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L-mode to H-mode Transitions with ECH in TCV Plasmas - First Results

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INTRODUCTION

A high power ECH system is currently being installed on TCV (R=0.88m, a≤0.25m, Ip≤1MA, B≤1.5T, 1≤κ≤2.56, -0.7≤δ≤0.9). The heating system now consists of 3 gyrotrons each with a maximum power of 0.5MW. The EC power (82.7GHz) can be launched with any polarisation from X2- to O2-mode and the mirrors at the end of the wave launchers can be adjusted to get the wave power deposition at the requested vertical position. In these experiments, the deposition regions were chosen such as to obtain a smooth power distribution along the plasma minor radius. The radial position of the resonance corresponds to the major radius of the plasma for the nominal field. Therefore, toroidal magnetic field scans are unfortunately not possible, although highly desirable for the LH transitions studies. With this EC frequency and magnetic field, the cut-off density lies at 4.25 $10^{19}m^{-3}$.

Although Ohmic H-modes are regularly obtained in a wide variety of TCV plasmas (limited or diverted, single null or double null, 3 <n_e<9 $10^{19}m^{-3}$, 1.1≤B≤1.5, 1.05≤κ≤2.05, -.2≤δ≤0.7, 2.05≤q≤4), LH transitions were only rarely observed in low density plasmas (n_e≤4 $10^{19}m^{-3}$). Thus, the first goal of these experiments was to find out whether the H-mode was accessible with a low density ECH target plasma.

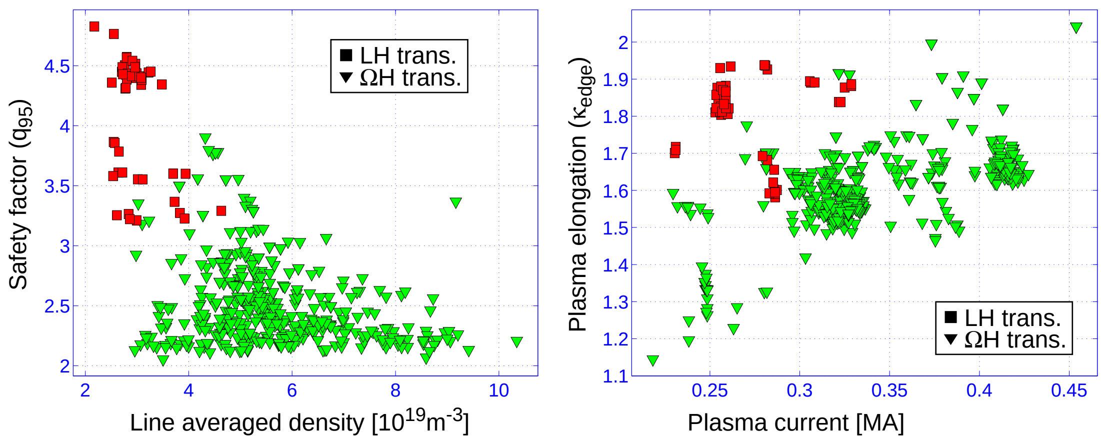

Figure 1: Operational Domain where LH transitions were obtained both for ECRH (■) and Ohmic heating (▼)

OPERATIONAL DOMAIN FOR LH TRANSITIONS IN ECH PLASMAS

The range of stationnary plasma parameters suitable for ECH injection was found to be rather small. The appearance of fatal modes occuring when crossing of q_{95}=3 and 4 in low density plasmas implied operation at higher q_{95} which is at the limit for vertical stability of highly elongated plasmas. Nevertheless, LH transitions have been obtained in this region of the operational domain. Moreover, the low density limit for ohmic H-mode accessibility is lowered when ECH power is added. The increased operational domain covered by these transitions is shown in Figure 1, together with the range covered by the ohmic transitions.

These transitions were obtained in discharges with 3 successive ramps of the ECH power while keeping all other plasma parameters constant, as shown on Figure 2. From shot to shot, the transitions occured at different values of injected ECH power, depending on the plasma parameters. In order to determine the relationship between the amount of additional power and the plasma parameters at the LH transition, the estimation of the power absorbed by the plasma must be addressed.

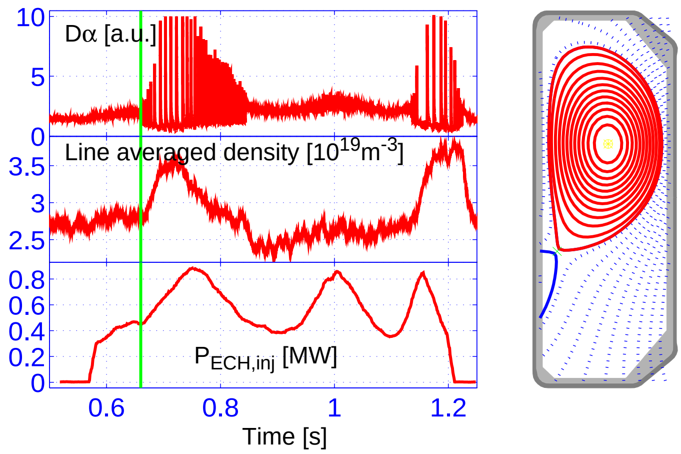

Figure 2: Time evolution of a discharge with a LH transition induced by the ECH power. The poloidal cross section shows the plasma shape at the LH transition indicated by the vertical line.

ESTIMATED ABSORBED ECH POWER INTO THE PLASMA

For all 3 gyrotrons, the ECH power injected in the plasma is measured near the end of the wave guides with 10% accuracy. However, the density profiles measured by Thomson scattering show a central plasma region, up to ρ=0.5, with a local density above the cut-off density for a line average density of 3.5 10^{19}m^{-3}. This implies a significant refraction of the beams and possibly the loss of the first pass absorbtion at the resonance location. Power not absorbed on the first pass will either be absorbed in the plasma after many reflections, absorbed by the walls covered by Carbon tiles or leave the torus through the ports.

To estimate the first path absorbtion, a 3D ray tracing code, TORAY, has been used [1]. From

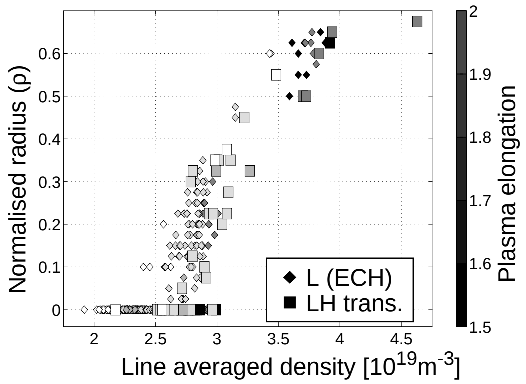

Figure 3: Normalised minor radius (ρ) of the plasma where the density equals the EC cut-off density as a function of the line averaged density.

the knowledge of the plasma shape, the ECH injection geometry, the density and temperature profile, this code determines the trajectory of the beams in the plasma and calculates the fraction of the power which is deposited at the resonance for each beam.

Although the launcher angles were adjusted to direct the beams mostly to large ρ's, the absorbed power in the first path was as low as 20% (n_e> 3.5 $10^{19}m^{-3}$). It is important to determine what fraction of the power not absorbed on the first pass is absorbed in the plasma. For these first experiments with similar shapes and density profiles, a simple model was used consisting of a simplified ray tracing code where the beam reflects at the wall and the plasma. At each interaction a fraction of the power is absorbed depending on the nature of the reflection: wall, window, absorbing or refracting plasma. The absorbtion coefficient of the wall is based on an empirical value of the reflexion of the wave on Carbon tiles. The effect of a variation of this parameter around the experimental value of 0.95 is more important than the fraction of refracting plasma. By means of this model, the absorbed power after multiple reflections was estimated to be about 50% on average for these shots. Hence, the absorbed ECH power can be expressed, for these experiments, as

$$P_{ECH,abs} = P_{ECH,inj} * A_{toray} + P_{ECH,inj} * (1-A_{toray}) * 0.5$$

In order to test the validity of the models used for the estimation of the absorbed power, the O2 polarisation of the waves was used in two otherwise identical discharges previously heated with the X2 polarisation. LH transitions occured with both polarisations of the waves and, once corrected using the above model, the absorbed ECH power at the LH transitions agreed within 10 %, which is a first confirmation of the modelling.

Figure 4 shows the relationship between the line average plasma density and the absorbed ECH power as defined previously. The ECH power at the LH transition clearly increases as the plasma density falls, although the scatter in the data is quite large. One cause of the scattering in the range of density between 2.5 and 3 $10^{19}m^{-3}$ originates in the dynamics of the ECH power injection: if the transition does not occur in the first 100 ms of the heating phase, it may occasionally happen later but a higher ECH power is needed for the same values of the controllable plasma parameters. In some cases no LH transition is encountered. In these cases as well as at lower densities (n_e<2.5 $10^{19}m^{-3}$), the central electron temperature is found to increase above 1.2keV. Above this temperature, no LH transition was observed. One possible link is a decrease in the coupling of the electron and ion populations. The value of the central plasma temperature could even be used

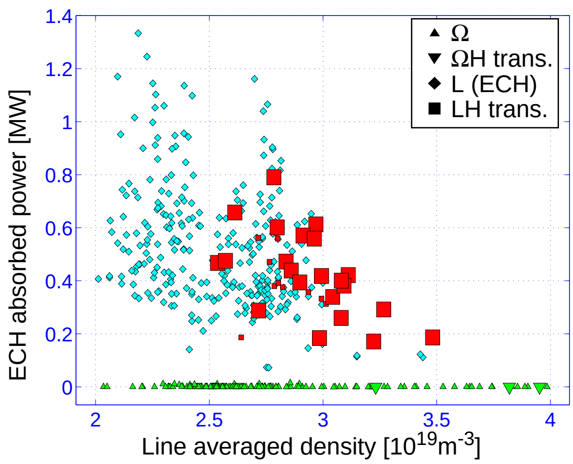

Figure 4: ECH Threshold power as a function of the plasma line averaged density

as an indicator of the possibility to get a LH transition.

Therefore, in order to reduce this scattering in the data, only the LH transitions occuring shortly after the beginning of the heating were selected. With this reduced set of transitions the dependence of the total absorbed power, $P_{OHM} + P_{ECH}$, on the plasma density is even clearer as shown on Figure 5. It is worth noting that this dependence estimated as $P_{thresh} \propto n_e^{-1.5}$ is in contradiction with the ITER power law scaling where the threshold power increases as the density increases: $P_{thresh} \propto n_e^{0.67}$ [2]. However, such a negative dependence of the power on the plasma density was already observed on COMPASS, where the LH transitions were obtained with ECH power too [3]. These observations on two different tokamaks tend to confirm the discrepency between heating schemes acting on the ions or on the electrons, in terms of H-mode accessibility.

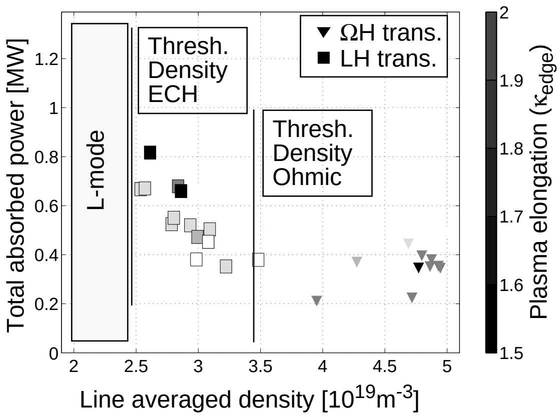

Figure 5: LH transition threshold power in ohmic (▼) and ECRH (■) heated discharges.

In this reduced set of LH transitions, the plasma elongation seems to have a little influence on the threshold power. However, changes in q95 also occured among these discharges. Therefore, more experiments are required to decouple the effect of the elongation from the effect of the current profile.

CONCLUSION

LH transitions have recently been obtained in EC heated plasmas in TCV. They were observed in a range of low density and high q_{95} values where ohmic LH transitions were never achieved. As already noticed in the ohmic case, although at a higher density, a low density threshold was found at approximatively 2.5 $10^{19}m^{-3}$ for the additionally heated discharges. In these experiments the LH threshold power was found to increase as the plasma density decreases. This strong negative dependence is in contradiction with the ITER threshold power scaling [2]. The plasma shape has not show any significant influence on the LH transition with ECH so far.

AKNOWLEDGMENT

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