EDGE DENSITY X-MODE REFLECTOMETRY OF RF-HEATED PLASMAS ON ASDEX

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Introduction

RF heating methods need special diagnostics to help better understand the interaction of the wave with the plasma. Of particular interest is the influence of the wave on the edge plasma in the direct vicinity of the RF heating antenna. One important parameter in this context is the electron density, which can be measured by means of microwave reflectometry.

In this paper we describe a fast X-mode reflectometer installed on ASDEX. We present measurements of the edge density profile in the range $10^{11} cm^{-3} < n_e < 1.5 \cdot 10^{13} cm^{-3}$.

Principle of the measurement and exoerimental set-up

Reflectometry has been used previously to measure electron density profiles (s. e.g. [1] [2]). We extended the range to the very edge (to 2.5 cm behind the limiter) and installed two system at different toroidal positions to give the density profile, which might be different at toroidally different positions in the SOL. Fig. 1 shows the principle, which is the same at the two positions. The microwaves from the generator (BWO) are split by a directional coupler (DC) into a signal branch (emitted to the plasma and reflected at the cut-off, the point in the plasma beyond which a propagation is not possible) and a reference branch. Changes in the relative phase of these two branches lead to maxima and minima (fringes) in the output signal of the phase detector. Due to the use of the X-mode (E perp. B) it is possible to follow the location of the cut-off from $r=r_{ant}$, the position of the antenna mouth, to about 20 cm into the plasma and consequently to calculate the density profile by sweeping the microwave frequency up from $f_1 < f_{ec}(r = r_{ant})$ to f2. In the final configuration a sweep from 60 - 80 GHz was performed in 150 μs, which gives a fringe frequency of about 1 MHz. A repetition time of about 2.5 ms together with a data acquisition of 2 x 100 ms at 10 MHz allowed to sample about 2 x 40 sweeps per shot. The two sets of microwave antennas we installed are located in the equatorial plane on the lowfield side of ASDEX. The first one consists of a hornantenna (opening: 8 mm x 10 mm, emitter) and an open-ended waveguide (1.9 mm x 3.8 mm, receiver) and is inserted in a diagnostic opening of the faraday screen of an ICRF-antenna. The second one consists of two hornantennas (16 mm x 10 mm, emitter, and 8 mm x 10 mm, receiver) and is placed about 6 cm toroidally away from the LH-grill antenna.

Influence of t[redacted]ensity fluctuations

In first tests with a slow sweep and an expected fringe frequency of 6 kHz no clear fringe pattern could be seen. Experiments at fixed frequency showed that the fringes were blurred out by strong intensity modulations of the reflected signal (fig. 2, fig. 3). Similar problems have also been reported in an O-mode system with much bigger antennas [3]. These strong modulations (factor of 10 and larger) cannot be explained by radial movements of the cut-off layer due to electron density fluctuations and are probably caused by interference effects due to poloidally inhomogeneous electron density fluctuations [4]. Our way to make possible the fringe counting despite these perturbations, was to reduce the sweep time and thus to increase the fringe frequency to values higher than that of most fluctuations. Fig. 3 shows that the bulk of the fluctuations are below 500 kHz, so that fringes at 1 MHz can clearly be distinguished from the fluctuations by frequency.

Results

Fig. 4 shows the raw data of the first 40 µs of a sweep. The reflection begins only at f_0, which is, within the error bars, identical to the electron cyclotron frequency at the antenna mouth. This is a particularity of the X-mode, and allows to give the location of the first reflection, which is not possible in an O-mode system (s. e.g.[5]). In an O-mode system the very low densities at the edge demand the use of very low microwave frequencies, which give a very poor spatial resolution. The fringes in the mixed signal (upper trace, fig. 4) are clearly seen. As a sweep is performed on the time scale of the fluctuations, one single sweep gives a momentary profile, which is not constant during the time of the sweep. Fig. 5 shows the momentary profiles of 35 sweeps during a stationary plasma phase. Averaging over these sweeps gives reproducible electron density profiles. Fig. 6 shows the profiles measured in two stationary phases, where the plasma has been moved 5.3 cm horizontally. The measured shift of only about 4 cm in the edge may be explained by toroidal asymmetries and by edge profile changes due to the bulk movement. From the momentary profiles we can also calculate absolute and relative fluctuation levels (fig. 7; comparison to other fluctuation measurements on ASDEX: [6], [7]). A comparison to Thomson scattering data shows good agreement (fig. 8). Reflection coefficients for the LH-waves calculated from density values we measure in the plane of the LH-grill (typically: $n_e = .5\ 10^{12}$ cm^{-3} and $dn_e/dr = .5\ 10^{12}$ cm^{-4}) are in good agreement with experimental ones.The influence of the LH can be seen in fig. 9. This steepening of the electron density profile at the very edge during LH is also reported on Castor [8].

Conclusions

We demonstrated that reflectometry is applicable to measure electron density profiles at the very edge of the plasma. This was only possible by the use of the X-mode, which has in contrary to the O-mode, even at very low densities a finite cut-off frequency ($f_{cut\text{-}off\text{-}X} > f_{ec}$). The perturbations by the density fluctuations could be overcome by increasing the fringe frequency to over 1 MHz. The very limited access to the plasma it requires (a few cm^2) and its good spatial resolution makes reflectometry an ideal diagnostic for the measurement of local effects during HF-heating. As it can measure the absolute edge electron density profile independently of other diagnostics and because of the possibility of a further improvement of the sweep and the data acquisition it can be considered as candidate for standard diagnostic.

References

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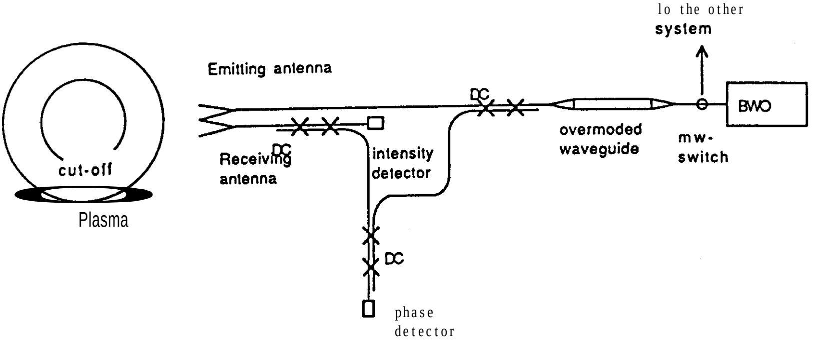

fig. 1 Principle of the reflectometer

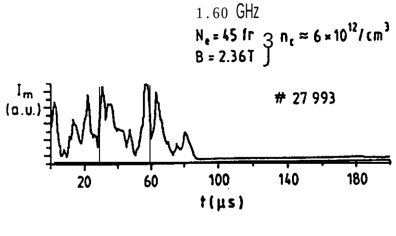

fig. 2 Intensity of the reflected signal from the plasma, fixed frequency; The launched signal has been chopped, so that the right part of the trace gives the baseline.

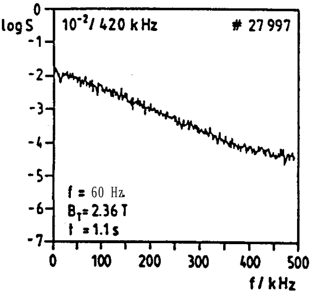

fig.3 A typical power spectrum of the reflected intensity (fixed frequency launched)

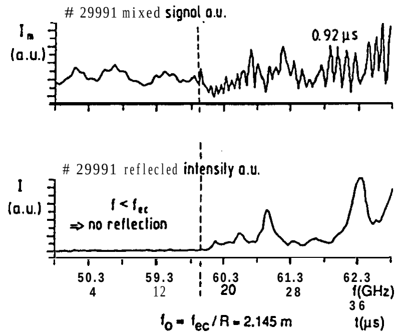

fig. 4 Raw data in sweep operation: upper tr.: mixed signal containing the phase information; lower tr.: intensity of the reflected signal (B =2.8T, I_p =320kA, n_e=2.0 x 10^{13}/cm^{-3})

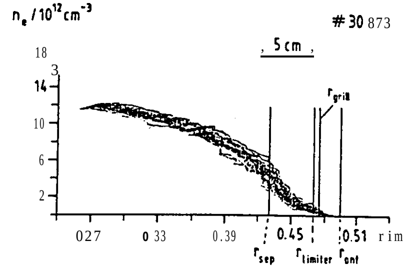

fig. 5 momentary profiles from 35 sweeps in a stationary plasma phase, superimposed (same plasma phase as in fig. 6, R = 167.7 cm) (B =2.8T, I_p =420kA, n_e=1.3 x 10^{13}/cm^{-3})

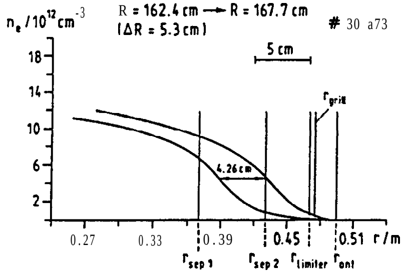

fig. 7 Absolute and relative electron density fluctuations as calculated from the data shown in fig. 5

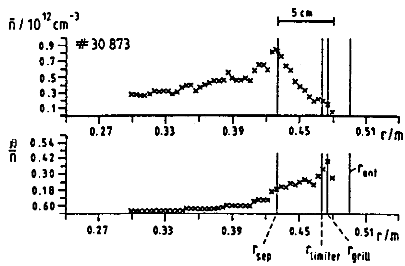

fig. 6 Density profiles measured in two stationary plasma phases in one shot, where the plasma has been moved horizontally 5.3 cm (B =2.8T, I_p =420kA, n_e=1.3 x 10^{13}/cm^{-3})

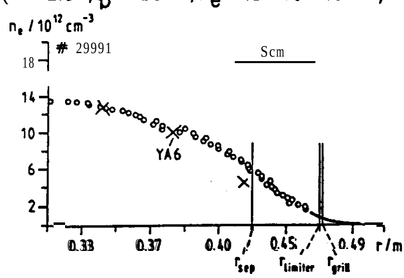

fig. 8 Comparison of the density profile measured with the reflectometer to the densities obtained with outermost channels of the Thomson scattering system (YAG). (B =2.8T, I_p =320kA, n_e=2.0 x 10^{13}/cm^{-3})

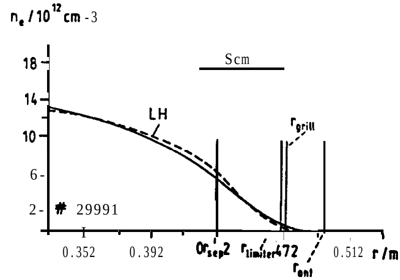

fig. 9. Profile change measured during LH experiments (B =2.8T, I_p =320kA, n_e=2.0 x 10^{13}/cm^{-3}, P_{LH}=1.3MW)

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