§21. Sustainment of a Plasma with the Electron Density over $1\times10^{19}m^{-3}$ for 39 Min. by Use of EC-Waves

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77 and 154GHz gyrotrons have been newly developed by collaboration with the University of Tsukuba and installed on the LHD ECH system in recent years. Each of the 77 and 154GHz gyrotrons generates more than 1.0MW port-through power. The 77GHz gyrotrons suffer gradual increases of internal pressure during long pulse operation delivering power to LHD. To mitigate the problem, quasi-steady operation by combination of on-off operations of the 77GHz gyrotrons should be performed for long pulse experiments. On the other hand, the first 154GHz#1 gyrotron works well for CW operation, without noticeable increase of internal pressure contrary to the 77GHz ones, due to its short wavelength reducing wave diffraction inside the tube and furnished sub-window to remove stray radiation inside the tube.

In the 18th campaign in 2014, a new 154GHz#2 gyrotron was applied for long pulse experiment for the first time, together with the former 154GHz#1. Using the EC-waves generated by the 154GHz#1 and injected from 2-OLL antenna, the 154GHz#2 from 2-OUL, the 77GHz#1 from 2-OLR, and the 77GHz#2 from 2-OUR, a long pulse plasma sustainment was attempted. The magnetic configuration was R_{ax} = 3.6m with B_t = 2.75T.

The injection powers from the gyrotrons were 120kW (154GHz#1), 91kW (154GHz#2), 110kW (77GHz#1), and 163kW (77GHz#2), respectively. Two 154GHz gyrotrons were operated continuously, and two 77GHz ones were operated alternately with 2 min. intervals. The time average of injection power P_{inj} was 350kW. Figure 1 shows the waveforms of the most successful 39 min. discharge #131059: from top to bottom, P_{inj}, central electron temperature T_{e0} measured with Thomson scattering measurement and line average electron density n_{e_ave} of a reference discharge #131054, radiation signals from impurities (FeXVI, OV, CIII), central ion temperature T_{i0} and n_{e_ave}. The fed gas for the discharge was hydrogen. The density n_{e_ave} was kept quite stably at $1.1\times10^{19}m^{-3}$ using a newly developed gas-feed system furnished with mass-flow controllers and a new feedback control scheme for density.

The Thomson scattering measurement failed in data acquisition procedure in the 39 min. discharge #131059 so that no electron temperature and density profile data exist for the discharge. T_{e0} and n_{e_ave} of the similar discharge #130154 are plotted until 940s in the second frame for reference.

Figure 2 shows the electron temperature profiles of the reference discharge #130154, at the timings of 800, 841 and 900s with P_{inj} of 320, 370 and 620kW, respectively. It is clearly seen that T_{e0} becomes higher and the profile becomes fatter with the increase of P_{inj}, that is, more robust plasmas against impurity influx, which is the major cause of the termination of long pulse discharges, can be sustained by higher P_{inj}.

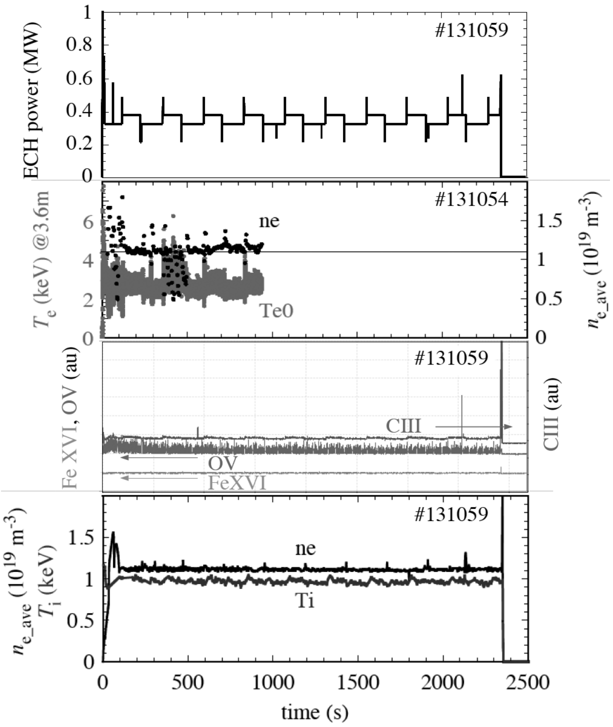

Fig. 1. From top to bottom, waveforms of EC-wave powers, n_{e_ave} and T_{e0} in a discharge #131054 for reference, radiation signals from iron, oxygen and carbon, and n_{e_ave} and T_{i0} in the 39 min. discharge #131059.

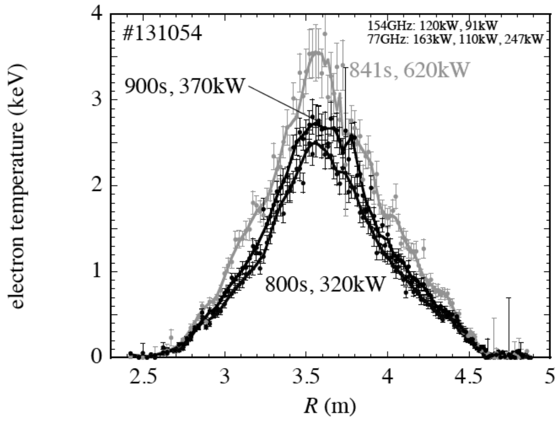

Fig. 2. Electron temperature profiles at 800, 841 and 900s with injection powers of 320, 370 and 620kW, respectively.