§19. Toroidal Flow Profile in High Ion Temperature Plasma on LHD

Yoshinuma, M., Ida, K., Nagaoka, K.

There is great interest in the driving mechanism of the spontaneous toroidal flow and the momentum transport physics to control the toroidal flow profiles connected to the stabilization of a resistive wall mode. In the large helical device (LHD) the toroidal flow profiles in high ion temperature discharges have been clearly observed with the charge exchange spectroscopy (CXS). Recently, a perpendicular neutral beam injector with the beam energy of 40 keV and positive ion sources (P-NBI) has been installed in LHD, while the neutral beam injectors with negative ion sources (N-NBI) injected tangentially had been installed. Central ion temperature is achieved over 4keV with steep gradient in the profile of the neutral beam heated plasma. The N-NBI injected tangentially can drive toroidal flow, while the P-NBI injected perpendicularly is used for the CXS as a probe beam. The ion temperature, toroidal flow velocity, poloidal flow velocity, and intensity of charge exchange emission from carbon impurity are measured with the CXS.

In order to achieve the plasma with steep gradient in ion temperature profile, a cylindrical carbon pellet is injected to the plasma sustained with the neutral beam heating. The ion temperature increases up to 4keV and become higher than the electron temperature (3.2keV) at the plasma center. In the high ion temperature discharges, the ion temperature profile becomes peaked with steep gradient at middle of the plasma radius, while the electron temperature is moderately increased toward the center.

Figure 1 shows the profiles of toroidal flow velocity in the plasma with co and counter dominant injection of the tangential neutral beams with taking into account the energy dependence of charge exchange cross section [1]. Although there are some of differences of the magnetic field configuration and the time of the neutral beam injection between the co dominant injection ($B = -2.75$T, $R_{ax} = 3.60$m) and the counter dominant injection ($B = 2.723$T, $R_{ax} = 3.63$m), the achieved ion temperature is identical and 4 keV at the center of the plasma. The ion temperature gradient at middle of the plasma radius ($R = 4.0$m) is changed from 1.26keV/m at 2.14s to 6.02keV/m at 2.44s in the co dominant injection, and from 2.24keV/m at 2.04s to 5.26keV/m at 2.34s in the counter dominant injection. There are steep gradients in the ion temperature profiles after the ion temperature rise.

The direction of toroidal flow near the plasma center is consistent with the direction of the momentum input by the tangentially injected neutral beams. It should be note that the toroidal flow at middle radius of the plasma is always driven in the co-direction and this is caused by the contribution of the toroidal flow driven with the ion temperature gradient [2]. The strong toroidal flow is driven in the co dominant injection where the toroidal flow driven with the ion temperature gradient is parallel to that driven by the neutral beams, while the toroidal flow is small in the counter dominant injection where the toroidal flow driven with the ion temperature gradient is anti-parallel to that driven by the neutral beam injection. The toroidal flow driven with ion temperature gradient becomes one of dominant components of toroidal flow in the high ion temperature discharges in LHD.

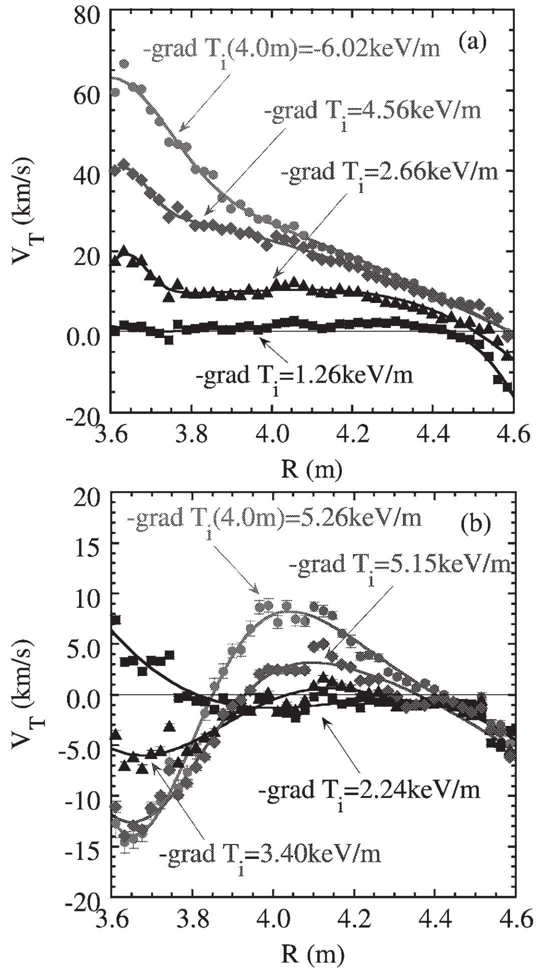

Fig. 1: Profiles of toroidal flow velocity in the case of (a) co-dominant injection case and (b) counter-dominant injection case.

1) W.M.Solomon, et al., "Extraction of poloidal velocity from charge exchange recombination spectroscopy measurements" Rev.Sci.Instrum. vol.75 (2004) 3481.

2) M.Yoshinuma, et al., "Observations of spontaneous toroidal flow in the LHD" Nucl. Fusion vol.49 (2009) 075036.