## §25. Observation of Toroidal Flow in LHD

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A moderate velocity shear of plasma flow is considered to play an important role to suppress turbulence and reduce transport, although a large velocity shear cases Kelvin-Helmholtz instabilities. Thus the measurement of radial profiles of flow velocity is important in the study of plasma confinement. Because the toroidal flow is coupled with poloidal flow through viscosity tensor, the toroidal flow determined by not only toroidal momentum driven by NBI and momentum transport but also by toroidal forces driven by poloidal flow and radial electric field through viscosity tensor. The profiles of toroidal flow velocity are measured with charge exchange spectroscopy (CXS) with tangential view using the emission from carbon impurity (CVI).

The magnetic field strength is 1.5T and the major radius of the magnetic axis is Rax=3.6m and the γ, magnetic configuration parameter, is 1.174 in this experiment. The plasma is sustained with tangentially injected NBI with negative ion source (n-NBI). The NBI with positive ion source (p-NBI) with beam energy of 40keV is injected perpendicularly as a probe beam for the CXS measurement. The p-NBI is modulated (100msec ON/ 100msec OFF) to acquire the background signal for the CXS measurement. The n-NBI is also used to control the toroidal flow driven by a tangential momentum injection directory.

Figure 1 shows the radial profiles of the toroidal flow velocity in the plasma with balance-injected, co-injected and counter-injected n-NBI. The counter flow observed all over the radius in the case of balance-injected n-NBI is considered to be spontaneous component. The co and counter injection of n-NBI drives toroidal flow in the direction of the neutral beam at the plasma core, while no significant toroidal flow is driven by the NBI injection. It is suggested that the toroidal momentum input is large at the core region where the NBI power deposition is large and the helical ripple is small. On the other hand, the toroidal momentum input is small at the edge region where the helical ripple is large.

It has been observed that the spontaneous toroidal flow is in the counter direction when the radial electric field is positive in the electron root plasmas in CHS [1]. This spontaneous flow is considered to be common characteristics in Heliotron plasma, where the pitch angle of minimum gradient B is always larger than the pitch angle of magnetic field averaged in magnetic flux surface. To observe the dependence of the toroidal flow on the radial electric field, the density scan experiment is performed. The radial electric field can be changed by controlling the density, because the collisonality affects the neoclassical transport which determines the radial electric field in the Heliotron plasma. Figure 2 shows the dependence of spontaneous toroidal flow on radial electric field at the edge region (R=4.4m). The counter toroidal flow becomes large when the radial electric field becomes large positive. The positive radial electric field in the electron root drives the toroidal flow in the counter direction at the edge of the plasma. On the other hand, it is also observed that the toroidal flow is driven in the co direction when the ECH is injected at the plasma core. In this case, the plasma may be in the core electron root confinement (CERC), which has the positive radial electric at the plasma center.

In summary, the toroidal flow is observed in LHD by using CXS with the tangential sight. The troidal flow driven by n-NBI is localized near the plasma center. The positive radial electric field drives spontaneous toroidal flow in the counter direction at the edge due to viscosity tensor because the plasma tends to flow along the minimum gradient B direction while the positive radial electric field drives spontaneous rotation in the co-direction near the plasma center.

Reference
1) Ida, K., et.al., Phys.Rev.Lett **86**, (2001) 3040.

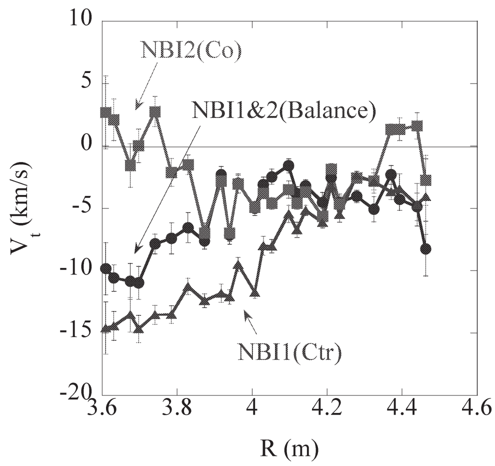


Fig. 1. Radial profiles of troidal flow velocity in the plasma with balance-injected, co-injected and counter-injected NBI. Positive (negative) toroidal flow corresponds to the toroidal flow parallel (anti-parallel) to the equivalent toroidal plasma current which produces the poloidal magnetic filed due to the external current in helical coils.

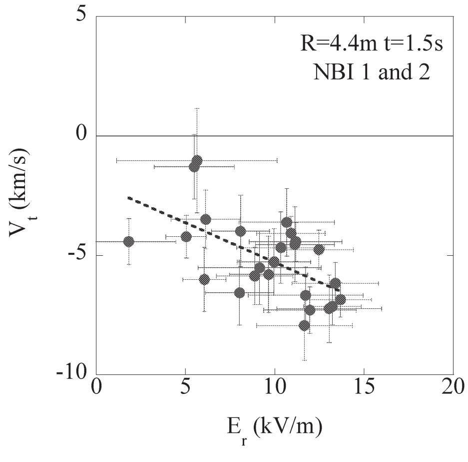


Fig. 2. Dependence of toroidal rotation velocity on radial electric field at R=4.4m.