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Co- and Counter – viewing oblique ECE measurements during ECH and ECCD on the TCV tokamak

T.P. Goodman, V.S. Udintsev, F. Felici, C. Zucca, Ch. Schlatter

CRPP – EPFL

EPFL - Lausanne , Switzerland

Association EURATOM – Confédération Suisse

Abstract

Using a new LFS receiving antenna in the oblique ECE configuration, we measure the emission during central co-ECCD and counter-ECCD discharges. The asymmetry of the electron distribution function (EDF) resulting from ECCD is put into evidence by performing 4 successive discharges measuring quasi-X mode and quasi-O mode in 2 separate discharges; then, repeating these measurements while viewing in the opposite toroidal direction. The plasma configuration and EC injection are identical in the 4 cases. The ratios of the X-mode signals are compared to simulations of the ECE by the NOTECTCV code and are found to be generally consistent with emission from a small, drifting, suprathermal, electron population carrying the ECCD current of the order calculated by the TORAY-GA code.

Introduction

A new LFS ECE receiver has been installed on TCV. It is connected in parallel (3dB coupler) to the 24-channel, 65GHz – 100GHz, LFS radiometer [1] and the 2-channel, variable frequency, correlation ECE diagnostic [2]. The radiometer frequencies correspond to the 2^{nd} harmonic of the cyclotron frequency across the poloidal plasma cross-section for the standard magnetic field of B = 1.45T. A separate high-field-side (HFS) radiometer views the plasma across the plasma midplane, ⊥ to the toroidal field. The outer wall of TCV has upper lateral (z=+0.46m), equatorial (z=0.00m) and lower lateral (z=-0.46m) ports interspersed between the 16 independently-powered poloidal plasma shaping coils. The new receiver is in an equatorial port and thus provides maximum viewing of plasmas at all heights within the vacuum vessel. The antenna is fully described in reference [3]. It can provide a moveable viewing angle with $acos(\mathbf{k}\bullet\mathbf{B}/|\mathbf{k}|/|\mathbf{B}|)$ between 80° and 35°. Experiments described here use a ~65° fixed view angle. Measurements are taken with close to circular polarization whereas the plasma emission is elliptically polarized (predominantly quasi-X-mode). Nevertheless, power is calculated to couple to the receiver with high efficiency for the oblique views, especially for the central channels.

Background

Six 82.6GHz gyrotrons can heat or drive current in the plasma. They are powered in 2 clusters, A & B, of 3 gyrotrons each. All gyrotrons are connected to individual launchers. Cluster A directs power to the plasma from 2 upper lateral launchers and 1 equitorial launcher (fig. 1b), as does cluster B.

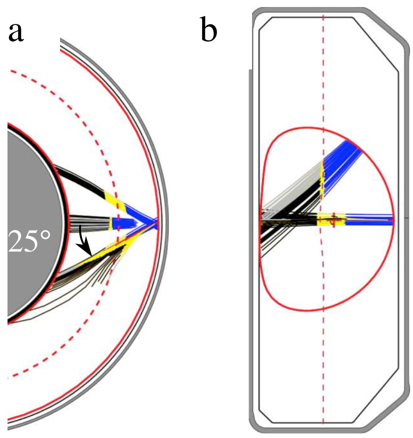

Fig. 1 a) Toroidal view of the plasma and EC heating/current drive beams b) Poloidal view. Yellow zones indicate the region of power absorption. The single thin line indicates the LFS radiometer co-view (single ray per frequency).

Experiment

The receiver is oriented to provide an oblique view in the plasma midplane at a constant angle (see figure 1a) in either toroidal direction during a given discharge. The ECE signals from two identical plasma discharges are recorded viewing once in the same direction as the electron current and once in the opposite direction. The parallel index of refraction is $N_{//}=\pm 0.52$ at the location where the optical thickness corresponds to ½ power absorption ($\tau \approx 0.7$) at 82.7GHz a frequency in the middle of the radiometer frequency range. The plasma is centered in the vacuum vessel (z=0) and is heated from above by 4 gyrotrons (Fig. 1b) while 2 beams drive current in the plasma center in opposite directions (Fig. 1a).

In each discharge, the power from each cluster begins at 0.35s and ends at 1.55s. It is adjusted in a descending “staircase” waveform for cluster A (every 0.2s, the power-per-gyrotron is decreased by 50kW starting at 450kW/gyrotron). Cluster B is powered in a similar manner but in an ascending staircase starting from 200kW/gyrotron: the input power to the plasma that is nearly constant at 2MW while the net driven current is scanned from counter- to co-ECCD due to the equatorial beams. The driven current increases from approximately -23kA to +23kA (TORAY calculation) in 6 steps (see Fig.

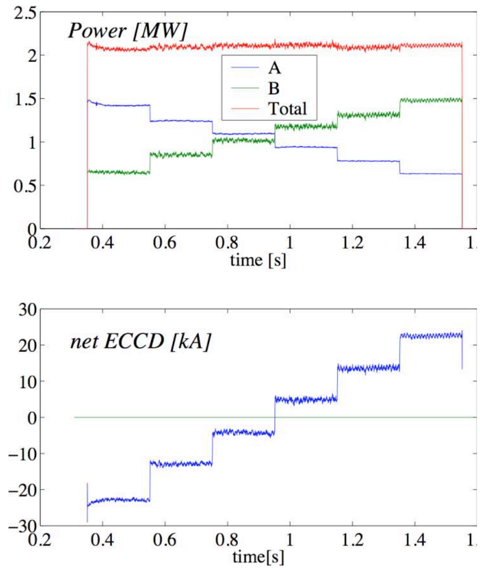

Fig. 2 Top: Power per cluster and total power. Both clusters have 2 gyrotrons heating off-axis and 1 gyrotron providing current drive. Cluster A: counter-ECCD; cluster B: co-ECCD. Bottom: Net EC driven current

2). The total plasma current of 145kA is held constant by feedback control. The ratio of the raw signals from co-viewing and counter-view discharges is analyzed to alleviate the need to calibrate the radiometer under oblique viewing with ECCD present [3].

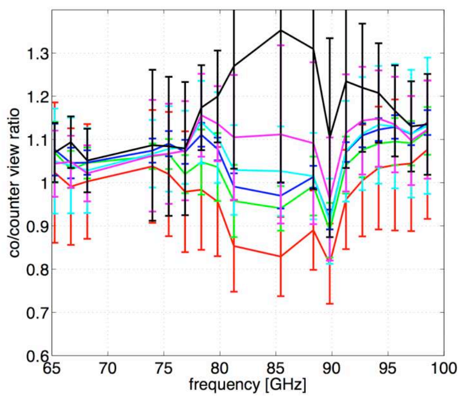

Fig. 3 The ratio of the co-/counter-viewing receiver signals as a function of frequency. The driven current is increased from counter- to co-ECCD (red to black curves). The central frequencies (81.25 – 88.34 GHz) are from the region of current generation. The EDF is seen to be asymmetric and emits more radiation in the direction of driven current.

Results

At the frequencies corresponding to the plasma center, the plasma is optically thick for the thermal bulk ($\tau > 3$ between ~68 to 88 GHz, T_{e0}=4keV, $n_{e0}=1.5\bullet10^{19}m^{-3}$, 25° view). Signals are averaged over 0.1s in the center of each current drive step.

In each shot, the absolute signal amplitude of any given channel *decreases* in steps as the net ECCD *increases*. In spite of this, Figure 3 shows that for each step the *ratio* of co-/counter-viewing signals increases for frequencies 81.25-88.34GHz (89.8GHz shows an anomalous behavior). This is direct evidence of the ECCD-induced asymmetry of the EDF. During counter-ECCD, the counter-view signal is stronger than the co-view signal and during co-ECCD the opposite is true.

During the discharges, the small amount of central ECCD is sufficient to change the behavior of the plasma; consistent with the expected driven current direction. Sawtooth oscillations only appear ~20ms after the step at which +14kA is driven and with co-ECCD lows the central safety factor to $q < 1$. The sawtooth crashes do not occur at exactly the same instant in the 2 discharges but some sawteeth have nearly identical periods (~7ms); therefore, the ratio of signals for the 2 views were carefully compared by shifting the time traces of one of the shots by a few milliseconds to align the sawtooth crashes. This confirmed that the trend shown in figure 3 is not strongly affected by the 0.1s averaging even though sawtoothing occurs at the highest currents.

The ECE radiation transport code NOTECTCV[3] has been used to investigate the effect of the current drive on the radiation temperature. A model EDF is posited in which a drifting suprathermal electron population is added to the bulk population (density and temperature measured by Thomson Scattering). The suprathermal electrons carry the ECCD current. An effective temperature of 12keV ($3\bullet T_{bulk}$) and a density (locally 1% of the bulk density) localized within $\rho < 0.2$ where the central beams are absorbed, is chosen based on previous experience with similar discharges. The density and temperature profiles are essentially flat within $\rho < 0.2$; the suprathermal energy is 0.6% that of the bulk EDF. For a drift velocity of the suprathermal population of 0.3 times the speed of light, the current carried would be approximately +22kA.

Figure 4 shows the calculated oblique ECE emission ratio from NOTECTCV. The peak amplitude of ~1.3 is consistent with the measured ratio in figure 3 The equilibrium model used is circular with a Shafranov shift of 2cm and thus is a crude approximation of the actual TCV plasma; yet, this provides a surpisingly good match to the data.

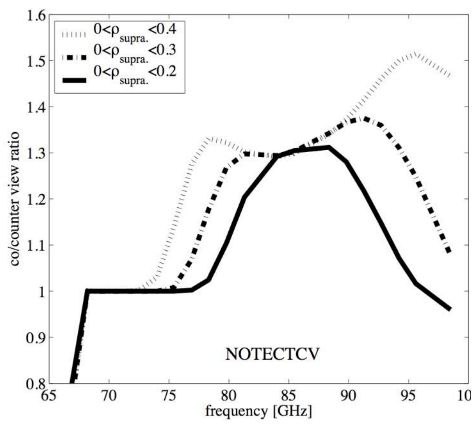

Fig. 4 The ratio of the co-/counter-viewing receiver signals calculated by NOTECTCV. The amplitude is consistent with a value of +23 kA in figure 3 for the case in which the suprathermal electrons are restricted to the region of ECCD drive in figure 1 (ρ<0.2). The other curves show the change in the profile for simulations in which suprathermals are spread farther, resulting in higher current.

Conclusions

First measurements of co- and counter-viewing oblique ECE show clear evidence of an asymmetry in the EDF consistent in sign with both counter- and co- driven ECCD currents. Simulations of the ECE, using the NOTECTCV code, with a drifting suprathermal population which carries a similar level of current to the experiments show similar ratios of co/counter - viewing oblique ECE. Some details of the profile predicted with NOTECTCV are not seen in the measurements. These discrepancies are now under investigation. During these first experiments, the potential of the diagnostic has been demonstrated but, detailed experimental investigations will require a modification to both the HFS and LFS radiometers to provide higher stability and dynamic range. This work is being undertaken at the present time.

Acknowledgements

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