§1. Multi-Scale MHD Simulation of LHD Plasma Including Continuous Heating and Background Pressure Diffusion

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In experiments in the Large Helical Device (LHD), high beta plasmas have been successfully obtained. Particularly, average beta of $\langle\beta\rangle = 5\%$ was achieved in the configuration with the vacuum magnetic axis located at $R_{ax} = 3.6$m. On the contrary, in this configuration, equilibria calculated under the assumption of a parabolic pressure profile that is close to the profile observed in the experiments are unstable against linear ideal interchange modes at much lower beta values than 5%. We investigate the mechanism from the point of nonlinear MHD dynamics of the plasma[1]. Since the stability property strongly depends on the beta value, we develop a multi-scale simulation scheme including beta-increasing effects based on the reduced MHD equations. In the scheme, effects of continuous heating and diffusion of background pressure are incorporated in the equation for the average pressure. Particularly in the present work, we control the heat source term in the equation so that the beta value should increase in a constant rate. This control makes it possible to avoid the saturation of the beta value due to the diffusion of the total pressure, which is observed in the original work[2] under the assumption of a fixed heat source, and to examine the time trace of the plasma behavior up to any high beta value in principle. By applying the scheme to the LHD plasma, we obtain a time evolution up to a beta value much higher than that in the calculation with the fixed heat source.

In the analysis of the LHD plasma, we follow the nonlinear evolution by using the heating source term Q given by $Q = Q_0(1-\rho^2)(1-\rho^8)$, where ρ denotes the square root of the normalized toroidal magnetic flux. The amount of Q_0 is controlled so that the increasing rate of $\langle\beta\rangle$ should be fixed to $0.5 \times 10^{-5}\%/\tau_A$ as shown in Fig.1, where τ_A denotes the Alfvén time. In this calculation, we treat time evolution of equilibrium and perturbed quantities with different time scales simultaneously by iterating the calculations of the equilibrium and the nonlinear dynamics.

As is also shown in Fig. 1, unstable modes are excited weakly and saturated immediately during the time evolution of the plasma. A mode-overlapping which causes a disruptive phenomenon is suppressed during the evolution. The suppression is attributed to deformation of the background pressure profile. As shown in Fig.2, the weak excitations generate local flat structure around the resonant surfaces. Such structure decreases the driving force of the modes and reduces the growth at higher beta. Therefore, the local reduction of the background pressure gradient due to the nonlinear dynamics is considered to be the stabilizing mechanism of the LHD plasma.

Furthermore, both the continuous heating and the background pressure diffusion have an effect to smooth out the local flat structure and also influence the interaction between the modes. Under the situation, the plasma is continuously self-organized as the beta increases so that the vortices of all of the modes should not overlap as a whole. Such self-organization can be obtained only in the analysis including the beta-increasing effect. The result obtained here indicates the existence of a stable path to the high beta regime obtained in the experiments.

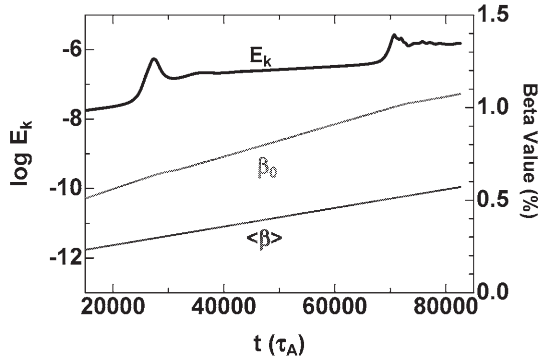

Fig. 1: Time evolution of kinetic energy and beta values.

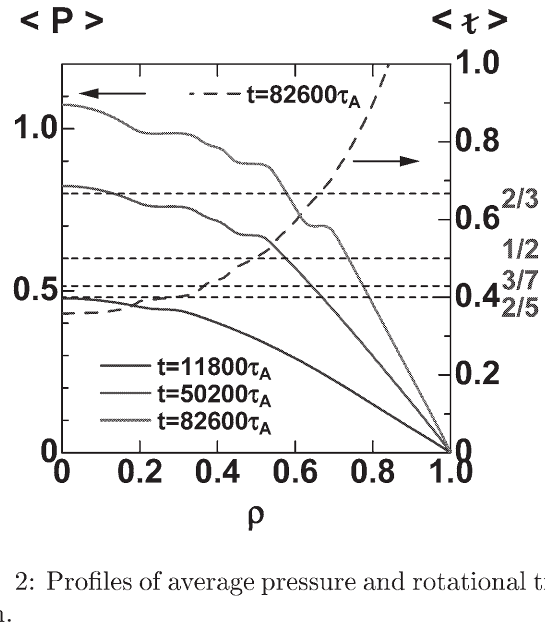

Fig. 2: Profiles of average pressure and rotational transform.

1) Ichiguchi, K. et al., Nucl. Fusion **43**, 1101-1109 (2003).

2) K.Ichiguchi, B.A.Carreras, J. Plasma Fusion Res. SERIES **8** (2009) 1171.