§16. The Effect of Net Toroidal Current on Shafranov Shift

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It is important to investigate the effect of the magnetic axis shift on confinement properties. A net toroidal current affects the MHD stability in heliotron/torsatron configurations. The effect of direction of the net toroidal currents on the local ideal MHD stability or Mercier criterion for plasma in the heliotron/torsatron configuration of the LHD have been investigated by Ichiguchi et al. In this calculation, the toroidal current in the direction opposite to equivalent plasma current is expected to cause the inward magnetic axis shifts in low beta value.

In order to investigate the effect of toroidal current on magnetic axis shifts, neutral beam current drive (NBCD) experiment was carried out with H2 and neon puff, the vacuum magnetic axis of $R_{\text{vac}} = 3.60$ m, the toroidal field of $B_t = 1.5$ T and the magnetic configuration of $\kappa = 1.02$. The NB drives net current of -110 kA in the direction to anti-parallel to equilibrium plasma current. The central electron density, $n_e(0)$, measured by FIR interferometer and the stored energy, $W_p$, estimated by diamagnetic loops increase up to $5 \times 10^{19}$ m$^{-3}$ and 310 kJ, respectively.

Figure 1 (a) shows the magnetic axis shift measured in this experiment, which is plotted as a function of net toroidal current. Figure shows that the magnetic axis shifts inward from position of the magnetic axis in vacuum magnetic flux surface at $R_{\text{vac}} = 3.60$ m as the magnitude of toroidal plasma current increase in counter direction. The plasma for this experiment is in the line averaged electron density $\langle n_e \rangle$ range of 0.3-0.8 x $10^{19}$ m$^{-3}$ and $W_p$ range of 70-180 kJ.

In order to compare the experimental results with equilibrium calculation, the magnetic axis shifts are calculated with VMEC code in finite beta, $\langle \beta \rangle = 0.24$ % and 0.34 % for different profiles of toroidal plasma current as seen in Fig. 1 (b). The electron density and temperature profiles used in this calculation are $n_e - (1 - \rho^p)$ and $T_e - (1 - \rho^p)$, respectively. In LHD the typical current profile is expected to be $J_1 - (1 - \rho^p)$ by current diffusion calculation. When the net toroidal current profile is $J_1$ and $J_2$ profile, the magnetic axis keep shifting inward as the magnitude of toroidal current is increased. This trend is consistent with the measurements. On the other hand, in $J_2$ profile, the magnetic axis start to shift outward at large toroidal current in the region $f_p \approx -40$ kA/T due to lower the rotational transform as seen in Fig. 1 (c). The NBCD experiment demonstrates that the magnetic axis shift can be reduced by driving the toroidal plasma current in the direction anti-parallel to equivalent plasma current (counter injection) without increase of the Shafranov shift due to lower the rotational transform.


Fig. 1 (a) The shifts of magnetic axis measured by soft x-ray CCD camera (symbols) and calculated with VMEC code (lines) for three type of net current profiles in finite beta as a function of the net toroidal current. (b) net toroidal current profiles using theoretical calculation (c) radial profiles of rotational transform for typical ($J_1 - (1 - \rho^p)$), broad ($J_2 - (1 - \rho^p)$) and peaked ($J_3 - (1 - \rho^p)$) current profiles with $f_p = -50$ kA/T ln $\langle \beta \rangle = 0.34$ %.