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Measurement of Neutral Beam Attenuation Using Atomic and Molecular Database on LHD
LHDにおける中性粒子ビーム減衰計測の原子分子データベースの活用

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Hydrogen Balmer emission (Hα: n = 3 → 2) emitted from neutral beam particles from NBI had been observed by Doppler spectroscopy on LHD. Large signal drop was appeared on beam-emissions after a small carbon pellet injection on hydrogen discharge. Beam stopping and emission coefficient on the atomic database had been applied to the beam attenuation analysis. Calculated beam-emission flux well fitted to the measured signals, and this result has confirmed strong beam attenuation after the carbon pellet injection along the beam injection path.

1. Introduction

Neutral beam injection (NBI) is a powerful and useful heating for fusion experiment devices. Detail of beam heating power is required for effective beam heating for the Large Helical Device (LHD) [1]. Hydrogen beam particles are ionized into plasma and trapped with confinement magnetic field. Other residual beam particles pass through plasma with optical emissions of hydrogen Balmer lines. This visible beam-emission with informations of beam attenuation can be measured easily by Doppler spectroscopy [2-4]. However the local beam attenuation along the beam injection path is difficult to obtain only using a signal intensity of beam-emission. We will report a diagnostic method and the beam-emission signals on LHD. We calculated the beam-emission intensity using the beam-stopping coefficient and beam-emission coefficient on an atomic database. Finally, we estimated beam deposition power with assuming carbon fraction in a hydrogen discharge.

2. Beam-Emission Diagnostic and Signals

Optical lines of sights (LOS) were set along the neutral beam (BL3) injection path [2,3] as shown in Fig. 1. The angles between the beam path and LOS are 62.4° and 134.7°. The wavelength of hydrogen optical emission (Hα) from neutral beam particle was shifted by the Doppler effect. The beam-emission signals were detected using an intensified charge-coupled device detector cooled to -20 °C which was positioned at the focal plane of a 25 cm Czerny-Turner spectrometer. The spectrometric system was calibrated using an Urbricht sphere with a standard lamp.

Figure 2 shows a typical example of hydrogen discharge with carbon pellet injection using five NBI heating. Total neutral beam (NB) power was 25 MW including a modulated NB from BL4 using for a charge exchange spectroscopy to obtain the ion temperature profile. Tangential third beam line (BL3), which is as the probe beam for beam attenuation measurement, injected 4.9 MW constant NB power as shown in Fig. 2(a). After a small carbon pellet (ϕ= 1 mm) injection at t= 3.85 s, the line averaged electron density, which was measured by a far-infrared laser interferometer (FIR), increased rapidly as much as two times of magnitude as shown in Fig. 2(b). Figure 2(c) shows the intensity of beam-emission signals. Those

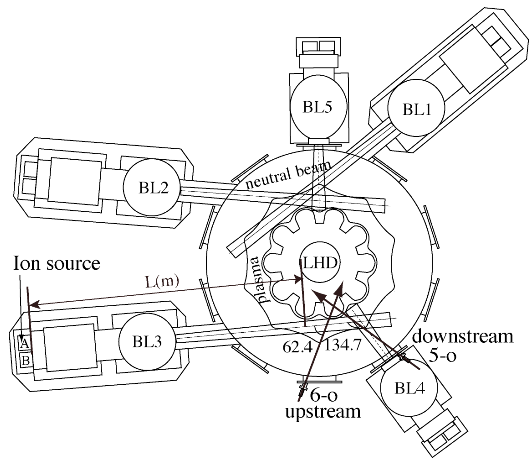

Fig. 1. Schematic drawing of neutral beam injectors and line of sights for beam attenuation measurement in LHD.

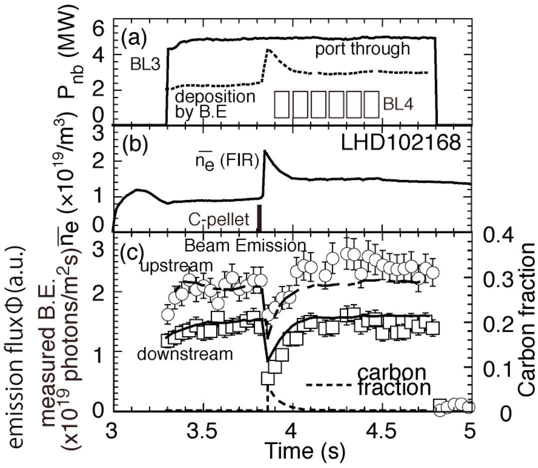

Fig. 2. (a) Bold line is the injection NB power of BL3 and dotted line is the deposition power estimated by beam attenuation analysis. (b) Line averaged electron density. (c) Beam emission intensities at the upstream and the downstream positions. Lines are beam emission flux calculated by beam attenuation analysis using ADAS database on the assumption of decaying a carbon fraction.

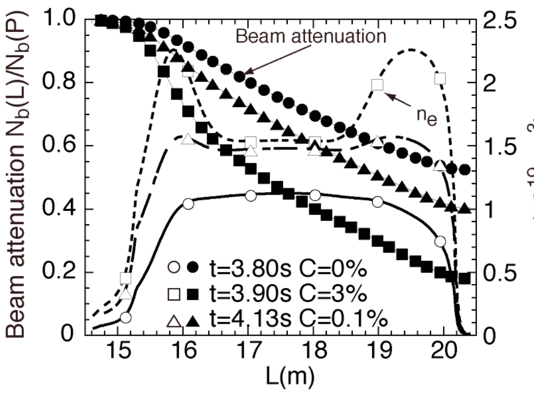

Fig. 3. Electron density and beam attenuation along the beam injection path.

signals dropped after the carbon pellet injection considering as strong beam attenuation due to the increasing of beam stopping cross-section by carbon impurity. Then the beam-emission signals gradually increased as decreasing of electron density.

3. Application of Atomic Database to Beam Attenuation Analysis

At the position of L, a local beam-emission flux $\Phi(L)$ is proportional to the product of local electron density $n_e(L)$, neutral beam density $N_b(L)$ and beam-emission coefficient ϵ_{cr} [4]. Here, we calculated neutral beam attenuation along the beam injection path using the effective beam-stopping coefficient S_{cr} on the Atomic Data and Analysis Structure (ADAS) database [5-7]. Local neutral beam density is expressed by an exponential decay function as follows

$$N_b(L) = N_b(P)exp(-\int_P^L n_e(l)S_{cr}(l)\sqrt{\frac{m}{2E}}dl),$$

here $N_b(P)$ is the initial neutral beam density path through the beam injection port, and m and E is the mass and the energy of beam particles, respectively. We estimated S_{cr} and ϵ_{cr} along the beam injection path using a hydrogen and carbon mixture model. When the carbon fraction is assumed 3% at t= 3.9 s as shown in Fig. 2(c), a large beam attenuation appears around L= 15.6 m where is the first peak position of n_e along the beam injection path. The total beam deposition rate increases from 49% to 88% due to increasing carbon fraction, then it decreases to 60% at t= 4.1 s with decaying to 0.1% carbon impurities. Relative beam-emission flux Φ estimated by the same analysis using the ϵ_{cr} also dropped by increasing carbon, and the recovering behavior similar to the electron density appears on Φ in Fig. 2(c). Then we estimated the beam deposition power by the product of the beam deposition rate and the port through power as shown in Fig. 2(a). Effective net heating power increases to 4.3 MW from 2.4 MW by carbon impurities. We confirmed strong beam deposition after the carbon pellet injection.

4. Summary

Beam stopping and emission coefficient on the atomic database had been applied to the beam attenuation analysis. Calculated beam-emission flux well fitted to the beam-emission signals measured from the Doppler spectroscopy on LHD. This analysis is useful to understand for the detail of beam heating and the beam attenuation along the beam injection path.

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