§10. Expansion of Neoclassical Transport Analysis in/around an m/n = 1/1 Magnetic Island

Kanno, R.,
Nunami, M. (Institute of Laser Engineering, Osaka Univ.),
Satake, S.,
Takamaru, H., Okamoto, M. (Chubu Univ.)

Recent Large Helical Device experiments show that the transport modeling based only on the fluid description is not sufficient for expressing transport phenomena in an $m/n = 1/1$ magnetic island formed at the edge, and that neoclassical effect should be considered in order to understand the edge transport phenomena, where m is the poloidal mode number and n the toroidal mode number. For example, it is observed that an $m/n = 1/1$ magnetic island, which is formed at the edge by using external coils, is healed, where m and n are the poloidal and toroidal mode numbers, respectively. The experimental results suggest that current depending on the pressure is expected to explain the healing. We have two conventional candidates of such current; one is the Pfirsch-Schlüter current and the other is the bootstrap current. In results of a previous simulation study based on the fluid description, it is shown that the healing phenomenon is not explained by the Pfirsch-Schlüter current only. Thus, the bootstrap current around the island is a possible mechanism related to the pressure. From the experiments, we see that the kinetic treatment is required for the edge plasma.

To study the edge transport phenomena, we develop a new transport simulation code, KEATS, treating the neoclassical theory in the island region. The code is programmed by expanding a well-known Monte-Carlo particle simulation scheme based on the δf method for taking account of the neoclassical effect.

We consider that the guiding center distribution function of plasma f is separated into an equilibrium-like background f_0 and a kinetic part δf of the distribution, i.e., $f = f_0 + \delta f$, where the kinetic part δf is considered as a small perturbation from f_0. Approximately, the edge plasma can be treated as fluid, thus the background is described by the fluid equations. Then the Maxwellian background is allowed. Thus, the zeroth-order distribution function f_0 is given as a local Maxwellian distribution. Applying the decomposition $f = f_{\mathrm{M}} + \delta f$ to the drift kinetic equation, we obtain the equation of the kinetic part δf. In evolution of the δf part, the background f_{M} is fixed.

For a test calculation of the KEATS code, we use a magnetic configuration which is formed by adding an $m/n = 1/1$ island component into a simple tokamak field, where the major radius of the magnetic axis $R_{\mathrm{ax}} = 3.6$ m, the minor radius of the plasma $a = 1.0$ m and the magnetic field strength on the axis $B_{\mathrm{ax}} = 3.0$ T. Hereafter, it is called the "test configuration." In the KEATS code, the number of test particles is $N_{\mathrm{TP}} = 16,000,000$. In the test calculation, the effect of neutrals and the effect of electric field are neglected for simplicity.

To investigate effect of the existence of the island on the transport phenomena, we evaluate the radial profile of ion energy flux $\boldsymbol{Q}_{\mathrm{i}}$ in a fixed temperature profile given as $T_{\mathrm{i}} = T_{\mathrm{ax}}\{0.02 + 0.98\exp[-4(r/a)^{2.5}]\}$ with $T_{\mathrm{ax}} = 2$ keV and $r = \sqrt{(R - R_{\mathrm{ax}})^2 + Z^2}$, which neglects the existence of the island. The density profile is set homogeneous, $n_{\mathrm{i}} = \mathrm{const.} = 1 \times 10^{19}$ $1/\mathrm{m}^3$. We estimate the radial energy flux in two cases, i.e., in the configurations (a) without islands (the simple tokamak field) and (b) with the $m/n = 1/1$ island (the test configuration). Because we have no magnetic coordinate system including several magnetic field structures as the island and the core region, for simplicity the radial energy fluxes are evaluated neglecting the existence of the island, that is averaged over concentric circular shell region in the whole toroidal angles as if there were nested flux surfaces. The estimation of radial energy flux is shown in Figure 1. From the results, we find that the energy flux is strongly affected by the magnetic island. In the case (a), the energy flux has a gentle profile (circles). On the other hand, in the case (b), we see that there are obvious difference compared with the case (a). In the island region, we obtain that the flux has a steeple peak (triangles). This result suggests that the flux arises to make the temperature flat in the region.

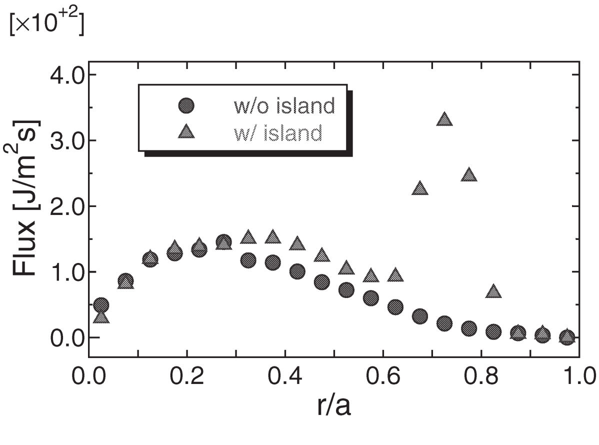

Figure 1: Radial profiles of ion energy flux in the simple tokamak field (circles) and in the test configuration (triangles), where $r = \sqrt{(R - R_{\mathrm{ax}})^2 + Z^2}$.