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Routine Density Profiles with High Spatial and Temporal Resolutions from the FM-Broadband Reflectometry System in ASDEX Upgrade

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1. Introduction

A variety of reflectometry techniques have been developed to measure density profiles in fusion devices. However, great difficulties were encountered to obtain the profile with sufficient accuracy, due to the effect of plasma turbulence on the probing microwaves [1]. So far, reflectometry has not been used routinely to provide density data for transport analysis.

The success of the profile measurement depends primarily on the performance of the diagnostic, and on the data processing, which is essential to extract the distance (versus density) information in the presence of noise. The multichannel FM broadband reflectometry diagnostic on ASDEX Upgrade, developed in 1991, is designed for high performance [2] and has recently been upgraded with the higher frequency channels equipped with heterodyne detection to cope with lower amplitude signals reflected from the core plasma. Great effort has been applied to the development of dedicated data processing and this has now permitted the evaluation of density profiles routinely between discharges, from the edge to the plasma core, in a wide range of plasma regimes. During each discharge 720 profiles are generated simultaneously for the high and low field sides (HFS/LFS) with high temporal resolution (20 μs, from single sweep data). The measurements can be either equally spaced to cover the complete discharge or closely spaced (minimum 10μs) in specific time windows to resolve in detail fast phenomena, namely the abrupt changes of the density gradients during L to H transitions, ELMs, Marfes, etc. The simultaneous probing at the high field and low field sides and the high temporal resolution make this density diagnostic unique in the fusion community. It is now appropriate to evaluate the automatic results in order to assess the importance of the density profile measurements aiming at plasma transport studies.

2. Diagnostic and data processing tools

The density profiles are obtained with four channels at the HFS and seven channels at the LHS, covering fundamental frequency bands in broadband operation. The system uses focused antennas installed both at the HFS and LFS. The O-mode probing frequencies [16 GHz to 110 GHz], cover the density range 0.3×10^{19} to 15×10^{19}; two X-mode channels [33 to 75 GHz] probe the outer plasma edge at the LFS from zero density. The higher frequency bands [50 – 110 GHz] are equipped with broadband heterodyne detectors compatible with the fast sweeping operation (20 μs). Two dedicated channels use fixed frequencies to monitor the level of plasma density fluctuations at specific density layers. The broadband channels can also be operated in fixed frequency to perform fluctuation measurements at several locations during the discharge.

The density profiles are evaluated automatically in every shot using only reflectometry data. Since January 2000 they are available in the form of “level 1” shotfiles (first round of processing from the raw data). The profiles have 20 μs temporal resolution (single sweep data) and are obtained with data analysis tools based on the time resolved short-time Fourier transform of the reflected signals and a best-path search algorithm [3]. The aim of the “level 1” shotfiles is to provide density profiles from reflectometry shortly after each discharge (typically 15 min). Due to the automatic procedure, the parameters used to generate the profiles are adjusted to a broad range of plasma regimes and therefore are not adapted to the specific plasma conditions. For example the digital filters used in the data analysis are wide enough to detect high and low density gradients. An automatic classification of the each profile measurement is being implemented based on parameters that are sensitive to the signal to noise ratio along the sweep [4]. This will provide a flag with the degree of confidence (γ) in each profile. The density profiles with low γ can be re-evaluated by adjusting the data analysis parameters, namely the digital filters. “Level 1” shot files do not include smoothing or averaging and “level 2” shot files are under development; they will feature smoothed profiles, and profiles obtained in the so-called "burst-mode", that uses data from several consecutive sweeps to improve the signal to noise ratio by software. In the following we will present only “level 1” density profiles.

3. Experimental Results

We have analyzed H-mode discharges with improved performance, corresponding to zero central shear. The examples shown refer to shot #13441, where 720 profiles were acquired every 1 ms, starting at 900 ms in the L-mode phase. From the Dα signal it can be inferred that the L to H transition occurs at t ~1.2s (see Fig.1 b), after the injection of the second neutral beam (Fig. 1a).

Figure 2 shows two typical “level 1” density profiles, one during the L-mode phase (t=1.083s), the other in the H-mode phase (t=1.564s). The abrupt increase of the edge gradient characteristic of the H-

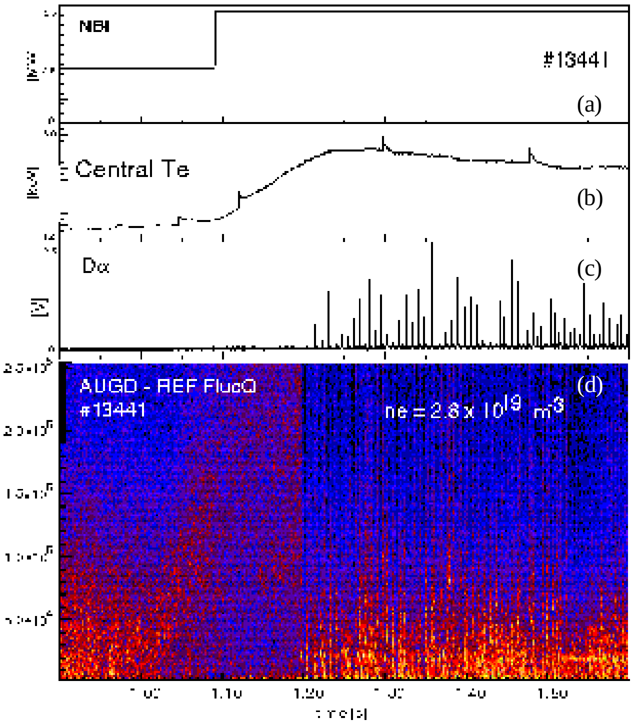

Figure 1

mode is observed, in good agreement with density measurements from Thomson scattering and DCN + Li-beam. It should be noted that the perturbations observed in the profiles can be due to local profile deformations, namely due to MHD activity. As reflectometry probes the plasma locally even small profile perturbation can be detected. Using a 2D code and introducing a periodic local flattening of the profile it was found that the reflectometry profile measurements exhibit perturbations similar to those observed in the experimental results [5].

As in shot #13441 the profile measurements are spaced by 1 ms, the evolution of the density profile can be resolved in more detail than with the other density diagnostics. It can be seen in Fig.3 that during the L phase (t = 1.054s and t = 1.107s), the most significant change is the increase of the density gradient in the inner part of the profile. However, analyzing other profiles the gradient seems to increase and decrease in a random way. The behavior of the density profile can only be clearly seen by plotting the density gradients of the 720 “level 1” density profiles, as depicted in Fig. 4. The density gradients were evaluated automatically (translated in degrees) at three plasma regions: (i) at the scrape-off layer, n_e: 0.5 – 1.5 × 10^{19} m^{-3}; (ii) at the edge, n_e: 1.5 - 3.0 × 10^{19} m^{-3} and (iii) at the inner plasma, n_e: 3 – 5 × 10^{19} m^{-3}.

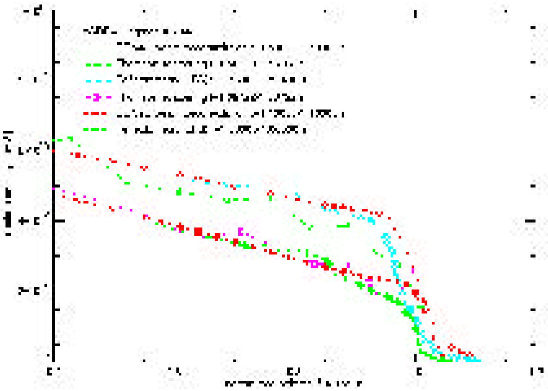

Figure 2

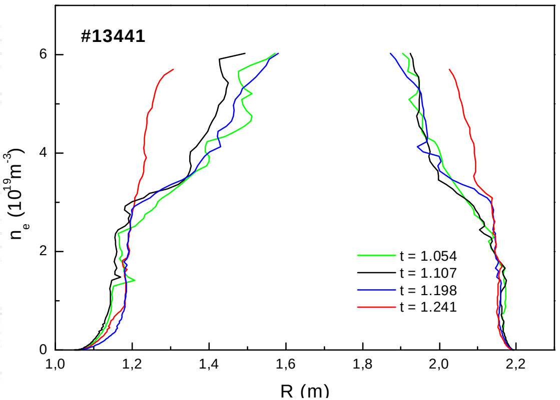

Figure 3

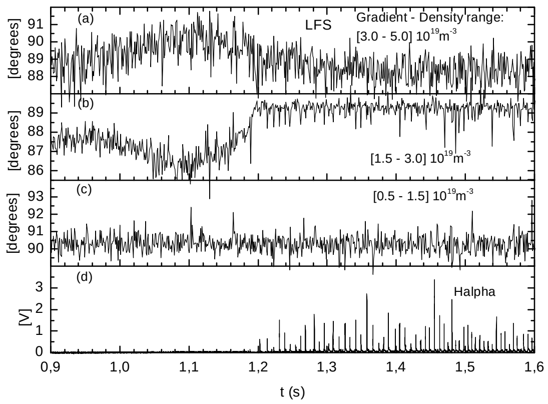

Figure 4

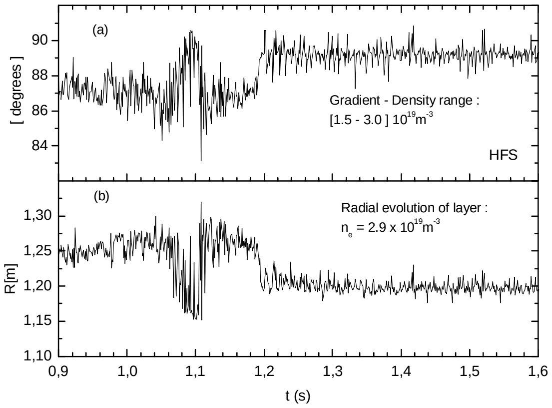

Figure 5

Whereas at the scrape-off layer the density gradient does not change significantly (Fig.4c), it starts to decrease at the edge (Fig.4b) and to increase in the inner plasma region (Fig.4a), around t = 1s, before the L-H transition, indicating a clear peaking of the density profile at the core plasma region. Following the modification of the profile a reduction of the turbulence is observed some 150 ms before the L-H transition (Fig. 1 c), with a reflectometry channel operating in fixed frequency probing an inner plasma layer (at $n_e \sim 2.8 \times 10^{19}\,m^{-3}$). The above characteristics seem to indicate an improvement of the plasma performance before the formation of the edge H-mode barrier, coinciding with the observed increase of central T_e (Fig. 1d).

At t~1.2 s the L-H transition is clearly detected by the abrupt increase of the edge gradient (Fig. 4b). It should also be noted that in the H phase the spread of the gradient values diminishes significantly as the level of plasma background turbulence decreases, exhibiting periodic abrupt decreases associated with ELMs.

At the high field side (Fig. 5a), the L-H transition is also detected by the sudden increase of the gradient but more pronounced modifications of the density gradient are observed before the transition. An abrupt transient increase occurs around ~ 1.1 s, followed by a profile relaxation just before the L-H transition. The observed change in the gradient around 1.1s corresponds to a radial inward displacement towards the HFS antenna of ~10cm, for the probed layer at $\sim 2.9 \times 10^{19}\,m^{-3}$ (as seen in Fig. 5b), in agreement with the changes in the separatrix location (R_{aus}) from magnetic measurements.

4. **Concluding remarks**

Automatic density profiles from reflectometry are being obtained routinely at ASDEX Upgrade with an FM Reflectometry system simultaneously at the high and low field sides, with a combination of high system performance and dedicated data analysis.

It is shown that density profiles with high temporal resolution (20 μs) evaluated routinely exhibiting perturbations due to the plasma macro and micro turbulence, permits to obtain the coherent behavior of the density gradient, which is a relevant parameter for transport analysis. This indicates that the statistical properties of the automatic density profiles may add to the understanding of the plasma phenomena. In the case here presented its application is demonstrated as a tool for the study of the interplay between edge and internal plasma regions.

References

[1] C.Laviron, A.Donné, M. E. Manso,J.Sanchez, Plasma Phys. Contr. Fusion (1996)
[2] A.Silva, M.E.Manso et al., Rev. Sci. Instruments, 67, 4138 (1996)
[3] P. Varela, M.E.Manso et al., Review Sci. Instruments, 70, 1 (1999)
[4] P. Varela et al., 13th Conf. HTPD, to be published in Rev.Sci.Instruments (2000)
[5] F.Silva et al., 13th Conf. HTPD, to be published in Rev. Sci. Instruments (2000)

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