of an LHD type fusion reactor[1)]. For analyzing the beta profiles of the "MHD stability beta limit", a hierarchy integrated simulation code TASK3D[2,3)] is extended to include the MHD dynamics such that the linearly unstable MHD instabilities flatten the pressure gradient.

The numerical scheme of the TASK3D code including the MHD dynamics is as follows. First, a pressure profile is given and the equilibrium quantities such as the rotational transform are calculated by the VMEC module[4)]. Next, the linear stability calculation is done by using a set of reduced MHD equations for a straight helical plasma. When the interchange mode becomes unstable, the effect of the MHD instability reflects on the transport coefficient by changing the transport coefficient to a larger value. For the numerical model introduced here, the width of flattening of the pressure gradient is the width of 1/e of the peak amplitude of the eigenmode structure. It is also assumed that there is an upper limit of the mode number of the MHD instabilities which directly affect the pressure gradient. Recent experimental results suggest that eigenmodes of the MHD instabilities with poloidal mode number of $m \leqq 4$ dynamically affect the pressure profile. Using the transport coefficient including the effect of the MHD instabilities, time evolution of the temperature profile is calculated in the transport module TR. The density profile is fixed in this simulation. With the newly obtained temperature (pressure) profile, the equilibrium quantities are calculated again by the VMEC module and then the MHD stability for the new equilibrium profile is evaluated. By repeating the procedure the steady pressure profile is obtained.

From the simulation, the achievable beta of 4.2% and 6.0% are obtained for a peaked profile and a broad profile, respectively. At the achievable beta value, the beta profile and the rotational transform profile are shown in Fig.1. For high beta plasmas, the interchange mode is stable in the core region since the magnetic well is generated and its depth becomes deep due to large Shafranov shift in the LHD configuration. Also the ballooning mode is considered to be stable[5)]. However, the interchange mode limits the pressure gradient in the periphery region ($0.7< \rho <1$). The achievable beta value is limited by the equilibrium limit for the peaked profile. For the broad profile, the achievable beta value is not limited by the equilibrium limit. It is limited by (m,n)=(4,1) mode for which the rational surface is located near the minimum of the rotational transform.

The achievable volume averaged beta value is expected to be beyond 6% from our calculations. In this study, the achievable beta value is investigated for only two types of the beta profile. From the results, there is a possibility that higher beta value is achieved for broader beta profile. In this simulation, the beta value is assumed to be zero in the region where the magnetic surface is predicted to be stochastic. However, a finite pressure gradient is experimentally observed in the stochastic region. When the beta value is finite at the boundary of the well-defined magnetic surface, the higher beta value than the achievable beta value calculated here may be obtained. In order to explore the capability of the LHD configuration, the analysis for various types of the beta profile including effects of the bootstrap current should be necessary.

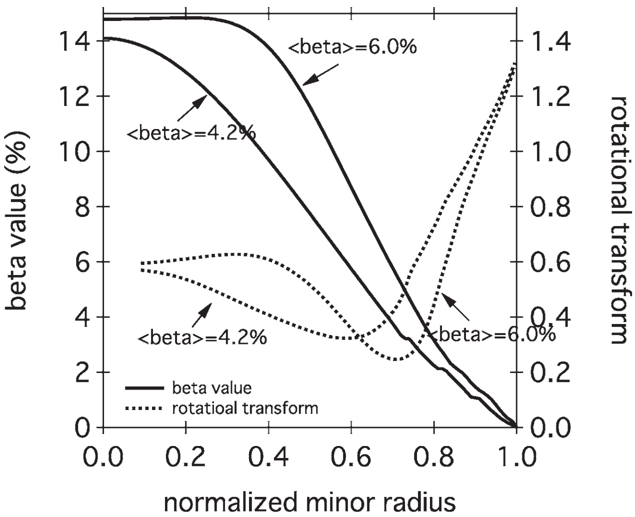

Fig. 1. The beta profile and rotational transform profile at the achievable beta value for a peaked profile and a broad profile.

1) M.Sato *et al.*, Proc. of 22nd IAEA Fusion Energy Conf. (Geneva, Switzerland, 2008) IAEA-CN-165/TH/P9-18.
2) M.Sato *et al.*, Plasma Fusion Res. **3** (2008) S1063.
3) Y.Nakamura *et al.*, Proc. of of 21st IAEA Fusion Energy Conf. (Chengdu, China, 2006) IAEA-CN-149/TH/P7-1.
4) S.P.Hirshman *et al.*, Phys. Fluid **26** (1983) 3553.
5) N.Nakajima *et al.*, Fusion Science and Technology, **51** (2007) 79.