§3. Observations of Toroidal Flow Driven with Tangentially Injected Neutral Beams

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i) Introduction There is great interest in the driving mechanism of the spontaneous toroidal flow and the momentum transport physics to control the toroidal flow profiles. It has been observed that there are both NBI driven toroidal flow and spontaneously driven toroidal flow due to the steep gradient of T_i in the high T_i discharges on large helical device (LHD). There are difficulties in identification of the contribution of the spontaneously driven component to the toroidal flow because the NBI is not balanced in the high T_i discharges and there is steep gradient of T_i which is considered to be driving source of the spontaneous toroidal flow. In order to obtain an information of how the toroidal flow decays in LHD plasma, time evolutions of toroidal flow profile are observed when the tangential NBI is switched off from co-injection or counter-injection.

ii) Experiment and Results The plasma is produced and sustained with NBI and the magnetic axis R_{ax} of 3.75m and the magnetic field strength B of 2.64T in this experiment. The electron density is $1 \times 10^{19}\mathrm{m}^{-3}$. The toroidal flow profiles have been measured with charge exchange spectroscopy. LHD equips three tangentially injected NBI. Co-direction and counter-direction are defined as the parallel and anti-parallel to the equivalent toroidal plasma current, respectively. In this experiment, the toroidal flow is driven with the neutral beam injected into co or counter direction tangentially, then the velocity decays after the beam off. Figure 1 shows the profiles of the toroidal flow velocity V_T with the co-injected beam or counter-injected beam under the normal directed magnetic field configurations ($B > 0$). The port through power of the co-injected beam and counter-injected beam are 4.8 MW and 4.5MW, respectively. There is asymmetry in the peak values of the V_T and the V_T in the counter direction is larger than that in the co direction. This is also observed under the inversed magnetic configuration ($B < 0$) and is not due to the difference of the injected power. It suggests the existence of spontaneous component driven in counter direction.

The width of the profile in the counter-injection case is narrower than that in the co-injection case. The T_i gradient in co-injection case and counter-injection case at $R = 4.1$m are 1.3keV/m and 2.2keV/m, respectively. The spontaneous toroidal flow driven with the T_i gradient of 2keV/m is expected as 8km/s in co-direction from past experimental observation [1]. It is considered that the co-directed spontaneous component driven with the T_i gradient makes the profile narrower in the counter-driven case.

Figure 2 shows the time evolution of the V_T after the beam off plotted with the log scaled y-axis to find the decay time of the toroidal flow. V_{offset} of 10km/s is added to V_T in order to avoid the negative value of the V_T. The slope shows the time scale of a few hundred milliseconds as comparable with the confinement time.

iii) Summary The time evolution of toroidal flow velocity after the beam off is observed. The toroidal flow is successfully driven with the tangential NBI under the magnetic axis position $R_{ax} = 3.75$m. There are no significant difference in the decay time between co-injection case and counter-injection case. The narrow profile of toroidal flow in the counter-driven case is considered to be due to the spontaneous component driven with T_i gradient.

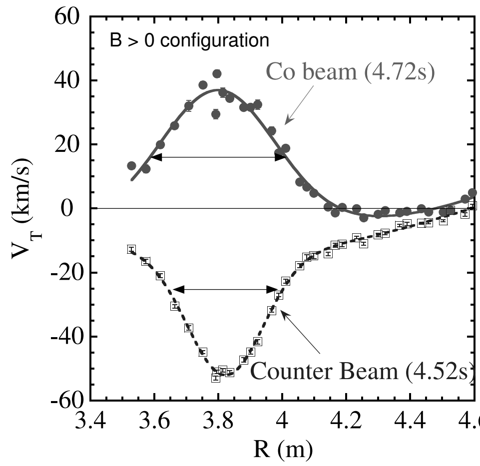

Fig. 1: Profiles of V_T in the case of $B > 0$ configuration with co-beam injection (circle) and counter-beam injection (square).

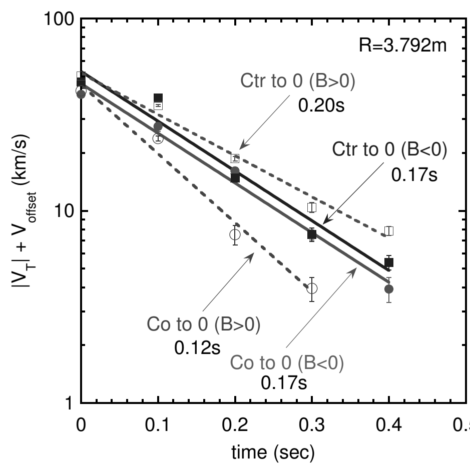

Fig. 2: Log plotted time decay of V_T at $R = 3.792$m after the beam off.

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