§20. Control of Magnetic Shear with Neutral Beam Current Drive in LHD

Ida, K., Yoshinuma, M., Kobuchi, T., Watanabe, K.Y., Nagaoka, K., Inagaki, S.

The Large Helical Device (LHD) is a heliotron type device which has three tangential neutral beams and two beams are used to drive the plasma current in the direction parallel (co-injection) or anti-parallel (counter-injection) to the equivalent plasma current, while one beam is always used as a probe beam of the Motional Stark Effect (MSE) spectroscopy (25 channel). The radial profiles of the rotational transform are derived from the polarization angle measured with MSE spectroscopy using an equilibrium code. The electron temperature is measured with a 27 channel electron cyclotron emission (ECE) radiometer. In this experiment the magnetic field, B, is 2.75T and the major radius of the plasma R is 3.6m, where the magnetic shear is negative (standard stellarator shear) with a magnetic hill configuration. The direction of the neutral beam is switched at the middle of the discharge with a relatively low density of $1 \times 10^{19} m^{-3}$.

Figure 1(a) and 1(b) show the time evolution of rotational transform at various radii and total plasma current. The direction of the injected neutral beam switches from parallel (co-direction) to anti-parallel (ctr-direction) to the equivalent plasma current or vice versa at t = 4.3sec. Although the change in rotational transform near the plasma edge ($\rho = 0.83$) is due to the neutral beam current drive and consistent to that of total plasma current, the change in rotational transform at the plasma core region ($\rho < 0.5$) is opposite to that at the plasma edge. The total plasma current driven by the neutral beam is in the range of -100kA (ctr-direction) to 50kA (co-direction), which is only 3 - 6 % of equivalent plasma current (1.8MA) produced by the external helical coils.

The change in rotational transform in the core region is due to the inductive current compensating the toroidal current driven by neutral beam. Since the time scale in the change of total current is longer than the beam pulse (4 sec each), there is no steady state phase in total current. However the time scale of the change in rotational transform due to the inductive current is only a half second. Therefore the rotational transform and the magnetic shear in the plasma core changes within a second after the direction of the beam is changed, where as the direction of total plasma current is unchanged. It should be noted that the rotational transform and magnetic shear in the plasma core at t = 5.5 sec in the discharge with co to ctr-injection [in Fig.1(b)] and t = 7.5 sec in the discharge with ctr to co-injection [in Fig.1(a)] are quite different, although the total plasma current is zero for both discharges. This experiment demonstrates that the toroidal current driven by neutral beam has a significant effect on the magnetic shear because of the inductive current associated with the injection of the neutral beam even the toroidal plasma current is only 3 - 6 % of the equivalent plasma current.

As seen in Fig.2, the magnetic shear in the core region ($\rho <$ 0.4) becomes close to zero. In contrast, the radial profile of the rotational transform in the discharge where the beam switches from ctr to co-injection has strong magnetic shear at the rational surface of $\iota = 0.5$ because the central rotational transform drops after the switch of the beam from ctr to co-injection. A flattening of T_e is observed when the magnetic shear at the rational surface is small as seen in Fig.2.

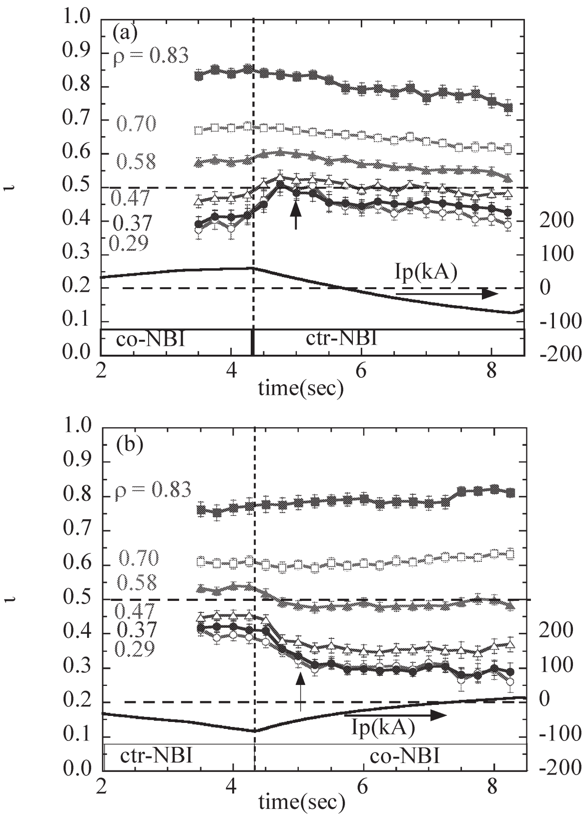

Fig.1. Time evolution of rotational transform at various plasma radii and total plasma current in the plasma with the neutral beam injection (a) from co-injection to counter-injection and (b) from the counter-injection to co-injection.

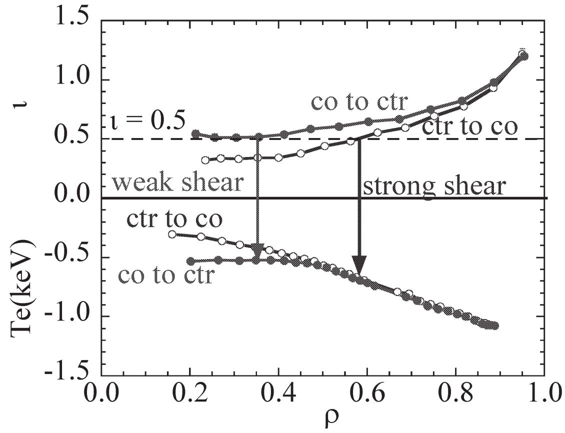

Fig.2. Radial profile of rotational transform and electron temperature in the plasma with weak magnetic shear (at t = 5sec in the discharge with co to ctr-injection in Fig1(a)) and a strong magnetic shear (at t = 5sec in the discharge with ctr to co-injection in Fig1(b))