§16. Trial of Long-pulse Discharge by Use of High-power 77 GHz ECH System

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Trial of steady-state operation (SSO) in the Large Helical Device (LHD) were started when a continuous wave (CW) gyrotron with the output power up to 0.2 MW was introduced to the electron cyclotron heating (ECH) system on LHD in 2003. A 3900 s sustainment of plasma with the line-average electron density n_e of 0.15×10^{19} m^{-3} and the central electron temperature T_{e0} of 1.7 keV by 0.1 MW injection power was successfully achieved in 2005. The magnetic field configuration was R_{ax} = 3.6 m and B_{ax} = 1.48 T, with which direct on-axis second harmonic resonance condition was realized for 84 GHz wave. To avoid radiation collapse, these SSO experiments were performed with rather low density.

Sustainment of higher density by increasing ECH power was planned, and improvement of ECH system by replacement of existing pulse-operational 168 GHz gyrotrons to newly developed 77 GHz CW gyrotrons was started since 2007. The design values for the output power of these gyrotrons are over 1 MW for several seconds and 0.3 MW for CW. Until the start of LHD 13th experimental campaign in 2009, three 77 GHz ECH systems were completed and started to be used for LHD experiments. In the 14th experimental campaign in 2010, conditioning operation of these 77 GHz gyrotrons progressed so that the maximum total injection power from four CW gyrotrons reached 598 kW (77 GHz 5.5-Uout: 215 kW, 77 GHz 9.5-Uin: 139 kW, 77GHz 2-Oright: 113 kW and existing 84 GHz 1.5-L: 131 kW).

In the 13th experimental campaign in 2009, 275 kW ECH power from two 77 GHz (9.5-Uin and 2-Oright) and one 84 GHz ECH systems stably sustained a plasma with the parameters n_e = 0.23×10^{19} m^{-3} and T_{e0} = 3.0 keV for 400 s with the magnetic field configuration of R_{ax} = 3.75 m and B_{ax} = 2.75 T, with which direct on-axis fundamental resonance condition is realized for both 77 GHz ECH systems: one injects the power at the vertically elongated poloidal cross section (9.5-U) and the other at the horizontally elongated poloidal cross section (2-O).

In the 14th experimental campaign, longer-pulse plasma sustainment with higher parameters was tried with much higher ECH power of 525 kW. The magnetic field configuration was R_{ax} = 3.6 m and B_{ax} = 2.705 T. With this configuration, direct on-axis fundamental resonance heating is realized for top-port injection from 9.5-U and 5.5-U, while a toroidally oblique beam injection is required for on-axis heating by the horizontal-port injection from 2-O. At first, for the adjustment and optimization of gas-puffing, 8 s discharges were generated. With this pulse width, a stable high-performance plasma with n_e of 0.9×10^{19} m^{-3} and T_{e0} of 2.8 keV was successfully obtained (Fig. 1, #102747).

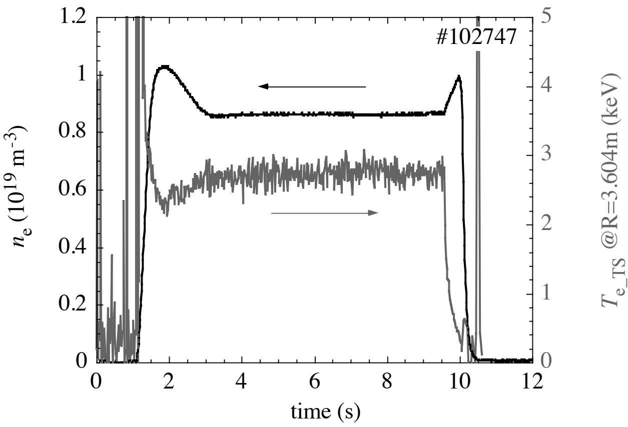

Fig. 1 A preparatory discharge for a long-pulse sustainment of high-performance plasma by ECH.

However, the pulse-width extention based on this preparatory discharge was not straightforward. At about 30 ~ 40 s, n_e started increasing and finally the plasmas collapsed. The plasmas suffered not only density increase but also sparks from around top-port ECH antenna. To sustain plasma longer, decreasing plasma density and/or reducing ECH power was needed. In the longest pulse-width discharge of 188 s in this experimental campaign (Fig. 2, #102753), n_e was reduced to 0.3×10^{19} m^{-3} and two gyrotrons (77 GHz 9.5-U and 84 GHz 1.5-L) happened to stop operation at 20 s. Further optimization of the density, ECH power and the magnetic field configuration, and the investigation for preventing density increase and sparks are required.

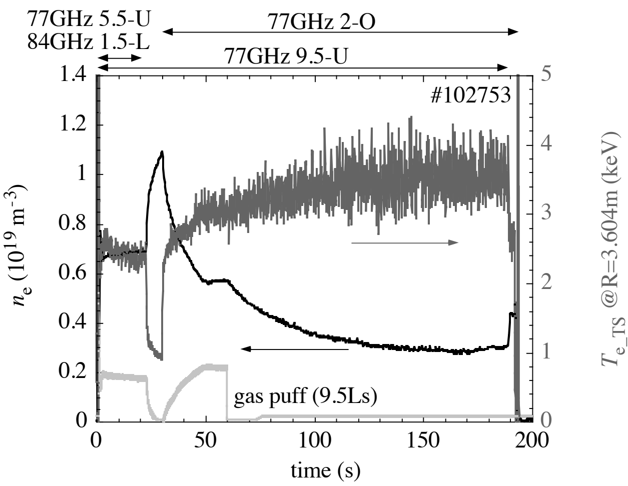

Fig. 2 Waveforms of the longest pulse-width discharge of 188 s in the 14th experimental campaign.