29th EPS Conference on Plasma Phys. and Contr. Fusion Montreux, 17-21 June 2002 ECA Vol. ***26B****, P-2.076 (2002)*

Modulated ECH Power Absorption Measurement with a Diamagnetic Loop in TCV Tokamak

G. Arnoux, A. Manini, J.-M. Moret, S. Alberti

Centre de Recherches en Physique des Plasmas
Association EURATOM-Confédération Suisse, EPFL, CH-1015 Lausanne, Switzerland

1. Introduction

The power absorption of additional plasma heating can be determined from the time derivative of the total plasma energy, which can be estimated from the diamagnetic flux of the plasma using a DiaMagnetic Loop (DML). A method based on the temporal variations of the diamagnetic flux of the plasma during Modulated Electron Cyclotron Heating (MECH) has been developed and applied to absorption measurements of second (X2) and third (X3) harmonic X-mode ECH in TCV [1]. A MECH frequency scan has allowed the determination of an optimum modulation frequency situated at about 200-250 Hz. For low field side launching configuration, full single-pass absorption of X2 has been measured and, during X3 low field side launching in plasmas preheated by X2 CO-ECCD, full single-pass absorption has been measured as well. In this paper, X3 absorption measurements with the recently installed top launch injection system is analyzed. The X3 ECH allows heating at plasma densities significantly higher than the X2 cutoff. With these higher density plasmas, additional electron-ion coupling must be taken into account in the MECH-DML analysis. In this model, the power balance equation contains a term describing the energy transfer between electrons and ions. The influence of these effects are discussed by modelling the power balance equation and preliminary X3 top launch absorption measurement are presented.

2. Experimental configuration and frequency response of the DML

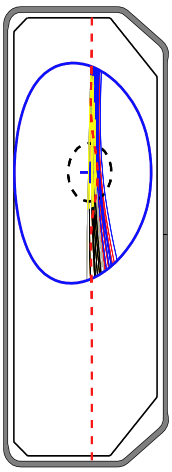

Figure 1 : X3 beam trajectory following the cold resonnance (dashed line). The circular dashed line is the q = 1 surface

The typical ohmic target plasmas and the launching geometry are shown in the figure 1. Two X3 beams are injected from the top launcher of TCV. The launching mirror allows to adjust the poloidal injection angle in real-time to optimize the absorption.The target plasmas have major radius $R_0 = 0.88$ m, minor radius $a = 0.25$ m, elongation $\kappa = 1.53$, triangularity $\delta = 0.15$, toroidal field $B_{0t} = 1.42$ T and plasma current $I_p = 240$ kA.

The DML is a 1-turn loop fixed on the vessel encircling it poloidally. in order to measure the diamagnetic flux, compensations are needed. The achieved frequency response of the DML of up to 1 kHz was obtained by a second order analogue compensation of the vessel image currents; without this, the bandwidth of the diagnostic would be limited to around 30 Hz which is given by the decay time constant of the vacuum vessel current. This large bandwidth, together with the negligible poloidal flux contribution to the DML flux modulation, allows a direct interpretation of the signals without requiring additional data analysis. As described in [1], these effects can be summarized in a system of three equations relating the voltages on the DML, on the compensation loop CL (Figure 2) and the diamagnetic flux $\Delta\phi$ itself. The diamagnetic flux is obtained through a hardware and digital treatment of these signals. The relation between the modulated diamagnetic flux and the modulated plasma energy is given in Fourier space by

$$\tilde{W} = \frac{3\pi}{\mu_0} B_{t0} R_0 \cdot \Delta\tilde{\phi},$$

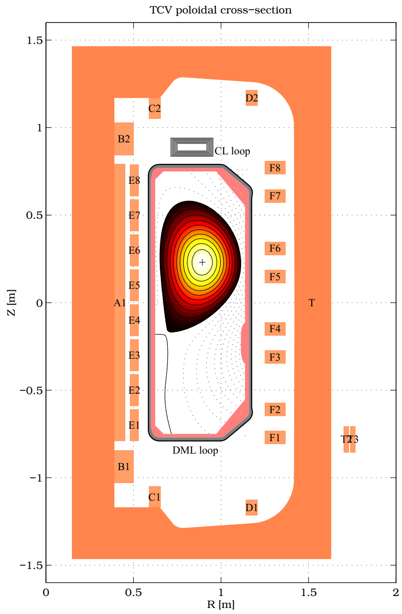

Figure 2 : The DML fixed around the vessel and the compensation loop CL above the vessel

The Shafranov integral terms contributing to the plasma energy can be neglected, since as shown in [1], they do not contribute to the modulation part of the plasma energy.

3. Dynamic response with electron-ion coupling

In reference [1], only the global power balance of the electrons was considered. The electron-ion coupling was negligible because of the temperature difference between electrons and ions and the operating densities were such that the two populations could be considered as uncoupled. Since the ECH waves couple to the perpendicular momentum of the electrons, a term describing the pitch angle scattering is included in the power balance equation. The analysis has shown that for these ECH discharges, the plasma can be considered as being isotropic. In reference [1] and for the optimum modulating frequency of 237 Hz, the plasma can be considered as being isotropic and transport effects can be neglected. In the present paper, the model is implemented by including a term which describes the electron ion coupling. for the same reason as before, the pitch angle scattering on the electrons can also be neglected. Under these assumptions, the power balance equation can be written as:

$$\frac{dW_e}{dt} = -\frac{W_e}{\tau_e} + P_{OH} + P_{RF} - \frac{1}{\langle\tau_{ei}\rangle}(W_e - W_i)$$

$$\frac{dW_i}{dt} = -\frac{W_i}{\tau_i} + \frac{1}{\langle\tau_{ei}\rangle}(W_e - W_i)$$

W_i is the ion energy, W_e the electron energy, P_{OH} the ohmic power and P_{RF} the ECH power. The energy confinement time of the electrons takes into account the heating power dependence by [2] $\tau_e \propto (P_{OH} + P_{RF})^{-0.7}$. The ion energy confinement time τ_i is kept constant. The global equipartition time is given by [3]

$$\langle \tau_{ei} \rangle = \frac{3 m_i}{8\sqrt{2\pi}\langle n_e \rangle Z_{eff} \ln(\Lambda)} \cdot \frac{\langle T_e^{3/2} \rangle}{m_e^{1/2}},$$

where $\langle \ldots \rangle$ is a volume average of the corresponding quantity, m_i the ion mass, m_e the electron mass, T_e the electron temperature and n_e the electron density. The volume averages are taken on a circular plasma and assume parabolic temperature and density profiles. The power balance equations are linearized with respect to the modulated RF power $\tilde{P}_{RF}$ around an equilibrium point defined by the average input power $P_{OH0} + P_{RF0}$. The Fourier transformation of the linearized system allows to write this system of equations as: $\tilde{W} = H(\omega, \tau_{ei}, \tau_i, \tau_e) \cdot \tilde{P}_{RF}$ where H is the complex transfer function and $\tilde{W} = \tilde{W}_e + \tilde{W}_i$ is the total energy. In Figure 3, the amplitude and phase of the complex transfer function H are shown. The asymptotic limit is defined by $\lim_{\omega \to \infty} H \propto 1/\omega$. For a density of $5\text{x}10^{19}$ m^{-3} the total amplitude (H_{ion}+H_e) stays lower than the asymptotic transfer function $1/\omega$. This means that, if the asymptotic limit $1/\omega$ of the transfer function is used, the measured power absorption is underestimated if no ion-electron coupling is considered.

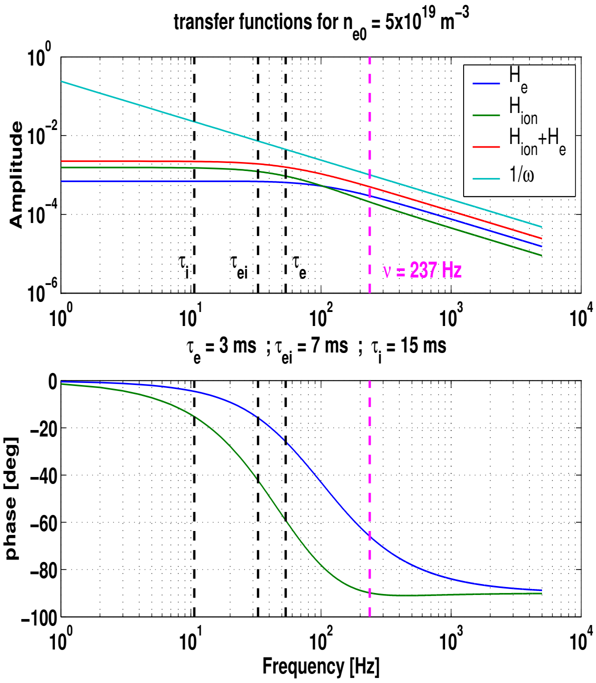

Figure 3 : The phase and amplitude of the transfer function calculated with a Z_{eff} = 2 and an ECH power of 1 MW. Z_{eff} = 2 means that the ionic density is equal to 70 % of the electron density

4. Preliminary results

The DML measurements are compared with the linear ray-tracing absorption code TORAY-GA. The experimental configuration is shown in Figure 1, while the most relevant traces are shown in Figure 4. Two X3 beams carrying 450 kW each are injected from the top of TCV during 1.1 s. Only one of the power sources is modulated at a frequency of 237 Hz during 350 ms. The absorption predicted by TORAY-GA is of 40 %, while the DML measurement results in 65 %. We believe that the discrepancy is to be found in the accuracy of the ray-tracing calculation, which is based on the equilibria calculated by the magnetic reconstruction code LIUQE. This effect together with other effects like diffraction and/or hot plasma effects are presently investigated. More details on experimental results during X3 ECH on ohmic target plasmas can be found in [4]

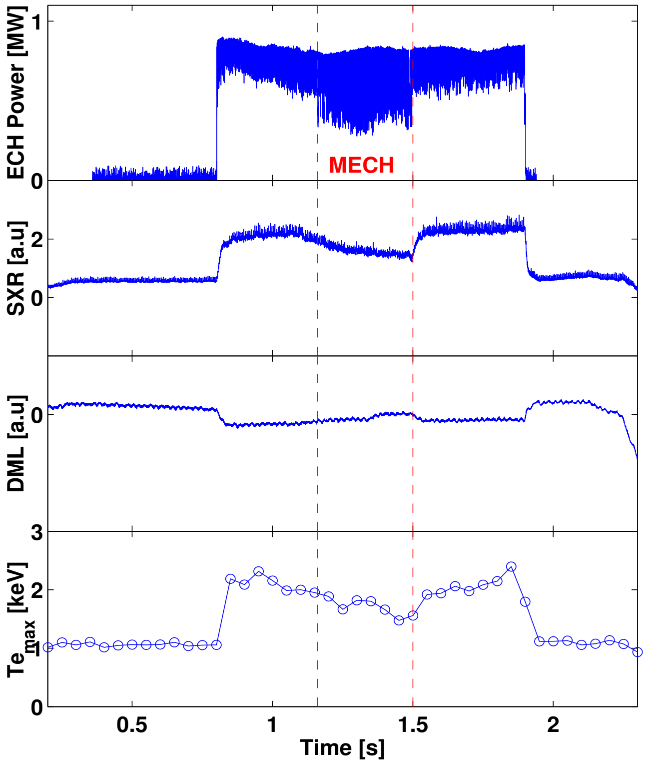

Figure 4 : Temporal traces of a typical shot with X3 MECH. From top to bottom: ECH power, soft-X ray emission, DML signal and Thomson maximum electron temperature.

5. Reference

[1] A. Manini et al., *Plasma Phys. Control. Fusion*, 44, 2002
[2] A. Pochelon et al., *Nucl. Fusion*, (39) 1807, 1999
[3] L. Spitzer Jr., *Physics of Fully Ionised Gases*, (New York: Interscience, 1962)
[4] S. Alberti et al., This conference, poster P-2.073