Plasma Position Using Reflectometry Edge Density Profile Measurements on ASDEX Upgrade

J. Santos, M. Manso and the ASDEX Upgrade Team*

Centro de Fusão Nuclear - Associação EURATOM/IST, P-1049-001, Portugal

*MPI für Plasmaphysik, EURATOM Association, D-85748 Garching, Germany

Introduction

In long pulse operation of next step machines like ITER magnetic systems may accumulate significant errors, therefore a new approach to plasma position and shape control is required. Reflectometry, a robust diagnostic that can measure the position of density layers close to the separatrix, has been proposed as an alternative method to control the location of the plasma boundary [1]. The FM-CW reflectometry system on ASDEX Upgrade has unique features to perform the experimental demonstration of such technique: (i) it measures edge profiles with O-mode only (X-mode is dependent on the B field); (ii) it measures plasma density profiles automatically in the presence of plasma turbulence; (iii) it is the only existing reflectometry system that probes simultaneously both High (HFS) and Low (LFS) field sides. Real time algorithms have to be developed in order to make these measurements useful for a plasma position control. In this paper we present plasma positioning results obtained with reflectometry in two different shots: (A) a radial scan and (B) a vertical scan of the plasma column. A short report on the application of neural networks to perform the density profile inversion from experimental group delay data (obtained in two ITB shots) is also presented.

A - Shot #13171 - Rscan

In this shot, used for H-mode pedestal movements, the plasma column was moved radialy from *2.3-3.9 s* (a *4 cm* change - see the magnetic radial position of the centre of the plasma column - *Rmag* in fig. 1d)). Figures 1a) and 1b) show the positions of several density layers as seen by reflectometry. Density layer movements are well correlated with the changes of *Rin* and *Raus* (the radial positions of the outermost closed flux surfaces computed from magnetic data) as soon as the density of the separatrix stabilises (fig. 1d) - from Li Beam diagnostic). It can be seen that until approx. *t=2.3 s* the average density, and thus the density at the separatrix, keep increasing. This can be observed in figs. 1a) and 1b) where both *Rin* and *Raus* cross the density layer position curves from lower to higher densities. The density profiles used to obtain these curves are plotted in fig. 1c). Each of these profiles was acquired in *20* μs every *5 ms*. Due to the long time between individual profiles no profile averaging was made. Instead, a moving average window of *35 ms* (5 profiles) was applied to the resulting layer positioning curves.

B - Shot #14325 - Zscan

In this shot the plasma column was to be moved along the Z-axis in a Z scan that started at *t=2 s* but ended with a plasma disruption at *t=2.2 s*. However, during the period from *0.5-2.5 s* there were vertical and horizontal changes of the magnetic center of the plasma, fig.2d). A L-H transition took place at approximately *t=1.25 s* and can be clearly seen in the profiles plotted in fig. 1c), and confirmed by the changes in H_α and the average density, fig. 1d). The curves of figs. 1a) and b) show that between the L-H transition and the disruption, *Rin* and *Raus* movements are in good agreement

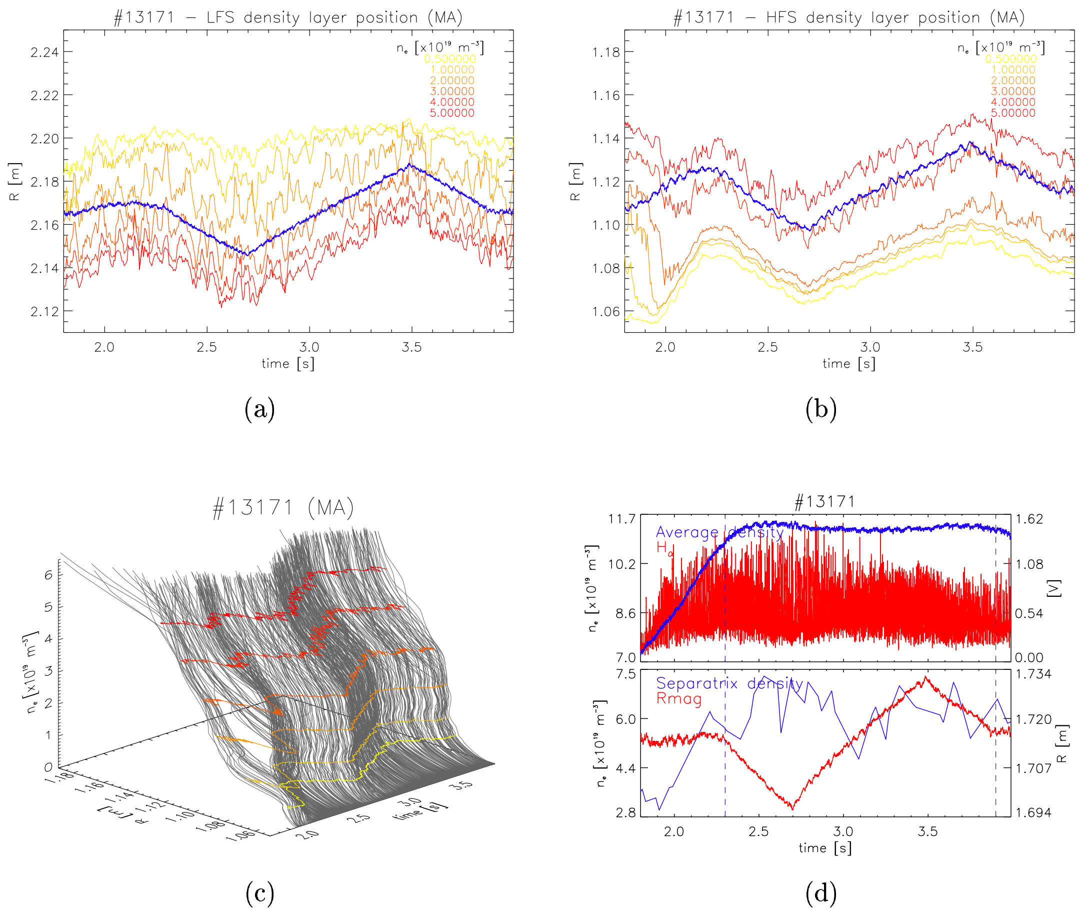

Figure 1: Shot *#13171*, a plasma column radial scan. a) and b) show the radial locations of fixed density layers as seen by reflectometry plotted against the location of the separatrix (blue curves) at the low and high field sides respectively; c) O-mode reflectometry density profiles used to extract the curves shown in a) and b); d) average density, H_α radiation, density at the separatrix and radial position of the magnetic center of the plasma column for the studied period.

with movements of the fixed density layers. Again, during the density ramp-up and immediately after the disruption, *Rin* and *Raus* cross the fixed density layer curves, showing an increase and decrease in the density at the separatrix respectively. In this case, the curves have an offset both at LFS and HFS regarding the position of the separatrix as seen by the magnetics. This offset can be due to a non-adequate guess of the starting position of the density profiles. Unfortunately, in this shot, the density at the separatrix data from *Li* Beam was not available thus not allowing a proper insight on the way to compensate this offset. On the other hand, the less noisy aspect of the shown curves (when compared with shot *#13171*) is due to the way profile data was acquired. Each of the profiles plotted in fig. 2c) (one every *15 ms*) is the mean of a bursts of 8 profiles acquired in *50 μs* each with a *70 μs* rate (a full burst of 8 profiles lasts *560 μs*). Then, a three point moving average was applied to the resulting density layer position curves.

Neural network application (ITB shots: *#12041*, *#12042*)

It was shown in [3] that a neural network (NN) approach to perform density profile inversion from reflectometry data has the potential to meet the tight timing requirements

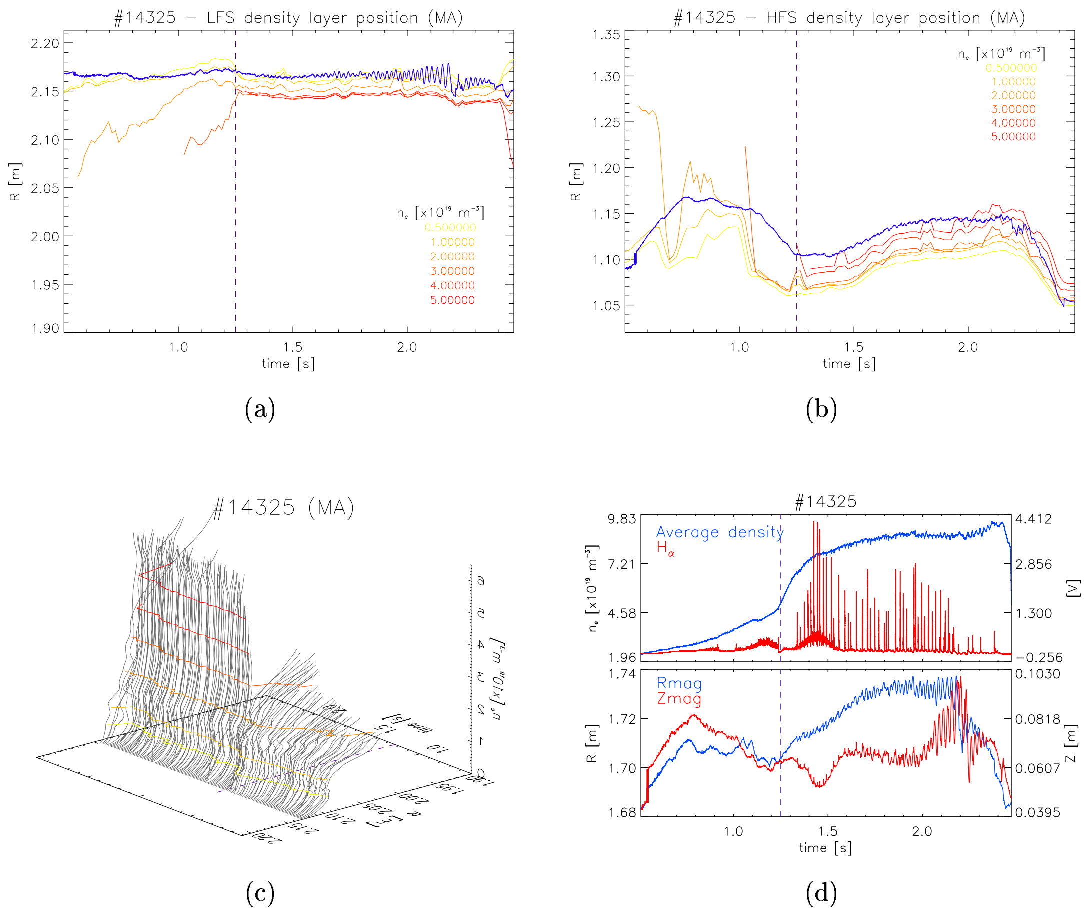

Figure 2: Shot *#14325*, a plasma column Z scan. a) and b) show the radial locations of fixed density layers as seen by reflectometry plotted against the location of the separatrix (blue curves) at the low and high field sides respectively; c) O-mode reflectometry density profiles used to extract the curves shown in a) and b); d) average density, H_α radiation, radial and Z positions (*Rmag* and *Zmag*) of the magnetic center of the plasma column for the studied period.

of control applications with sufficient accuracy. This is true provided that realistic profiles are used during the training phase of the neural networks. In [3], a 32 hidden unit neural network was used to produce a 34 point smoothed density profile from a 32-point group delay vector. These 32 input values were taken from the experimentally measured group delay in the probing frequency range *F: 17.9-47.5 GHz* reflecting at layers with n_e*: 0.4-2.7x10*^{19} m^{-3} . From this non-initialised (density layers below *0.4x10*^{19} m^{-3} are not probed by O-mode reflectometry) experimental group delay vector the neural network was trained to produce a smoothed version of the corresponding complete profile (n_e*: 0-2.7x10*^{19} m^{-3}). For this study, the training universe was composed of a total of 137 profiles taken from two similar shots (*#12041* and *#12042*) where the plasma develops internal transport barriers. In those discharges different plasma regimes (L and H mode), with different plasma shapes, occur. In fig. 3 are shown the two worst, a), and the two best, b), cases of inverted profiles using this technique. Since the output of the NN is actually a vector of the radial positions of 34 equally spaced density layers in the range n_e*: 0-2.7x10*^{19} m^{-3} , the errors are evaluated in cm. The observed total RMS error converged during training to values around *0.25 cm*. The extreme cases seen in fig. 3 account for a maximum RMS

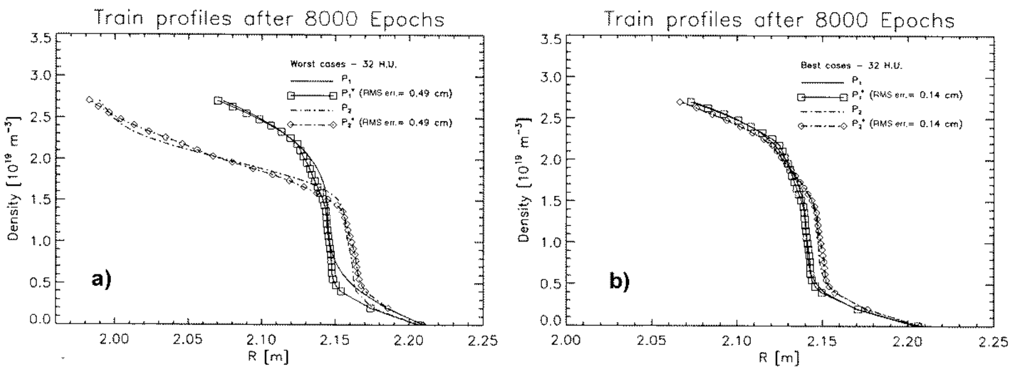

Figure 3: Output profiles after 8000 training epochs ($P\#$ are the original profiles and $P^*\#$ are the corresponding neural network evaluated): a) two worst results; b) two best results.

error below *0.5 cm* for the worst case profile inversion and a minimum below *0.14 cm* (roughly half the expected error - *0.25 cm*) for the best case.

Concluding remarks

This early study shows that reflectometry as the potential to provide edge density positioning information for control purposes. Plasma column movements are correctly followed by the position information extracted from the automatically calculated density profiles. Fast reflectometry profile measurements provided by modern reflectometers, like the one installed in ASDEX Upgrade, satisfy ITER control requirements (*1 cm* accuracy and *10 ms* time resolution). The capability of producing complete profile measurements with a *25-30* μs rate allows an improvement in the accuracy of the measurements by averaging out the effects of the fluctuations on individual measurements in the required *10 ms* period. Preliminary results using neural networks for profile inversion of experimental data suggest that this approach can be successfully used to provide position control information in real-time.

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