

Long Pulse Discharge with ICRF Heating in LHD

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1. Introduction

The large helical device (LHD) [1] is suitable for steady state discharge operation, for plasma current is unnecessary to confine the plasma. A high-power ion cyclotron range of frequency (ICRF) heating system was developed for use in long pulse discharge. The best ICRF heating performance has been achieved with minority ion heating with hydrogen as the minority and helium as the majority [2]. The plasma duration of 150 seconds was carried out, but the duration time was limited by an uncontrollable increase in density due to an over heat of the divertor plates [3].

2. Hot spot on the ICRF antenna

Hot spots were observed on two ICRF antennas in the same positions at the top of the left side protectors attached to the upper antennas during long pulse operation. For one antenna, an infrared camera was installed to measure the temperature of the antenna. The temperature

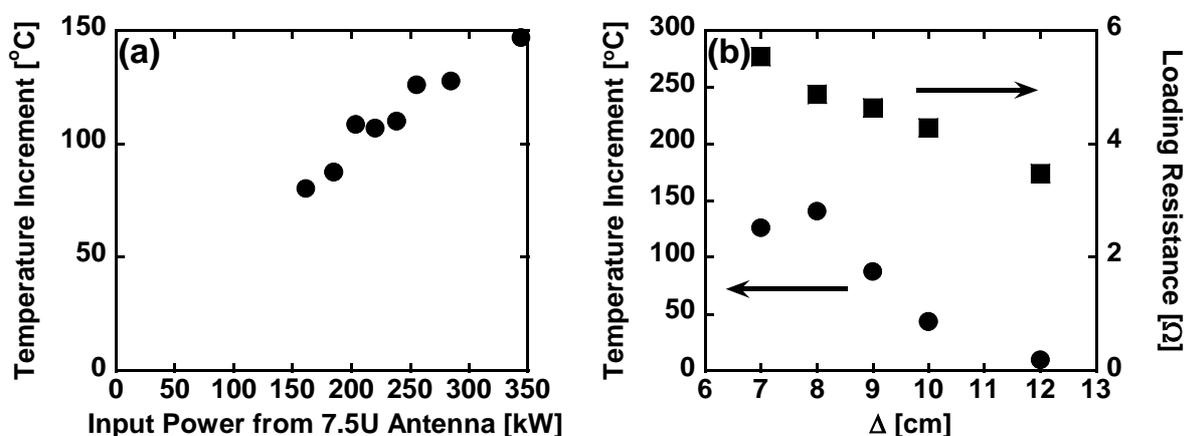


Figure 1. Temperature increment depending on (a) input power and (b) distance between the antenna and the last closed flux surface.

increment of the hot spot was proportional to the radio frequency (RF) input power from the antenna, as shown in Fig. 1a. In this experiment, the input power from the other antennas was kept almost constant at approximately 500 kW, therefore, the hot spot was heated by the antenna itself. The temperature of the hot spot and the loading resistance decreased with increasing distance Δ between the antenna and the last closed flux surface, as shown in Fig. 1b. In the long pulse discharges, a long distance Δ was selected to decrease the temperature, though the loading resistance decreased.

3. High-energy ion tail

In order to study confinement of high-energy ions accelerated by ICRF heating with the energy of the MeV range, a silicon-diode-based fast neutral analyzer (Si-FNA) [4] was installed at an inner port of the LHD. In the discharge of 80 seconds of ICRF injection, a high-energy ion tail was observed up to 600 keV owing to the long plasma duration time. Figure 2 shows the energy spectrum of hydrogen accelerated by ICRF heating and effective temperatures. Degradation of the confinement was not observed until 600 keV since the effective temperature did not decrease with energy.

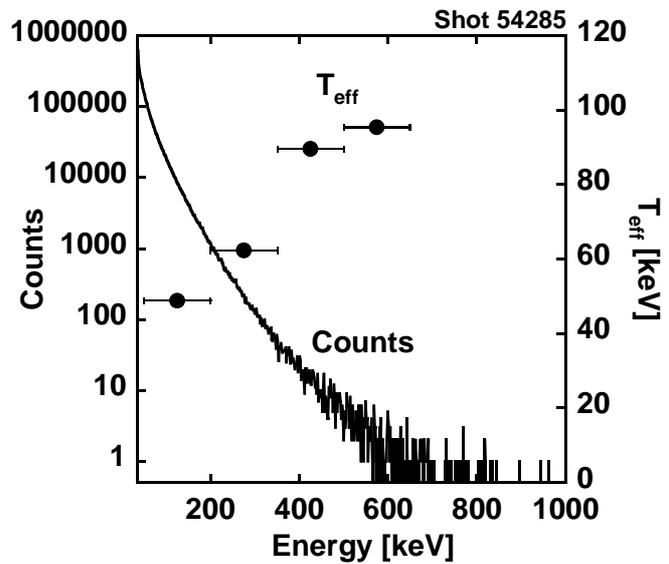


Figure 2. Energy spectrum of high-energy particles and effective temperatures.

4. Impedance matching during long pulse discharge

For the long pulse discharge, two methods of impedance matching were employed. One was the manual-frequency control method, which can adjust the electric length between the antenna and the tuning system. Figure 3a shows temporal increases in a reflected RF power fraction. Without frequency control, the reflected power fraction increased to 20%, and RF operation was stopped by the interlock system. The frequency was initially 38.47 MHz, and then was decreased manually to 38.44 MHz by increments of 0.01MHz. The final power amplifier could not function at frequencies under 38.44 MHz with the same output tuning conditions, therefore frequency control was stopped at 55 seconds and the reflected power

fraction gradually increased. The other was an automatic feedback control method using the liquid stub tuners [5]. Figure 3b shows the temporal evolution of the reflected power fraction with this method. Two liquid heights of stub tuners were alternately controlled. The first two chosen directions of shifts of liquid heights were unfortunately incorrect, but after that, the correct directions were determined and the reflection fraction decreased gradually.

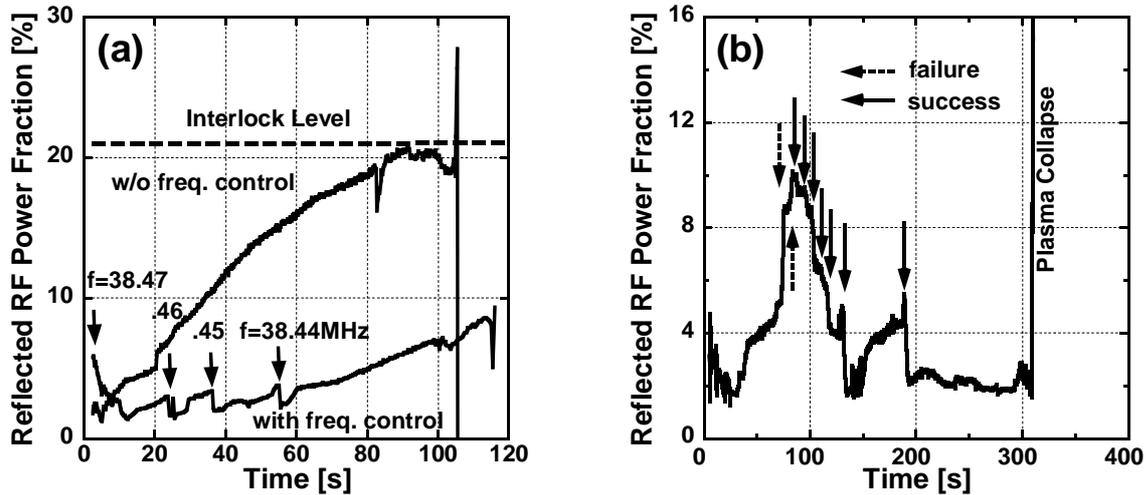


Figure 3. Impedance matching (a) with frequency control and (b) with control of liquid heights.

5. A discharge of over 30 minutes with ICRF heating

A plasma discharge of over 30 minutes was achieved with ICRF heating supported by electron cyclotron heating (ECH) and negative-ion-based neutral beam injection (NNBI) heating [6]. Figure 4 shows the time evolutions of various parameters of the discharge of 1905 seconds. NNBI was injected intermittently. The averaged injection powers of ICRF heating, ECH and NNBI were 516 kW, 100 kW and 45 kW, respectively. The total injection energy reached 1.26 GJ. The ion temperature on the axis was 2 keV and the line-averaged electron density was $0.7 \times 10^{19} \text{ m}^{-3}$. For better energy confinement, the major radius of the magnetic axis is usually employed at 3.6 m, however, in this discharge, the radius of the magnetic axis was set outward and was swung from 3.67 m to 3.70 m to reduce the local intense plasma heat load on the divertor plates [7]. This discharge was suddenly terminated without any sign of collapse, e.g., gradual increases in the density or the radiated power. The cause of the collapse was thought to be the injection of impurities into the plasma by sparks because in several discharges sparks were seen to occur on the inner side of the vessel, accompanying the collapse of plasmas. Sparks from an unused pair of antennas that were not water-cooled were

also seen during long pulse discharges.

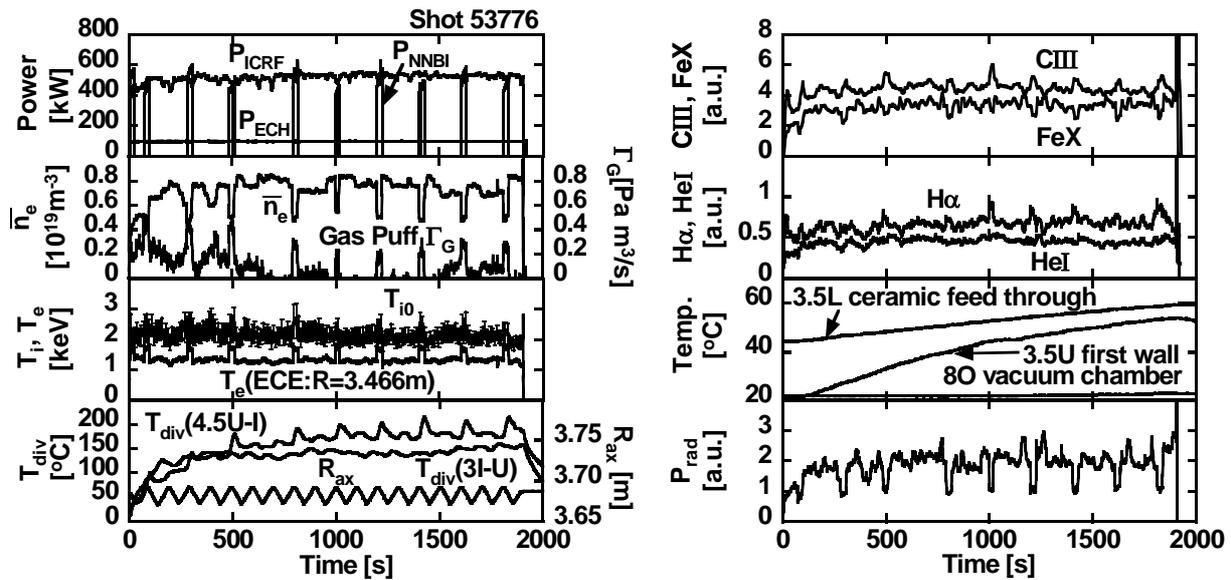


Figure 4. Longest pulse discharge of ICRF heated plasma.

6. Summary

Hot spots were observed in the same position on two different antennas. The temperature was found to decrease with increasing distance between the antenna and the plasma. Therefore, long pulse discharge experiments were conducted with a large distance. A high-energy ion tail was observed up to 600 keV owing to the long plasma duration time. No degradation of confinement was seen until this level of energy. An automatic impedance matching was conducted first using liquid stub tuners, and the reflected power fraction was sufficiently decreased. The duration time of ICRF heated plasma exceeded 30 minutes supported by ECH and NNBI heating. Most discharges were suddenly terminated due to the injection of impurities into the plasmas by sparks.

References

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