§18. Development of High Power, Long Pulse, High Frequency Gyrotrons and Improvement of Plasma Parameter in LHD by Use of the Gyrotrons

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NIFS collaboration research program with University of Tsukuba has been conducted for the sake of development of high power, long pulse, high frequency gyrotron and improvement of plasma parameter in LHD by use of the gyrotrons. Following to the successfully accomplished former program which resulted in three high power 77GHz gyrotrons actively working for LHD experiment, this new program aims at realization of high power and higher frequency 154GHz gyrotron to perform plasma heating at high density region up to 14.7×10^{19}m^{-3} by 2nd harmonic X-mode heating at the magnetic field of 2.75T.

In 2014, fabrication of a second 154GHz gyrotron (154GHz#2) and setup of auxiliary facilities were completed so that the number of high power gyrotrons available in the 18th experimental campaign became five, together with three 77GHz gyrotrons and one 154GHz gyrotron already applied for experiment. The total injection power to LHD by these 5 gyrotrons is expected to be over 5MW.

Though the 77GHz gyrotrons worked well for pulse operations, each of them generated over 1MW injection power to LHD for a few seconds, long pulse operations for LHD experiments were limited in low power level of about 100kW and in time duration of about 10 minutes due to increases of the pressure inside the gyrotrons.

On the other hand, the first 154GHz gyrotron 154GHz#1 demonstrated its ability for long pulse operation. The 48 min. long pulse discharge in 2013 was sustained with the 154GHz#1 and 84GHz ECH and ICH powers. The short wavelength due to the high frequency and furnished sub-window to remove stray radiation inside the 154GHz gyrotron make the advantage for the long pulse operation, which is an important information for the improvement of the 77GHz tube. In 18th exp. campaign, two 154GHz gyrotrons operated continuously and two 77GHz gyrotrons operated alternately with 2 min. intervals successfully sustained a plasma of $n_{e\_ave} = 1.1\times10^{19}$ m^{-3}, $T_{e0} > 2.5$keV, $T_{i0} = 1$keV for 39 min. by time averaged injection power of 350kW.

High power heating experiment made a significant progress using the new 154GHz#2 gyrotron and existing four (three 77GHz and 154GHz#1) gyrotrons. Figure 1 shows the waveforms of ECH power, line average electron density, plasma stored energy W_p, and electron temperature profile obtained in a discharge #127214. Powers of 77GHz waves (5.5-U: 1.21MW, 2-OUR: 1.03MW, 2-OLR: 0.85MW) were applied from 3 s to generate and sustain the plasma, then powers of 154GHz waves (2-OLL: 1.04MW, 2-OUL: 1.01MW) were additionally applied from 3.1s. Power of 82.7GHz (0.27MW) was also applied for a support of plasma start up from 3.0 to 3.3s. The electron temperature profile measured at 3.64s with Thomson scattering measurement clearly shows that $T_{e0} > 10$keV is achieved with $n_{e\_ave} = 2\times10^{19}$ m^{-3}, that is, one of the major goals of LHD, $T_{e0} = 10$keV with $n_{e\_ave} = 2\times10^{19}$ m^{-3} is successfully executed by the upgrade of ECH system performed under the collaboration research program with University of Tsukuba for development of high power and long pulse gyrotrons.

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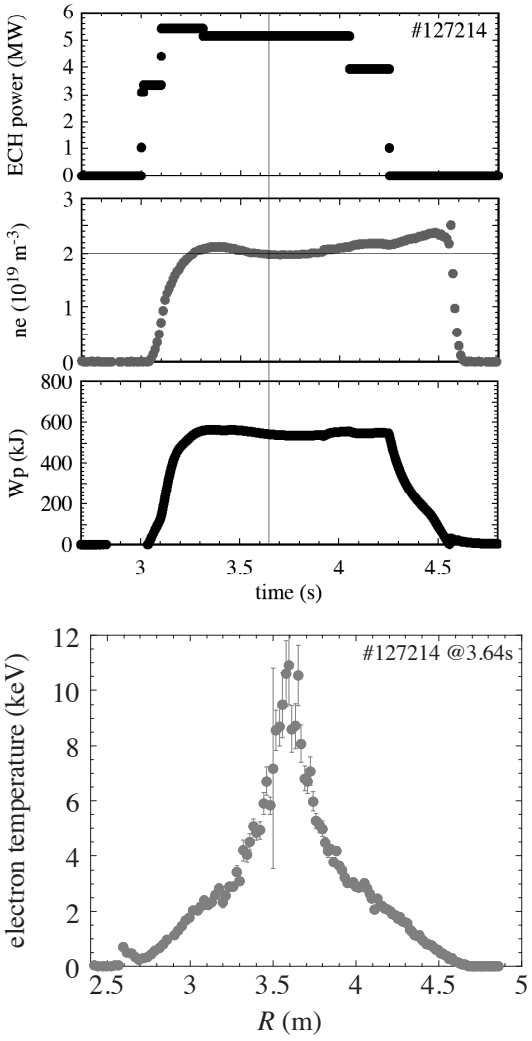

Fig. 1. From top to bottom, time traces of ECH power, line average electron density, plasma stored energy, and electron temperature profile at the timing of 3.64s obtained in a high power ECH discharge #127214.