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SPATIAL DISTRIBUTION OF HIGH-ENERGY PARTICLE NBI AND ECH PLASMAS OF LARGE HELICAL DEVICE

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1. Introduction

In the helical devices, the particle orbit of the NBI co-injection beam against the direction of the torus magnetic field is different from that of the counter injection. According to the calculation, the guiding center of the particle orbit is close to the magnetic axis and shifted to the high magnetic field side in the co- and counter-injection, respectively. The tendency is remarkable in the low magnetic field. On the simulation in the Large Helical Device (LHD), the spatial distribution of the particle of co-injection on the mid-plane is expanded to the entire plasma[1]. On the contrary, that of the counter-injection is localized near the high magnetic field side. Therefore the part of the particles is lost by the collision with the inner wall. The disadvantage can be overcome by the increase of the magnetic field. The difference of each orbit strongly reflects the charge exchange neutral particle flux.

In the 4th experimental campaign, NBI#1 as the counter-injection and NBI#2 as the co-injection are prepared. In 5th cycle, NBI#3 is added as the counter injection beam. NBI#1 and #3 change to the co-injection and #2 changes to the counter-injection by the inversion of the magnetic field direction in some shots on the 5th cycle.

2. Experimental Setup and Diagnostics

The time-of-flight type NPA (maximum /minimum observable energy 0.5/370keV, typical energy resolution 7%) has the capability of a high S/N ratio against the radiation including soft/hard X-rays from plasmas[2]. The analyzer and the movable stage are installed at the mid-plane of LHD on the 10-O port. There are two NBIs (NBI#1 and #2) at neighboring ports to 10-O (Fig.1). NBI#3 is installed in the parallel direction with NBI#2 from the 5th campaign. In particular, the beam path of NBI#1 crosses the sight line of the analyzer. Therefore a large amount of particles from the plasma center can be expected, which is suitable for the high-energy distribution measurement. The

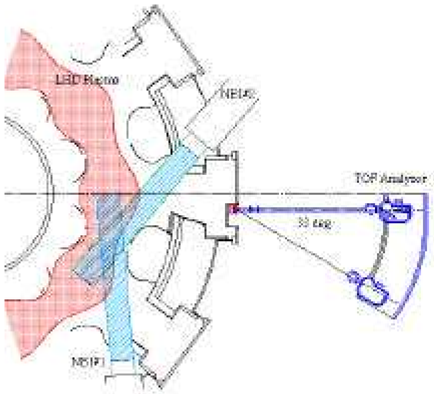

Figure 1. The experimental configuration of LHD, NBI and the neutral particle energy spectrum in LHD.

scanning is performed with the pivot in front of the 10-O port by using a motor, which is remotely controlled from -2 degrees to +31 degrees (0 degrees indicates the direction perpendicular to the 10-O port flange surface). The angles are equal to the pitch angle (the angle between the magnetic axis and the sight line) of 100 degrees and 40 degrees, respectively.

The position (=angle) can be measured from the length of the stainless wire between the stage and a fixed point. The position data are sent to the Windows computer. At the same time, the timing data can be provided to the computer from the timer, which is triggered by the LHD discharge initiation.

3.Experimental Results

Two different experiments are performed to compare the behavior of the co-injection with the counter injection. The plasma initiated by ECH heating is sustained by NBI#1 (counter). Modulated NBI#2 (co) is added to the plasma. The TOF analyzer is set perpendicular against the plasma magnetic axis in order to investigate the comparison.

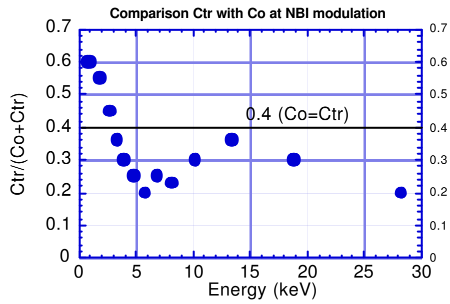

Figure 2. Intensity ratio of the particle flux between the co- and counter injection NBI.

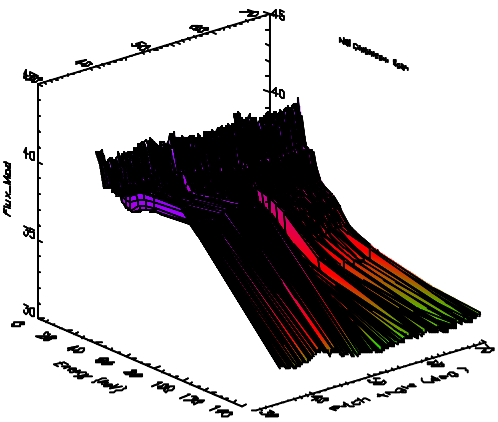

Figure 3(a). The spatial-resolved neutral particle energy spectrum in NBI long discharge (co-injection).

Figure 2 shows the intensity ratio between the flux during NBI#1 (counter) and that during NBI#1+NBI#2 (modulated, co-injection). The neutral particle flux in the counter injection is less than that in co-injection even if the difference of number of the beam particle is considered. Background neutrals, which produce the high-energy neutral particles by the charge exchange reaction, are distributed near the plasma edge. The neutral particle flux in the counter injection is not much because the particle orbit in the counter injection is not located near the plasma edge. The particle confinement in the counter injection may be worse than that in co-injection. However the possibility cannot be verified only by this experiment. The pitch angle distribution of the high-energy neutral particle cannot be observed in the modulation experiment. The trapped particle instead of the transit particle can be mainly observed in the modulation

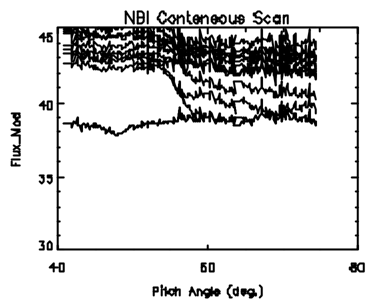

Figure 3(b). The contour plot of Fig. 3(a).

experiment because the analyzer is set perpendicular to the magnetic axis.

To overtake the disadvantage, the pitch angle scan experiment during long discharge is performed. The accurate experimental result can be expected in the scanning on the long discharge rather than the scan shot-by-shot. The accurate comparison between the co- and counter injection can be expected so the horizontal scan of the analyzer during long discharge is also done in the inverse magnetic field. The spatial resolved energy spectra can be observed during a long discharge of NBI plasma by continuously scanning the neutral particle analyzer[3,4]. Figure 3(a) shows the time evaluated (=angular distributed) three-dimensional spectrum obtained by overlapping of three NBI plasma discharges. The pitch angle means the angle between the sight line and the central magnetic axis. In these discharges, the plasmas are initiated by the ECH heating, after that NBI#2 (co-injection) sustains the plasma during 40 – 60 seconds. The scanned pitch angle is from 44 degrees to 74 degrees. The electron density measured by the interferometer is kept to be almost 2×10^{19} cm^{-3} during discharge except the plasma initiation phase. At the initiation phase by ECH plasma, the high-energy particle flux is enhanced as the density is too low and the background neutral density is high. The injected hydrogen neutral beam energy of NBI#2 is only 130 keV because the original ion source polarity is negative. To make clear the pitch angle dependence, the contour plot of Fig.3 (a) is shown in Fig. 3(b). Figure 3(c) shows the spectra at some typical pitch angles. The shape of spectra is almost similar from 44 degrees to 53 degrees. However the spectra from 55 degrees are strongly varied. It reflects the injection pitch angle of the beam according to the simulation (53 degrees at Rax=3.75 m in simulation). The beam keeps the pitch angle at incidence until the beam energy becomes to the energy, which the pitch angle scattering is occurred by the

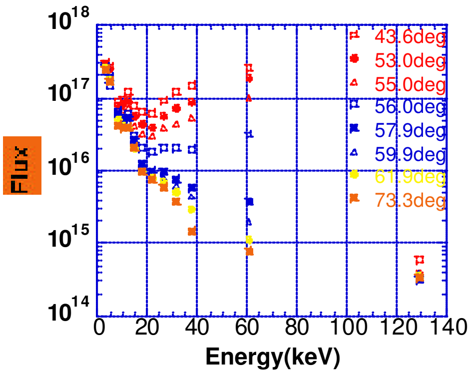

Figure 3(c). Energy spectrum of each pitch angle obtained by Fig. 3(a).

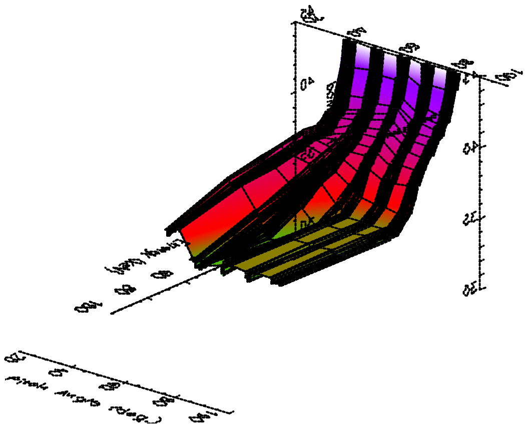

Figure 4(a). The spatial-resolved neutral particle energy spectrum in NBI long discharge (counter-injection).

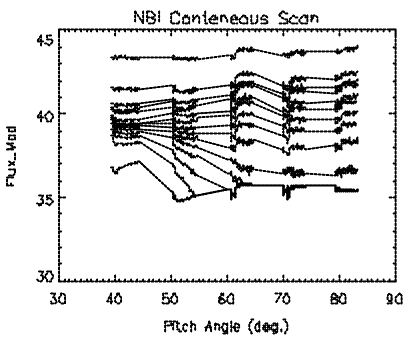

Figure 4(b). The contour plot of Fig. 4(a).

energy loss due to the electron collision. The low flux region can be observed around 10-15 keV, which is 15 times the electron temperature. The energy region may be equal to the energy at which the pitch angle scattering is occurred.

The pitch angle distribution and the contour plot are shown in Fig. 4(a) and Fig. 4(b), respectively when the magnetic field is inversely applied. The large variation at 48 degree can be observed. The pitch angle of the particle is almost conserved in high-energy region because the pitch angle scattering occurs near the energy of the 15 times of the electron temperature. It is not believed that only the particles with large pitch angle are localized near the plasma center where the back ground neutrals is not rich. Therefore it is reasonable that the particle with the pitch angle between 48 to 53 degree is lost. The neutral particle flux in the counter injection is less than that in the co-injection same as the modulation experiment. The main reason is that the guiding center of the particle orbit in the counter injection is shifted to the high field side. Another candidate of the flux decrease comes from the particle loss with large pitch angle. However the loss of the counter injected particle does not strongly affect to the heating efficiency and the stored energy because the contribution of the particle with large pitch angle is not so much.

4.Conclusion

The experiments for the comparison between the co- and counter neutral beam injection are performed. The pitch angle distribution of the neutral particle spectrum in the both injections can be precisely obtained by the scanning of the analyzer in long discharge by changing the magnetic field direction. In the counter injection the neutral particle flux is not so much because the particle orbit passes through the low background neutral region. It can be found that the particle with large pitch angle is lost in the counter injection from the spectrum of the pitch angle distribution of the neutral particle.

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