§9. Observation of Troidal Flow Driven with Co and Counter Injected Neutral Beam

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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). And the dumping of the toroidal flow with the stochastization of the magnetic filed has been also observed. So, it is unusual that the toroidal flow is driven simply to co-direction and counter-direction with the co-beam and counter-beam injection, respectively. In order to study the mechanisms of the toroidal flow formation in LHD plasma, it is important to find the birth and the growth of the spontaneous component in the toroidal flow formation.

ii) Experiment and Results The plasma is sustained with perpendicularly injected NBI (P-NBI). The magnetic axis R_{ax} of 3.6m and the magnetic field strength B of 2.74T in this experiment. The electron density is $2-3\times10^{19}\mathrm{m}^{-3}$. We can avoid the dumping of the counter toroidal flow by stochastization of the magnetic field with just a bit higher electron density than the $2.0\times10^{19}\mathrm{m}^{-3}$. 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. Injection of the tangential NBI starts at the time of 3.8s.

Figure 1 (a) and (b) show the time evolution of ion temperature at the plasma center and the gradient of ion temperature near the mid-radii of the plasma, respectively. There are two cases in the plot. The one is the co-injection case and the other is the counter-injection case. The ion temperature and the gradient is increased with the injection of tangential NBI. There is no significant differences of the time evolutions of ion temperature and its gradient in both the cases of co and counter-injection.

Figure 1 (c) shows the time evolution of toroidal flow at the plasma center in both the cases of co and counter-injection. The toroidal flow is increased rapidly to the direction of injected neutral beams just after the injection. The absolute values are almost same at $t=4$s in both the cases. It is considered that the symmetric change is due to the momentum input with the neutral beam injection. After the rapid change of the neutral beam driven component, the toroidal flow velocity changes slowly toward the co-direction in both the cases. Co-direction is an opposite direction to the injected beam in the case of Counter-injection.

Time evolution of averaged value of flow velocity in both the two cases is shown with triangle symbols in Fig.1 (c). The flow component driven in same co-direction which is not depend on the direction of injected beam is considered to be a spontaneous component. The spontaneous component is increased monotonically while the ion temperature and its gradient change rapidly then slowly after the NBI. It is suggested that the observed spontaneous component is not coming from the ion temperature or ion temperature gradient directly.

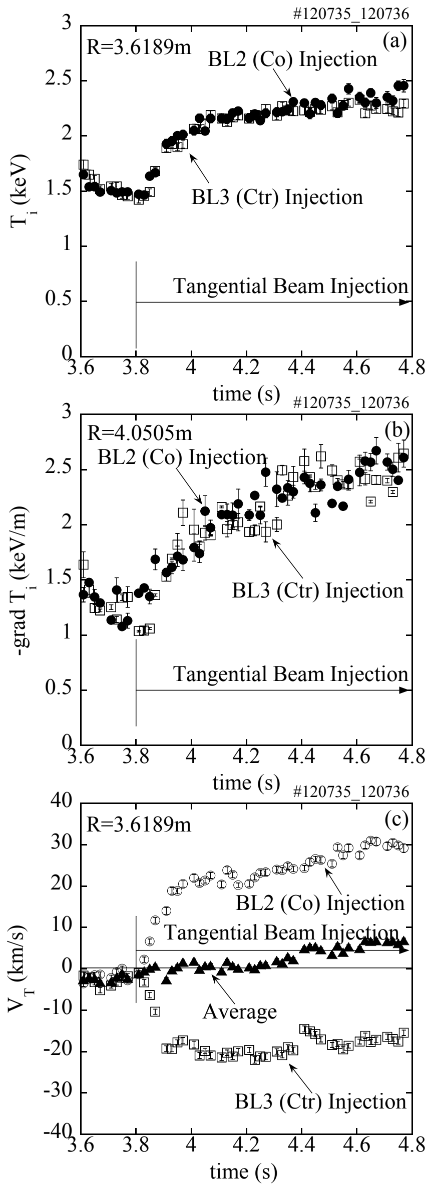

Fig. 1: Time evolutions of (a) ion temperature at the plasma center, (b) the gradient of ion temperature near the mid-radii of the plasma, and (c) the toroidal flow at the plasma center in the case of co-injection (circle) and counter-injection (square) of NBI. Averaged value of the toroidal flow driven in both the cases are also plotted (triangle).