§4. Transition from Ion Root to Electron Root in NBI Heated Plasmas in LHD

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The transition of radial electric field from negative values (ion root : large neoclassical flux) to positive ones (electron root : small neoclassical flux) is theoretically predicted, when the collisionality of plasma becomes low enough in helical plasmas. In LHD, the transition from ion root to electron root is observed first in plasmas with "neutral beam injection (NBI) heating alone" at the low density of 0.4 – 1.0 x $10^{19}m^{-3}$. Here the radial electric field is derived from the poloidal and toroidal rotation velocity (v_θ , v_ϕ) and pressure gradient of Neon impurity measured with charge exchange spectroscopy at the mid plane in LHD (vertically elongated cross section) using a radial force balance as $E_r = (en_I Z_I)^{-1}(\partial p_I/\partial r) - (v_\theta B_\phi - v_\phi B_\theta)$. The toroidal rotation is damped to less than 10km/s due to the toroidal viscosity, and the effect of diamagnetic drift velocity is also small due to the high Z_I (=10) of Neon. Therefore the radial electric field is mainly determined by the poloidal rotation velocity.

The electric field is negative when the electron density is above 1.0 x $10^{19}m^{-3}$ and it becomes more negative as the electron density and its gradient are increased. On the other hand, the transition from negative electric field to positive electric is observed at the electron density below 1.0 x $10^{19}m^{-3}$. Fig.1 shows the density dependence of the radial electric field near the plasma edge ($\rho = 0.9$) for the plasma heated by NBI with the magnetic axis of 3.75m and with the magnetic field of 0.75, 1.5, 2.5T. In these plasmas, the central ion temperature is 0.6 keV (0.75T) – 2.0 keV(2.5T) and close to the central electron temperature ($T_i(0) = 0.7 - 1.0\ T_e(0)$). The edge radial electric field increases up to 15 kV/m in the electron root as the electron density is decreased to 0.4 x $10^{19}m^{-3}$, while it is almost constant at –5kV/m in the ion root over a wide range of electron density of 1.0 – 3.0 x$10^{19}m^{-3}$. The transition from ion root (negative E_r) to electron root (positive E_r) is observed at $\rho > 0.8$ and there is no large radial electric field observed in the plasma core.

The measured radial electric field is compared with that predicted by neoclassical theory. The radial electric field is calculated with the balance of neoclassical ion flux and electron flux using measured electron density, electron temperature and ion temperature profiles[5]. There are three roots at the low electron density, while only one root (ion root) exists in the higher density as shown in Fig.1(a). The transition from ion root to electron root is observed in the density where three roots exist. The radial electric field calculated with neoclassical theory in the electron root becomes larger towards the plasma edge as shown in Fig.1(b), which shows qualitative agreement with the measured E_r. It is noted that the electron root plasma, where the helical ripple loss is expected to be suppressed, is achieved in the NBI heated plasma with the ion temperature roughly equal to the electron temperature.

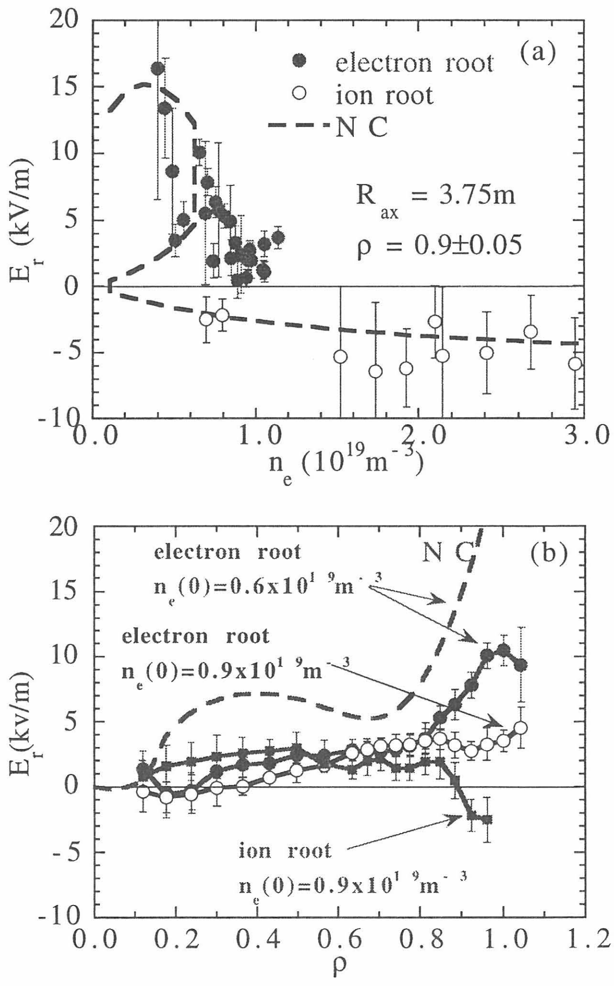

Fig.1 Density dependence of radial electric field, E_r, near the plasma edge (ρ =0.9) and (b) radial profiles of E_r in the density regime near the transition from ion root to electron root for NBI heated plasmas