§23. Comparison of Neoclassical Flow Calculations by the Moment Method with CXRS Measurement on Heliotron J

Nishimura, S.,
Nishioka, K., Nakamura, Y., Lee, H.Y., Kobayashi, S. (Kyoto Univ.)

Numerical and experimental analyses of neoclassical flows are one of the important issues in fusion plasma studies. Careful calculation would provide the reasonable estimation of the bulk ion flow velocity, which is difficult to be measured experimentally. Experiments for investigating a configuration dependence of the neoclassical flows are now actively performed in Heliotron-J [1]. The moment method [2] is a powerful method to analyze neoclassical flows and viscosity numerically with the collisional interactions between different particle species satisfying the self-adjoint and Galilean invariant properties and the momentum conservation. Especially, the external parallel momentum input had never been investigated in previous experimental studies applying this theory [3]. We applied this method to estimate the multi-species parallel ion flows and parallel particle viscosities for neutral beam injection plasmas in the Heliotron J. The results on fully ionized carbon ions (C^{6+}) are compared with the charge exchange recombination spectroscopy (CXRS) measurements with a toroidal viewing [1].

The Laguerre expansion coefficients $\int v\xi L_j^{(3/2)}(x_a^2)C_{af}\left(f_{aM}, f_f\right)d^3\mathbf{v}$ of the RMJ operator for collisions between thermalized particles' Maxwellian f_{aM} and the tangentially injected fast ions' velocity distribution f_f are added to the simultaneous parallel force balance equations, which are previously generalized to cases with multiple ion species [4]. The fast ion distribution f_f is determined by using HFREYA and MCNBI in the FIT3D code [5]. Its energy space structure is determined by a method in Ref.[6]. The Onsager symmetric transport matrix including the fast ion driven parallel flows and radial fluxes is obtained by solving this simultaneous equation numerically. Though this radial fluxes are generated by an orbit effect analogous to well-known Ware pinch, they are non-ambipolar ones in contrast to the usual Ware pinch due to inductive parallel electric fields in tokamaks. Radial electric fields are determined by the ambipolar condition including this fast ion driven particle fluxes, and then the parallel particle flow velocities of each particle species, which are driven by the radial gradient forces X_{a1}, X_{a2} [2,4] and the external parallel momentum input, are obtained. Though the experiments have been conducted for three types of magnetic configurations (high-mirror, standard, reversed-mirror) [1], here we show a calculation example in the standard configuration. Figure 1 shows the calculated parallel velocities of the target plasma ions in co- and counter- NB(30keV, H^+) injection shots. Here, used target plasma parameters are $n_e(r)=1.5\times10^{19}[1-(r/a)^2]\mathrm{m}^{-3}$, $T_e(r)=300[1-(r/a)^2]\mathrm{eV}$, $T_i(r)=175[1-(r/a)^{1.57}]^{1.11}\mathrm{eV}$, and the target particles' density ratio is $e^-:D^+:C^{6+}=1:0.82:0.03$ ($Z_{eff}=1.9$).

Figure 2 shows comparisons of the calculation results for C^{6+} with the CXRS measurements [1]. A good agreement can be seen for both of the co- and counter-injection shots. In this calculation, a difference between the co- and counter-injections on the ambipolar radial electric field strength is predicted since this theory includes the fast ion driven non-ambipolar radial current. A poloidal CXRS measurement to investigate this radial electric field is planed in near future.

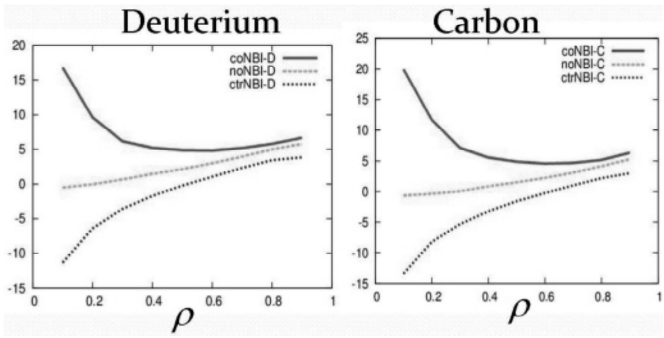

Fig.1 Calculated ion flow velocities $\left\langle Bu_{\|a}\right\rangle$ [T•km/s]. The co- and counter-injection shots and a case without the external momentum input are compared.

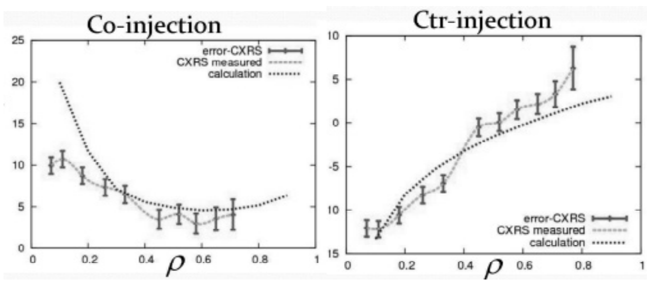

Fig.2 The calculated and measured $\left\langle Bu_{\|a}\right\rangle/B$ [km/s] of the C^{6+} ions.

[1] Lee,H.Y., Kobayashi,S., et al. Plasma Phys. Control. Fusion **55**, 035012 (2013)

[2] Sugama,H., Nishimura,S., Phys.Plasmas **9**, 4637 (2002)

[3] Briesemeister,A., et al., Plasma Phys. Control. Fusion **55**, 014002 (2013)

[4] Nishimura,S., Sugama,H., et al., Phys.Plasmas **17**, 082510 (2010), **18**, 069901 (2011)

[5] Murakami,S., et al., Trans.Fusion Technol., **27**,259 (1995)

[6] J. D. Gaffey,Jr., J.Plasma Physics **16**,149 (1976)