§11. Multi-Scale MHD Simulation Incorporating Pressure Transport Equation for LHD Plasma

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To understand consistently the MHD dynamics of the magnetically confined plasma in the increase of beta, it is necessary to examine a continuous evolution of the plasma. In this case, we have to treat the time evolution of the perturbation and the equilibrium simultaneously. For this purpose, we have developed a multi-scale MHD simulation scheme based on the reduced MHD equations. In the previous version of the scheme[1)], effects of the diffusion of the background pressure and the continuous heating were not taken into account. Thus, we have improved the scheme so as to include these effects.

In the present scheme, the pressure P is decomposed into the average and the oscillating parts as

$$P(\rho,\theta,\zeta;t) = \langle P\rangle(\rho;t) + \widehat{P}(\rho,\theta,\zeta;t). \qquad (1)$$

The angle bracket and the hat indicate the average and the oscillating parts, respectively. Then, the equation for $\langle P\rangle$ in the reduced MHD equations is given by

$$\frac{\partial\langle P\rangle}{\partial t} = -\langle[\widehat{P},\tilde{\Phi}]\rangle + \kappa_{\perp 0}\langle\Delta_*\langle P\rangle\rangle + \kappa_{\parallel 0}\langle\nabla_{\parallel}^{\dagger 2}\langle P\rangle\rangle + Q. \quad (2)$$

Here $[y,z]$ denotes the Poisson bracket. The diffusion operators Δ_* and $\nabla_{\parallel}^{\dagger 2}$ are defined as

$$\Delta_* f = \left(\frac{R}{R_0}\right)^2 \nabla_\perp \cdot \left(\frac{R_0}{R}\right)^2 \nabla_\perp f \qquad (3)$$

and

$$\nabla_{\parallel}^{\dagger 2} f = \nabla_{\parallel}\left[\left(\frac{R_0}{R}\right)^2 \nabla_{\parallel} f\right], \qquad (4)$$

respectively, where R/R_0 denotes the normalized major radius. The operators of $\nabla_\perp$ and $\nabla_\parallel$ are perpendicular and parallel differential operators, respectively. The factors of $\kappa_\perp$ and $\kappa_\parallel$ are the perpendicular and the parallel heat conductivities, respectively. The heat source term Q is added in Eq.(2).

In this formulation, we treat $\langle P\rangle$ as the background equilibrium pressure. Hence, Eq.(2) can be regarded as a transport equation for the background pressure. The equation consists of the convection term, the perpendicular and the parallel diffusion terms and the heat source term. These terms correspond to the anomalous diffusion due to the nonlinear turbulence, the classical heat diffusion and the continuous heating for the background pressure, respectively. By using the equation, we can follow the dynamics of the background pressure incorporating the continuous heating and the background diffusion. The equation (2) is incorporated in the NORM code[2)].

The scheme is applied to the analysis of the low-beta inward-shifted LHD plasma. The beta value is increased as shown in Fig.1. Self-organization of the pressure profile is obtained as a result of the frequent interaction of the weak interchange modes which are resonant at the different surfaces. The resultant pressure profile is shown in Fig.2. The continuous heating and the background diffusion are crucial for the frequent weak activity. In the time evolution, the reconstruction of a global pressure gradient and the reduction of the mode amplitude are seen as beta increases. This tendency indicates a stable path to a high beta regime, which has been achieved in the experiments.

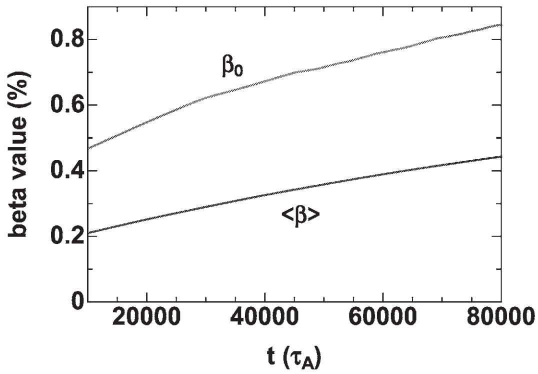

Fig. 1: Time evolution of beta values.

Fig. 2: Bird's eye view of total pressure profile at $t = 80,000\tau_A$.

1) Ichiguchi, K., Carreras, B. A., Plasma and Fusion Research **3** (2008) S1033.

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