ICRF heating experiment using poloidal array antenna and HAS antenna in LHD

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1. Introduction

In order to increse a clue to improve the heating performance for the ion cyclotron range of frequencies (ICRF) heating, the HAS antenna [1] was installed in Large Helical Device (LHD) in 2010. The plasma heating experiment with the HAS antenna and the poloidal array (PA) antenna, which has been used in the past experiments [2,3] was carried out in the last experimental campaign. Those antennas are shown in figure 1. The HAS antenna can control the parallel wave number of the launched waves and installed in the 3.5 upper (U) and lower (L) port. The PA antenna was located at the 7.5-U,L ports. By the toroidal phasing of the HAS antenna, it is expected that the wave-plasma interaction at the plasma periphery will be reduced and suppression of the impurity influx and improvement of the core heating will be caused.

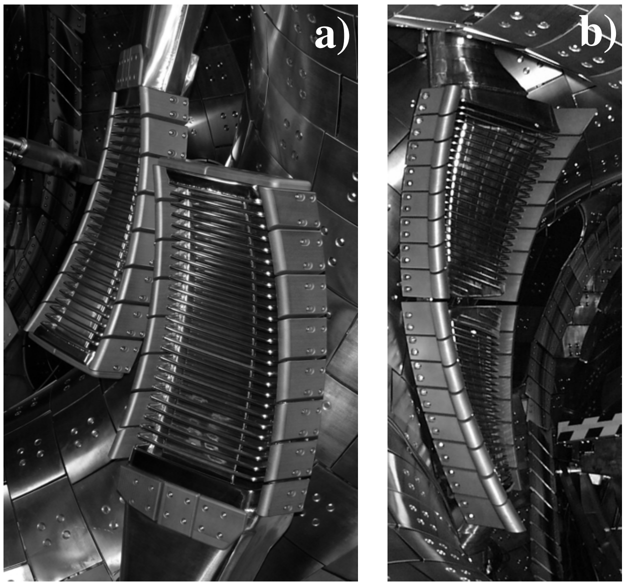

Figure 1. a): HAS antenna inatalled at the 3.5-U,L ports, b): PA antenna installed at the 7.5-U,L ports.

2. Plasma heating experiment with PA antenna and HAS antenna

Plasma heating experiments were carried out in a minority ion heating mode, in which the magnetic field strength at a magnetic axis and the wave frequency is 2.75 T and 38.47 MHz, respectively. Majority and minority ion species are helium and hydrogen, respectively. An ion cyclotron resonance layers of the fundamental hydrogen cyclotron resonance are located at the saddle point of the magnetic configuration.

As a measure of the heating performance, an achievable highest density by the ICRF heating was investigated. A plasma density was increased gradually by a gas puff until the plasma was destroyed by radiation decay.

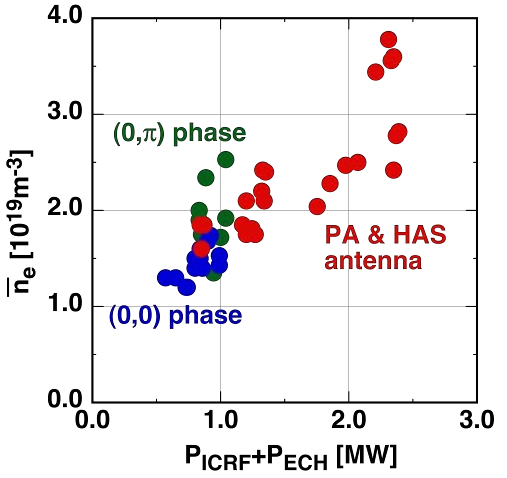

Figure 2. Achieved density as a function of the injected RF power. Using HAS antenna only with (0,π) or (0,0) phase, and both antennas of PA and HAS antenna are plotted.

Figure 2 shows the achieved density as a function of the RF power. Sustained plasma density increased with the injected RF power. In comparison with the toroidal phasing of the HAS antenna, higher density was obtained in (0,π) phase than in case of (0,0) phase. The toroidal wavelength launched in the (0,π) phase is shorter than that of the (0,0) phase. We could obtain higher density plasmas than achieved ever before using the HAS antenna with the (0,π) phase and the PA antenna.

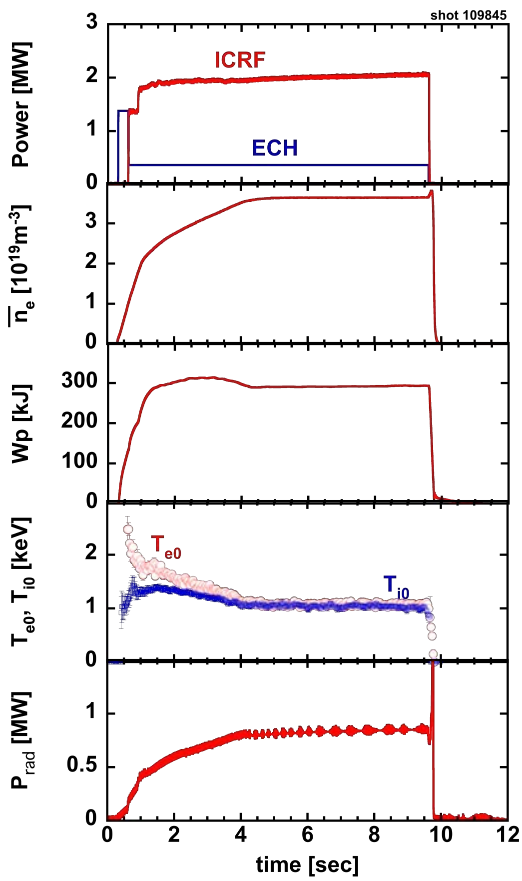

Figure 3. Time evolution of the plasma parameters of the highest density shot produced by the ICRF heating.

Figure 3 shows the time evolution of the plasma parameters for the highest density discharge achieved by the ICRF heating. A line-averaged electron density of $3.6\mathrm{x}10^{19}$ m^{-3} was sustained by the injection of the RF power of 2.4 MW. The plasma parameters were constant after 5 seconds and it suggested that the discharge time would be extended more.

3. Study of particle fueling during the ICRF heating

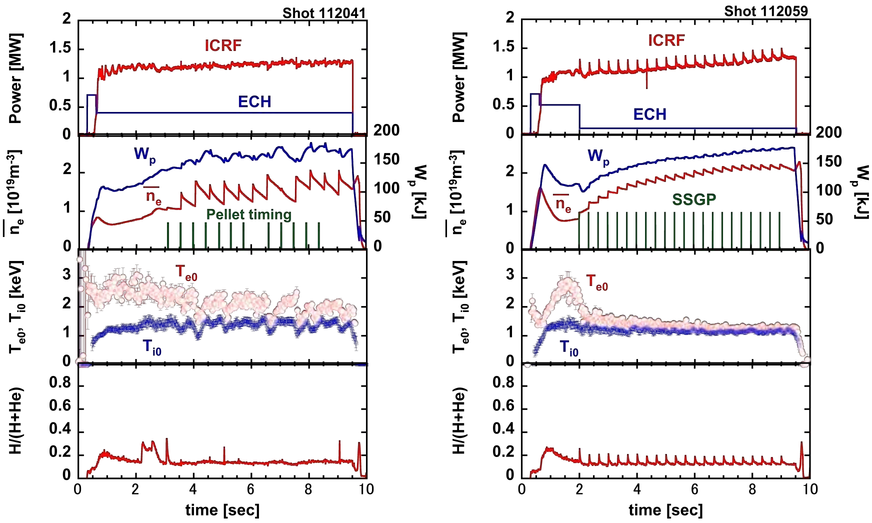

Figure 4. Time evolution of the plasma parameters in the case of the pellet injection (left columns) and SSGP (right columns).

For conducting the ICRF heating in a high heating efficiency, a control of the minority ion ratio is important. A constant density control is required in the long pulse operation. Two types of particle fueling method was tried during the ICRF heating. One is a hydrogen pellet injection [4,5]. The other is a super sonic gas puffing (SSGP) [6,7]. Examples of the shot of the pellet injection and SSGP are shown in figure 4. In the left columns, hydrogen pellets were injected at 2 Hz. The increase of the density is about 5x10^{18} m^{-3} in each injection. A deduced minority ion ratio by a spectroscopy showed a very small change. An injection condition of the pellet need to be investigated furthermore. In the right columns in the figure 4, SSGP injected the hydrogen gas at 5 Hz and the density incresed by 1x10^{18} m^{-3}. A deduced minority ion ratio increased corresponding to the SSGP. The injected ICRF power was also increased with SSGP. An antenna loading resistance was enhanced by the SSGP and it increased the coupling of the antenna and the plasma.

A profile of the density rise was obtained from the difference of the density profiles before and after the injection. Figure 5 shows the profiles of the dnsity rise at the inner side and outer side of the torus. The data was obtained

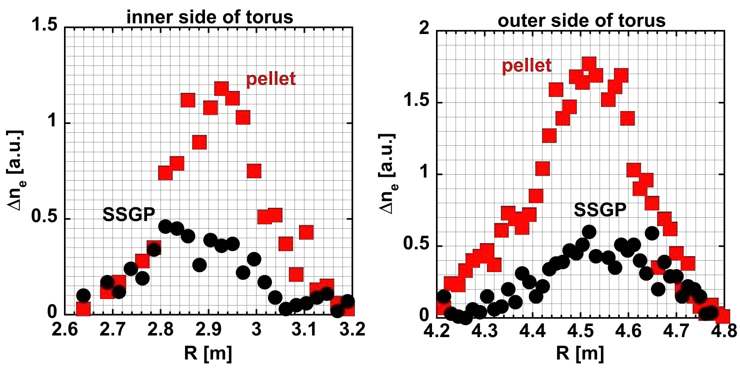

Figure 5. Profile of the density rise by the pellet injection and SSGP for the inner (left figure) and outer side (right figure) of the torus.

from a Thomson scatteing measurement at a sampling frequency of 30 Hz. It was comfirmed that the density was not decreased in a low level after the injection by a FIR interferometer at a sampling frequency of 100 kHz. SSGP fueled relatively peripheral of the plasma compared to the pellet injection. It reflected in the difference of the behavior of the minority ion ratio and the injected ICRF power.

4. Summary

The ICRF heating experiment using the PA and HAS antenna was carried out. The HAS antenna with (0,π) phasing could sustain the higher density plasma. The density region of the ICRF heating was extended higher than achieved ever. Figure 6 shows the electron temperature and the line-averaged electron density mainly obtained in the last experimental campaign. We were trying to extend the plasma parameters to the higher density region in a long pulse operation. Fueling is important for a long pulse operation and minority ion heating. The pellet injection and SSGP were tested and further research is required to optimize the injection condition.

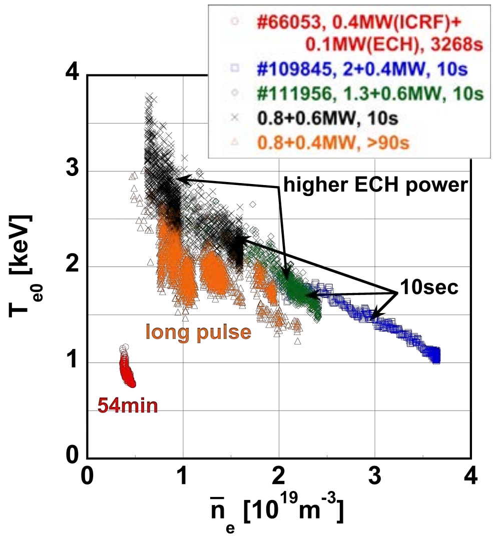

Figure 6. Temperature and density region achieved in the last experimental campaign plotted with the longest pulse operation (labeled as 54min) [8].

Acknowledgement

Authors would like to thank the technical staff of the RF and LHD group at the National Institute for Fusion Science for their continuous support. This work is supported by NIFS11ULRR703 and ULRR704.

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