§1. Extension of Operational Regime in High-$T_i$ Plasmas in the LHD


Realization of high-$T_i$ plasmas is one of the most important issues in helical plasmas, which have an advantage for steady-state operation comparison with tokamak plasmas. Since 2010, newly installed perpendicular-NBI with the beam energy of 40 keV has been operational in the LHD and the total-heating power of perpendicular-NBIs increased from 6 MW to 12 MW. Such low-energy NBIs are effective for ion heating and enabled us to achieve a higher $T_i$ than that obtained previously [1]. In the last experimental campaign, ICRH-discharge cleaning was adopted to reduce particle recycling from the wall. As a result, NBI-heating-power profile became peaked and the density-normalized ion heating power in the core region increased by 18%.

In the LHD, high-$T_i$ plasmas have been realized in combination with a carbon pellet [1-3]. The kinetic-energy confinement was improved by a factor of 1.5 after the pellet injection. Figure 1 shows the typical time evolution of (a) the port-through NB power, (b) line-averaged-electron density, (c) the radiation power, (d) the plasma stored energy, (e) $T_{e0}$, (f) $T_i$, (g) the radial profiles of $T_n$, $T_e$ and $n_e$ in the high-$T_i$ discharges, which recorded the highest $T_{i0}$ and (h) the progress of the achieved $T_{i0}$ in the LHD as the dependence of $T_{i0}$ on the density-normalized ion heating power $P_i/n_i$. The plasma was sustained by three tangentially injected NBs and two perpendicularly injected NBs with the total-port-through power of 27 MW and the column-shaped C pellet ($\phi = 1.0$ mm, $l = 1.0$ mm) was injected at $t = 4.57$ s. One line of the perpendicular NBIs was modulated for $T_i$ measurement by CXRS. After the pellet injection, the central $T_{i0}$, $dT_i/dr_{eff}$ at the core region clearly increased indicating the formation of the ion-ITB. On the other hand, there was little change in $T_e$. The radiation power increased just after the pellet injection but went back to the previous level due to the formation of the impurity hole. Ion temperature of 7 keV at the plasma center was successfully obtained and the achieved $T_{i0}$ has been increasing approximately linearly with $P_i/n_i$.

ICRH-discharge conditioning exerted a preferable effect also on quasi-steady-state operation of high-$T_i$ discharges without C-pellet injection. The sustain time of the plasma with $T_{i0} > 4.5$ keV has been successfully extended to 1 s from 0.5 s, which is the previous record, even the $P_{NB}$ was 4 MW lower than that of the previous one.


![Fig. 1. The typical time evolution of (a) the port-through NB power, (b) line-averaged-electron density, (c) the radiation power, (d) the plasma stored energy, (e) $T_{e0}$, (f) $T_i$, (g) the radial profiles of $T_n$, $T_e$ and $n_e$ in the high-$T_i$ discharges, which recorded the highest $T_{i0}$ and (h) the progress of the achieved $T_{i0}$.](image-url)