§67. Improved Pellet Charge Exchange Measurements in Large Helical Device

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In the LHD, TESPEL (tracer encapsulated pellet) has been developed mainly in order to measure impurity transport. To obtain the accurate energetic particle distribution function, three subjects should be considered. The first one is the energy dependence of the neutralization factor in the pellet cloud. The flux of the charge exchanged neutral particles is proportional to the neutralization factor. The charge exchange occurs not only between the protons and the neutrals in the pellet cloud, but between the protons and the partially ionized ions (carbon ions). The charge exchange cross section between the protons and the ions has been calculated by Tolstikhina. The neutralization factor has also been introduced by Goncharov. The neutralization factor depends on the ion charge state distribution. To obtain the ion charge sate distribution, the electron temperature and electron density of the pellet cloud are required. The electron temperature and density dependence of the ion charge state distribution is shown in Fig.1. In this calculation, The ADAS database has been used. The temperature and density of the pellet cloud has been measured to be 5 eV and 7.1×10^{16} cm^{-3} by Tamura and Miroshnikov. Therefore C^{+2}:C^{+3} is assumed to be 50%:50%. Finally the accurate energy dependence of the neutralization factor can be obtained.

The second subject is the attenuation of the charge exchanged neutral particles. The attenuation strongly depends on the plasma density and Z_{eff}. The typical value of the attenuation factor is one-tenth at the proton energy of 10 keV.

The third subject is the pitch angle distribution of the energetic particle. The observed spectrum is a reflection of the real distribution function in the cases of perpendicular NBI or ICH heatings because the CNPA is positioned perpendicularly to the plasma. However only the particles scattered to the CNPA direction can be detected on the tangential NBI. Therefore a correction for the non-uniformity of the distribution function is necessary.

As the pellet cloud temperature and density and the bulk plasma parameters are known, we can obtain the neutralization factor and the attenuation factor from Fig. 1 and the referenc. Here the scattering correction can be ignored because the ICH plasma will be analyzed. The accurate energy distribution function can be obtained. Here the radial energy spectra of the energetic particles can be obtained by using the above correction, especially in ICH plasmas in order to investigate the heating mechanism of the ICH.

A second harmonic heating at the frequency of 38.47 MHz selectively accelerates the proton in the helium gas containing a small amount of hydrogen gas. Generally the higher harmonic heating is used in the high density and high temperature plasma. Here we verify whether it is available in LHD if the plasma density is low. Second harmonic heating at 38.47 MHz is realized at the magnetic field of 1.375 T. The perpendicular NBI is applied at the same time because particles with high pitch angle can be easily coupled with the cyclotron resonance in ICH. In this configuration, the resonance layer is slightly far from the plasma center (off-axis). The trajectory of TESPEL turns 20-degrees from the horizontal axis because TESPEL is injected towards the torus center on the equatorial plane from the position of 4 degrees rotated toroidaly. The time corresponds to the position of the TESPEL. The peak of the flux can be found near ρ=0.7, where the particle acceleration occurs. The width of the resonance layer is several times the Lamor radius and seems to become wider as the energy becomes lower. When the plasma density increases, the accelerated energy seems to be low. However any change of the flux in the low energy range cannot be observed by the passive charge exchange measurement.

Second harmonics heating has been performed at 51 MHz. By tuning the magnetic field, the same configuration of the resonance layer can be obtained as at 38.47 MHz. Due to higher magnetic field, slightly higher performance plasma can be expected. The particle acceleration of the beam from the NBI can be observed when the perpendicular NBI is injected. The particle acceleration around the resonance layer can be clearly observed in the PCX although it cannot be found by the passive method. When the magnetic axis is moved inward to 3.53 m, good particle confinement should be expected because usually the trapped particles are well confined at the inner magnetic axis shift. Indeed the high-energy tail can be observed at the magnetic axis position of 3.53 m rather than at 3.75 m although the particle acceleration between 20 and 60 keV is larger at 3.75 m. However the high-energy tail at 3.75 m seems to decrease in the passive measurement. Usually the passing particle passes near the region where the background neutral is rich at the outer magnetic axis position. The passive measurement is line integration. Therefore the particle acceleration by ICH is not clear because the passive measurement is line integrated.

We can perform second harmonic heating at the magnetic field of 2.75 T by using ICH at the frequency of 85 MHz. Here ICH with 85 MHz is overlapped on the plasma with ICH at 38.47 MHz (fundamental heating) and unbalanced tangential NBI. The particles over 20 keV can be accelerated by the addition to the ICH with 85 MHz although the particle acceleration is not enough only by ICH with 38.47 MHz. The energetic particles, which come from the tangential NBI are mainly accelerated in this experiment. Therefore ICH with 85 MHz seems to be effective in LHD. In the passive measurement, a clear discrepancy cannot be found although small particle acceleration around 150 keV may be observed.

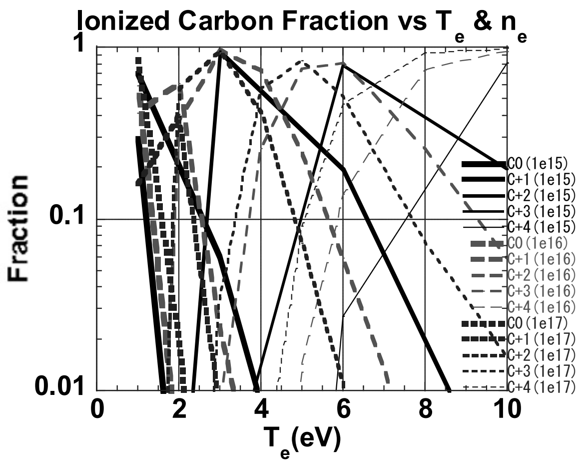

Fig. 1 Carbon ion charge state distribution
The carbon ion charge state distribution depends on T_e and n_e of the pellet cloud.