§38. Analysis of Toroidal Current Profile Evolution in LHD NBI Experiment

Watanabe, K.Y., Sakakibara, S., Murakami, S.,
Sasao, H. (General Univ. for Adv. Studies)

We study the time evolution of the toroidal current profile, I_p, in LHD NBI experiment based on the solving the 1D diffusion equation. When we estimate the toroidal current, we take the bootstrap current and the ohkawa current into account as the non-inductive current, I_{NI}.

The basic equation is as the followings,

$$\mu_0 \frac{\partial I_p}{\partial t} = 4\pi S \frac{\partial}{\partial S}\left[\frac{1}{\sigma}\frac{\partial}{\partial S}\left(I_p - I_{NI}\right)\right] ,$$

where S is the area and I_p (S) is the toroidal current flowing inside a magnetic flux and

$$J_p(S,t) = \frac{\partial}{\partial S} I_p \cdot$$

The boundary condition is as the followings,

$$I_p(0,t) = 0 ,$$

$$\left.\frac{\partial}{\partial S}\left(I_p - I_{NI}\right)\right|_{S=\pi a^2} = \sigma \frac{1}{2\pi R_0}\left(V_{loop} - \frac{\partial I_p}{\partial t}\right) .$$

Here V_{loop} is the one turn voltage. We assume that the ohmic current is zero because we don't induce the one-turn voltage actively. The initial condition is as

$$J_p(S,0) = J_0(S) \cdot$$

Here we adapt the slender torus model as the external inductance, L_{ext}, and the neoclassical tokamak model as the conductivity, σ. The bootstrap current is estimated by SPBSC code [1] and the ohkawa current is evaluated considering orbit and charge exchange losses with the 3D Monte Carlo simulation [2] consistently with the experimental data.

Figure 1 shows a time evolution of the plasma stored energy, W_p, the electron density, n_e, and the electron temperature, T_e. This discharge starts with 2 NBI beam lines and after 1.2s only co-injected NB is injected. The stored energy increases with the density increase and the temperature keeps constant. Figure 2 shows the calculation results of the toroidal currents. In the phase of A in Fig.2, the non-inductive current is almost constant even the stored energy increases. That is the reason why the ohkawa current decreases with the density increase, on the contrary, the bootstrap current increases with the stored energy increase, then the summation of them is almost constant. The time evolution of the toroidal current is slower by L/R time than that of the non-inductive current. Here, L/R is 1.0s. Then, the toroidal current takes 1.5s to saturate. In the phase of B, the stored energy, the density and the electron temperature are almost constant. However, the bootstrap current increases rapidly and the ohkawa current is almost constant, then the non-inductive current increases rapidly at 2.7s. That is the reason why the electron temperature profile changes, and then the bootstrap current increases rapidly. As you know well, the bootstrap current strongly depend on the temperature and the density gradient as well as the stored energy. On the contrary, the ohkawa current doesn't depend on the gradients. Figure 3 shows the comparison between the experimental data and the calculation result based on the toroidal current profile analysis. As you know from Fig.3, the waveforms look same as well as the amplitude.

From this study, in LHD NBI experiments, we find that the toroidal current is induced by ohkawa current and bootstrap current, and that the change of the gradient in the temperature and the density leads to the change in the net toroidal current.

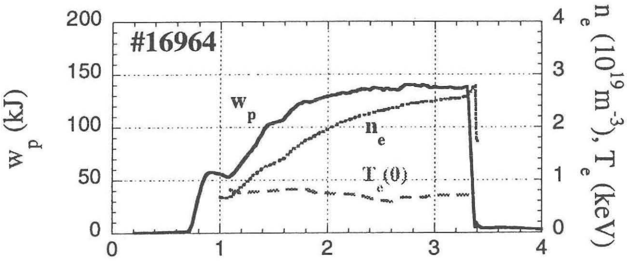

Figure 1 The time evolution of W_p, n_e, and T_e.

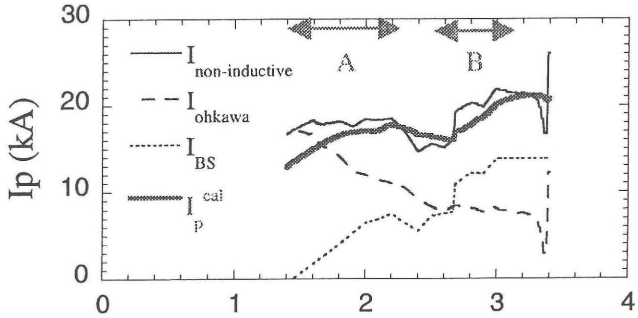

Figure 2 The time evolution of the calculated toroidal currents.

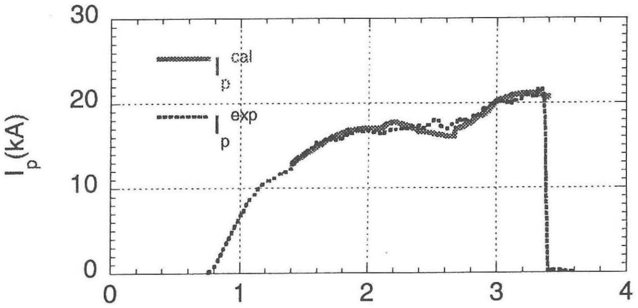

Figure 3 The time evolution of the toroidal currents observed in the experiment and obtained by the calculation.

[1] K.Y. Watanabe et al, Nuclear Fusion 35, 335 (1995).
[2] S. Murakami et al, Trans. Fusion Technol. 27, 259 (1995).