§10. Studies on the Edge E_r Structure

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Recent experiments in the LHD NBI heated plasmas, a clear reduction of ion thermal diffusivity was observed at the transition from ion root to electron root as predicted by neoclassical theory when the neoclassical ion loss is more dominant than the anomalous ion loss.[1)] In the neoclassical theory, a positive radial electric field (E_r) is expected to play an important role on the reduced transport at the e-root. The Er derived from the poloidal and toroidal rotation velocities and pressure gradient of neon impurity ions measured by the CXS diagnostic (using tangentially injected heating neutral beam having negative ion source with a beam energy of 150–180 keV) at the mid-plane in LHD (vertically elongated cross section) were found to be in qualitative agreement with those estimated by neoclassical theory.[2)] The positive E_r structure seen in the plasma edge at the e-root is essential for the Helical system in comparison with Tokamaks (such as H-modes), which is important to understand a plausible origin of E_r in the torus system comprehensively.

With regard to determining the edge radial electric field in LHD, by means of upgrading CXS diagnostics (using perpendicularity injected heating neutral beam having positive ion source with a beam energy of 40 keV) at the X-point in LHD (vertically elongated cross section), an improved signal-to-noise ratio (S/N) was achieved, even at faster time resolutions of up to 200 Hz. This involved replacing the measured impurity species from puffing neon to intrinsic carbon. A quantitative estimation of the first (and, possibly second) derivative of E_r profile at the plasma edge region has also been possible by means of intensely increased spatial channels at around the plasma edge region.

In the 14th cycle LHD experimental campaign, we measured the plasma edge region, extensively. As a result, a new information on the location of LCFS has been obtained, which is related to the location at the $E_r \sim 0$ (and/or the local maximum in the dE_r/dr) regardless of the plasma condition such as e- or i-root. In this analysis, we only takes the contribution of poloidal velocity term ($v\theta xB\phi$) to total E_r into account.

As shown in Fig. 1, a negative E_r structure is observed at the $R \leq 4.55$ m (i.e. E_r well) due to the neoclassical effect (so-called ion root), while it is a positive value at the $R \geq 4.55$ m (i.e. E_r hill). The origin in a positive E_r structure is considered to be due to faster losses of electron than ions to the 1st wall (or divertor) at the region very near, or possibly outside, the separatrix, where E_r has a zero or positive derivative, suggesting that this region is related to be a open field line (such as stochastic and/or SOL region).

The detailed determination of the LCFS is still important issue in the torus devices, especially for the Helical system having a complex 3-D magnetic configuration. Figure 2 shows the result of density scan at $R_{axs} = 3.6$ m with $\gamma = 1.197$ and 1.254. The locations of local maximum in the dE_r/dr at the low beta plasma ($\leq 1\%$) are found to be consistent with the location of LCFS calculated in the vacuum field, while their locations shift linearly towards the torus outside up to 20 cm at the high beta plasma ($\leq 3\%$) due to a finite beta effect. It is noted that the location of $E_r = 0$ seems to agree with the location of the local maximum in the dE_r/dr (Fig. 1 (c)), although their locations are not always consistent with the a99 (the location of the 99% of the stored energy in the electron determined by the Thomson scattering diagnostic).

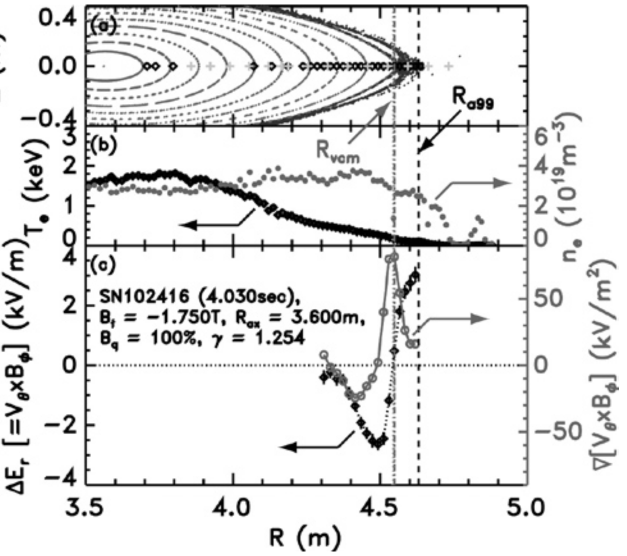

Fig. 1. (a) Poloidal cross-section of the magnetic flux surface with the magnetic axis of 3.6 m in the vacuum. Profiles of (b) electron temperature and density and (c) E_r and dE_r/dr are also plotted.

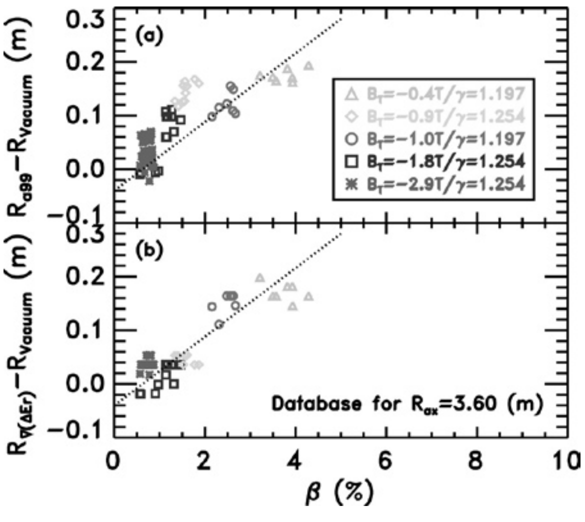

Fig. 2. Beta dependence of the shift from the vacuum magnetic field for the location of (a) a99 and (b) local max. in the dE_r/dr.

1) Ida, K. et al. : Phys. Rev. Lett. **86** (2001) 5297.
2) Ida, K. et al. : Nucl. Fusion **45** (2005) 391.