§29. Application of ICRF Mode Conversion Heating to Long-pulse Discharges in LHD

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Electron heating is a promising heating method for steady-state operation, since plasma was sustained for 65 minutes by ECH with the power of 110kW without any problem [1] in LHD. ICRF electron heating by the mode conversion was also investigated for the steady-state operation with the frequency of 28.4MHz and magnetic field strength on an axis of 2.75T. Plasma consists of hydrogen and helium ions. The ion cyclotron resonance layers of hydrogen locate at the top and bottom of the plasma in front of the ICRF antenna, as shown in Fig. 1, where the RF field is thought to be weak. The fast wave excited by ICRF antenna is converted to a slow wave at the ion-ion hybrid resonance layers. By the analysis of power absorption, it was clarified that only electrons were heated directly [2]. An ICRF heating power of 580kW could be injected and the plasma sustained for 9 seconds with mode conversion heating alone. Then the line averaged electron density and electron temperature on the axis were $0.8\times10^{19}\mathrm{m}^{-3}$ and 0.8keV, respectively. However, this heating method has the disadvantage of a low loading resistance, which results in high voltage in the transmission line (line impedance: 50Ω) and limits the injection power. However, it was found that the loading resistance increases until approximately 3.5Ω by the increase of electron density in the case of the distance of 8cm between the antenna and last closed flux surface The loading resistance of 3.5Ω corresponds to 630kW per one antenna in the case of the voltage limit of 30kV in the transmission line [3].

ICRF heating by the use of mode conversion was applied to a long-pulse operation in LHD in 2006. By the averaged ICRF power of 260kW and ECH power of 110kW, the plasma was sustained for 88 seconds, as shown in Fig. 2. Pellets were injected repetitively to supply hydrogen. The voltage interlock system dropped the injection power twice for the protection of the transmission line. An increase of the loading resistance by a high-density operation would reduce the voltage. The final power drop was due to a problem of an amplifier (excess screen grid current in tetrode tube). Figure 3-(a) shows the temperature distribution on the divertor plates. Temperature profile of the minority ion heating ($\bar{n}_e$=0.5, P_{ICRF}=0.9MW) is shown in Fig. 3-(b). It was found that the temperature profile of the mode conversion heating was less localized in the toroidal direction than that of the minority ion heating. Therefore, ICRF mode conversion heating may be useful for high-power steady-state operation. The temperature of the lower side is larger than that of the upper side, unlike with minority ion heating. This is because of the difference of the magnetic field direction. In the mode conversion heating case, the magnetic axis was fixed at 3.6m. By using the technique of axis sweeping, the increases in temperature would be more alleviated.

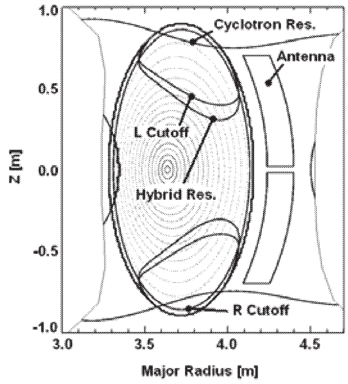

Fig.1 Location of resonance layers.

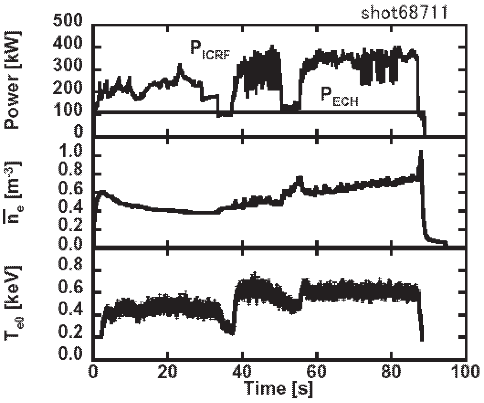

Fig.2 Long-pulse discharge by mode conversion heating.

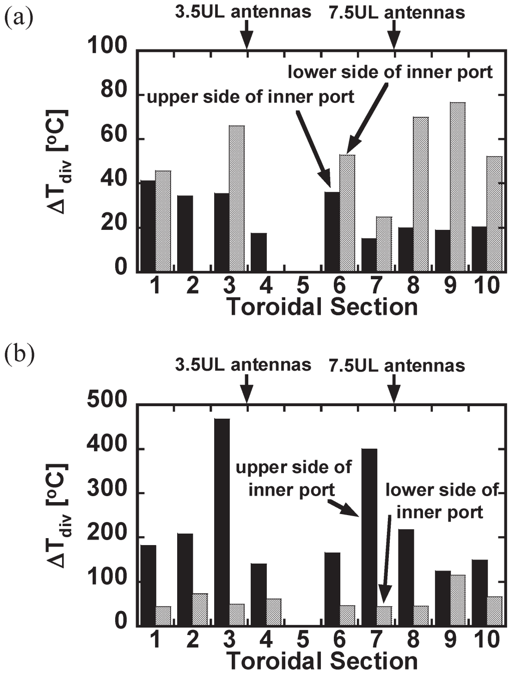

Fig.3 Distribution of temperature rise on divertor plates for (a) mode conversion heating and (b) minority ion heating.

References
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2) Saito, K, et al. Nucl. Fusion **41**, (2001) 1021
3) Saito, K, Annual report of NIFS 2005-2006, p73