§11. Development of a Drift-kinetic Simulation Code Including Effects of Resonant Magnetic Perturbations and Radial Electric Field

Kanno, R., Nunami, M., Satake, S., Matsuoka, S. (RIST), Takamaru, H. (Chubu Univ.)

To understand properties of plasma transport in a perturbed magnetic field is important for control of fusion plasma by employing resonant/non-resonant magnetic perturbations (RMPs/non-RMPs) [1]. In the recent tokamak experiments [2,3], RMPs/non-RMPs are used to suppress edge localized modes. It has been found simultaneously with the suppression that the theoretical estimates of radial transport in the perturbed region, which are based on the field line diffusion derived by Rechester-Rosenbluth [4], are too large compared to the experimental results [2]. The purpose of this study is to reconsider the fundamental properties of the plasma transport. In order to approach the 'puzzle' of plasma transport in a perturbed region, we have started from the step to examine the dependences of the radial thermal diffusivity on several important parameters (e.g., the strength of RMPs, collisionality, etc.) by using the drift-kinetic simulation code, KEATS. In the previous simulation studies under an assumption of zero electric field [5,6], we have found that 1) the radial thermal diffusivity in an ergodic region is close to the theoretical one derived by [4] if the diffusivity is estimated at $t \ll {\omega_{\rm t}}^{-1}$, where t is time and $\omega_{\rm t}$ is the transit frequency, 2) the diffusivity in a quasi-steady state is extremely small compared with the theory of [4], and 3) the dependence of the diffusivity on the parameters in the quasi-steady state is approximately same as in the formula of [4]. At the present, the study is progressing for investigating effects of radial electric field E_r on the plasma transport. To investigate the transport in a perturbed region, we use a magnetic field $\boldsymbol{B}$ that is formed by adding an RMP field $\delta\boldsymbol{B}$ to a circular tokamak field $\boldsymbol{B}_0$ having concentric circular flux surfaces, where the major radius of the magnetic axis $R_{\rm ax} = 3.6$ m, the minor radius of the plasma $a = 1$ m, and the magnetic field strength on the axis $B_{\rm ax} = 4$ T. The unperturbed magnetic field $\boldsymbol{B}_0$ is given by $B_{0R} = B_{\rm ax}Z/qR$, $B_{0\varphi} = B_{\rm ax}R_{\rm ax}/R$, and $B_{0Z} = B_{\rm ax}(R - R_{\rm ax})/qR$. The RMPs causing resonance with the rational surfaces of $q = 3/2$, 10/7, 11/7, 13/9, 14/9, 16/11, 17/11, 19/13, 20/13, 22/15, 23/15, 25/17, 26/17 are given as the perturbation field $\delta\boldsymbol{B} = \nabla \times (\alpha\boldsymbol{B}_0)$, and the total magnetic field is $\boldsymbol{B} = \boldsymbol{B}_0 + \delta\boldsymbol{B}$. Details of the RMP field are explained in [5].

It is well known that the drift-kinetic equation in regular closed magnetic surfaces satisfies the following relation: $E_r = (T/e)(1/n)({\rm d}n/{\rm d}r)$ or $n = n_0 \exp(-e\Phi/T)$ if $u_{||} = 0$ and $\nabla T = 0$ [7], where the Maxwellian background is assumed, T is the temperature, n the density (n_0 the density at the magnetic axis), e the elementary charge, Φ the electric potential, and $u_{||}$ the parallel flow velocity. The neoclassical transport with the self-consistent electric field E_r, which satisfies $E_r = (T/e)(1/n)({\rm d}n/{\rm d}r)$, is confirmed by using KEATS code, as shown in Fig.1, and is compared to the case without E_r. In the case without E_r, a self-collision-driven ion flux is seen, see also [7].

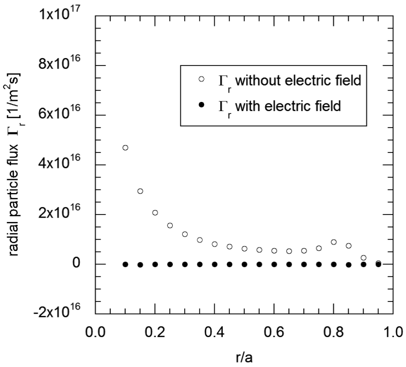

Fig. 1: Radial particle fluxes of ion with/without E_r in the unperturbed field B_0, where $\delta f(t = 0) = 0$.

We preliminary calculate the particle flux of electron affected by RMPs and radial electric field. It is found that the electron particle flux is reduced by radial electric field E_r; see Fig.2.

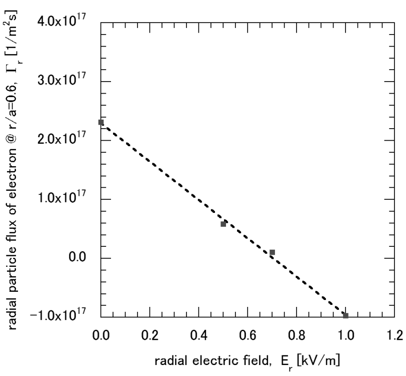

Fig. 2: Dependence of radial particle flux of electron on E_r at the center of the perturbed region.

[1] R.J. Hawryluk *et al.*, Nucl. Fusion **49** (2009) 065012.
[2] T.E. Evans *et al.*, Nature Phys. **2** (2006) 419.
[3] W. Suttrop *et al.*, Phys. Rev. Lett. **106** (2011) 225004.
[4] A.B. Rechester and M.N. Rosenbluth, Phys. Rev. Lett. **40** (1978) 38.
[5] R. Kanno *et al.*, Plasma Phys. Control. Fusion **52** (2010) 115004.
[6] R. Kanno *et al.*, Plasma Phys. Control. Fusion **55** (2013) 065005.
[7] W.X. Wang *et al.*, Phys. Rev. Lett. **87** (2001) 055002.