Exploration of fast particle generation and density fluctuations in front of the lower hybrid grills on Tore Supra

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1. Introduction

Generation of fast electrons in front of lower hybrid frequency (LHF) antennas is known to be caused by Landau damping of high N// components of the launched spectrum [1]. These high N// components (|N//|>20) are expected to be absorbed within a very narrow layer (1-2mm) whereas infrared imaging of plasma facing components indicates a much broader (>5mm) heat flux deposition [2]. Moreover this heat flux is found to depend on LHF electric field much more strongly than simulations predict [3].

A possible explanation of these discrepancies is the theoretically predicted [4] enhancement of fast electron generation by spontaneously arising random fields (fluctuations, LHF wave scattering). In this case a decrease of fluctuation level by absorption on fast electrons is expected along flux tubes connected to the antenna. In order to assess this hypothesis, two probes were installed on top of the LHF antenna. For further investigation of the fast electron flux, a retard field analyzer (RFA) was reciprocated into the scrape-off layer during LHF power injection.

2. Density fluctuation measurements

Lower hybrid experiments were carried out with the safety factor q_a varying between 3.1 and 4.5 (by varying the plasma current between 1.0 and 1.45MA), and the LHF power between 0 and 3MW (power density up to 19MW/m^2). Electron volume-averaged density was $2.5\pm0.5\times10^{19}$m^{-3}. Probes (5mm diameter, 1mm behind the magnetic line grazing the extremity of the waveguides) were biased to -100V. Ion saturation current and root mean square (RMS) of the fluctuating component of the signal were recorded for the entire pulse with a sampling rate of 1kHz. In addition, fast acquisition (1MHz) was triggered at specific times (3-5 per pulse) in order to investigate the probability distribution function (PDF) and the frequency spectrum of fluctuations. Because of the tilt of the magnetic field lines, one of the probes (P1) is never magnetically connected to the radiating waveguides whereas the

other one (P2) is connected for low values of the safety factor ($q_a < 3.3$) to the upper row of waveguides.

For the higher values of the safety factor, the saturation current I_s of both probes is found to be of comparable amplitude ($I_{s-P2}/I_{s-P1} \approx 0.67$). When q_a is lowered, both signals decrease with the same rate because confinement improves until the q value for which P2 becomes connected to the waveguides is reached, then I_{s-P2} decreases much strongly. The database indicates that, on average, I_{s-P2}/I_{s-P1} is 0.33 when the safety factor is bellow 3.15. Lower particle flux for specific areas is expected from modelling of plasma flows, which arises in front of LH antennas [5]. At the same time a decrease of the fluctuation level, measured by the normalized RMS, is found when P2 is connected (figure 1).
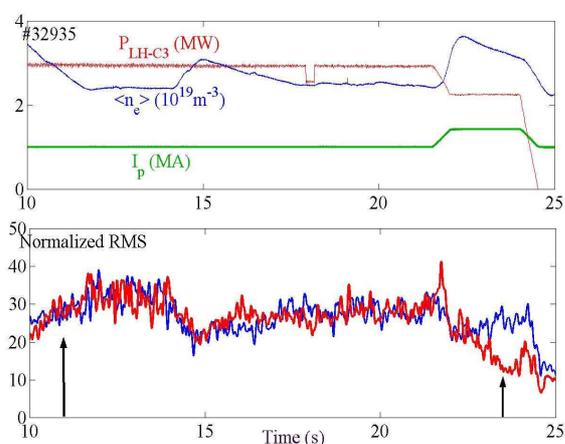

Figure 1. Normalized RMS for Probe 1 (blue) and Probe 2 (red) as a function of time. Probe 2 is connected for t>22s.
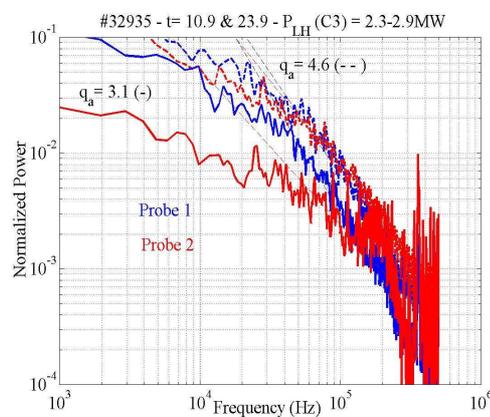

Figure 2. Frequency spectrum at t=10.9s (dotted line) and t=23.9s (solid line) for pulse shown in figure 1.

Bursts of large amplitude are suppressed and narrow Gaussian PDF are obtained in this case. Frequency spectrum indicates that low frequency turbulence (f < 50kHz) is mostly reduced (figure 2). Averaged over 11 measurements, we found that the normalized RMS was reduced by 39% when probe 2 is connected (figure 3). When the probe is not connected, the fluctuation level increases with LH power. In the case where the probe is connected, there is no clear power dependence at least between 1.5 and 3MW and in some cases the fluctuation level remains as low as the ohmic one.
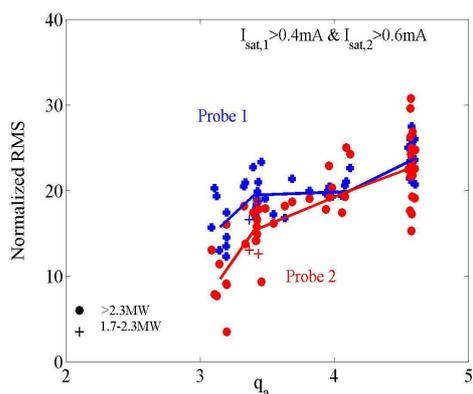
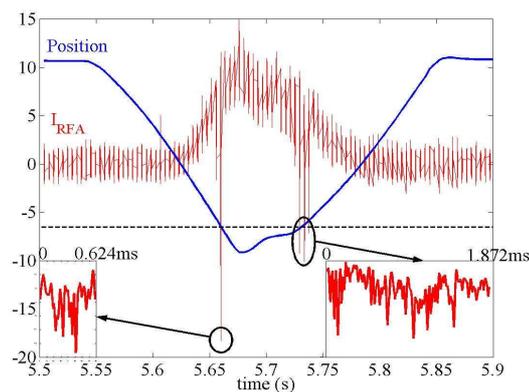*Figure 3. Normalized RMS of density fluctuations as a function of safety factor.*

Figure 4. RFA position (blue) and signal (red).

3 Retarding field analyser measurements

For the first time an RFA was used during lower hybrid current drive experiments to measure the flux of suprathermal particles emanating from the near field region in front of the LH grill mouth. For these preliminary experiments, the RFA was set in order to collect electrons with energy larger than 100eV. The LH power launched from two antennae (labeled C2 and C3) located in adjacent ports was varied between 0.15 and 3.4MW. The RFA was reciprocated in ~250ms up to 1cm behind the last closed flux surface. For specific values of the safety factor (q=5.5-6.3) and of the RFA position, a strong increase of the collected current, up to ten times the background noise, was measured (figure 4). Field line tracing indicates that this increase occurs when one of the waveguide rows is magnetically connected to the RFA.

The spatial resolution (~ 5 mm) allows to assess that the radial width of the collected fast electron beam is of the order of 0.5-1 cm. This result is consistent with measurements obtained by infrared imaging of connected in-vessel component. With the time resolution ($\Delta t=8\mu s$) of the signal, burst of fast electrons are indeed obtained (blow-ups of figure 4). Similar bursts are obtained from the signal of the antenna probes, which are not connected for these high q_a values. This suggests that bursts of thermal electrons are the source for the bursts of suprathermal electrons. The fast electron flux is expected to depend on the strength of the RF electric field and on the number of electrons flowing in front of the LH antenna (electron density). Electron density was inferred from two probes embedded in the equatorial plane of C2 antenna and one probe located on top of C3 antenna. The quality of the magnetic

connection is estimated by a factor K varying from 0 when the RFA is not connected to 1 when the RFA is fully connected to a waveguide row. When the RF electric field, corrected by this connection quality factor, is weighted with the edge density, we found a reasonable good scaling of the RFA signal with the electric field. Finally data of the RFA were confronted to the data of the RF probe 2. It was found that, for different normalizations of the RMS of the RF probe, this signal is likely to decrease when the flux of fast particles increases (figure 5).
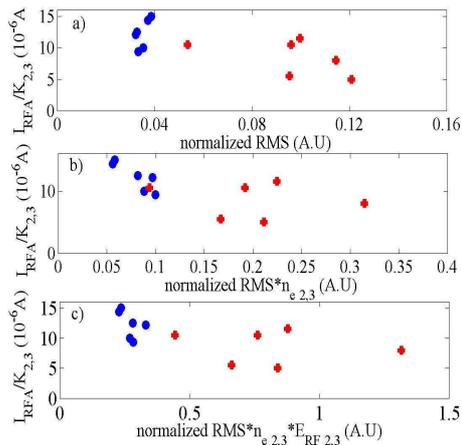

Figure 5. RFA signal vs normalized RMS. a) Without weighting, b) with edge density weighting, c) with edge density and electric field weighting. Blue circles are for C2 and red squares for C3.

4. Conclusions

A decrease (~ -40% on average) of the fluctuation level ($\Delta n_e/n_e$) and mean density is found only when the probe is magnetically connected to the waveguide row. Although the point scatter is fairly large we believe this average decrease to be significant. The RFA allowed to measure the fast electron flux and to confirm than the width of the beam is larger than 0.5cm. The decrease of the fluctuation level when the RFA signal increases is an other fact that could support the role of random fields in the acceleration process. However reduction of fluctuations could also be the consequence of a reduced perpendicular transport caused by a local shear of the radial electric field. Accurate measurements of the plasma potential profile will address this topic in foreseen experiments.

References

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