§42. Parallel Momentum Input by Tangential Neutral Beam Injection in Stellarator and Heliotron Plasmas

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Recently, impurity flow velocities of NBI heated plasmas in Heliotron-J were successfully explained by the neoclassical transport theory [1-2]. That study applied a recently developed moment equation approach for general non-symmetric toroidal plasmas including the external momentum input [2]. In the moment method, problems including the field particle portion $C_{ab}\left(f_{aM}, f_b\right)$ of the linearized collision operator with the local Maxwellian distribution f_{aM} are converted to generalized parallel force balance expressed in an algebraic form. The recent study handled the external parallel momentum input by including the parallel friction collision moments $\int v_{\|} L_j^{(3/2)}(x_a^2) C_{af}\left(f_{aM}, f_f\right) d^3\mathbf{v}$ of each target plasma species (denoted by the subscript "a") with the fast ions ("f") in this simultaneous algebraic equation. Here, $L_j^{(\alpha)}(K) \equiv \left(e^K K^{-\alpha}/j!\right) d^j \left(e^{-K} K^{j+\alpha}\right)/dK^j$ is the Laguerre (Sonine) polynomial corresponding to the algebraic expression of the energy space structure, and $x_a^2 \equiv m_a v^2 / \left(2\langle T_a\rangle\right)$. The fast ion birth profile was obtained by using the HFREYA and MCNBI in FIT3D code [3]. Although the prompt orbit effect in non-symmetric toroidal configurations just after the beam ionization is taken into account in this method, a simple analytical formula of the fast ions' slowing down velocity distribution f_f for uniform magnetic field strength $\mathbf{B}\cdot\nabla B = 0$ is used for these collision integrals. It means that the fast ion trapping effect, which will be important for lower energy regions of f_f broadened to full pitch-angle range, is neglected.

Here we shall apply the eigenfunction method, which is originally proposed for the α-particle diffusion in axisymmetric tokamaks [4], for plasma flow studies based on the parallel force balance including the neoclassical parallel viscosity of both of the fast ions and target plasma species in non-symmetric stellarator/heliotron configurations.

Figure 1 shows the substantial magnetic field strength modulation $\varepsilon^{1/2}$ determined by the circulating particles' fraction for a model configuration $B/B_0 = 1 - \varepsilon_t(s)\cos\theta_B + \varepsilon_t(s)\left\{1 - \sigma_D(s)\cos\theta_B\right\}\cos\left(L\theta_B - N\zeta_B\right)$ Figure 2 shows the dependence of the total momentum input and the momentum input to ions on the **B**-field strength modulation. Detailed definitions of these quantities are explained in Ref.[5]. Assumed plasma parameters at the radial position r/a=0.5 and the beam energy are those in the Heliotron-J experimental condition reported in Refs.[1-2]. Results in Fig.2(b) indicates that the momentum input to the ions being a contribution of a slow velocity range $v \le v_c$ of the slowing down distribution f_f is sensitive to this modulation. The reduction ratio is about $\propto\varepsilon^{1/2}$ analogously to aforementioned neoclassical parallel viscosity of thermal particles. However, the input to the electron is insensitive since it is a contribution of a high-energy range $v \ge v_c$ where the f_f is still localized in the circulating pitch-angle range. The reduction is 14% at most for the field strength modulation $\varepsilon^{1/2} \le 0.7$ in Figure 1. Therefore the reduction of the total friction in Fig.2(a) also is only ≤30% for the investigated modulation.

In the theoretical calculation in Refs.[1-2], a phenomenological reducing factor $1-\sqrt{\varepsilon}$ was multiplied to the total friction moment of the fast ions $\left\langle \mathbf{B}\bullet\mathbf{F}_{f1}\right\rangle = -m_f\left\langle \mathbf{B}\bullet\int \mathbf{v} S_f d^3\mathbf{v}\right\rangle$ given by the MCNBI code, and the obtained ion flow velocity reproduced the CXRS measurement result. However, present investigation clarified that this method can be justified only for the ion flow calculations. In future studies on plasma flows and/or current requiring flow calculations of all particle species in more general non-symmetric toroidal configurations, the eigenfunctions investigated in the present work will be useful.

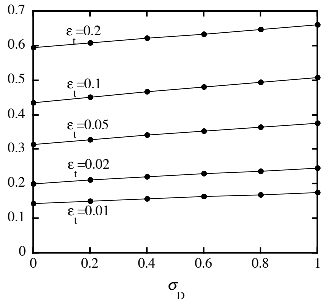

Fig.1 the substantial magnetic field strength modulation $\varepsilon^{1/2}$ determined by the circulating particles' fraction for a model configuration

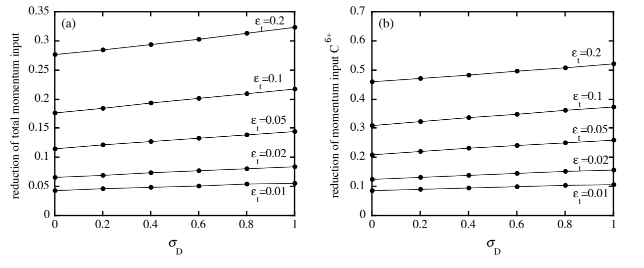

Fig.2 (a) The total momentum input, and (b) the momentum input to ions on the **B**-field strength modulation.

[1] Kobayashi,S., Lee,H.Y., et al., 25th IAEA-FEC, Saint Petersburg, Russia, 13-18 Oct. 2014, EX/P4-28
[2] Nishioka,K., et al., submitted to Phys.Plasmas
[3] Murakami,S., et al., Trans.Fusion Technol. **27**,259 (1995)
[4] Hsu.C.T., et al., Phys.Fluids B2,280 (1990)
[5] Nishimura,S., et al., submitted to Phys.Plasmas