§16. Long Pulse Operation in the Second Harmonic ECH Condition

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Former long pulse discharge of 65 minutes with 84 GHz ECH in LHD was performed with the limited injection power of 110 kW. The line average electron density n_e and the central electron temperature T_{e0} were 0.15×10^{19} m^{-3} and 1.7 keV, respectively. The magnetic field configuration was R_{ax}=3.75 m with B=1.48 T, that was, in the second harmonic resonance condition. The working gas was helium. The sustainable density was low due to the low power, but the discharge was quite stable. The plasma duration time was determined from a limitation about data acquisition.

These years, ECH power has been increased by introducing 77 GHz gyrotrons. The maximum injection power from three 77 GHz gyrotrons reached 3.7 MW for pulse operation and ~0.5 MW for long pulse operation. In LHD 14th and 15th experimental campaigns, using the ~0.6 MW ECH power from the 77 and the 84 GHz gyrotrons, improvement in the plasma parameters especially in the electron density was tried. The magnetic field configurations were R_{ax}~3.6 m with B~2.7 T, or, in the fundamental resonance conditions. The working gas was helium, considering the continuity with the ICRF discharges before and after. Though the plasma sustainment with n_e over 1×10^{19} m^{-3} was intended, unavoidable gradual increase in the electron density made the discharges terminated by radiation collapses, with the duration times shorter than 90 seconds. Thus, density control has been an important subject for long pulse discharges with the higher ECH power.

In the 15th experimental campaign, expecting easier density control due to density clumping or density exhaustion by second harmonic ECH, a trial of long pulse discharge with the second harmonic condition was also performed. The magnetic field configuration was R_{ax}=3.75 m with B=1.375 T, and the 77 GHz ECH injection power was 475 kW from 3 gyrotrons. The working gas was hydrogen. A scan of electron density in 10 s pulse discharges exhibited periodic changes with a few seconds in T_e, n_e and radiation power from iron impurity in the case of n_e > ~1×10^{19} m^{-3}. Figure 1 shows the oscillations in n_e and total radiation power measured with bolometer, in a 1 minute discharge. The behavior of plasma parameters is quite similar to that of the "breathing[1)]" phenomenon, which appeared in LHD formerly during a period when stainless steel was used for diverters, and disappeared with a replacement of the stainless steel diverters to carbon ones. It should be noted that ignoring the periodic change in n_e, time-averaged n_e is nearly constant at ~1×10^{19} m^{-3}, contrary to the high field (fundamental resonance) case.

As seen in Fig. 2, the profiles of electron temperature and density have shrink and expand phases at the peripheral region. The shrink phase is characterized by intense radiation from iron (for example, λ=16.912 nm measured with SOXMOS spectrometer: see Fig. 3). Investigation on the source of iron will contribute to preventing the breathing and achieving stable plasma sustainment.

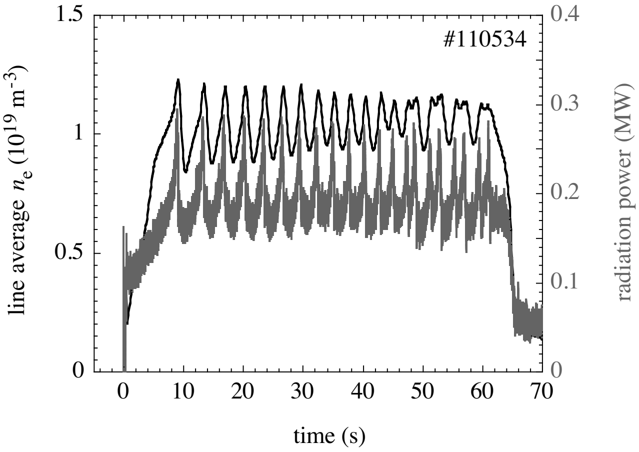

Fig. 1. Oscillations in line average electron density and total radiation power measured with bolometer in breathing discharge.

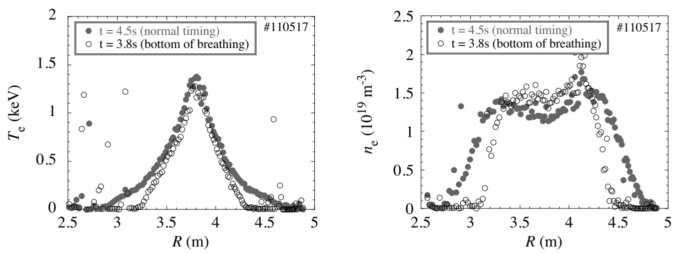

Fig. 2. Changes in electron temperature and density profiles in breathing discharge.

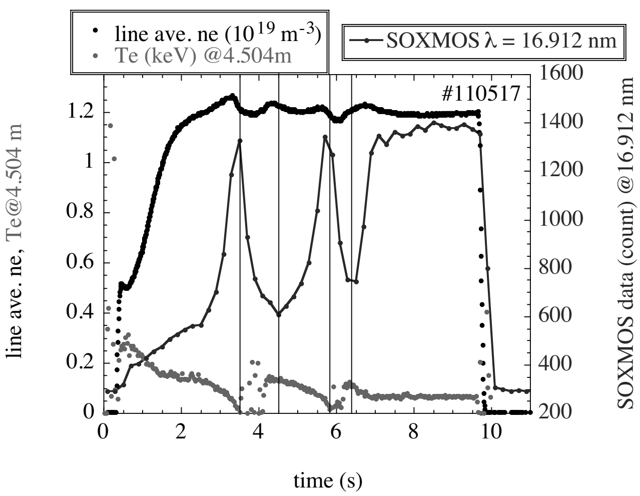

Fig. 3. Waveforms of line average electron density, electron temperature at the peripheral and radiation intensity from iron (λ=16.912 nm) in breathing discharge.

1) Peterson, B. J. *et al*.: Nuclear Fusion **41** (2001) 519.