§38. 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. Experiments for investigating a configuration dependence of the neoclassical flows are now actively performed in Heliotron-J [1]. In a previous report [2], a comparison of theoretical calculations of the NB- (neutral beam) driven ion flows and the CXRS measurement is shown.

However, spontaneous flows driven by the radial gradient force $\partial p_a/\partial r$, $\partial T_a/\partial r$, $\partial \Phi/\partial r$ were not discussed in detail. When applying the theory in Refs.[3], an important issue in this radial gradient force effect is the non-diagonal coupling between parallel flows and radial transport included in the full Onsager symmetric transport matrix

$$\begin{bmatrix} \left\langle \mathbf{\Gamma}_a^{\mathrm{bn}}\cdot\nabla s\right\rangle \\ \left\langle \mathbf{q}_a^{\mathrm{bn}}\cdot\nabla s\right\rangle/\left\langle T_a\right\rangle \end{bmatrix} = \sum_b \begin{bmatrix} L_{11}^{ab} & L_{12}^{ab} \\ L_{21}^{ab} & L_{22}^{ab} \end{bmatrix} \begin{bmatrix} X_{b1} \\ X_{b2} \end{bmatrix} + \begin{bmatrix} L_{1E}^{a} \\ L_{2E}^{a} \end{bmatrix} \frac{\left\langle \mathbf{B}\cdot\mathbf{E}^{(\mathbf{A})}\right\rangle}{\left\langle B^2\right\rangle^{1/2}} + \begin{bmatrix} L_{1F}^{a} \\ L_{2F}^{a} \end{bmatrix} \frac{\left\langle \mathbf{B}\cdot\mathbf{F}_{\mathrm{f}1}\right\rangle}{\left\langle B^2\right\rangle^{1/2}}$$

When the NB-driven flows of ions and electrons are generated, they change the radial particle and heat fluxes and thus there will be a minor correction on the ambipolar radial electric field. In the present analyses on the Heliotron-J experiments, this determination mechanism of the radial electric field is consistently included in the parallel flow calculations. Figure 1 shows the calculated parallel velocities of the target plasma ions in co- and counter-NB(E=30keV, H$^+$) injection shots. Here, used target plasma parameters are $n_{\mathrm{e}}(r)=1.5\times10^{19}[1-(r/a)^2]\mathrm{m}^{-3}$, $T_{\mathrm{e}}(r)=300[1-(r/a)^2]$eV, $T_{\mathrm{i}}(r)=175[1-(r/a)^{1.57}]^{1.11}$eV, and the target particles' density ratio is e$^-$:D$^+$:C^{6+}=1:0.82:0.03 (Z_{eff}=1.9). The total external momentum input is calculated by applying the HFREYA and MCNBI included in the FIT3D code[4]. Various energy components of the beam (E,E/2,E/3) generated in the positive ion source injector are taken into account. The Laguerre expansion coefficients $\int v\xi L_j^{(3/2)}(x_a^2)C_{af}\left(f_{a\mathrm{M}},f_{\mathrm{f}}\right)\mathrm{d}^3\mathbf{v}$ of the RMJ operator for collisions between thermalized particles' Maxwellian $f_{a\mathrm{M}}$ 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 [5]. It can be seen that the NB-driven flow component is dominant at core region in the Heliotron-J experimental condition. Figure 2 shows calculated ambipolar potential in these shots. This direction of the correction by the NB-driven radial particle fluxes is consistent with a qualitative prediction by the well-known mechanism of so-called Ware pinch.

A next step improvement of the numerical code is to implement the eigen function method [6] for taking account the fast ion trapping effect in the friction collision term $C_{af}\left(f_{a\mathrm{M}},f_{\mathrm{f}}\right)$. A poloidal CXRS measurement to investigate this radial electric field experimentally is also planed in near future.

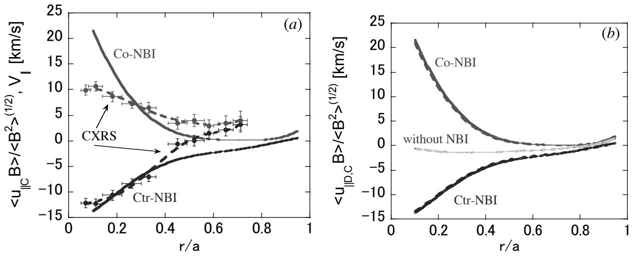

Fig.1 (a) Measured and calculated flow velocities $\left\langle Bu_{\parallel a}\right\rangle/B$ [km/s] of C^{6+} ions. (b) calculated flow velocities of D$^+$ (dashed lines) and C^{6+} (solid lines) ions. The co- and counter-injection shots and a case without the external momentum input are compared.

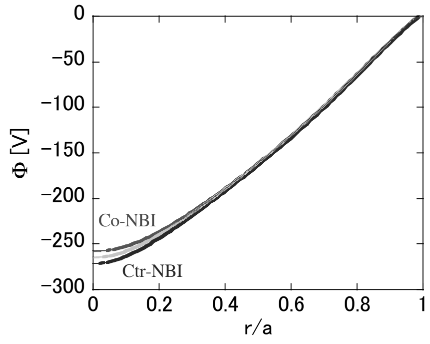

Fig.2 Calculated ambipolar potentials for co- and counter-injection shots.

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