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Fast Neutral Particle Spectra in Different Pitch Angles in Large Helical Device

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Introduction

It is not easy directly nor experimentally to observe the loss cone itself. The loss cone is strongly depended on the pitch angle and it is especially observed at higher pitch angle. In the Large Helical Device (LHD), the device design is devised so that the loss cone at ρ (radial position on the magnetic surface) <1/2 may not exist. Moreover, most of the particles heated by tangential NBI (Neutral Beam Injection) do not have a pitch angle perpendicular to a magnetic field. However, if the slowing down of the incident particle by electron collision occurs in NBI heating, the particle with a large pitch angle actually will be generated due to the scattering between the particle and plasma ion at several times the plasma temperature. These particles cause drift motion and rotate poloidally. They can almost be confined in the plasma because the energy of these particles is not so large. However part of them are not confined by balance with the electric field E. It is known for helical devices that the particle with a specific energy is lost by cancellation of the *grad B* drift and the *ExB* drift resulting from the electric field E [1]. This phenomenon occurs at the negative radial electric field. The reason why we are interested in the resonant loss is that we can find it from the dip in the high-energy particle spectra measured by the neutral particle analyzer.

The neutral particle analyzer in LHD has an ability of wide range scanning as a feature [2]. We have obtained various data in horizontal scan of the analyzer until now. Recently in addition of the horizontal scan, the high-speed perpendicular scan has become possible, and new information on the poloidal direction can be acquired [3]. We can obtain the pitch angle dependence of the resonant loss by horizontal and continuous scanning of the analyzer during long steady-state discharges [4]. The somewhat large resonant loss can be observed in higher pitch angle, however it is not remarkable. The vertical scan has been also tried in order to obtain the radial information. The resonant loss is varied by the poloidal position although the pitch angle is not so different. This may be originated due to the spatial variety of the electric field. According to the experimental results, the dependence of the pitch angle is not so remarkable. The typical time scale of the pitch angle scattering is estimated to be a few milliseconds for the actual LHD plasma although the NPA detection duration is several tens of milliseconds [4]. Since pitch angle scattering is dominant and reaches equilibrium at the energy of 5 keV, the number of particles with lower pitch angle also decrease if the particle with higher pitch angle are lost.

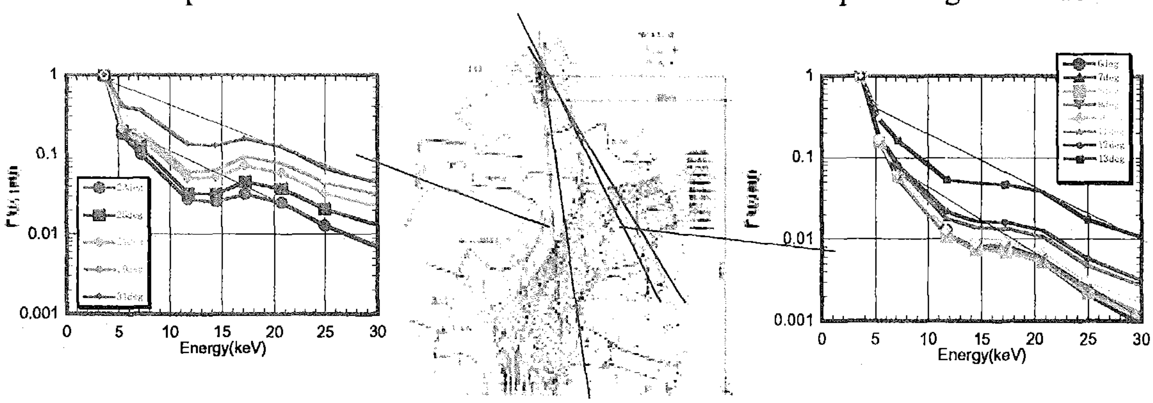
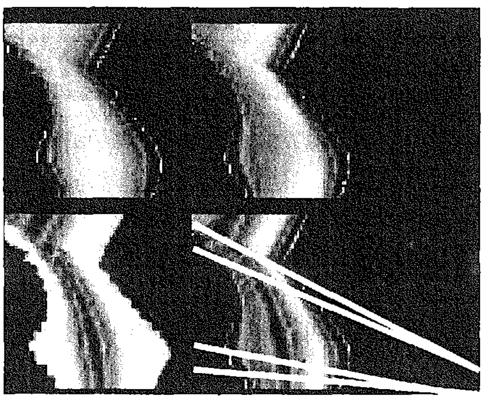


Fig.1 Horizontal scan results and the simulation.
(a) (Upper center) Sight lines, (b) (Upper left) Tangential scan spectra, (c) (Lower right) Perpendicular scan spectra, (d) (Lower left) Simulation. Lower right in the figure is the effective particle generation region.

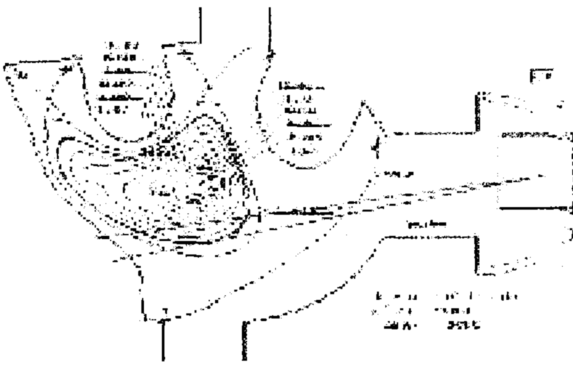


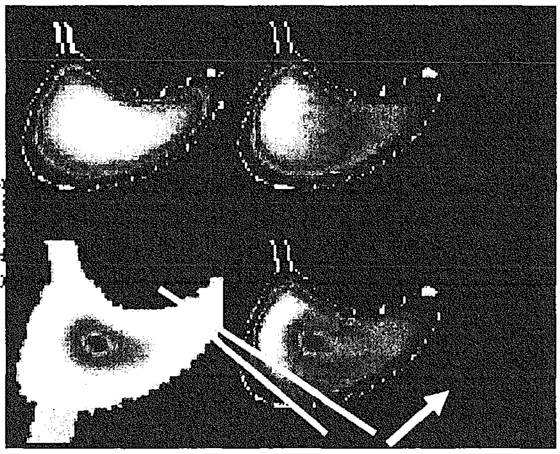
The Results from Horizontal Scan

The horizontal scan of NPA was performed by remote motor drive of the NPA stage. The scanning speed is 0.17 degree per second. The scanning center pitch angle, which is defined as the angle between the magnetic axis and the sightline, ranges from 40 degrees to

100 degrees. The experiments have performed in two middle duration discharges of 30 seconds. Figure 1(a) shows the experimental arrangement and the sight lines. During discharge, the analyzer was scanned horizontally. Figure 1(b) and (c) are the spectra in pitch angle of 30-40 and 70-80 degrees (the angle between the sight line and the magnetic axis). The resonant loss can be seen from 5 keV-15keV in the spectra. The dips at both pitch angles are not so different in spite of the different pitch angle.

To study the reason, we calculate the particle behavior in plasma using the simulation. The background neutral profile in the plasma parameter is obtained from the Aurora code. By considering the atomic process in plasma, we can obtain the generated particle profile with the energy of 5-15 keV including the particle loss from the source to the analyzer as shown in Fig. 1(d). The potential profile $\phi(\rho)$ in NBI plasma can be assumed to be $\phi(\rho)= -|\phi(0)|\{1-e^{(\rho 2-1)}\}$ from the data in Compact Helical System and LHD [5,6]. The electric field can be assumed to be $E_r=-|\phi(0)|\{2\rho\, e^{(\rho 2-1)}\}$. Therefore we can specify the position and the electric field of the observed particle. In calculation, the electric field at the generated point was not so varied by the horizontal scanning. The small variety of the dip can be explained by this reason.





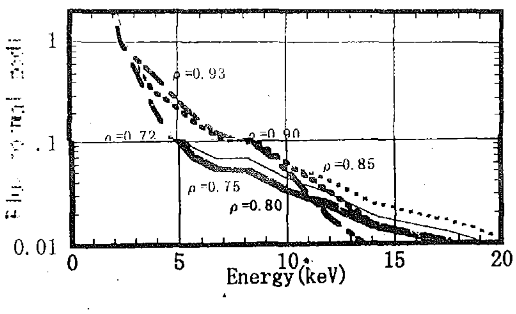


Fig.2. Vertical scan results and the simulation.
(a) (Upper left) Sight lines, (b) (Lower left) Scan spectra, (c) (Upper right) Simulation. Lower right in the figure is the effective particle generation region.

Vertical Scanning Results

The vertically scanning system is realized by adding a movable mechanism to a current horizontally scanning system. The analyzer slides along three stainless steel rails, which are arcs with radii of 4 m. One of the rails defines the accurate position of the analyzer. Another rail, which is set at the front of this rail, fixes the vertical position and the other rail, which is set at the side, fixes the side position. Therefore, a smooth and non-vibrating vertical driving can be obtained. Two chains and the gears, which are connected with the motor, support the analyzer. Two stainless blocks are set on the opposite sides of the chain in order to balance the weight (700kg) of the analyzer and reduce the load in the motor. Therefore a very high scan speed of one degree per second can be obtained.

In horizontal scan the pitch angle dependence of the dip was not clear because the resonance loss depends on the electric field at the generation point. In the radial scan, the electric field and the generation points are obviously different by the radial position. Therefore the radial dependence of the dip can be expected. During steady-state operation of NBI plasma, the analyzer has been scanned continuously from ρ=0.9 to 0.7 as shown in Fig. 2(a). The typical spectra are shown in Fig. 2(b). The dips are varied in spite of the similar pitch angle. The inner region of plasma, larger dip can be observed. According to references [5,6], the large negative electric field at ρ=0.7 can be expected than at ρ=0.9. Figure 2(c) shows the simulation results. The bright color means much particle fluxes which are affected by the strong electric field in the observing energy range. The simulation results reflect the experimental results.

Summary

The 2-dimensional scanning neutral particle measurement system has been completed in order to investigate high-energy particle confinement. In the horizontal scan, the small variety of the dip can be expected because the electric field at the generated point was not so varied by the horizontal scanning. By adding the vertical scan, the radial variation of the signal loss associated with the resonant loss due to magnetic ripple was obtained in preliminary experimental results. The profile of the dip depth may reflect the electric field profile according to the comparison with the simulation.

References

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