# §10. Effect of Time Evolution of the MHD Equilibrium on Transport Properties in Helical Plasmas

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In the helical plasma of LHD type, the MHD equilibrium properties, especially in the core region, changes so much as the beta increases because the Shafranov shift is large due the the small rotational transform. And the bootstrap current changes the properties so much as the beta increases and the collisionality decreases because the bootstrap current is not suppressed in the design. Then, the discharges with the super high density in the core region (SDC)[1] would have the much more different MHD equilibrium property than that of the vacuum. The large Shafranov shift is predicted due to the large central beta value and the large gradient. And the bootstrap current is expected to increase due to the increase of the beta gradient after the pellet injection, and to decrease due to the large Shafranov shift, which means that the consistent evaluation with MHD equilibrium is necessary. The Ohkawa current is expected to decrease due to the increase of the density. And the plasma resistivity increases due to the decreases of the electron temperature, which affects the inductive current. As mention in the above, when the transport property in a SDC discharge is studied, we should take the time evolution of the MHD equilibrium and its effects on the transport unto account.

Figure 1 shows the time evolution of the beta value and the electron density in a typical SDC discharge. There ECH started the discharge, NBI maintains it, and after the $H_2$ ice pellets injection during t=0.6~0.9s, the density and the beta value rapidly increases. Figure 2 shows the time evolution of the bootstrap current and the Ohkawa current predicted by a numerical calculation. There the bootstrap current is evaluated by BSC code[2] and the Ohkawa current is by the FIT[3] code and BSC code. BSC can calculate the geometric factor, which is necessary to calculate the bootstrap current. the Ohkawa current and the neoclassical resistivity from the MHD equilibrium results by VMEC code. FIT can calculate the source current of the Ohkawa current. In the begging phase of the discharge (before t=0.6s), the Ohkawa current is expected more than 100kA due to the high temperature and the low density, the bootstrap current is small due to the low beta value. After the pellet injection, the Ohkawa current rapidly decreases due to the rapid rise of the density. On the contrary, the bootstrap current increases due to the increase of the beta value. In Fig.2, the observed current in the discharge of Fig.1 is also shown. The difference between the observed current and the sum of the predicted bootstrap current and the Ohkawa current is expected the inductive (ohmic) current, which means the inductive current is much larger than the observed current in the SDC discharge, then suggests that it is quite important to establish the evaluation method of the inductive current when we study the transport property in the SDC discharge. We have already proposed a evaluation method of the inductive current in helical plasmas. And a numerical code (task/ei) was developed for the analysis for the discharges with the relatively small change of the beta value. The basic equation is as the follows.

$$\frac{\partial \iota}{\partial t} = \left(\frac{\phi_a}{s}\frac{\partial \phi_a}{\partial t}\right)\frac{\partial \iota}{\partial s} + \frac{1}{\phi_a^{\,2}}\left[\frac{\partial}{\partial s}\left\{\eta_\parallel \mathcal{V}'\frac{\langle B^2\rangle}{\mu_0^{\,2}}\frac{\partial}{\partial s}\left(S_{11}\iota + S_{12}\right)\right\} + \frac{\partial}{\partial s}\left\{\eta_\parallel \mathcal{V}' p'\left(S_{11}\iota + S_{12}\right) - \eta_\parallel \mathcal{V}'\left\langle \mathbf{j}_{NI}\cdot\mathbf{B}\right\rangle\right\}\right].$$

The notation should be referred in ref.[4]. For the SDC discharge, which has the rapid change in the beta vale, we need to take the additional effect into account. The effect is due to the change of the toroidal flux at the plasma edge. Now we are equipping the function in the basic equation.

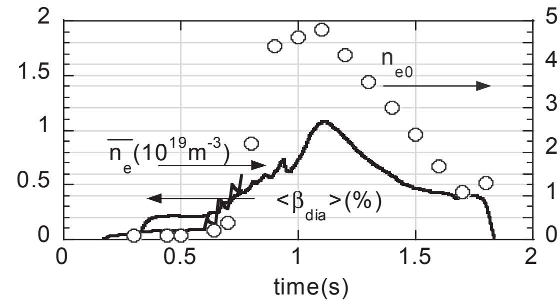


Fig.1 The wave form a typical SDC discharge (#64359).

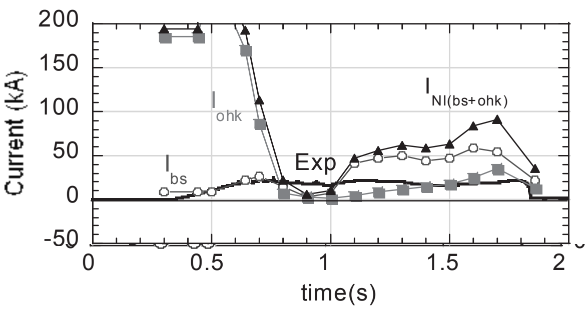


Fig.2 The prediction of the bootstrap current ($I_{bs}$), the Ohkawa current (k) and the observed plasma current (Exp) in the discharge in Fig.1

[1] R. Sakamoto et al., Nucl. Fusion 49 (2009) 085002.
[2] K.Y. Watanabe et al., Nucl. Fusion 35 (1995) 335.
[3] S.Murakami et al., Trans. Fusion Thechnol. 27 (1995) 259.
[4] Y.Nakamura et al., 22nd IAEA Fusion Energy Conference, Geneva(Switzerland), Oct. 2008, EX/P6-20.