§18. Verification of the Dynamic Plasma Profile Description Model

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In order to predict the plasma profile changes in the LHD discharges, the direct profile extrapolation (DPE) method, in which gyro-Bohm type parameter dependence is assumed, has been extended to a dynamic plasma profile analysis combining with a diffusion equation. The dynamic plasma profile description model has been verified comparing with the pellet injected LHD discharge, in which density profile and temperature profile are significantly changed in a short time.

The followings are calculation procedures and assumptions which are taken into account in this model.

1. particle transport is dominated by the diffusion equation,

$$\frac{\partial n}{\partial t} = D\frac{\partial^2 n}{\partial r^2} + \left(\frac{D}{r} + \frac{\partial D}{\partial r} - V\right)\frac{\partial n}{\partial r} - \left(\frac{V}{r} + \frac{\partial V}{\partial r}\right)n + S. \quad (1)$$

2. The particle transport coefficients has been scaled by the power scan experiments in the NBI heated long pulse discharges, and it can be expressed as a function of the power density (Fig. 1).

$$D(r) = 2.79\times10^7 \left(\frac{P}{< n >}\right)^{0.6} B_{\mathrm{T}}^{-0.8}, \quad (2)$$

$$V(r) = 0. \quad (3)$$

3. Only pellet fueling is considered as a particle source because it is the only possible solution to inject particle inside the last closed flux surface under the burning plasma condition at this moment. Although the high field side pellet injection is one of the effective solutions to enhance fueling efficiency in tokamaks, similar improvement of the fueling efficiency has not been observed clearly in LHD. Therefore, a conventional Neutral Gas Shielding (NGS) pellet ablation model has been employed to estimate the particle source profile of the fueling. The recycling effects is taken into account by changing a boundary condition of a density profile.

4. A stationary solution of a pressure profile which corresponds to a density profile can be estimated from the $p_{\mathrm{norm.}}$, which is evaluated from the LHD experiments by the DPE method. On the other hand, since the pressure profile should be changed on a time scale of the energy confinement time, a dynamical pressure profile at a given instant $p(r,t)$, should be estimated taking into account the energy confinement time τ_{E} as follows,

$$\frac{\partial p}{\partial t} = \frac{1}{\tau_{\mathrm{E}}}\left(P^{0.4} n^{0.6} {B_{\mathrm{T}}}^{0.8} p_{\mathrm{norm.}} - p\right), \quad (4)$$

$$\tau_{\mathrm{E}} = \frac{W}{P - \frac{dW}{dt}}. \quad (5)$$

5. Once the density and pressure profiles are known, temperature profile $T(r,t)$ and fusion output can be derived from the profiles of the density and pressure.

Adequacy of the above-described model is verified by reproducing the LHD discharge with intensive pellet injections. Fig. 2 is a comparison of waveform between the LHD experiment and model calculation. Multiple pellets are injected in the period between 3.7 s and 4.0 s and the central electron density; $n_{\mathrm{e}}(0)$ increases from 0.2×10^{20} m^{-3} to 2.5×10^{20} m^{-3} during the pellet injection sequence, while the central electron temperature $T_{\mathrm{e}}(0)$ decreases from 2.3 keV to 0.3 keV. After the pellet injection sequence, the temperature recovery is faster than density relaxation, and therefore the plasma stored energy continues to increase for 300 ms. The model calculation results agree well with the measurements not only in attainable values but also in a time constant despite the fact that the normalized collisionality ν_{b}^*, which is the electron-ion collision frequency normalized by the trapped electron bounce frequency, is varies by two orders from 0.28 to 22.

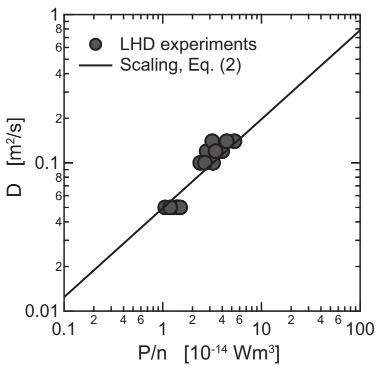

Fig. 1: Power density dependence of the observed and scaled diffusion coefficient.

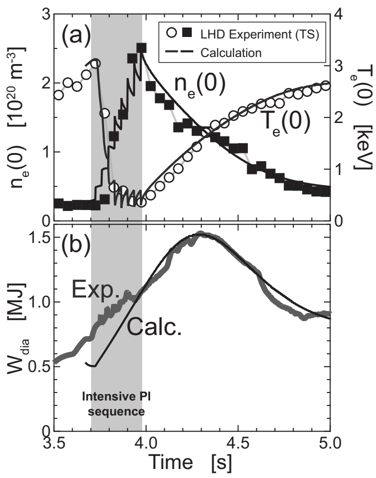

Fig. 2: Comparison of the temporal evolution in an intensive pellet fueled discharge between the LHD experiment and simulation. (a) Central density and temperature, (b) plasma stored energy.