§5. Improvement in Plasma Parameters of Long-Pulse Discharge Sustained by ECH

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In LHD, long-pulse discharges have been performed using variety of heating equipments which were capable of long-pulse operation: ECH[1)], ICRF[2)] and NBI[3)]. A comparison of the parameters of the long-pulse plasmas performed with those heating equipments makes it clear that ECH increases the electron temperature twice or more with less power than ICRF or NBI. Figure 1 plots the central electron temperature as functions of the average electron density (T_{e0}-n_e characteristic curve) obtained in the long-pulse discharges sustained longer than 7 s. Most of the discharges were performed with the magnetic configurations of R_{ax}=3.6 m with B_{ax}=2.75 T and R_{ax}=3.75 m with B_{ax}=2.75 T to realize on-axis fundamental resonance condition for 77 GHz EC-waves generated with the newly developed high-power, long-pulse gyrotrons[4)]. It is shown that an increase in the ECH power pulls up the T_{e0}-n_e characteristic curve drastically with less power compared with ICRF and NBI. For example, with the density of 0.6x10^{19}m^{-3}, the electron temperature of the plasma sustained with the ECH power of 660 kW is 3 times higher than those sustained with the higher power of 720 kW (220 kW ECH + 500 kW NBI) or 1 MW (100 kW ECH + 900 kW ICRF). This plot exhibits an advantage of ECH for effective plasma sustainment due to centrally localized power deposition.

Moreover, in the case of ICRF long-pulse discharges, toroidally and poloidally localized increase in the temperature of the diverter tiles over 400 deg. due to the high-energy ion component and the resultant increase in the impurity caused the radiation collapses. On the contrary, in the case of ECH and/or NBI long-pulse discharges, the temperature distribution of the diverter tiles in the toroidal direction was rather flattened, so that the increase in the temperature of each tile was able to be suppressed.

Figure 2 shows the waveforms of T_{e0} measured with Thomson scattering measurement system and line-averaged central n_e measured with FIR interferometer in a long-pulse discharge #96009 of the duration time of 400 s sustained with the ECH power of 275 kW from three gyrotrons (two 77 GHz and an 84 GHz gyrotrons). T_{e0} and n_e are 3 keV and 0.23x10^{19}m^{-3}, respectively. The plasma was quite stable, and the cause of the termination of the discharge was a stop of the oscillation of one of the gyrotrons. The conditioning operation of the gyrotrons for stable long-pulse operation and for increase in output power, and trials to increase electron density (shift the point on the T_{e0}-n_e characteristic curve toward higher n_e region) are required to achieve steady-state, higher density plasmas with hour-order duration time, which will provide necessary PWI data and information for the steady-state operation planned for ITER.

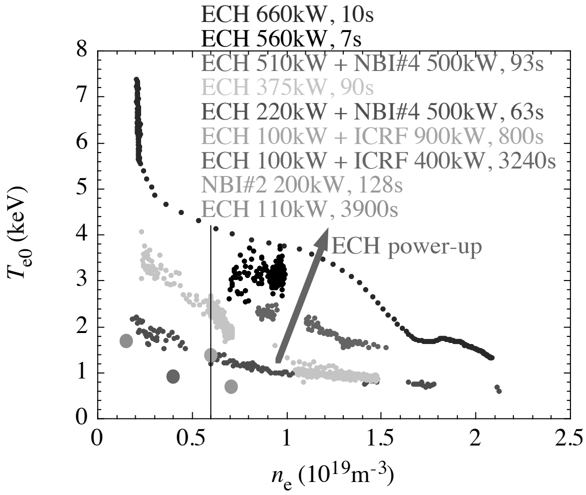

Fig. 1 T_{e0}-n_e characteristic curves obtained in the long-pulse discharges (> 7 s). Increase in the ECH power is quite effective for pulling up the T_{e0}-n_e characteristic curve.

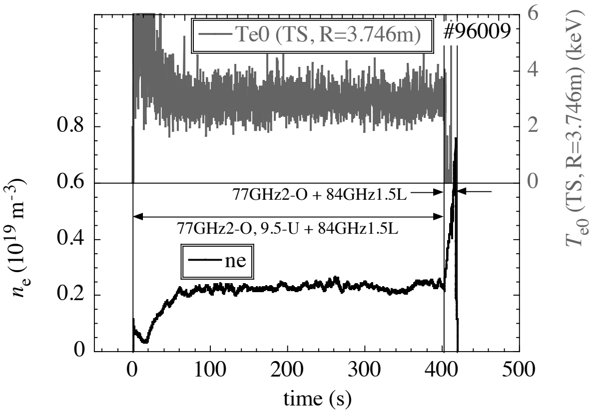

Fig. 2 Waveforms in a 400 s discharge sustained with the ECH power of 275 kW. The plasma with T_{e0} of 3 keV and n_e of 0.23x10^{19}m^{-3} was sustained quite stably during the EC-wave power injection.

1) Y. YOSHIMURA et al.: to be published in Fusion Sci. Technol.
2) T. MUTOH et al.: Nucl. Fusion, **47**, 1250 (2007).
3) Y. TAKEIRI et al.: to be published in Fusion Sci. Technol.
4) H. TAKAHASHI et al.: Fusion Sci. Technol, **57**, 19 (2010).