§ 28. The Effect of the Radial Electric Fields on the Geometric Factors for the Bootstrap Currents in Non-symmetric Magnetic Configurations

Nishimura, S., Sugama, H.

Including self-consistent bootstrap currents in the studies of MHD equilibrium and stability becomes important also in recent design activities for advanced stellarators . These MHD calculations require the iteration of 3D equilibrium codes with analytical calculations of the currents. For this kind of MHD calculations and the comparison of the experimentally measured parallel plasma flows with the theoretical calculations, the derivation of reliable analytical formulas and the benchmark tests to clarify their validity in various magnetic configurations are required. A recently developed neoclassical transport calculation method[1] is applied to study the geometric factor for the bootstrap currents in the banana collisionality regime in non-symmetric toroidal configurations. In past studies related to the bootstrap currents using the neoclassical transport codes based on the direct calculation of the linearized drift kinetic equations or the Monte Carlo method, quantitative discussions have not yet been done since these codes used the pitch-angle-scattering (or Lorentz) collision operator [2-5]. Due to breaking the collisional momentum conservation by employing this simplified collision model, the obtained "bootstrap current coefficient" D_{13} does not give the exact current value and it has been used only for some qualitative discussions. In analytical derivations of the bootstrap currents in non-symmetric configurations based on so-called moment method in which the collisional momentum conservation is already taken into account, the magnetic configurations are characterized by two kinds of coefficients expressing the parallel viscosity effect, the parallel viscosity coefficients μ_{aj} and the geometric factor $G^{(BS)}$, in contrast to axisymmetric tori where only the parallel viscosity coefficients are required to the neoclassical transport calculations. Although several analytical formulas for the geometric factor have been proposed and applied to the studies of MHD equilibrium and stability [2,6-7], the benchmark tests of these formulas by using the numerical calculation codes also have not yet been done by the same reason mentioned above. Especially, the calculation of the geometric factor for the banana regime is complicated, and thus to investigate the geometric factor in the banana regime using the new method which also follows the line of the moment method[1] is an important task.

Figure 1 shows the numerically obtained mono-energetic geometric factor in the configuration in Ref.[1] with the helical ripple of ϵ_h=0.05. It is given as the function of ν/v and E_r/v where $\nu(v)$, v, and E_r are the pitch-angle-scattering collision frequency and the velocity of the test particle, and the radial electric field strength, respectively. The banana regime ($\nu/v<10^{-3}$ m^{-1}) value for the radial electric field strength of $E_r/v=3\times10^{-3}$T, which is the largest value to avoid the effect of the so-called toroidal resonance ($E_r/B \cdot vB_p/B_t$), corresponds to the banana regime formula given in Ref.[2] where the $1/\nu$ component of the distribution function for the ripple trapped particles is neglected. Although this $1/\nu$ component, which is sensitive to the radial electric field and suppressed under the strong radial electric field, does not directly contribute to driving the parallel flow, it affects the ripple-trapped/untrapped boundary layer in the velocity space($\triangle\mu\propto\nu^{1/2}$)[8]. The contribution of this boundary layer to the parallel flow and its dependence on the radial electric field cannot be negligible in the cases with relatively weak radial electric fields and relatively large collision frequencies. The dependence on the radial electric field and the collisionality in the low collisionality regime shown in Fig.1 suggests the importance of this boundary layer effect. Therefore the derivation of an analytical formula for the geometric factors including the boundary layer effect is a future theme.

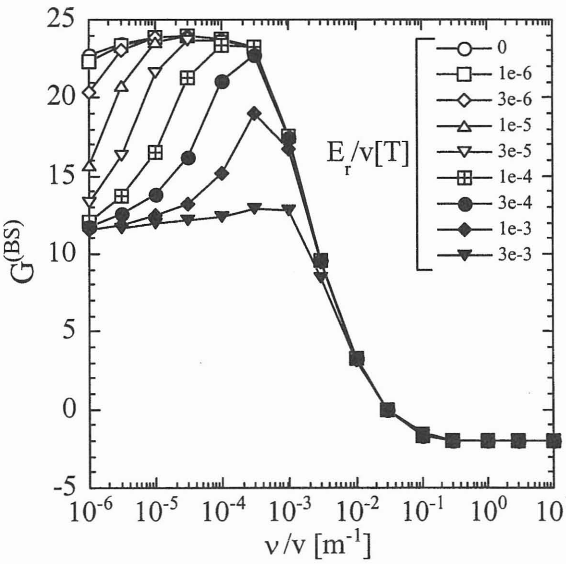

Fig.1 The numerically obtained mono-energetic geometric factor G(BS) for case with ϵ_h=0.05 in Ref.[1] as the function of the collisionality(ν/v) and the radial electric field (E_r/v). The banana regime ($\nu/v<10^{-3}$ m^{-1}) value for $E_r/v=3\times10^{-3}$T corresponds to the analytical formula in Ref.[2].

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