Influence of ELMs on Edge Temperature and Density Profiles in TCV

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1. Introduction

In this paper we present the results of measurements of the T_e and n_e profiles in the plasma edge region during quasi-stationary ELMy H-mode under ohmic heating conditions in the TCV tokamak. Measurements are provided by the edge Thomson scattering (TS) diagnostic, which improves the spatial resolution in 9 scattering volumes by a factor 3 compared to the main TS system, and was installed in collaboration with Consorzio RFX. Profiles have been characterized in terms of the pedestal height and width using a modified tanh function [1,2]. The time evolution of the profiles during an ELM cycle has been studied using random sampling during an extended quasi-stationary ELMy H-mode phase, sorting the measurements from TS according to the time delay with respect to the nearest ELM.

2. The Edge TS diagnostic on TCV

The TS diagnostic on TCV was designed to collect the scattered radiation along a vertical chord covering almost the entire height of the vacuum vessel, to account for the wide variety of possible plasma equilibria. The main system [3] comprises a set of 25 spatial channels with 3cm spatial resolution in vertical direction and 3 pulsed ND:YAG lasers each with a pulse repetition rate of 20Hz. Studies of temperature and density profiles during H-mode experiments require higher accuracy and spatial resolution in the edge region. Therefore, nine additional polychromators [4], on loan from RFX, were installed on TCV to cover the range near the last closed flux surface (LCFS) with a resolution of 1cm in vertical direction (fig.1), equivalent to ~5mm when mapped onto the plasma midplane along flux surfaces.

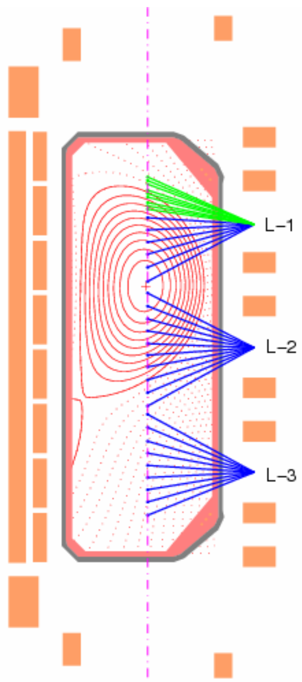

Fig. 1: *TCV poloidal cross section and flux surfaces for shot 26393 at t=0.7s. Viewing chords of TS system main (blue) & edge (green).*

3. Analysis method

The system has been used during dedicated studies of the ELMy H-mode phase in quasi-stationary conditions, when it is possible to follow the time evolution of n_e and T_e profiles using TS measurements at relatively low sampling rates. Since the laser pulses (fixed repetition rate of 20Hz for each laser) cannot be synchronized to the ELMs (average ELM frequency of ~200Hz), random sampling has been used to build up the time evolution during a typical ELM cycle. Under well controlled conditions in TCV with constant plasma current, density and heating power, regular ELM sequences with small variations of ELM frequency and amplitude can be obtained. Random sampling provides measurements at different delays (Δt_{ELM}) with respect to the ELMs (referring to the peaks in the D_α emission). Under the specified conditions, these measurements (within the same shot or even from different but reproducible shots) can be combined to obtain a data set from which the time evolution is reconstructed. For analysis of the spatial variation, the positions of the scattering volumes are mapped onto magnetic flux surfaces and then projected onto the plasma midplane. The profiles are fitted by a linear-tanh function (fig.2) so that they can be parameterised in terms of pedestal height and width, as explained in [2]. These parameters have been used to describe the evolution of T_e and n_e profiles before and after the occurrence of an ELM.

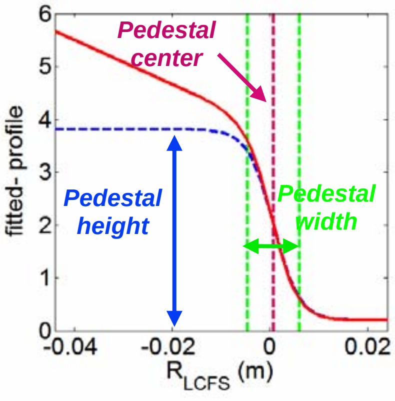

Fig. 2: *Modified tanh fitting function.*

4. Results

Using the method described above, the n_e and T_e data from the quasi-stationary phase of shots 26387 to 26393 (I_p~400kA, n_e~$6.5\cdot10^{19}m^{-3}$, κ~1.6, δ~0.4), have been grouped into two time

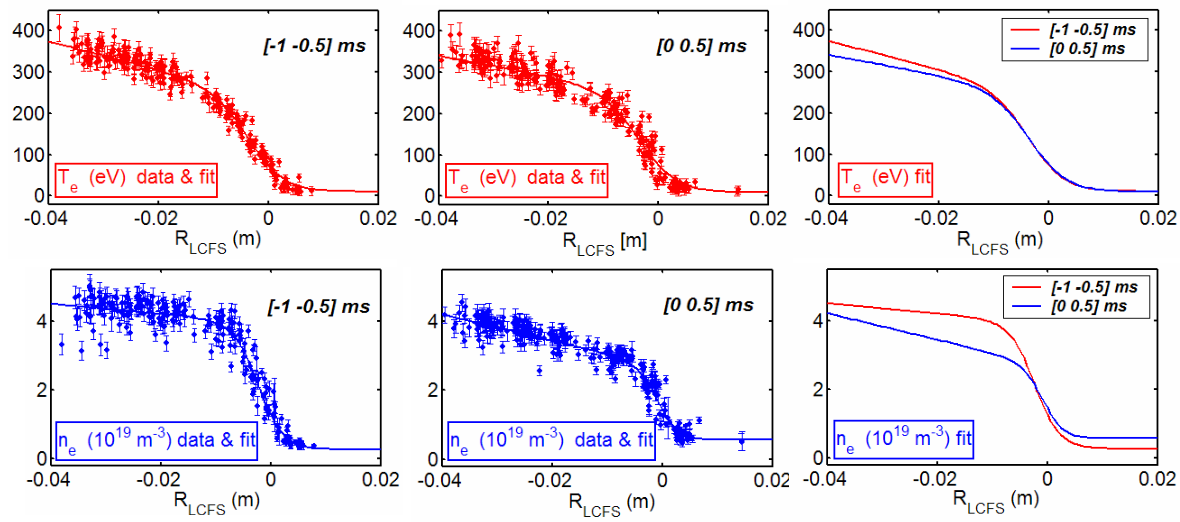

Fig. 2: *Results of analysis in bins, n_e and T_e profiles data from series of reproducible shots (TCV-# 26387 to 26393) superposed, bin [-1,-0.5]ms and bin [0,+0.5]ms delay with respect to ELM.*

windows (bins), [-1,-0.5] ms before and [0,0.5] ms after the ELM. The data and the fitted profiles are plotted in fig.3. The scatter of the data points around the fitted curve is small (in particular for T_e), which shows that the assumption of reproducible ELM events is justified. The spread of points in the R-coordinate, after mapping to the outer midplane, is due to small vertical displacements of the flux surfaces. They are caused by periodic external perturbations using current pulses in a set of coils inside the TCV vessel. These perturbations were applied for ELM triggering [5]; however, the associated displacements were beneficial for this study, since they permitted better spatial coverage of the edge profiles with a TS system of still marginal spatial resolution. The comparison of the measurements in the two time windows reveals a clear difference before and immediately after the ELM. The n_e profile shows a collapse of the edge pedestal, whereas the T_e profile appears to be unaffected.

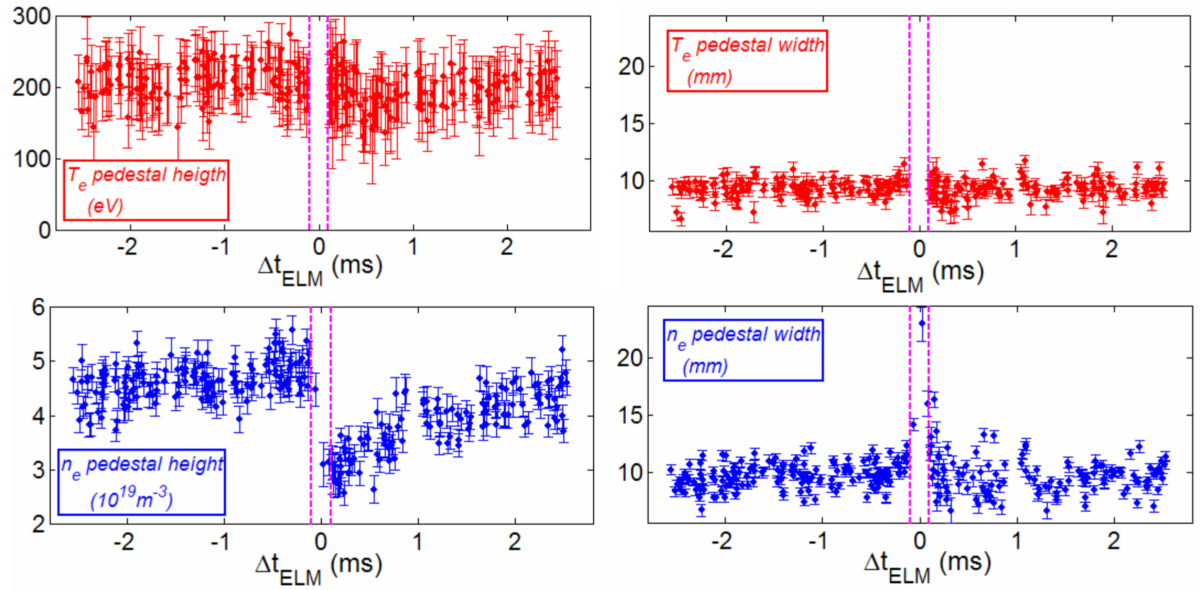

Fig. 4: *Variation of pedestal height and width of n_e and T_e profiles during an ELM cycle. (TCV-# 26379 to 26393). Transient period is evidenced by magenta dashed lines.*

In order to reconstruct the time evolution of the pedestal height and width during the ELM cycle in more detail, the analysis has been based on fits to data obtained for each individual time step. The results from a series of reproducible shots (26379 to 26393) are presented in fig.4. We observe that at the time of an ELM event the density pedestal reacts immediately, with a collapse of about 35% (from ~4.5 to $\sim 3 \cdot 10^{19} m^{-3}$ in these cases). The pedestal recovers with a time constant of about ~500µs and then increases linearly until the next ELM occurs. The effect of an ELM on the T_e pedestal is much weaker, but still present: it decreases by about 15% (from ~210eV to ~180eV) and reaches a shallow minimum at about 500µs after the ELM peak. These measurements confirm that the energy loss caused by ELMs is essentially due to a convective process and occurs on a time scale much shorter than the global energy confinement time. The drop in energy calculated on the basis of the measured profiles is consistent with measurements by a diamagnetic probe and reached values between 2 and 4%. The pedestal width, which gives a measure of the width of the edge transport barrier, is found to be ~10mm, close to the value of the poloidal ion Larmor radius. It remains essentially constant during most of the ELM cycle, disregarding the narrow time window of ±100μs around the ELM peak. In this interval the profile fits by a tanh function often failed and did not allow us to quantify the pedestal parameters.

Concentrating our attention to this time window, we observe that in most cases (~75% when the time of the measurement falls inside this narrow interval), the profiles are modified; they extend beyond the LCFS and a pedestal can no longer be identified. In about 18% of the cases distinct structures (bumps) appear on the T_e and the n_e profiles at or outside the LCFS. At present, the low sampling rate of the TS measurements and a marginal spatial resolution set limits to a more detailed analysis of the profiles in this transient phase. Nevertheless, the measurements show a relaxation of the gradients and indicate that the outward flux of particles and energy across the separatrix occurs on a fast time scale (see fig.5). However, without further information about the poloidal and toroidal structure it is not possible to quantify the associated losses of particles and energy. These transient features are not yet fully understood, but they show similarities to observations on MAST [6,7].

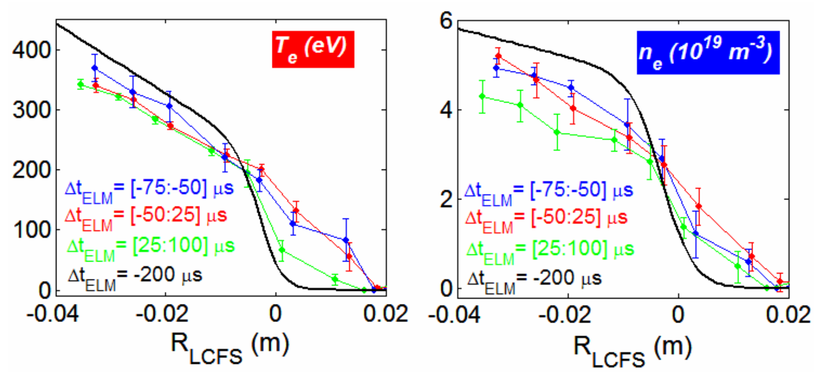

Fig. 5: *Averaged T_e and n_e profiles measured in different time windows during the transient phase (±100μs from the peak of the ELM signal). A profile fit for Δt_{ELM} = -200μs is shown as reference.*

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