§20. Viscous Damping against Plasma Flow in CHS-qa Configurations


CHS-qa is a quasi-axisymmetric stellarator designed as a candidate for the next satellite machine at NIFS. Viscous damping against plasma flow in CHS-qa is considerably lower than that in conventional stellarators due to its tokamak-like field structure. This nature of low viscosity is favorable for appearance of improved confinement regimes based on shear of radial electric field driven by fast plasma rotation. In this study we have estimated how much viscous damping is expected in CHS-qa in comparison with the equivalent tokamak and a conventional stellarator CHS.

The neoclassical theory shows that viscous force against plasma flow is expressed with a diagonal viscosity tensor $\tau$ as $(\dot{u} \cdot \nabla \cdot \tau) = (p_{\perp} - p_{\parallel}) (\dot{u} \cdot \nabla B) / B$, where $\dot{u}$, $p_{\perp}$, $p_{\parallel}$, and $B$ are unit vector along a stream line, perpendicular pressure, parallel pressure, and magnetic field strength, respectively, and $\langle \rangle$ means taking flux surface average. According to the precise calculation of $(p_{\perp} - p_{\parallel})$ in a nonaxisymmetric torus, the viscous force is roughly proportional to the square of modulation of magnetic field strength $\gamma$ defined by $\gamma^2 = \langle (\dot{u} \cdot \nabla B) / B \rangle^2$ except for banana regime. In this study we consider $\gamma$ as a measure of viscous damping caused by variation of field strength, and calculated $\gamma$ by using the results of three-dimensional equilibrium code VMEC (Variational Moments Equilibrium Code).

Figure 1 shows pitch angle dependence of modulation of magnetic field strength $\gamma$ in CHS-qa, CHS and a tokamak equivalent to the CHS-qa configuration for the outermost flux surfaces. The equivalent tokamak here is defined as a tokamak which has the same axisymmetric components of the boundary shape as CHS-qa in the cylindrical coordinates. Though the variation of $\gamma$ with the pitch angle in CHS-qa is similar to that of the equivalent tokamak, toroidal $\gamma$ in CHS-qa is finite due to residual ripples. As for the poloidal direction, $\gamma$ in CHS-qa is between 0.3–0.4 m$^{-1}$ which is slightly lower than that in the equivalent tokamak in spite of the same elongation averaged over the toroidal direction ($Z_{10}/R_{10} = 1.54$). It may be attributed to distinctive three dimensional plasma shaping and magnetic axis of CHS-qa in the real space.

In addition, the effect of higher-order bumpy ripple arising from discrete 20 modular coils in an actual device is also discussed. Configuration of the modular coils to reproduce the desired plasma shaping is calculated by the NESCOIL code. Consequently, distinct increase in the toroidal $\gamma$ was clearly observed as shown in Fig. 2. In spite of smaller components other than the $n=20$ bumpy ripple, $\gamma$ apparently increases over the entire plasma area. Therefore this increase can be attributed to the addition of small bumpy ripple by modular coils. However, $\gamma$ still remains below 0.1 m$^{-1}$ except for the outermost flux surface. This indicates that toroidal viscosity is low enough to be determined by shear viscosity even with bumpy ripples added by modular coils.

References
