§1. Present Operational Regime of High Temperature Plasmas in the Large Helical Device

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Realization of high-temperature plasmas is one of the most important issues in helical plasmas, which have an advantage for steady-state operation comparison with tokamak plasmas. In the Large Helical Device (LHD), a lot of effort has been invested in the extension of the high-temperature regime. LHD equipes three negative-ion-based NBIs, which produce hydrogen neutral beams with a beam energy of 180 keV and with the total port-through power of 16 MW. The negative NBs are tangentially injected into the LHD plasma. A positive-ion-based NBI with a low energy of 40 keV is perpendicularly injected for ion heating. Since 2010, a second 40-keV-perpendicular NBI has been operational in the LHD and the total-port-through power for perpendicular NBI has thus increased from 6 MW to 12 MW. Enhancement of the output power per gyrotron has been planned in the LHD and the replacement of the existing gyrotrons with higher-power tubes is in progress. An electron cycrotron resonance heating (ECRH) system with eight gyrotrons has been operated for preionization and plasma heating. Of these, high power 77-GHz gyrotrons with an output power of more than 1 MW each have been operated since the experimental campaign in 2007. At present, three 77-GHz gyrotrons are operational for plasma experiments. In addition, a high power gyrotron with the frequency of 154 GHz (1 MW/5 s, 0.5 MW/CW) was newly installed in 2012. Figure 1 shows the history of (a) the port-through power of NBI P_{NBI_pt}, (b) ECRH P_{ECRH_pt}, (c) the achieved-central-ion temperature T_{i0} and (d) central-electron temperature T_{e0}. The heating capability on the LHD has been upgraded year by year. The LHD now has 28 MW of NBI power and 4.6 MW of ECRH power available for experiments. The achieved T_{i0} and T_{e0} have been extended due to the improvement of the heating system. Central T_i of 7.3 keV in the NBI-heated plasmas and central T_e of 20 keV in the ECRH plasmas have been successfully realized up to now. Note that the reason why T_{i0} increased from 2010 to 2012 despite the same NBI power is due to the new operation scenario using ICRF-wall conditioning.

Figure 2 shows the map of simultaneously attained T_{e0} and T_{i0}. The solid triangles and the solid circles are the data obtained in high-T_e and high-T_i discharges, respectively. The lines are the neoclassical calculation at r_{eff}/a_{99} = 0.25. The plasma profiles of electron-ITB and ion-ITB were used for the calculation of the broken and the solid lines, respectively. These lines represent the boundary, which separate confinement states. There are three confinement states in the map; ion root confinement, electron root confinement and three-roots regime. In the LHD, high-T_i and high-T_e experiments have been carried out independently and the temperature regime dissociated as seen in fig.2. An experimental scenario to achieve high-T_i and high-T_e at the same time is under construction. The realization of three-roots regime for high-T_i plasmas or increasing T_i in high-T_e plasmas keeping electron-root confinement is a possible direction to be taken because ion-confinement improvement is expected due to the presence of positive-radial-electric field. Integration between high temperature and long-time sustainment is also an important issue in the LHD and has progress.

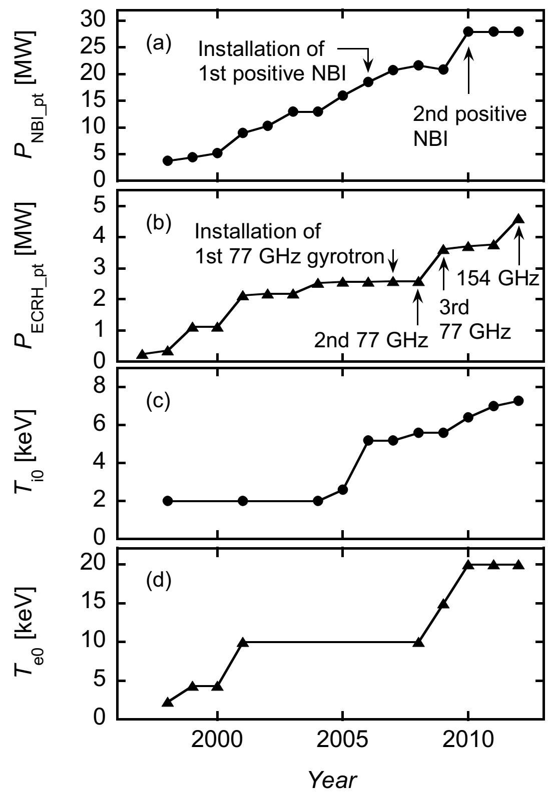

Figure 1. The history of (a) P_{NBI_pt}, (b) P_{ECRH_pt}, (c) T_{i0} and (d) T_{e0}.

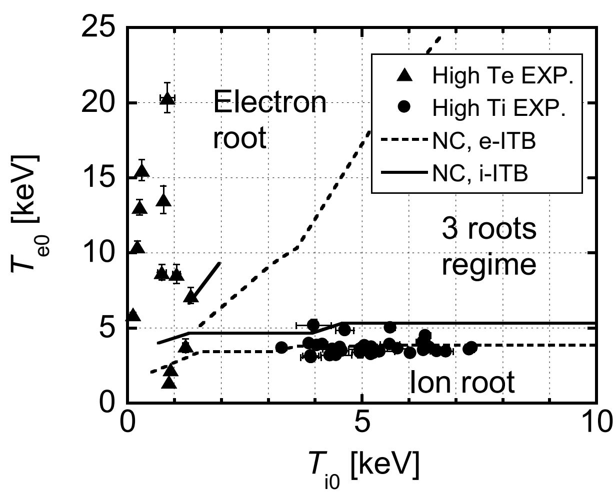

Figure 2. The map of simultaneously attained T_{e0} and T_{i0}.