LOCAL MEASUREMENT WITH MICROWAVE REFLECTOMETRY OF DENSITY PROFILE PERTURBATIONS DUE TO MHD ACTIVITY ON ASDEX UPGRADE

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1. Introduction

Reflectometry can perform localised measurements of the plasma fluctuations due to its great sensitivity to density perturbations existing close to the plasma cutoff. Usually for fluctuation measurements constant frequency is used to probe a fixed density layer, over a large time interval. To obtain the density profile the incident frequency is swept over a large range in short time windows (20-100 μs). The profile data is extracted usually by filtering the main group delay (or beat frequency) component. In ASDEX Upgrade we developed a new data analysis method where the time versus (beat) frequency distribution (TFD) of the energy of the reflected signals is computed [1]. This gives the time frequency (TF) trace corresponding to the plasma profile and also the TF zones to where the signal energy has been displaced (scattered) by fluctuations. The new method allows to obtain the density profiles automatically with great accuracy by using decision algorithms (based on the properties of the TFD) [2] and provides as well the localisation of density layers where perturbations are present.

Here we apply this technique to study locally the density perturbations due to MHD activity during H-mode discharges in ASDEX Upgrade. Profile modifications due to magnetic islands seems to reveal the potentialities of reflectometry to estimate the location of the rational q surfaces. A fixed frequency channel measuring over the complete discharge is used to obtain the frequencies of the observed profile perturbations in good agreement with the corresponding Mirnov data.

2. Experimental results

2.1. ASDEX Upgrade reflectometry system

The broadband FM reflectometry diagnostic has been recently upgraded [3], and has now twelve channels probing simultaneously the high-field (HFS) and low-field (LFS) sides of the plasma, with ultrafast sweeping (20-100 μs). *X* mode (33-75 GHz) is used for the scrape-off layer at LFS, and the O-mode (16-110 GHz) is reflected from densities 0.3×10^{19} to 15×10^{19} m^{-3}. A fast sweeping heterodyne system was developed for the highest frequency channels (50-110 GHz) to cope with higher losses and lower incident power. It is fully operational up to 75 GHz , and for higher frequencies (W band channel) it is installed and shall be commissioned after calibration tests of the reference pin (with a mirror inside the vessel). With heterodyne detection it has been possible to improve significantly the sensitivity of the system allowing to probe further inside the plasma.

A new dedicated channel (33-50 GHz) operating in fixed frequency provides during the whole discharge a signal to monitor continuously the level of density fluctuations at selected density layers. The data acquisition system is now based on specially developed VME boards with up to 1 Gsamp/s sampling rates, and the diagnostic is fully operated by remote control.

2.2. Density profiles

The density profiles of #10267 shown in Fig. 1 demonstrate the capability of the reflectometry diagnostic to measure density profiles automatically in a wide range of regimes, from the OH to the H phase. An important feature of the system is its capability to measure layers in a wide range of distances (between ~15 cm and ~40 cm) with the same antenna. This is possible due to the sensitive heterodyne detection.

The measuring possibilities of the diagnostic were greatly increased with the recently installed fixed frequency channel. The main purpose is the on-line detection of L to H transitions, through the monitoring of the abrupt changes in the fluctuations spectrum. The complete reflected signal is also available for other fluctuation studies. Simultaneous fixed and swept frequency probing (with multichannel broadband swept operation) gives the possibility to localise the reflecting layers (where the fluctuations are being continuously probed) from the measured density profiles .

2.3. Effects of magnetic islands on density measurements

In the example of Fig. 2b (H-mode #9904), the time resolved power spectra of the reflected signals (using a sliding FFT technique) are shown as contour plots from t = 1.4 s to 2.3 s , for the probing frequency f = 42 GHz (n_e ~2.2 × 10^{19} m $^{-3}$). The L to H transition is detected at t ~1.55s by a sharp decrease of density fluctuations in the range above ~30 kHz. After the transition, broadband structures having the periodicity of the ELMs are observed, in agreement with the D_α data (Fig. 2a). At t ~1.65s a coherent structure (f ~20 kHz) decreasing in frequency appears, which is correlated with a m = 1, n = 1 mode with fishbones, as detected by Mirnov coils (Fig.2c). At t ~1.85s another coherent structure is triggered, corresponding to a neoclassical (3/2)-mode, connected to the increase of the frequency towards ~22 kHz.

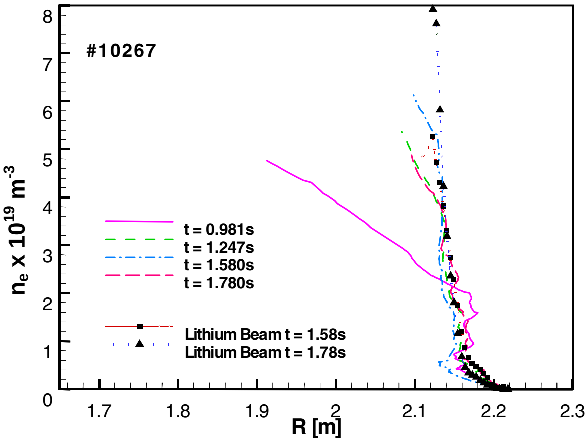

Fig. 1 *Reflectometry density profiles measured at the OH (t = 0.981s), L (1.274s) and H-phases (quiescent: 1.58s, and between ELMs: 1.78s) for #10267. Li-Beam measurements are shown also for t = 1.58s, 1.78s.*

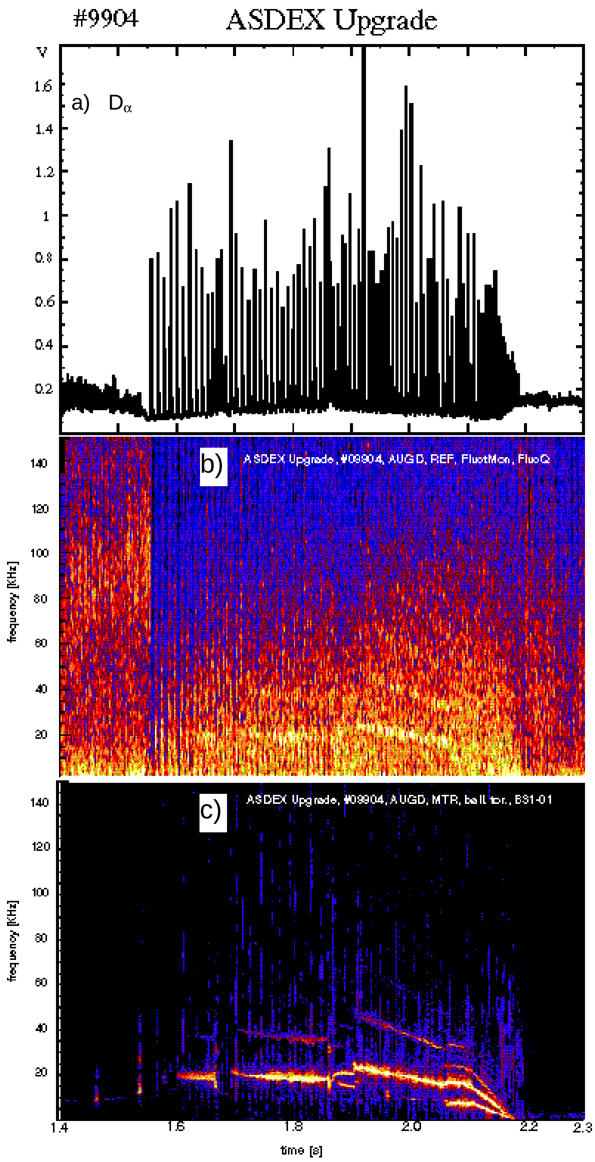

Fig. 2 *a) Magnetic signal from a pick-up coil; b) Time evolution from FFT power spectra of the reflectometry signals; c) time evolution of magnetic fluctuations frequency data*

These fluctuations subsequently decrease in frequency until at t ~2.06s also a neoclassical (2/1)-mode is observed. This mode approaches locking, occurring at t ~2.19s, when its harmonic (3,1), and the (3/2)-mode also lock . Both on reflectometry and on the Mirnov data higher harmonics at flux surfaces closer to the edge can be observed.

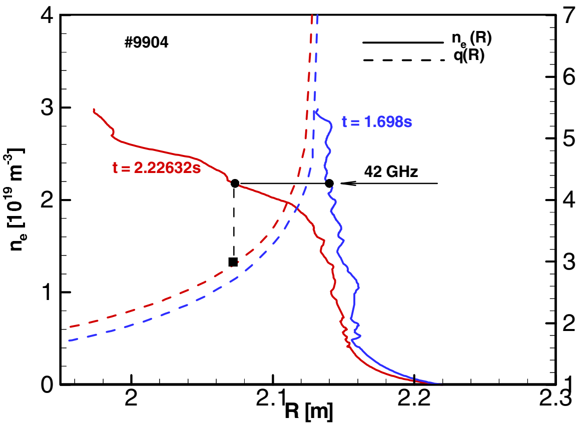

Fig. 3 *Density profiles obtained from broadband reflectometry, at t =1.698s and 2.226s . The location of the density layer probed by the fluctuations monitor (42 GHz* $\Leftrightarrow 2.19 \times 10^{19}$ m^{-3}*), is indicated, both in* n_e *and q(r).*

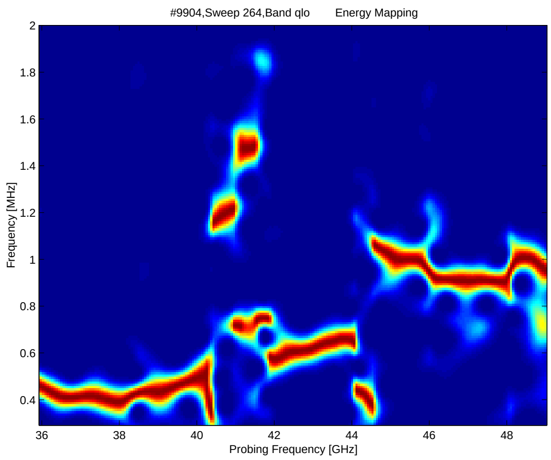

Fig. 4 *Time-frequency distribution of the reflected signal (Q-band channel: 33-50 GHz), for the case of Fig.3.*

Using density profiles measured by broadband reflectometry during the same discharge, the radial location of the probed (42GHz) density layer was determined. Fig. 3 shows n_e (r) during the H-phase (t=1.698s) and after mode locking (t= 2.226s); the corresponding q (r) profiles are estimated from MHD equilibrium reconstruction. At t = 1.698s the fixed frequency channel is probing inside but very close to the magnetic separatrix ($n_s \sim 2.08 \times 10^{19}$ m^{-3}); the good agreement of the frequencies of the modes detected by reflectometry (Fig.2b) with Mirnov data (Fig.2c) shows that the perturbations seen by reflectometry at outer flux surfaces are associated with some modes located well inside the plasma (e.g. 1/1).

For the case of mode locking (t=2.22632s) the probed layer has moved inwards due to the change of the plasma profile and is found to be close to the rational surface q = 3. The localisation of the modes can be confirmed from the perturbations of the broadband signals. Fig.4 shows the time-frequency distribution (obtained with sliding FFT) of the reflected signal in the range 33–50 GHz, for t = 2.22632s (#9904). In the horizontal axis the frequencies define the probed densities n_e; the corresponding radial positions are evaluated from the integration of the group delay (or beat frequency, f_B) depicted in the vertical axis.

It is observed that energy of the reflected signal is scattered due to plasma fluctuations and the main line corresponding to the average profile is distorted. The perturbation seen around 41 GHz ($n_e \sim 2.1 \times 10^{19}$ m^{-3}, very close and outside the layer probed with fixed frequency) should correspond to the profile modifications due to a magnetic island centred at the q=3 surface; the presence of a (3,1) mode at q=3 is consistent with the higher harmonics of the dominant (2,1) mode observed before the mode locking. The effect of a stronger MHD mode, leading to a jump in f_B, is also observed more inside the plasma (~ 44GHz, n ~2.4×10^{19} m^{-3}), close to q=5/2; it corresponds to a plateau in the density profile and indicates a possible electromagnetic coupling between (3,1), (5,2) and (2,1) modes.

Comparison High-Field side/Low-Field side

Fig. 5 shows the TFDs corresponding to t = 2.913s, when the magnetic island (2,1) is locked, during H-mode discharge #10631. The changes in the beat frequency indicating a local flattening of the density profile, are observed both in the a) HFS at F ~ 45 GHz and b) LFS, F ~44 GHz. These density perturbations are seen in the evaluated profiles shown in Fig. 6. From the comparison with the q-profile, also depicted in Fig. 6, it can be concluded that the profile flattening occurs close to the surface q = 3.

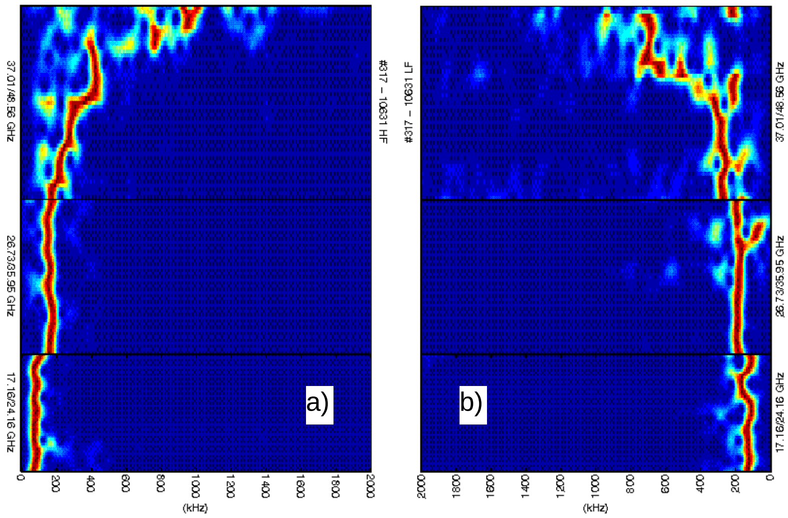

Fig. 5 *TFD for all channels (17-49 GHz) at HFS and LFS*

3. Concluding remarks

With heterodyne detection, new channels and a new data analysis method the reflectometry diagnostic on ASDEX Upgrade has greatly improved its performance and measuring capability.

The measurements with simultaneous operation of fixed frequency and multi sweep broadband channels revealed the great potentialities of reflectometry to perform localised measurements of density fluctuations induced by the MHD activity as well to give their radial localisation. It is striking that the frequency evolution detected by reflectometry agrees so well with the corresponding Mirnov data, in view of the fact that in some cases the density perturbations detected by reflectometry are located in regions close to the separatrix whereas some of the magnetic modes are present close to the plasma center.

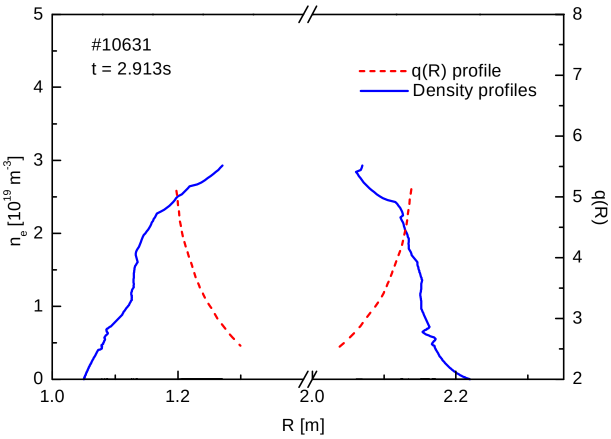

Fig. 6 *Density and q profiles for the case of Fig. 5 (t = 2.913s, #10631)*

The study of profile deformations due to magnetic modes is especially important in phases where locked modes are present , for which information from magnetic data is not available The analysis here presented, although restricted to the edge plasma (q ≥ 2.5) illustrate the potentialities of the reflectometry system to identify the rational q surfaces. Further extension of the measuring capability is planned with the swept operation of the upper frequency channel, probing densities between 6.9×10^{19} and 15×10^{19} m^{-3}. Fixed frequency probing at other selected higher densities will also enlarge the understanding about the link between the core and edge plasmas.

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