§17. Effects of Configuration Control on the Neoclassical Viscosity in Heliotron-J

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The three mono-energetic viscosity coefficients are investigated in Heliotron-J (H-J) as a benchmarking of the analytically approximated formulas of the neoclassical viscosities [1]. One purpose is to validate an analytical theory for the ripple-trapped/untrapped boundary layer in the velocity space [2] even for configurations with arbitrary magnetic field Fourier spectra and large rotational transform per toroidal period. Therefore dependence of the non-diagonal coefficient, which determines spontaneous parallel flows such as the bootstrap (BS) current, on configurations, collisionality, and radial electric fields is investigated in detail.

The H-J [3,4] is a helical axis heliotron with a helical coil with the poloidal and toroidal mode numbers of $(L,N)=(1,4)$, and major and minor radii of $R=1.3$m and $a=0.16$m. Figure 1 shows the B-field strength on a field line as functions of the poloidal angle θ_B in the Boozer coordinates (s, θ_B, ζ_B) at radial position of $(\psi/\psi_{edge})^{1/2}=0.5$. These are configurations used in recent experiments investigating the configuration dependence of the bootstrap (BS) currents [4]: (1) the low bumpiness ($\varepsilon_b=0.01$), (2) the medium bumpiness ($\varepsilon_b=0.06$), and (3) the high bumpiness ($\varepsilon_b=0.15$) configurations. (Following discussions in Ref.[4], we use here a notation of $\varepsilon_b \equiv B_{01}/B_{00}$ at $(\psi/\psi_{edge})^{1/2} \cong 0.67$ defined by using the Boozer coordinates to represent effects of $m=0, n\neq 0$ Fourier modes in B.) For this kind of situations with higher non-axisymmetric Fourier modes $n\geq 2$ and with large $(N\psi'/\chi'-L)^{-1}$ values making a displacement of the trapping well structure from a simple sinusoidal curve, the conventional analytical methods for the ripple-trapped particle dynamics and the boundary layer equation may be thought to be inappropriate. As discussed previously on NCSX and QPS [5], however, we still can apply these theories only with minor modifications in the modeling method of B especially when we calculate the boundary layer correction on the non-diagonal coefficient $N^*_{(boundary)}$ and the $1/\nu^{1/2}$ diffusion effect in the diagonal coefficient $L^*_{(-1/2)}$ since these correction terms are relatively insensitive to the ripple amplitude δ_{eff}.

Figure 2 shows the non-diagonal coefficient N^* in a normalized form (often called as “geometrical factor” [1,2,5]) of $G^{(BS)} \equiv -\langle B^2\rangle N^*(\nu/v, E_s/v)/M^*(\nu/v)$. The analytically approximated formula reproduces the configuration dependence of the DKES results. It also should be noted that this dependence is consistent with the experimental observations on the BS current. [1]

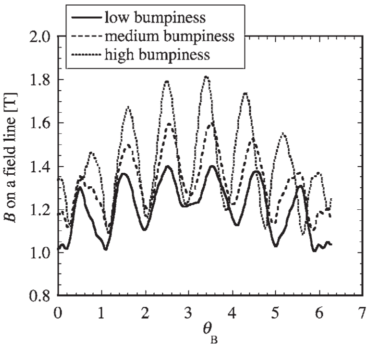

Fig.1 The magnetic field (B) strength on a field line as functions of the poloidal angle θ_B at radial position of $(\psi/\psi_{edge})^{1/2}=0.5$ (corresponding to $\langle r\rangle \cong 0.08$m) in three configurations in Ref.[4].

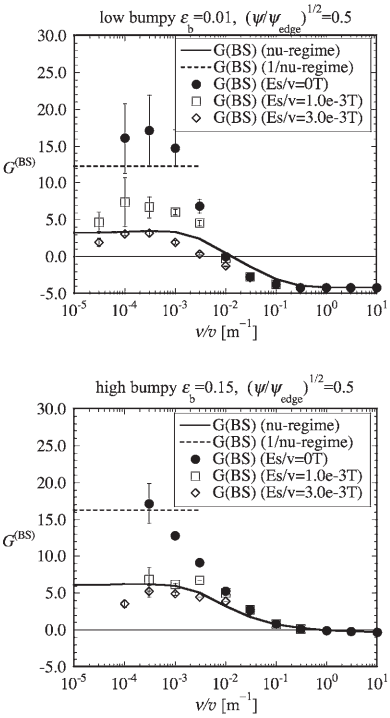

Fig.2 The geometrical factor $G^{(BS)} \equiv -\langle B^2\rangle N^*/M^*$. In the analytical results shown by solid curves, the boundary layer correction in the $1/\nu$ regime is omitted and therefore they correspond to conditions with sufficiently large E×B parameter E_s/v ($\approx 10^{-3}$T) in which the $1/\nu$ diffusion is suppressed. Dot lines indicate $1/\nu$ regime asymptotic values. The DKES results are indicated by closed symbols for the $1/\nu$ regime ($E_s/v=0$) and by open symbols for the ν (or $\nu^{1/2}$) regime ($E_s/v \approx 10^{-3}$T).

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4) G.Motojima, et al., Fusion Sci.Technol. **51**, 122 (2007);
Nucl.Fusion **47**, 1045 (2007).
5) S.Nishimura, et al., Plasma Fusion Res. **3**, S1059 (2008)