

§11. Prospect of Steady-State Plasma Sustainment by New 77GHz ECH System on LHD

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The former experiments of steady-state plasma sustainment in LHD have been performed with rather low density ($0.15 \times 10^{19} \text{ m}^{-3}$ in ECH one hour discharge, $0.4 \times 10^{19} \text{ m}^{-3}$ in ICRF and ECH 55 minutes discharge, $0.6 \times 10^{19} \text{ m}^{-3}$ in ICRF and ECH 13 minutes discharge, and $0.8 \times 10^{19} \text{ m}^{-3}$ in NBI (neutral beam injection) and ECH 63 seconds discharge) to avoid radiation collapse. For those steady-state experiments the ECH power was only 0.1 MW from an 84 GHz CW gyrotron.

Sustainment of higher density by increasing ECH power was planned, and since 2007 improvement of ECH system by replacing existing pulse-operational gyrotrons to newly developed CW gyrotrons was started. The frequency, designed output power in pulse operation up to 5 s, output power in CW operation are 77 GHz, 1 MW and 0.3 MW, respectively. In 2008, two 77 GHz ECH systems were completed and started to be used for LHD experiment. Due to lack of enough conditioning operation before the start of experiment, the pulse width and the power were gradually improved by on-the-job conditioning. Till the end of LHD 12th experimental campaign on 2008, each gyrotron could inject EC-wave power up to 0.67 MW in pulse, and 0.35 MW for operation up to 60 s. By using the 77 GHz gyrotrons, existing 84 GHz CW gyrotron and positive ion source NBI, necessary ECH power for steady plasma sustainment with NBI was investigated. Applying NBI accompanies increase in the plasma density, and without density control plasmas suffer radiation collapse. Applying ECH works for not only heating but also density suppression by enhancing radial electron loss. NBI power of 0.5 MW was continuously injected and heated the plasma, and ECH power up to 0.51 MW was additionally applied. ECH power of 0.22 MW could not prevent the plasma from collapse and a radiation collapse occurred at 63 s. On the other hand, ECH power of 0.51 MW could keep the density nearly constant and the plasma was sustained until the end of ECH power injection at 93 s. The line average electron density, central electron temperature and ion temperature at the late period of the discharge were $1.3 \times 10^{19} \text{ m}^{-3}$, 1.6 keV and 1.1 keV, respectively.

Possibility of steady-state plasma sustainment by ECH was experimentally estimated at the phase when the maximum pulse length of the 77 GHz gyrotrons were increased up to 10 s. The configuration of the experiment was selected as $R_{ax}=3.75 \text{ m}$ and $B_{ax}=2.75 \text{ T}$, with which on-axis fundamental resonance condition is realized for both

77 GHz ECH systems (one injects the power at the vertically elongated poloidal cross section, and the other at the horizontally elongated poloidal cross section). Figure 1 shows the waveforms in a discharge for the estimation of steady-state sustainment by ECH. The discharge was started with the power from two 77 GHz and one 84 GHz gyrotrons, and sustained by the 77 GHz ones for 7 s. The total injection power from the two 77 GHz gyrotrons was 0.55 MW. During the latter 4 seconds, the plasma was quite stable. All the plasma parameters such as density, temperature, stored energy, H_α light emission and radiation power from plasma were kept constant. The line average electron density, central electron temperature and plasma stored energy were $1.0 \times 10^{19} \text{ m}^{-3}$, 3.0 keV and 55 kJ, respectively. According to this result, it would be expected that steady-state plasmas with the density higher than $1.0 \times 10^{19} \text{ m}^{-3}$ and the electron temperature in keV level is possible provided that the 77 GHz gyrotrons continue power injection. For next 13th experimental campaign in 2009, conditioning operation of the 77 GHz gyrotrons for CW operation will be continued. Moreover, replacing one more existing 168 GHz gyrotron to 77 GHz gyrotron is underway.

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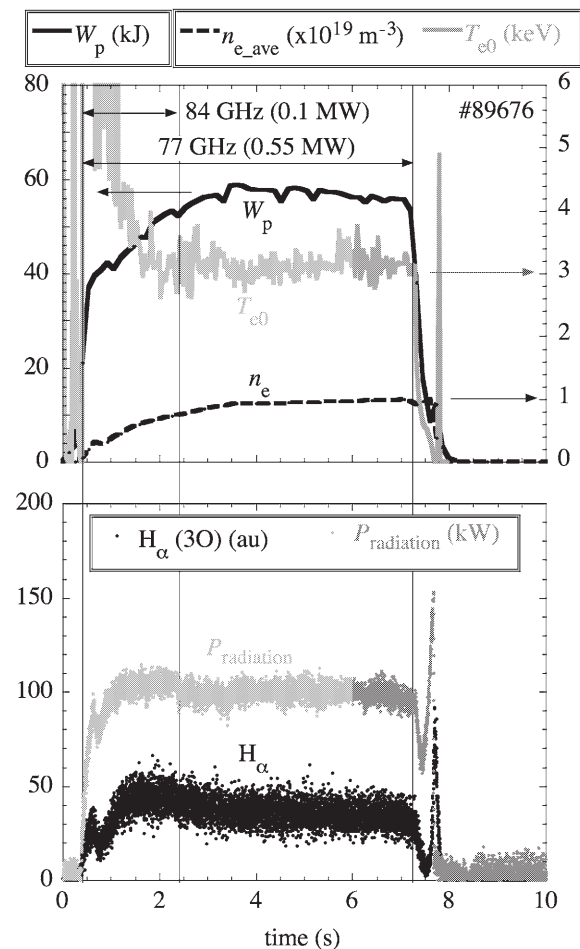


Fig. 1. Waveforms in the steady-state plasma sustainment by 77 GHz ECH.