Spatial Resolved High-Energy Particle Diagnostic System using Time-of-Flight Neutral Particle Analyzer in Large Helical Device

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I. Introduction

High-energy particle measurement is important for an ion temperature monitor, the study of the high-energy particle confinement, the clarification of the electric field formation mechanism and particle transport research. Especially, in the helical system like Large Helical Device (LHD), there are various particle orbits, not only transit particle orbit but also the trapped particle orbit due to the complicated magnetic configuration. These orbits create new electric field and the electric field produces new particle orbits. In addition, there are three different heating systems in LHD, neutral particle injection heating (NBI), ion cyclotron resonance frequency heating (ICH) and electron cyclotron resonance frequency heating (ECH). They produce high-energy particles with different energy ranges and pitch angles. The neutral particle measurement system with the spatial scannable mechanism is indispensable to study the high-energy particle confinement. Therefore 2-dimensional scanning system using the time-of-flight neutral particle analyzer (NPA) has been prepared on the horizontal port in LHD.

The vertical scan system has been available from the middle of the 6th cycle in addition to horizontal scanning system. The detail explanation of the vertical scan will be described in section III. Various experiments, for example, the ion temperature profile at the single shot, the neutral particle flux distribution on the poloidal direction, the optimization of the ion temperature measurement by combination with the horizontal scan and the different pitch angle measurement at the same average radius, can be expected by the vertical scanning.

Here we will summarize the typical results obtained by the horizontal scanning of the NPA, and describe the preliminary results obtained from the newly installed vertical scannable NPA system, especially the ion temperature profile.
II. The Results from Horizontal Scan

The horizontal scan of NPA has been performed by carrying out the remotely motor drive of the NPA stage. A scanning speed is 0.17 degree per second. A scanning center pitch angle, which is defined as the angle between the magnetic axis and the sight line, is from 40 degrees to 100 degrees. [1]

The high-energy neutral particle spectrum during NBI discharge has been measured by scanning of the NPA shot by shot. The transit particle can be mainly observed at the tangential position of NPA, although the trapped particle can be observed at the vertical position. The high-energy particle was confined in LHD plasma without large loss mechanism because the experimental result has been agreed with the simulation result. [2]

Comparison between the co- and the counter injection of NBI has been studied. The experiments have been performed on two different long discharges with the normal and reverse magnetic fields. The NPA scan has been continuously proceeded during the long discharge to obtain the accurate dependence on the pitch angle. The higher energy particle can be confined in co-injection case than the counter-injection case. [3]

The horizontal scan experiment has been performed in ICH plasma too. The result is that the spatial distribution of the neutral particle flux had the butterfly shape predicted theoretically. [3,4] The ripple loss can be observed about at 5 keV, especially in low magnetic field and the outer magnetic axis configuration. The pitch angle dependence of the ripple loss was not clear. In the ECH experiments, the disappearance of the ripple loss can be observed by the radial electric field produced by the strong ECH. [5]
III. Vertical scanning system

The vertical scanning system is realized by adding a movable mechanism to a current horizontal scanning system (Fig. 1). The analyzer slides along three stainless steel rails, which are arcs of the radii of 4 m. One of rails defines the accurate position of the analyzer. Another rail, which is settled at the front of the rail, fixes the vertical position and the other rail, which is settled at the side, fixes the side position. Therefore, the smooth and non-vibrated vertical driving can be obtained. The two chains and the gears, which are connected with the motor, hang up the analyzer. Two stainless blocks are set on the opposite side of the chain in order to balance the weight (700kg) of the analyzer and reduce the load for the motor. Therefore very high speed of one degree per second can be obtained. To avoid the tilting of the bellow at the pivot point, there are two different bellows for the horizontal and for the vertical scans. Both scannings are performed by the remote control with a personal computer. While acting as the monitor of the position with a CCD camera, the time history of an exact position is read using the position detector, and stored in the personal computer.

VI. Ion temperature profile

The time history of an ion temperature profile can be obtained by changing the vertical position shot by shot. The plasma poloidal section is varied by changing the toroidal position. We choose the horizontal position of the center pitch angle of 60 degrees to avoid the observation at the diverter region where there is much background neutral. (Fig. 3 and Fig. 4)

![Fig. 3. Time history of ion temperature profile.](image1)

The ion temperature profile can be obtained by changing the vertical position shot by shot.

![Fig. 4. Ion temperature profile.](image2)

The ion temperature profile can be obtained by vertical scanning the analyzer during a single long discharge.
2) The time history of the ion temperature profile is shown in Fig. 3. The ion temperature profile is comparatively flat and a central temperature is low observed as compared with other measurement. Since the main component of this plasma is the argon, the contribution of the charge exchange between lower ionized argon and proton should be considered. The lower ionized argon exists near the plasma outer region. Therefore the observed ion temperature may be affected by the contribution of the neutral flux contribution at the outer region rather than at the portion of the smallest plasma radius of the sight. In calculation, these cross sections are too small, the contribution for the neutral flux. Neutral particle scattering with high-Z plasma may be one reason of the profile flattening.

It is possible to obtain the poloidal profile of the neutral particle flux or the ion temperature profile by vertical scanning the analyzer during the single long discharge. Fig. 4 shows the typical ion temperature profile by vertical scanning the analyzer from +9 to -9 degrees with the scanning speed of 1 degree per second during 40-second discharge. Time change corresponds to an observation position. Horizontal measurement positions are at the central pitch angles of 60 degrees. The fluctuation of the ion temperature at $\rho = 0 - 0.5$ may reflect the charge exchange neutral from the dense background neutral at the diverter region.

V. Summary

The 2-dimentional scanning neutral particle measurement system has been completed in order to investigate the high-energy particle confinement. In the horizontal scan, the difference between co- and counter injection of NBI, the heating mechanism of ICH and the ripple loss can be observed. By adding the vertical scan, the ion temperature profile can be obtained as the preliminary experimental result.

References