Rapid Communications

Increase of Central Ion Temperature after Carbon Pellet Injection in Ne-Seeded NBI Discharges of LHD

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A cylindrical carbon pellet with a size of 1.0 mm$^{\phi}$ × 1.0 mm^{L} was injected into low-density (n_e = 0.3–0.5 × 10^{13} cm^{-3}) neon-seeded NBI plasmas of the Large Helical Device (LHD). When the two NBI beam pulses were delayed just after the pellet injection, a large increment of central ion temperature up to 5 keV was observed with the appearance of a peaked density profile ($n_{e0}/\langle n_e \rangle$~2.5) and enhanced toroidal rotation speed up to 35 km/s. Improvement of the ion transport is expected with the suggestion of a new operational scenario for confinement improvement in the LHD.

Keywords:
impurity pellet, ion temperature, NBI heating, density peaking, helical plasma

Ion heating experiments have been extensively carried out in the LHD. The ion temperature at the plasma center, $T_i(0)$, is measured by a crystal spectrometer with a CCD detector observing the Doppler broadening of x-ray lines of He-like TiXXI and ArXVII [1]. Successful ion heating was found in ICRF discharges (H-minority, He-majority), although the ion heating was not sufficient in H_2 and He NBI discharges [2] because of the high beam energy (E_{NBI} = 150–180 keV). Most of the NBI absorption power, P_{abs}, is deposited in bulk electrons (P_e/P_{abs}~80%) due to a higher value of E_{NBI}/T_e ratio (~50). The $T_i(0)$ saturates at less than 2.5 keV [2].

Recently, neon gas was seeded in order to increase the P_{abs} and to reduce the bulk ion density, n_i, in low-density discharges. As a result, the ratio of P_i/n_i (P_i: direct deposition power from fast ions to bulk ions) could be increased roughly by 5 times in these neon discharges. A $T_i(0)$ of up to 5 keV was successfully obtained under a neutral beam injection power, P_{NBI}, of 8 MW and a linear relation was also found between the $T_i(0)$ and P_i/n_i [3,4], although the hydrogen amount could not be sufficiently reduced.

On the other hand, an H_2 ice pellet has been injected to achieve a peaked profile followed by the confinement improvement. However, an apparent temperature increase was not observed, although the operational density range was successfully extended [5]. Thus, a carbon pellet with a much higher melting point was injected as an alternative way to modify the density profile and to increase the P_{abs} at the plasma center using a newly installed impurity pellet injector [6]. Spherical and cylindrical carbon pellets (size: 0.5–1.0 mm) have been injected into NBI discharges.

A typical result for the large pellet (1 mm$^{\phi}$ × 1 mm^{L}) injection is shown in Fig. 1 (right). The carbon pellet was injected in Ne-seeded discharges. Waveforms of the Ne-seeded NBI discharge without carbon pellet are also traced in Fig. 1 (left) for comparison. Both discharges are carried out for the R_{ax} = 3.60 m configuration. The density of n_e = 0.4–0.5 × 10^{13} cm^{-3} is produced mainly by the puffed neon and recycled

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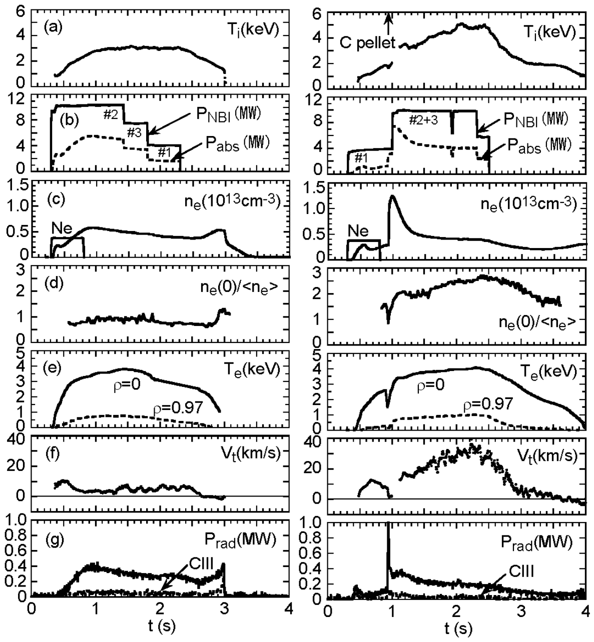

Fig. 1 Ne-seeded NBI discharges without (left) and with (right) carbon pellet injection. (a) central ion temperature, (b) NBI power (solid: port-through power, dashed: absorption power), (c) line-averaged electron density (N_e: neon gas puff), (d) density peaking factor ($n_e(0)$: central electron density, $\langle n_e \rangle$: line-averaged electron density), (e) electron temperature from ECE, (f) central toroidal rotation speed and (g) radiation power (dashed: CIII intensity in arb. unit).

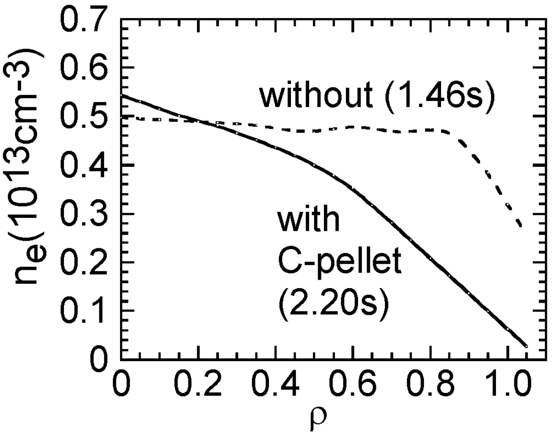

Fig. 2 Electron density profiles without (dashed line) and with (solid line) carbon pellet.

hydrogen. A $T_i(0)$ of 3 keV is sustained during the Ne-seeded discharge (see Fig. 1 (a) left). When the carbon pellet is injected, the $T_i(0)$ gradually increases and reaches 5 keV. The lack of T_i data after the pellet injection is caused by a decrease in ArXVII emission due to the sudden T_e drop.

In low-density discharges, the beam-ion slowing-down time becomes quite long because of the high beam energy and the beam-stored energy becomes also very large. The heat flux from the beam ions strongly influences the pellet ablation [7]. Therefore, the NBIs #2 and #3 are injected just after the pellet injection in order to avoid ablation at the outer plasma region and to achieve a central particle deposition. This was very effective in increasing the $T_i(0)$. The density profiles are shown in Fig. 2. The density peaking factor increases up to ~2.5 after carbon pellet injection, whereas it is around 1 for the Ne-seeded discharge. Due to the density peaking, the central toroidal rotation speed, V_t, is largely increased and reaches 35 km/s, which corresponds to 12% of the carbon thermal velocity. The $T_i(0)$ continuously increases, whereas the P_{abs} becomes constant after t = 1.5 s. Improvement of the ion transport, at least at the plasma center, is expected. Ion transport analysis is currently underway, based on the estimation of H, C, and Ne ion densities in both discharges.

[1] S. Morita and M. Goto, Rev. Sci. Instrum. **74**, 2375 (2003).
[2] S. Morita *et al.*, Nucl. Fusion **42**, 1179 (2002).
[3] S. Morita *et al.*, *19th IAEA Fusion Energy Conference*, Lyon, 2002, EX/P2-18.
[4] Y. Takeiri *et al.*, Phys. Plasmas **10**, 1788 (2003).
[5] R. Sakamoto *et al.*, Nucl. Fusion **41**, 381 (2001).
[6] H. Nozato *et al.*, Rev. Sci. Instrum. **74**, 2032 (2003).
[7] S. Morita *et al.*, Nucl. Fusion **42**, 876 (2002).