§15. Neoclassical Viscosities in Helical Devices with Low Aspect Ratios II: QPS

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In viewpoint of the future applications in the LHD[1], investigating the boundary layer effects on the non-diagonal coefficient N^* (or $G^{(BS)} \equiv -\langle B^2\rangle N^*/M^*$) in the QPS (Quasi-poloidal Stellarator)[2] is important since a basic idea of the drift-optimization[3] in this device is analogous to that in inward shifted configurations of the LHD. The QPS is a quasi-poloidal torus with N=2, R_0=1m, a=0.3m, and $B_0 \leq 1$T. As shown in Fig.1, this configuration is designed based on a concept contrasting with QA configurations, which reduce the fraction of the ripple-trapped particles. Instead of reducing the fraction, the radial drift of the trapped particle[3] is reduced in this configuration. In so-called $1/\nu$ collisionality regime in configurations with large fractions of the ripple-trapped particles, however, the ripple-trapped/untrapped boundary layer at $\kappa^2 \cong 1$ causes a coupling effect between the bounce-averaged motion of ripple-trapped particles and the non-bounce-averaged motion of untrapped particles (collisional detrapping/entrapping)[4]. As confirmed by recent our calculations[5], we have to interpret a previous theory for the parallel viscosity by Shaing, et al.[6] as that for the collisionless detrapping ν regime ($E_s/v \neq 0$, $\nu/v \to 0$), because they neglected this coupling effect in the $1/\nu$ regime ($E_s/v \approx 0$), which gives a finite correction term $N^*_{(\mathrm{boundary})}$. Although correct $1/\nu$ regime values can be obtained by using numerical solvers handling 3D phase space (poloidal angel θ, toroidal angle ζ, pitch-angle ξ), a simple analytical formula[5,7] for this boundary layer correction $N^*_{(\mathrm{boundary})}$ is favorable for calculating neoclassical flows such as the bootstrap current in the integrated simulation system[1]. Therefore it is important to use the bounce- or ripple-averaging methods to obtain $\partial f_{a1}/\partial\mu$ in the ripple-trapped pitch-angle range, which gives the boundary condition for the boundary layer analysis, together with the analytical solution for the boundary layer, as complimentary methods.

In the example in Fig.2(a), we used well-known Shaing-Hokin theory with a minor modification[7] for the $\partial f_{a1}/\partial\mu$ term. Therefore, in Fig.2(b), we show also the $1/\nu$ diffusion coefficient $L^*_{(-1)}$ given by their formula, to confirm a validity of the analytically obtained $N^*_{(\mathrm{boundary})}$. Even for $L^*_{(-1)} \propto \delta_{\mathrm{eff}}^{3/2}$, the Shaing-Hokin theory still retains an accuracy of factor 2 in spite of the complex ripple well structure in Fig.1. Therefore we can investigate also characteristics of the boundary layer correction $N^*_{(\mathrm{boundary})}$ with a weaker dependence on δ_{eff} by applying this theory. The N^* connection formula including the ν regime asymptotic value given by the theory in Ref.[6], which is shown as a solid curve in Fig.2(a), approximately reproduces the strong E_s/v limit (i.e., the ν regime) of the numerically obtained N^*. The $1/\nu$ regime asymptotic value of N^* given by adding the correction term also approximately predicts the numerical result for a weak radial electric ranges ($1/\nu$ regime) of $E_s/v < 1\times10^{-4}$T.

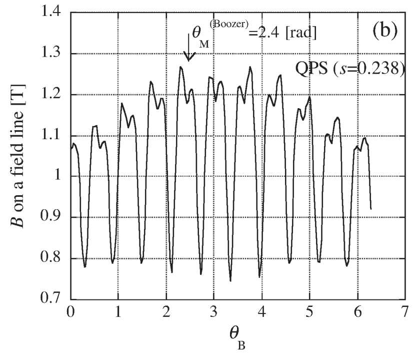

Fig.1 Magnetic field strength at $(\psi/\psi_{\mathrm{edge}})^{1/2}$=0.49

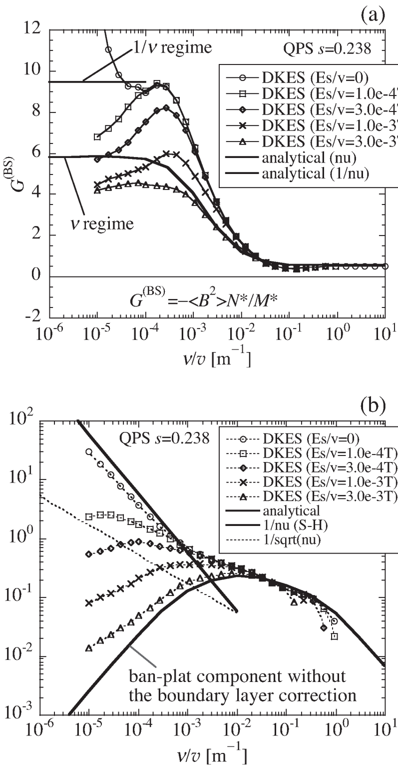

Fig.2 Mono-energetic viscosity coefficients in the QPS given by the analytical methods (solid curves) and by the DKES (lines with symbols). (a) the geometrical factor $G^{(BS)} \equiv -\langle B^2\rangle N^*/M^*$, (b) components of the diagonal diffusion L^*.

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