§26. Study on the He Exhaust Characteristics during LID Operation in LHD

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To expand the ignited operation regime, the ratio of the alpha ash confinement time to the energy confinement time (τ_α^*/τ_E) should be as small as possible as ~4 in the FFHR helical reactor. In the previous campaign, the charge exchange recombination spectroscopy (CXS) with positive NBI (40 keV) was used to measure He^{++} ions directly in the density regime up to 5×10^{19} m^{-3}. However in this fiscal year, LID operation with the pumping function was not conducted. Therefore, in this report we present the numerical results on how the line integrated signal from He^+ ions is seen on the viewing sight line, which is important to analyze the experimental data on the He^+ ion profiles and the time decay.

In the LHD CXS system viewing tangentially, light He^+ ions excited by NBI charge exchange expand quickly to the toroidal direction (Plume effect), and these plume He^+ ions will emit the line (4868 Å) by the electron excitation. Therefore the signal contains the line from the plume He^+ ion together with the charge exchanged He^+ ion. This signal is estimated by the formula

$$B(R_{sj}) = \frac{1}{4\pi} n_{He++}(R,t) n_{NBI}(R) \langle \sigma V \rangle_{CX}(R) \Delta L_{NBI} + \frac{1}{4\pi} \int n_e(R) n_{He+CX}(L(P),R,t) \langle \sigma V \rangle_{e-ex}(R) dy \qquad (1)$$

where the first term gives the direct signal from the charge exchanged He^+ ions by NBI, and the second term from the plume effect. This plume He^+ ions expand by the mean free path $L=V_{He}\tau_{ion}=V_{He}/n\langle\sigma V\rangle_{ion}$ until ionization by the electron collisions. For LHD He exhaust experiments with T= 1 keV, $\langle\sigma V\rangle_{ion}\sim4\times10^{-15}$ m^3/s, the electron density of $n=1\times10^{19}$ m^{-3}, $\tau_{ion}\sim1/(10^{19}\times4\times10^{-15})=25$ μs and He^+ ion thermal velocity $V_{He}=(kT/M_{He})^{0.5}=1.5\times10^5$ m/s, the mean free path is $L\sim1.5\times10^5\times25\times10^{-6}=3.75$ m. Therefore, it is recognized that the signal from plume He^+ ions drifted toward the CXS detector is detected together with main signals.

In Fig. 1 is shown the detection layout in the LHD and approximated flux line on the equatorial plane. Here we assume no rotational transform of the magnetic field line for simplicity. We estimate that how we see the plume He^+ ion signal in the integrated sight lines in the complicated helical system.

Using the polar coordinate to express the LHD magnetic flux line and viewing sight lines, the integrated signal along the sight line for Bi-Fermi profiles (exponential term) is given by

$$\overline{I(y)}/I(0) = \int_{-\phi\max}^{\phi\max} \left[\frac{1}{e^{40\left\{\left(\frac{\rho_\phi}{a_\phi}-\frac{r_{ED}}{a_\phi}\right)^2-\Delta a_\phi\right\}}+1} + \frac{1}{e^{40\left\{\left(\frac{\rho_\phi}{a_\phi}+\frac{r_{ED}}{a_\phi}\right)^2-\Delta a_\phi\right\}}+1} \right] \times \sqrt{\frac{1}{c^2}+1}\, \frac{\left(x_{ob}-\frac{y_{ob}}{c}\right)}{\left(\cos\phi-\frac{1}{c}\sin\phi\right)^2} d\phi \qquad (2)$$

where c is the inclination of the sight line and (x_{ob},y_{ob}) is the detector focal point, and ρ_ϕ is the minor radius and ϕ is the toroidal angle of the observation point.

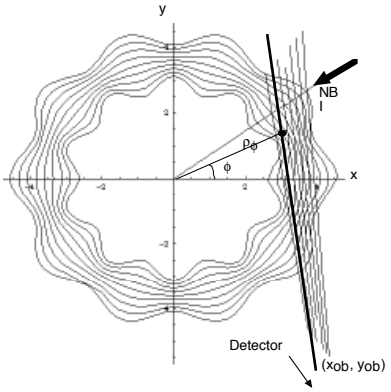

Fig. 1. Approximated magnetic flux line on the equatorial plane in the LHD, and the observing lines of the CXS.

In Fig. 2-(a) the signal viewing on the sight line through the point of R=3.6m at the NBI injection line is shown. For example, He^+ ions are assumed to exist near the plasma outer surface to express He gas puffing. The signal at -30 degree (closer to the detector) is from the outboard profile of He^+ ions, and signal at -20~+30 degree from the inboard profiles of He^+ ions on waving magnetic field line, and one at the positive angle of 45 degree again from the outboard profile of He^+ ions. Fig. 2-(b) provides the integrated signal along the sight line for various minor radii. We see that the quite complicated signal profiles are obtained, which is different from the original He^+ ion profiles.

Thus, we can proceed to more precise data analysis for He^+ ion decay time and profile analysis.

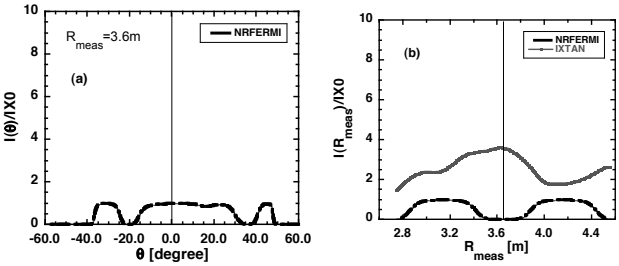

Fig. 2. (a) Signals seen on the straight line through the measuring point of 3.6 m on the NBI injection line.
(b) Integrated signal (solid red line) along the viewing line for the various observation point on the NBI injection line, and assumed He^+ ion profile (black dashed line).

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