J. Plasma Fusion Res. SERIES, Vol. 3 (2000) 452–455

Measurements and Modeling of Transmitted Power of EC Waves Propagating for Normal and Oblique Injection in FTU Tokamak during ECRH Experiments at 140 GHz

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(Received: 18 January 2000 / Accepted: 18 April 2000)

Abstract

A continuous monitor of waves absorption during ECRH experiments is performed by a set of three low-gain probes, installed in the FTU tokamak walls, collecting the residual scattered and depolarized RF radiation. One probe is located in the same sector of the launching system; the other two are toroidally displaced by 60° and 90° respectively. Two gyrotrons at 140 GHz delivering 0.5 MW each up to 0.5 s have been used to inject EC waves from the low field side at the fundamental harmonic ordinary mode. The estimated of the transmitted power is carried out by a 3D ray-tracing code taking into account both the beam diffraction effects and a statistical model for describing multiple reflections and scrambling of polarization at the tokamak walls. Fair agreement is found between the measured and calculated values of residual electromagnetic radiation.

Keywords:

tokamak, electron cyclotron resonance heating

1. Introduction

Measurements of residual radiofrequency (rf) power are an important monitor of the wave absorption efficiency during plasma heating experiments in magnetically confined fusion devices. In particular, in FTU tokamak (major radius R=93.5 cm, minor radius a=30 cm, central magnetic field B=5–6 T) electron cyclotron (EC) waves, at high frequency (140 GHz) and high power (up to 0.8 MW), are employed to heat the plasma in high density and high temperature regimes. The central magnetic field of 5–6 tesla allows strong wave absorption at the fundamental ordinary mode (OM). In most conditions more than 95% of the injected EC power is deposited off/on-axis during the first transit through the plasma. The fraction of transmitted power is re-absorbed after multiple reflections on the vessel walls. The amount of rf power in the neutral gas region close to the walls is therefore strictly related to single pass-absorption, and its measure is important both for checking the absorption predictions and for preventing excessive rf loading of plasma-facing instrumentation. A system of three low-gain probes (sniffers) of 2.7 cm diameter, located in three vertical ports, is used to collect the residual power. One probe is in the same poloidal section of the EC launcher, while the other two are toroidally displaced by 60° and 90°, respectively (Fig. 1) [1]. In this paper we compare the measured residual power with the linear theory predictions by means of a statistical model, which takes into account multiple wall reflections at random angles and with polarization scrambling. Several experimental conditions have been examined, both in perpendicular and oblique injection, with full and partial OM polarization.

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2. Statistical model

The propagation and absorption of EC waves are described by a fully 3D code, the ray-tracing taking into account the measured plasma parameter distribution and the diffractive behaviour of the Gaussian beams, which enter the plasma from the low field side [2]. The beam propagation is modelled by the quasi-optical approach in the first transit through the plasma. From the second passage on, the beam is replaced by independent rays. In order to properly describe the amount of the residual power at the probe's position, a statistical approach is considered. The input beam is discretized in a number of single rays, each carrying the amount of power appropriate to the initial gaussian distribution. A single ray is randomly selected, with a weight given by the gaussian distribution, and its propagation followed by single ray tracing. At the wall, the ray is randomly reflected. At each reflection the power in the ray is reduced according to an effective wall reflection coefficient (0.85–0.87), which has been estimated by fitting the code predictions with measurements performed by launching EC waves in the empty vessel [3]. When into the plasma, the power in the ray is propagated and absorbed accordingly to the relativistic dispersion relation. The ray is abandoned when the level of the carried residual power becomes less than a fixed threshold. The residual power of all rays reaching the probes' positions is counted. Many random selections (up to 50000) are performed, in order to have a large enough statistics.

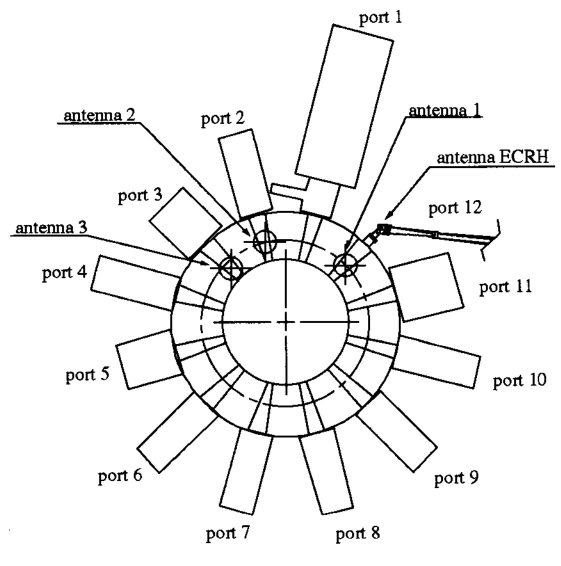

Fig. 1 Scheme of the sniffer locations in FTU tokamak

3. Experimental results

The Electron Cyclotron Resonance Heating (ECRH) campaign on FTU tokamak has been performed up to now by using 2 gyrotrons delivering up to 0.5 MW each for a maximum pulse length of 0.5s. Each gyorotron feeds a launching antenna with poloidal and toroidal (±10°, ±20°, ±30°) beam steering capability.

During ECRH experiment the FTU plasma is characterized by high electron density (central density up to n_{e0}=1.8 10^{20} m^{-3}) and temperature (up to 7–8 keV with n_{e0}≈0.6 10^{20} m^{-3}, central absorption). We present, here, three discharges with density n_{e0}=6–8 10^{19} m^{-3} and electron temperature T_{e0}=3–5 keV. In Figs. 2–4 the residual power, collected by the three probes, is shown for two shots with ±10° of toroidal injection, the plasma axis placed at R_{ax}=98 cm, B_{ax}=5.1 T (r_{abs}/a 0.15),

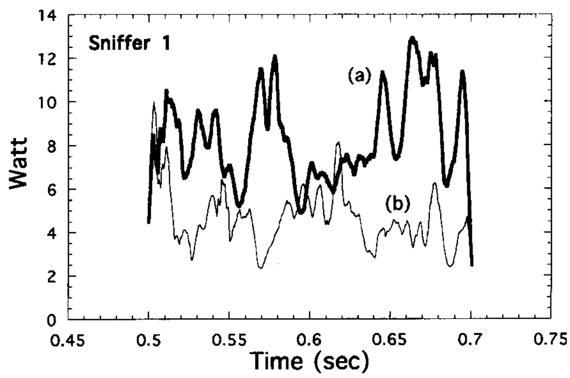

Fig. 2 Rf power collected by the sniffer 1 for EC injection at −10° toroidally away from perpendicular (a), opposite to probes 2 and 3, and at +10° (b).

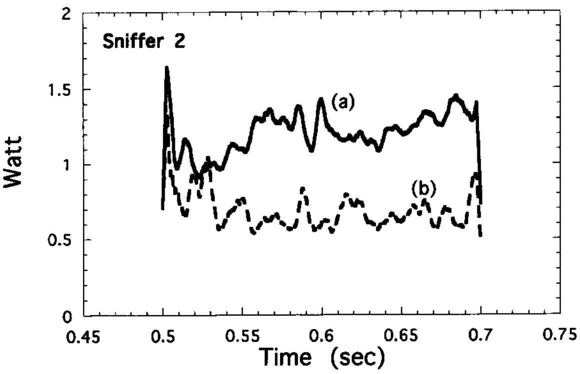

Fig. 3 Same as Fig.2 for the sniffer 2. The model estimates 4 W for the case (a) and 1 W for case (b).

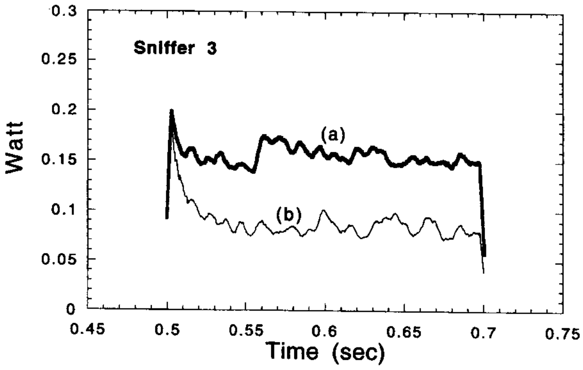

Fig. 4 Same as Fig.2 for the sniffer 3. Model estimate: 0.01 W for the case (a) and .001 W for case (b)

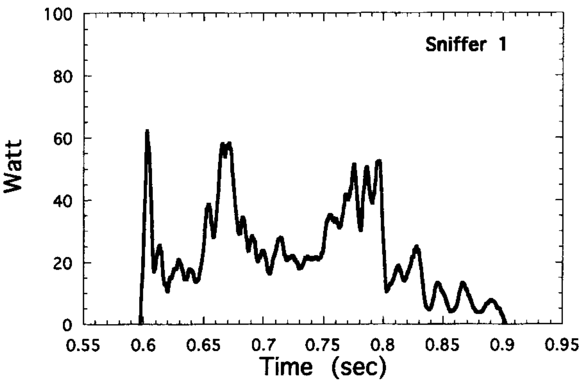

Fig. 5 Level of the sniffer 1 for an ECRH pulse with two gyrotrons (200 ms) and only one (100 ms).

$n_{ax}=n_{e0}=6\ 10^{19}\ m^{-3}$ and $T_{ax}=T_{e0}=5$ keV.

Since the wave propagation from symmetric launching conditions in the same (co) and in the opposite (counter) magnetic field direction is characterized by different values of the parallel refractive index because of the poloidal field components, different levels of the residual power are expected to be measured. In particular, in our examples, at the resonance layer the counter-case parallel index is larger (|0.224|) than the co-case one (0.2).

The higher levels of the transmitted power refer to the rf injection in counter-B direction, away from probes 2 and 3, while the lower traces are measured for co-B direction, or towards the measuring probes 2 and 3.

In Figs. 5–7 results are shown for a discharge with R_{ax}=96.7 cm, B_{ax}=5.4 T, $n_{ax}=7.6\ 10^{19}\ m^{-3}$ and T_{ax}=3 keV, perpendisular injection. One gyrotron is on for 200 ms, and the second one for 100 ms.

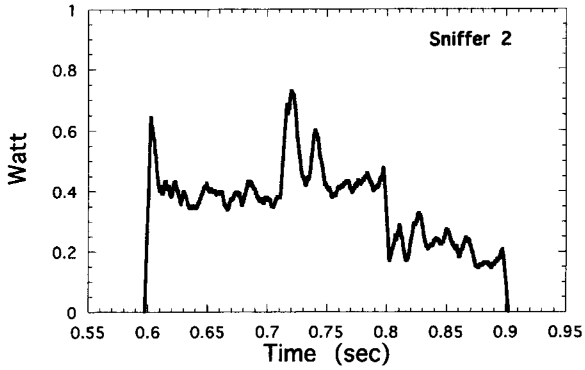

Fig. 6 Same as Fig.5 for the sniffer 2.

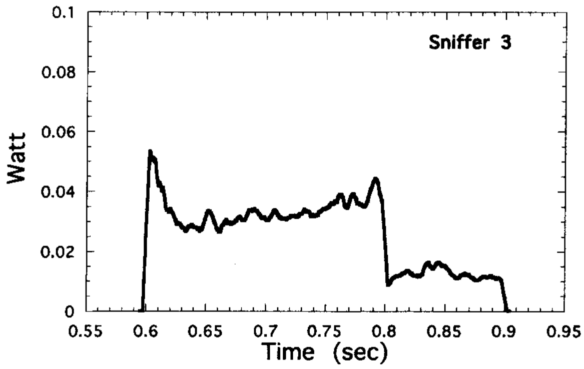

Fig. 7 Same as Fig. 5 for the sniffer 3.

4. Comparison of calculated and measured data

We compare the residual power measured by the three probes with model estimates. The traces of Figs. 2–4 show that about 4 and 8 W are measured by the sniffer 1, 0.5 and 1.0 W by the sniffer 2, 0.15 and 0.08 by the sniffer 3. The simulations give 10 and 30 W, 1 and 4 W, 0.01 and 0.001 for the three antennas, respectively, showing an agreement within a factor ≈2 with the experimental data, which is well within the order of magnitude. Also for the third shot of Fig. 5–7 the comparison is acceptable. During the first 200 ms of ECRH with two gyrotrons the sniffer 1 collects about 30 W, the second probe 0.5 W and the third one 0.04 W.

The statistical model gives residual power levels of 100 W (probe 1), 1 W (probe 2) and 0.009 (probe 3), respectively with 2 gyrotrons on. The largest discrepancies are found for the farthest probe, likely due to the low statistic of the rays with enough power left to reach the probe 90° away from the launchers.

There is a systematic overestimate by a factor ≈2 of the value of the power coupled to the sniffer probes, which might be due either to an effective wall reflectivity somewhat lower than assumed (0.85–0.87), with zero reflectivity at large wall ports), and/or to an inadequate modelling of the effects of the upper hybrid layer on X-mode propagation and absorption.

Improvements on both issues are under way, in particular on the description of the ray tracing on reaching the upper hybrid. A correction of the average wall reflectivity is also considered, mostly determined by a less stringent condition of port reflectivity, still consistent with the measurements made with the empty vessel.

5. Conclusions

In FTU tokamak a set of three low-gain probes allows during ECRH experiment a continuous monitoring of EC absorption by collecting the not-absorbed power. A 3D code has been used to follow, with a statistical approach, the wave propagation and absorption after multiple reflections and polarization scrambling. Experimantal and calculated data are in agreement within a factor 2. Extension of the theoretical model to more complicate geometries could be made.

References

[1] C. Sozzi *et al., High power system for ECRH at 140 GHz, 2 MW, 0.5s on FTU tokamak,* Proc. of the 13th Topical Conf. on Radio Frequency Power in Plasmas, **AIP 485**, 462(1999).

[2] S. Nowak and A. Orefice, Phys. Fluids **B 5**, 1945 (1993); Phys. Plasmas **1**, 1242 (1994).

[3] S. Nowak, A. Airoldi, A. Bruschi, S. Cirant *et al., Measurements of residual power of EC waves propagating in FTU tokamak during ECRH experiments at 140 GHz,* Proc. of 11th Joint Workshop on ECE and ECRH, 4-8 October 1999, Oh-arai, Japan.