Density pedestal measurements with microwave reflectometry on ASDEX Upgrade

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The understanding of confinement improvement through the formation and sustainment of localized transport barriers requires diagnostics with high temporal and spatial resolutions. One diagnostic that can meet such high requirements is broadband microwave reflectometry. In particular, it can measure the density profile with better than 30μs temporal resolution and millimetre spatial resolution. The main difficulty has always been the evaluation of the density profile in the presence of plasma turbulence. Recent advances in the data analysis techniques and the high performance of the reflectometry diagnostic enabled the automatic and routine evaluation of density profiles in all plasma regimes of ASDEX Upgrade. The large number of profiles measured during a discharge makes it possible to obtain the detailed evolution of plasma parameters crucial for transport analysis, such as the edge pedestal density, even under moderate levels of plasma fluctuations. Here a new method is presented that automatically extracts the temporal evolution of the edge pedestal density from the measured group delays. To reduce the effect of plasma fluctuations and to improve the accuracy of the pedestal detection, the method can use burst sequences of closely spaced reflectometry samples. The automatic evaluation of the pedestal was applied to ASDEX Upgrade standard H-mode plasmas. The results presented show that reflectometry can accurately detect the formation of the edge pedestal at the L to H transition, and also that the detailed evolution of the density profile can be resolved, in particular during ELMs (edge localized modes).

I. INTRODUCTION

The H-mode plasma regime with type I ELMs is considered to be the reference scenario for ITER. One parameter that is crucial to understand H-mode performance is the density of the edge pedestal, due to the impact of this plasma region in the global energy confinement and stability and also on the divertor plates life-time, due to the effect of ELMs. It is therefore crucial to have measurements with high temporal and spatial resolutions to be able to resolve the density profile changes at the edge and the associated fluctuations levels. Existent measurements do not have the required temporal resolution and/or lack spatial coverage of the edge pedestal region.

In ASDEX Upgrade, around 3000 density profiles with 30μs temporal resolution and millimetre spatial resolution (under good propagation conditions) are obtained with broadband reflectometry in each discharge at each side of the plasma, covering the density range $0.4-15\times10^{19}m^{-3}$. Thus, broadband reflectometry meets the requirements for edge measurements and is able to contribute substancially to the study of edge plasma physics, in particular in the pedestal region, where it can complement the measurements performed by the Thomson scattering, interferometer, and Li-beam diagnostics.

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Due to advanced data analysis techniques that have been developed, reflectometry density profiles are now automatically evaluated and are routinely available shortly after each ASDEX Upgrade discharge. A new method has also been developed to automatically extract the density of the edge pedestal from the measured group delays. The application of this new method to ASDEX Upgrade standard H-mode discharges is reported here. The results obtained demonstrate that reflectometry can resolve the detailed evolution of the density profile during the L to H transition and during the occurrence of ELMs. In particular, it is shown that reflectometry can follow the evolution of the density of the edge pedestal since its formation immediately before the L to H transition.

The remainder of the paper is organized has follows. In Sec. II, the a brief description of the profile evaluation techniques is given. Section III describes the method developed to automatically detect the edge pedestal density. In Section IV the experimental results are presented. Section V discusses the results and gives some hints concerning future work.

II. PROFILE EVALUATION

The ASDEX Upgrade broadband reflectometer features ultra-fast sweeping and the unique capability of probing from both magnetic field sides simultaneously.[1,2] Profile measurements can be performed in three modes: (i) equally spaced sweeps covering the complete discharge, (ii) in bursts of closely spaced sweeps with a larger interval between the bursts, and (iii) in mixed mode, where parts of the discharge are covered with equally spaced measurements and others with bursts. Burst-mode measurements offer the possibility to obtain average profiles in plasma regimes where single measurements would fail such as the ones characterized by high levels of plasma fluctuations. The profile evaluation system is based on the best-path algorithm.[3] This method uses the spectrogram of the reflected signals that shows how the reflected energy is distributed in the time-frequency domain.

In ASDEX Upgrade, the results obtained so far show that the signal-to-noise ratio (S/N) of the reflected signals plays an important role in the evaluation of the profiles. If it is high the inversion of the profile from single sweep data presents no problems, which is normally the case in plasma regimes with low levels of plasma turbulence, such as H-mode plasmas. As the level of turbulence increases, the S/N ratio may become very low, which prevents the accurate inversion of the density profile.

The solution is usually adopted is to average over several consecutive sweeps to improve accuracy. We adopted a different approach that takes advantage of both the ultra-fast sweeping capability of the diagnostic and of the large number of measurements that can be performed in a single discharge. In burst-mode, the average profile is not obtained from simple averaging over the ensemble of group delays, as it would be too sensitive to strong perturbations in the individual samples, but using the burst-mode data processing method.[4] Typical measurments have bursts of eight closely spaced (10μs) ultra-fast sweeps (20μs) to obtain an average profile every 230μs. The burst-mode spectrogram still retains all features common to the different sweeps and simultaeously reduces the perturbations of the individual group delays, therefore giving a more accurate and reliable burst profile.

III. AUTOMATIC PEDESTAL DETECTION

In ASDEX Upgrade, density measurements are also performed by the Li-beam diagnostic, at the edge, by the Thomson scattering, and by the interferometer. A density profile has been routinely provided that combines Li-beam and interferometry data. Reflectometry is expected to improve the resulting profile firstly by providing the density at which the pedestal occurs. In order to provide the evolution of the pedestal as soon as the density profiles are available we developed a method which automatically determines the density of the pedestal from the computed group delays.

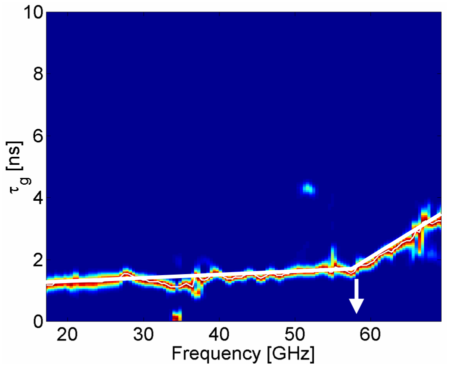

FIG. 1 – Schematic representation of the automatic detection of the pedestal density.

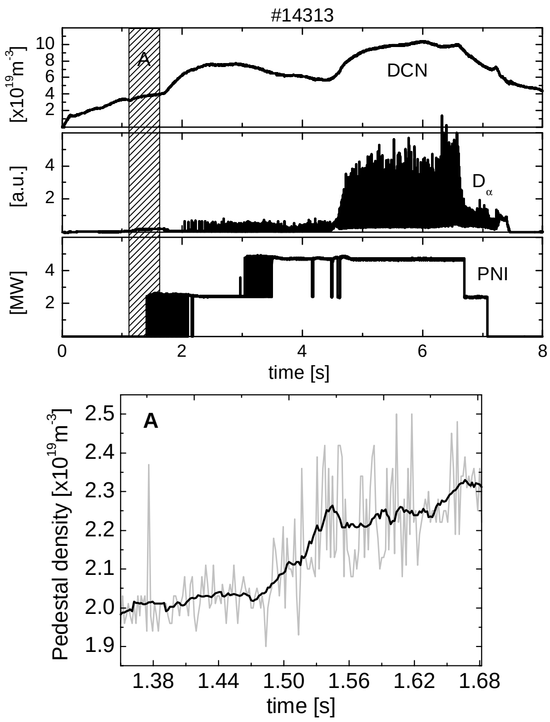

FIG. 2 – Automatic detection of the pedestal density: upper part – evolution of the average density (DCN), flux of particles at the divertor (D_α), and neutral beam injection power (PNI), along the discharge; lower part – evolution of the pedestal density. The gray curve was obtained directly from the group delays while the black curve results from a smoothing using a 15–point window.

Figure 1 shows a schematic representation of the method used. The turning point, which results from the gradient change at the pedestal, is determined as the intersection of two lines: the first one is obtained through a linear fitting performed over the frequency range 18 – 35 Ghz; the second one results from another linear fitting this time in the range defined by the frequency above which the group delay deviates from the previous linear fitting more than a pre-defined value, and the last measured frequency. The pedestal density is obtained from the frequency f, where both lines intersect, through the relation $n_{ep} \cong f^2/81$.

Figure 2 shows the results obtained in ASDEX Upgrade standard H-mode discharge #14313. The upper part of fig. 2 shows the evolution of the average density (DCN), the flux of particles at the divertor (D_α), and the neutral beam injection power (PNI), along the discharge. The lower part of fig. 2 shows the evolution of the pedestal density obtained with the method described above in the time interval corresponding to the dashed region A in the upper part of the figure, going from the L phase up to the L to H transition. The results show that the density of the pedestal starts to increase before the transition occurs. After the transition, the profile peaks and the pedestal is lost as the density increases. Figure 3 shows the density profiles right before and after the L to H transition. As shown, reflectometry can follow the abrupt peaking of the density profile typical of the L to H transition. These results clearly demonstrate the capabilities of reflectometry to accurately follow the profile changes both temporaly and spatially.

IV. ELM MEASUREMENTS

Due to its good temporal and spatial resolutions, reflectometry can greatly contribute to further the study about the impact of ELMs in the density profile.

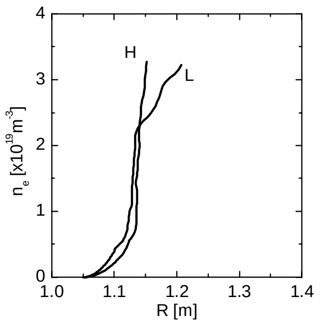

FIG. 3 – Density profiles measured at the high-field side right before and after the L to H transition.

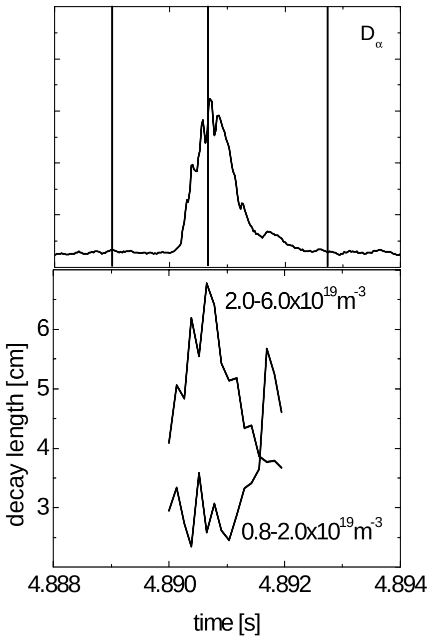

FIG. 4 – Decay length evolution in two distinct profile regions, showing that the inner region flattens and peaks in the ELM time scale, while the outer one flattens only at the outset of the ELM.

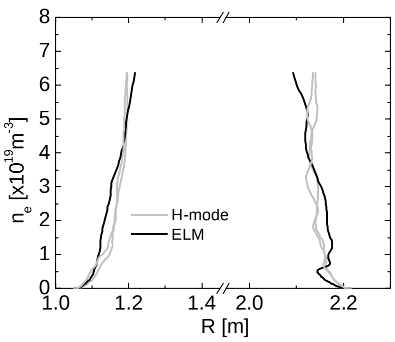

FIG. 5 – Density profiles measured simultaneously at the low- and high-field side right before, during and after an

Figure 4 shows the profile changes measured at the high-field side during an ELM. The upper part of fig. 4 shows the D_α signal during the ELM. The lower part shows the evolution of the decay length in the density ranges $0.8-2.0\times10^{19}m^{-3}$ and $2.0-6.0\times10^{19}m^{-3}$. The decay length at the inner layer is shown to follow the time scale of the ELM. However, the outer layer remains peaked and only flattens at the outset of the ELM.

Figure 5 shows the density profiles measured simultaneously at the low- and high-field sides of the plasma right before, during, and after the ELM depicted in fig. 4. The characteristic flattening of the profile due to the ELM can be clearly seen as well as the reduced level of fluctuations on the high-field side.

V. DISCUSSION

The results presented in this paper show that reflectometry is able to play a major role in the study of the edge plasma. The major advances in the data processing system of the ASDEX Upgrade broadband reflectometer, which improved the accuracy and reliability of the density profiles, allow reflectometry to make a major contribution to the improvement of the standard density profile of ASDEX Upgrade as well as to the understanding of edge plasma phenomena, like ELMs. The method presented here to automatically evaluate the pedestal density is now undergoing extensive testing before we make the pedestal density evolution routinely available.

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1. Silva *et al.*, *Fusion Technology*, edited by C. Ferro, M. Gasparotto, and H. Knoepfel, (North-Holland, Amsterdam, 1992), Vol. 1, p. 747.
2. Silva *et al.*, *Rev. Sci. Instrum.* **72**, 307 (2001).
3. P. Varela *et al.*, *Rev. Sci. Instrum.* **70**, 1060 (1999).
4. P. Varela *et al.*, *Rev. Sci. Instrum.* **72**, 315 (2001).