ECE IMAGING DIAGNOSTIC AT THE RTP TOKAMAK: PERFORMANCE AND FIRST MEASUREMENTS OF T_e – FLUCTUATIONS

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1. Introduction

A 16-channel electron cyclotron emission (ECE) imaging diagnostic system has been developed for the Rijnhuizen Tokamak Project (RTP, R=0.72m, a=0.164 m) for measuring T_e profiles and fluctuations [1]. This novel diagnostic system has better spatial resolution (~1cm) than conventional ECE radiometers (~ 3-5 cm) in the transverse direction of the sight lines. It is capable of 2-D measurements, which is very important for resolving the mode structures of T_e fluctuations. The detailed description of the diagnostic system can be found in [1]. Here, the principal aspects of the diagnostic will be discussed. Experimental results emphasizing T_e fluctuation measurements will be presented.

2. The ECE Imaging Diagnostics

As shown in Fig. 1, conventional radiometers have single sight lines along the major radius. The sample volume positions are defined by the frequencies of the ECE radiation they receive. The spatial resolution in the transverse direction of the sight line is limited by the divergence of the Gaussian beam. In the case of ECE imaging (ECEI), a vertically aligned Schottky barrier diode mixer array is utilized as the receiver to measure ECE radiation at the same frequency. A special optics system images an array of sample volumes in the plasma onto the mixer array. The vertically aligned sample volumes are located in the focal plane of the imaging optics, thus achieving good spatial resolution of about 1 cm. The channel spacing is about 1.3 cm. Along the sight lines, the sample volume thickness is ≤1 cm, which is determined by the intermediate frequency (IF) signal bandwidth [1]. By varying the local oscillator (LO) frequency or/and the magnetic field, the sample volumes can be scanned through the plasma cross-section to achieve 2-D measurements. In these cases, a translation stage is utilized to keep the system focused at the resonant layer, in a shot to shot basis.
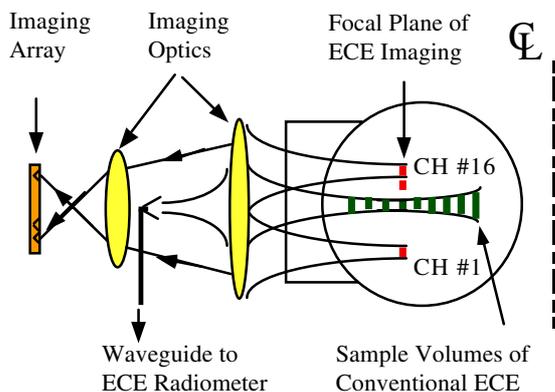

Figure 1: Schematic of the ECE Imaging diagnostic system plotted together with a conventional ECE radiometer of a tokamak, showing the differences in the sample volume alignments and spatial resolutions between the two systems.

Signals from each of the mixer channels are split into "A" and "B" channels with non-overlapping bandpass filters. The correlation between the resulting sub-channels is a measure of the local T_e fluctuations [2,3]. When the sample volumes are aligned across the plasma centre, cross correlation between signals from different mixer channels yield the radial correlation properties of the T_e fluctuations. By displacing the sample volumes from the plasma centre, poloidal correlation measurements are obtained. To resolve the low level (~1%) T_e fluctuations, inter-channel crosstalk originating from both the optics and the electronics is carefully minimized. The video amplifiers of the system exhibit a flat response up to 1MHz, and can be reduced according to the measured fluctuation frequencies in RTP.

3. Experimental Results

The T_e profiles shown in Fig. 2(a) are obtained in a RTP discharge with I_p=60 kA, $\bar{n}_e$=3×10^{19} m^{-3}, and B_t=2.03 T. The Electron Cyclotron Resonant Heating (ECRH) power is deposited at r~4 cm (3 cm below the midplane) and is switched off at 305 ms. The sensitivities of the ECEI channels are calibrated against the T_e profile measured by the Thomson Scattering (TS) system at 300 ms. It is seen that the T_e profile is centrally peaked and is quite stable in the ECRH phase (300 & 305 ms). After ECRH, non-smooth T_e profiles are observed, demonstrating the high spatial resolution of the ECEI system. At 322 ms, flat T_e regions appear at r ~2-3 cm. These correspond to the off-axis peaks in the density profile, measured by a multichannel interferometer at the same time (with a spatial resolution of 2 cm). At 325 ms, the T_e profile is flattened within r~4 cm. A sawtooth like event of the plasma density (at 335.5 ms) leads to the centrally peaked stable T_e profiles in the Ohmic phase (340 & 345 ms).
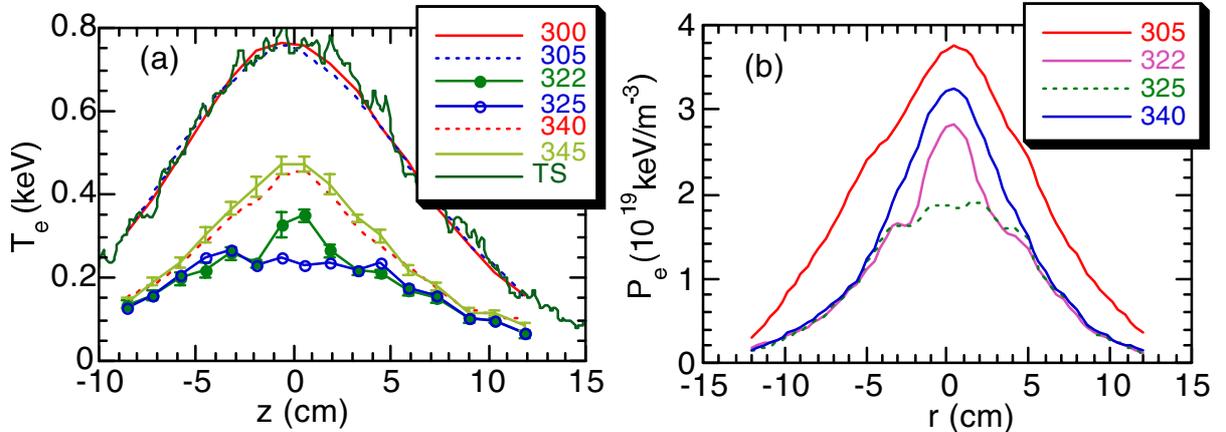

Figure 2: The evolution of T_e profiles measured by the ECEI system with LO frequency of 115 GHz (a), and the corresponding pressure profiles (b) obtained from the interpolated ECEI and interferometer data. The data are averaged over 0.1 ms and the error bars in (a) denote the standard deviations of the mean. The T_e profile measured by the Thomson Scattering (TS) system is also plotted in (a). The time of measurement is listed in the legends in ms.

Plotted in Fig. 2(b) are the corresponding pressure profiles, obtained from the interpolated ECEI and interferometer data. Flat regions are also seen at 322 ms and at 325 ms. Flat T_e regions similar to that shown at 322 ms were observed in other tokamaks before [4]. They were localized to the rational surfaces and were associated with MHD fluctuations. In our case, however, a significant reduction in the MHD signals measured with magnetic coils

is observed from 300 ms to 350 ms. The low frequency fluctuations of the ECEI signals are also reduced significantly. The q-profile is unknown in this period. From the data obtained after 350 ms, the q=2 surface is estimated (by the method discussed below) to be at r=3.5 cm, which is close to the flat T_e regions at 322 ms.

Shown in Fig. 3 are typical results of cross correlation measurements of T_e fluctuations. The data are taken during the flat-top phases of four similar Ohmic discharges, with a total duration of one second. From the cross power spectral density and wavenumbers (Fig. 3(a)), two different modes are distinguished. The lower frequency mode (<30 kHz) propagates in the electron diamagnetic drift direction ($k_z<0$), while the higher frequency mode propagates in the ion diamagnetic drift direction ($k_z>0$). This is consistent with the cross correlation function shown in Fig. 3(b). The broad bandwidth of the higher frequency mode indicates the turbulent nature of the fluctuations.
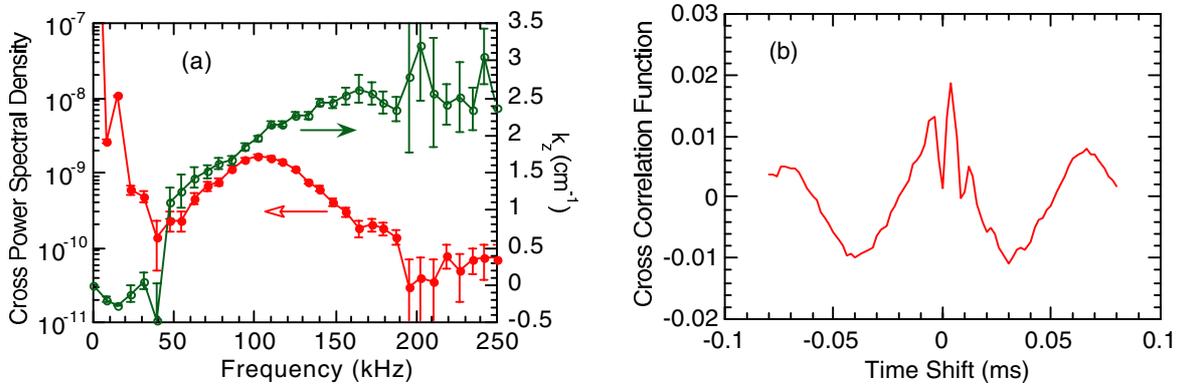

Figure 3: Cross power spectral density and wavenumbers (a) and the cross correlation function (b) measured at *r/a=0.7* with *I_p=100 kA, $\bar{n}_e$ =3.3×10^{19} m^{-3}, B_t=1.88 T, f_{LO}=120 GHz*. The error bars in (a) denote the standard deviation over multiple realizations. The average of the cross correlation function has been subtracted.
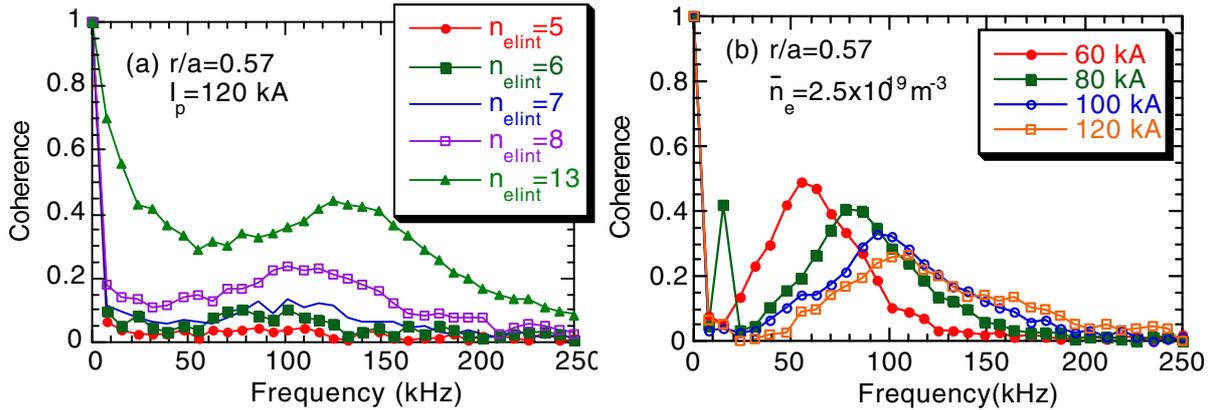

Figure 4: Dependence of T_e fluctuations on the plasma electron density (a) and current (b), measured with *B_t=1.9 T, f_{LO}=115 GHz*. In (a), a line integrated density of *8(×10^{18} m^{-2})* corresponds to *$\bar{n}_e$ =2.5×10^{19} m^{-3}*.

The variation of T_e fluctuations with plasma density and current is shown in Fig. 4. Here, the channel positions, the LO frequency, and the toroidal magnetic field are all kept fixed. In Fig. 4(a), only the plasma density is changed. In Fig. 4(b), only the plasma current is

changed. It is seen that the amplitude of the turbulent mode increases with plasma density (Fig. 4(a)) and decreases with plasma current (Fig. 4(b)). The frequency and bandwidth increase with plasma current (Fig. 4(b)). However, the dependence of the fluctuation frequency and bandwidth on density is different from that shown in Fig. 4(a) at different plasma currents. For I_p= 60 kA, the frequency decreases from ~70 kHz at $\bar{n}_e$=1.5×10^{19} m^{-3} to ~50 kHz at $\bar{n}_e$=2.5×10^{19} m^{-3}.

Density fluctuations may affect the measurements of T_e fluctuations [5]. One should expect to see more effect at lower densities than at higher densities, as the optical thickness is smaller. However, in Fig. 4(a), the coherence function at n_{elint}=5×10^{18} m^{-2} is almost down to zero. This shows that the features measured are real plasma temperature fluctuations, and the density fluctuation contribution is small. In Fig. 4(b), the low frequency (~16 kHz) mode is seen only at I_p=80 kA. This occurs when the rational surface scans through the sample volume. Thus, the low frequency mode is the MHD mode. The mode number (m=2) can be obtained from the cross phase measurements. By measuring the spatial dependence of this mode, the position of the rational surfaces can be estimated. Shown in Fig. 5 is an example. This may provide a very convenient method for measuring q-profiles.
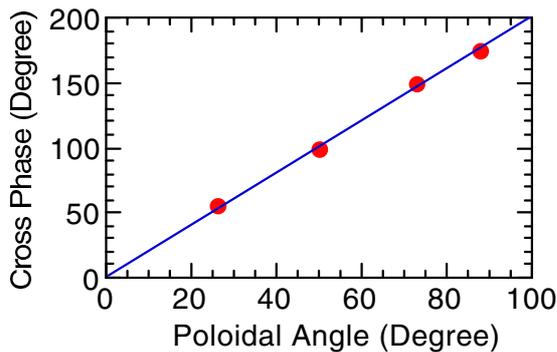

Figure 5: The measured cross phases (at 16 kHz) are twice the poloidal separations between the sample volumes centered at about *r=3.5 cm*. Thus, the *q=2* surface is at this radius. This is measured with *I$_p$=60 kA, B$_t$=2 T, $\bar{n}_e$ =2.5×10^{19} m^{-3}*.

Preliminary 2-D measurements of T_e fluctuations have been performed in RTP. Large scale structures comparable to the plasma minor radius are observed. More measurements are being performed and will be presented later.

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