3-1. Fusion Plasma Simulation

§1. Multi-Scale MHD Analysis of Beta-Increasing LHD Plasma

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In the LHD experiments, high beta plasmas have been successfully obtained beyond $\langle\beta\rangle = 5\%$ in the configuration where linear ideal interchange modes are unstable even for $\langle\beta\rangle < 1\%$. We investigate the stabilizing mechanism utilizing a nonlinear simulation code NORM[1], which is based on the reduced MHD equations. Since the stability property strongly depends on the beta value, we develop a multi-scale simulation scheme including beta-increasing effects. We can treat both time evolutions of perturbed and equilibrium quantities with different time scales simultaneously with this scheme. In the scheme, the equation for the average pressure is regarded as a pressure transport equation, which consists of nonlinear convection, diffusion of background pressure and continuous heating source. The heating source $Q(\rho)$ is adjusted so that the beta value should increase in a constant rate.

We apply the scheme to the LHD plasma to analyze the nonlinear dynamics in the beta increasing phase[2]. We have followed the dynamics up to $\langle\beta\rangle = 1.05\%$. The numerical result shows a stable evolution of the LHD plasma with weak fluctuations as shown in Fig.1. At a low beta just larger than the marginal value, an interchange mode is weakly excited and saturates immediately because the driving force is small. The weak excitation generates local flat regions around the resonant surface in the background pressure profile. Such structure decreases the driving forces of the mode at higher beta. Similar weak activity occurs for multiple modes with different helicities simultaneously. As a result, as shown in Fig.2, each mode is localized around its resonant surface and the profile of the background pressure becomes staircase-like. Thus, the local reduction of the background pressure gradient due to the nonlinear dynamics is considered to be the stabilizing mechanism of the LHD plasma. That is, the plasma is continuously self-organized as a whole in the increases of beta so that no disruptive phenomenon occurs.

By utilizing the evolution of the background pressure profile $\langle P\rangle(\rho)$, we evaluate an effective diffusion coefficient D_{eff}, which is defined as

$$D_{eff}(\rho) = \frac{\dfrac{\partial W}{\partial t} - S_P}{\langle\sqrt{g}\rangle \dfrac{\partial \langle P\rangle}{\partial \rho}}. \quad (1)$$

Here

$$W(\rho) = \int_0^\rho \langle P\rangle(\rho)\langle\sqrt{g}\rangle d\rho, \quad S_P(\rho) = \int_0^\rho Q(\rho)\langle\sqrt{g}\rangle d\rho, \quad (2)$$

where ρ is a radial coordinate and $\sqrt{g}$ is the Jacobian. As shown in Fig.3, the coefficient also locally enhances around the resonant surfaces and increases as beta. This property reflects the enhanced diffusion due to the interchange dynamics.

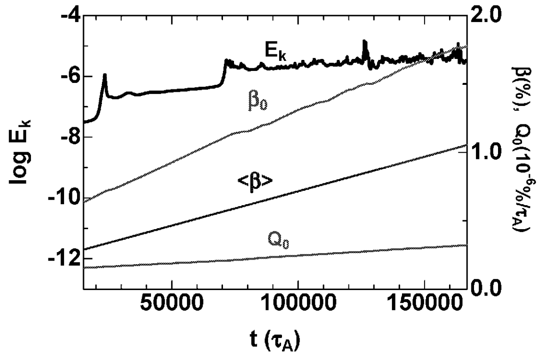

Fig.1 : Time evolutions of kinetic energy (E_k), axis (β_0) and average ($\langle\beta\rangle$) and amount of heat source.

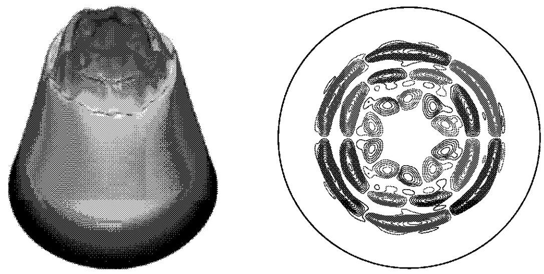

Fig.2 : Birds eye view of pressure and mode pattern at $t = 166800\tau_A$.

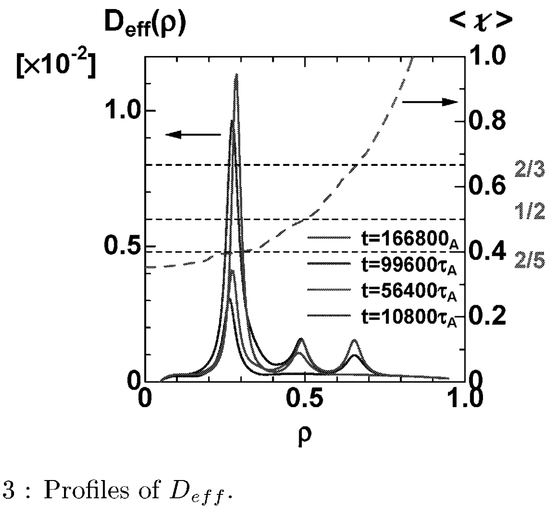

Fig.3 : Profiles of D_{eff}.

1) Ichiguchi, K. et al., Nucl. Fusion **43**, 1101 (2003).
2) Ichiguchi, K. et al., Nucl. Fusion **51**, 053021 (2011).