

Time Evolution of Temperature Profiles measured by ECE on LHD

S. Inagaki, Y. Nagayama, H. Sasao, P.C. de Vries, Y. Ito, K. Kawahata,
K. Narihara, S. Kubo, A. Komori, H. Yamada, O. Kaneko, K. Y. Watanabe,
LHD Exp. Group 1 and Group 2

National Institute for Fusion Science, 322-6 Oroshi-cho, Toki-shi, 509-5292 Japan

1. Introduction

The electron cyclotron emission (ECE) has been measured to determine the time evolution of the electron temperature profile on the Large Helical Device (LHD). From the point of view of ECE diagnostics, helical plasmas are quite different from tokamaks. The ECE radiation is collected along the major radius R on the equatorial plane of LHD. Along this line of sight, the LHD magnetic field is characterized by a large magnetic shear and non-monotonically change in strength B . Both effects complicate the determination of the temperature profile on LHD. The large shear generally leads to a polarization rotation of the electron cyclotron wave. Because of the saddle-shaped geometry of the magnetic field in LHD, the position of emission layer can not be defined by the frequency of the emission.

In this paper, the diagnostic system is described first. The diagnostic potentiality of ECE on LHD is discussed second. Finally, the first result of temporal behavior of temperature profile determined by ECE is reported.

2. ECE System in LHD

To obtain intensity profiles of the ECE, a pair of mirrors, which couples the free space waves to the waveguide, which transfers ECE to the heterodyne receiver, has been designed¹. A pair of mirrors system provides a spot size on the order of 6 cm within the emitting plasma volume. A 32-channel filter bank radiometer has been used on LHD. In the radiometer, the ECE is mixed with the 70 GHz Gunn Oscillator and the IF signal is divided by a 32-channel band-pass-filter bank with the bandwidth of 1 GHz. At present, the radiometer is operating in the band 54-86 GHz. Since gyrotrons at 84 GHz and 82.6 GHz are used for plasma production and heating, the leaked ECH powers are too large to be measured by the radiometer. Therefore, both quasi-optical notch filters and rectangular waveguide notch filters at 84 GHz and 82.6 GHz are mounted in the waveguide to reduce the ECH signal. A universal polarization rotator is installed in the waveguide system to select X-mode polarization at the input to the heterodyne radiometer.

3. The Diagnostic Potentiality of ECE on LHD.

3.1 non-monotonically change in the strength of magnetic field

Figure 1 shows the electron cyclotron frequency f_{ce} and the strength of magnetic field B as a function of R along a line of sight. The electron cyclotron frequency has the same value at the different two positions of R , as shown in Fig. 1. One is in the inner half of torus, and the other is in the outer region. Because the ECE mirror system is mounted on the outer port, only the ECE that comes from the outer region can be measured if the plasma is optically thick.

The ECE can propagate to the outer region if the frequency f satisfy following conditions: $f > f_{pe}$ (for O-mode), $f < f_{lh}$ or $f_{lc} < f < f_{uh}$ or $f_{uc} < f$ (for X-mode), where f_{pe} , f_{lh} , f_{uh} , f_{lc} and f_{uc} is the electron plasma frequency, the lower hybrid frequency, the upper hybrid frequency, the lower cutoff frequency and the upper cutoff frequency, respectively. These frequencies are also plotted in Fig. 1, where the density profile is assumed to be flat,

$n_e = n_{e0}(1 - \rho^2)^{0.1}$ and $n_{e0} = 1.0 \times 10^{19} \text{ m}^{-3}$, where ρ is the normalized averaged radius. It is found that the O and X-mode electron cyclotron wave can propagate to the outer region of torus except for the fundamental X-mode. However, the density cutoff still remains with respect to the fundamental O-mode and the second harmonics of X-mode.

3.2 Polarization.

The polarization of the ECE spectrum has been numerically studied². In the high-density case, the polarization of the ECE wave rotates in the laboratory frame. However, using the polarization rotator it is possible to select the second harmonic X-mode for all frequencies.

3.3 Optical Depth.

From the point of view of the temperature diagnostic, the optical depth τ is important. The intensity of the ECE radiation from plasma is proportional to the local electron temperature, if plasma is optically thick ($\tau \gg 1$). Using the expression for the absorption coefficient³, measured density (FIR laser interferometer) and temperature (Thomson scattering) profiles and calculated B -field profile, we calculated the optical depth for straight-line propagation through the plasma. Figure 2 shows the optical depth with respect to the second harmonic X-mode radiation of typical LHD plasma. The typical plasmas (the line averaged density is higher than $1 \times 10^{19} \text{ m}^{-3}$ and the central temperature is higher than 1keV) are optically thick except for the edge region ($\rho > 0.9$), as shown in Fig. 2. Therefore, the ECE measurements can be used to determine the electron temperature except for the edge region. In fact, little emission is received from the edge region, i. e. optically thin region.

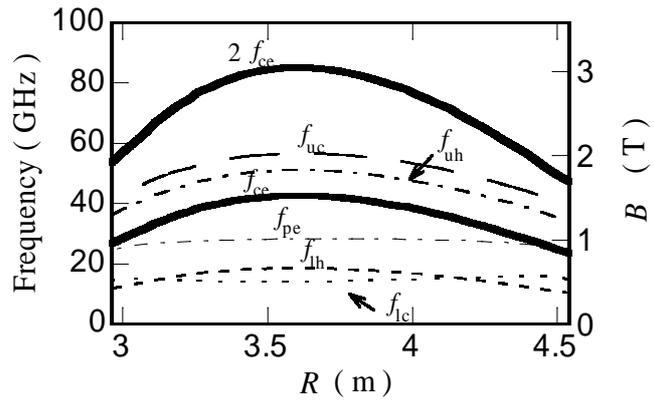


Fig.1 Radial dependence of electron cyclotron frequency. The magnetic axis is located at 3.75 m in this configuration. The strength of the field at the magnetic axis B_0 is 1.5 T for low field operation.

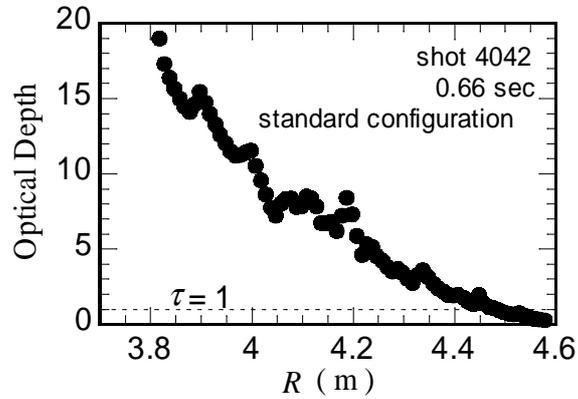


Fig. 2 Optical depth of typical LHD plasma.

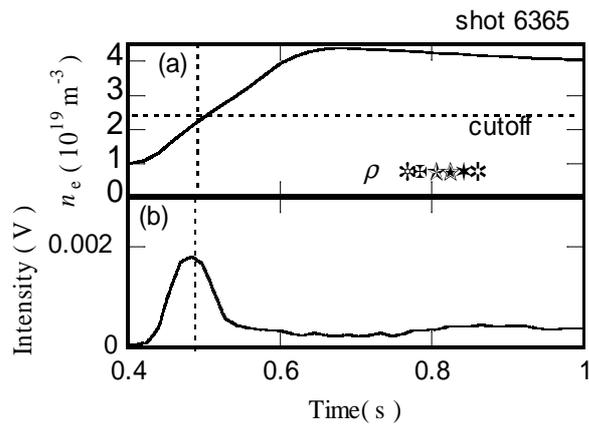


Fig. 3. The reduction of ECE intensity when the cutoff appears.

3.4 Cutoff.

Due to the restriction of optical depth, the second harmonics of X-mode is selected to provide the temperature profile in LHD. For the X-mode, the cutoff density is about $4.4 \times 10^{19} \text{m}^{-3}$ at the magnetic axis. However, the cutoff will occur in the edge region even if the $n_{e0} = 2.0 \times 10^{19} \text{m}^{-3}$, depending on its profile. The flat density profile causes appearance of cutoff layer in the edge region. As the density increases, the cutoff layer expands to the core region. When the cutoff layer appears, the ECE radiation that comes from the cutoff layer decreases significantly, as shown in Fig. 3. Because the cutoff density is proportional to B^2 , the cutoff density increase a factor of 4 for high field operation ($B_0=3\text{T}$) and thus, the cutoff restriction becomes loose.

4. Experimental Results

Due to the cutoff restriction of second harmonics of X-mode, the first result of temporal behavior of temperature profile have been determined with the low-density discharges (the line averaged density is about $1-2 \times 10^{19} \text{m}^{-3}$). The ECE evaluations are cross-calibrated to the Thomson scattering data.

When the plasma is heated by the NBI with power of about 1 MW for about 8 sec, the oscillations of plasma parameter e.g. line averaged density and radiation loss are observed. In this case the electron temperature also oscillated, as shown in Fig. 4.

The T_e oscillations ($\rho < 0.7$) is

late about 0.2-0.3 s from the oscillation of the averaged density. The phase delay of about 0.1 s between the core ($\rho < 0.7$) and the edge ($\rho > 0.7$) T_e oscillations is also observed as shown in Fig. 5. The T_e rises up in the core region at first and subsequently, the edge temperature begins to increase. The rise of T_e in the edge region becomes more sharp compared to the core region just after the density begins to decrease. Furthermore, it is shown that the edge temperature ($\rho = 0.86$) is constant (approximately 120 eV) all the time when the average density begins to decrease. The edge temperature is also related to the radiation loss. When the radiation loss become maximum during one period, the edge temperature become minimum. The changes in radial profile of T_e and n_e indicate that the plasma repeats shrinkage and expansion (see Fig.5).

5. Summary

To obtain intensity profile of ECE on LHD, a pair of mirror and a 32-channel filter bank radiometer have been developed. In helical system, additional difficulties arise to use ECE as temperature diagnostics compared to the tokamak case due to complicated magnetic

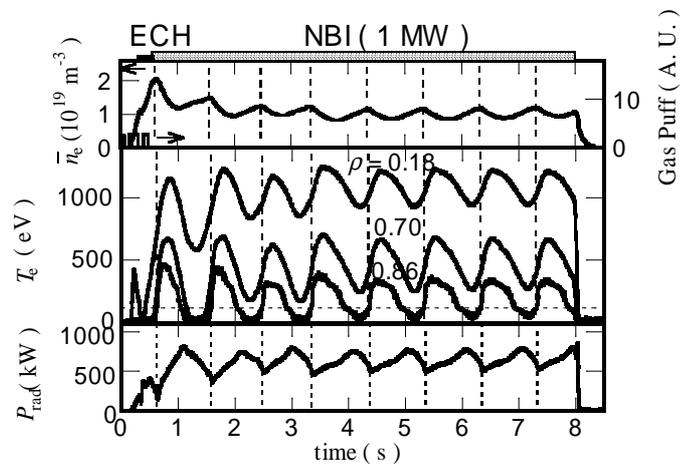


Fig. 4. The temperature oscillation during the long pulse NBI. P_{rad} is the radiation loss.

field structure. When a plasma is optically thick, the second harmonics of X-mode of ECE indicates a temporal behavior of electron temperature profile in the outer region of torus. The first result has been obtained in low-density discharges due to the cutoff restriction. Because the cutoff density increase a factor of 4. The cutoff restriction becomes loose for high field operation ($B_0=3T$). The oscillation of temperature is observed in the long pulse NBI plasma.

References

- ¹Y. Nagayama et al., Rev. Sci. Instrum. **70**, 1021 (1999)
- ²P.C. de Vries et al. "Polarization of Electron Cyclotron Emission Spectra in LHD", Proc. 26th EPS Conf. on Controlled Fusion and Plasma Physics, Maastricht 1999, to be published.
- ³M. Bornatici, R. Cano, O. De Barbieri and F. Engelmann, Nucl. Fusion **23**, 1153 (1983).

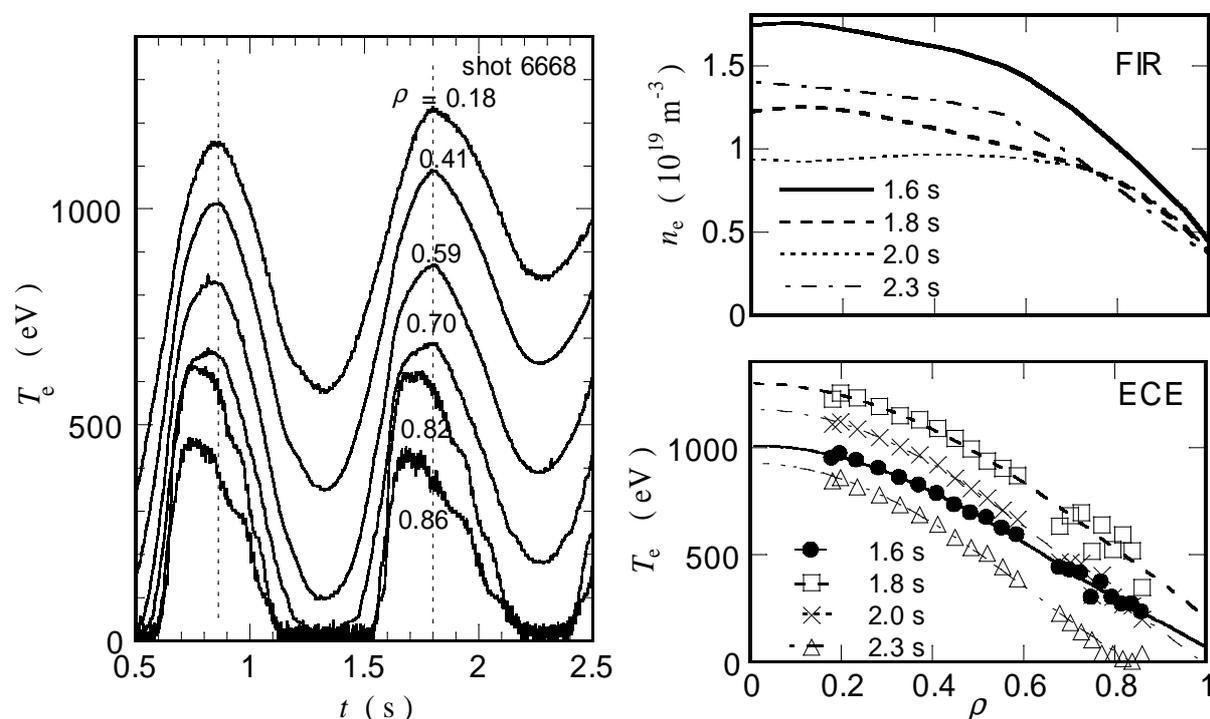


Fig. 5. The detail of the time evolution of the electron temperature profiles and the density profiles. The averaged density begins to decrease at 1.6 s and to increase at 2.0 s.