Mutual Influence between the ICRF Antennas and the Edge Density on ASDEX Upgrade

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ABSTRACT - Significant changes of the density in the shadow of the antenna limiters can be seen on field lines connected to an active ICRF antenna. The changes are sudden at turn-on and turn-off of the antenna, indicating that this is a direct effect due to the RF. For experiments where densities in the shadow of the antenna limiter were in the 2x 10^{18} m^{-3} range, the density decreases. At lower density values, the effect is less pronounced. Under completely detached H-mode (CDH) conditions, where the density in the shadow of the antenna was above 1x 10^{19} m^{-3}, the density increased slightly.

INTRODUCTION

In ASDEX Upgrade, the distance between the separatrix and the vacuum chamber is large (≈ 35 cm in the equatorial plane). Two main regions can be identified : 1) from the separatrix to the first limiting surface (this is on the low field side, under most conditions, the antennas) and 2) beyond the antennas. The plasma density *between separatrix and antennas* plays an important role in the coupling resistance of the ICRF antennas. We have measured this density to investigate whether the ICRF affects its own coupling resistance. In the region *beyond the ICRF antennas*, plasma is still present. The plasma density there (near and in the antenna) influences its voltage stand-off. Changes of the density in this region due to the RF can also be indicative of edge plasma/RF and edge plasma/antena interactions.

METHOD

The edge/SOL density is measured in ASDEX Upgrade using a fast Li beam diagnostic [1]. The radial distance between plasma separatrix and the Ion Cyclotron Resonance Frequency (ICRF) antennas [2] is 3 to 5 cm in the equatorial plane. The Li beam allows a space and time resolved (0.6 cm, 1 ms) measurement in a range $R-R_{sep}$ = -5 to +9 cm relative to the separatrix position R_{sep}. Thus, radial locations up to 6 cm behind the front face of the ICRF antennas are covered by the Li beam measurement.

The "shadow" of a particular antenna, as obtained by following the contours of that antenna along field lines, can map (or not) to the location of the Li beam (horizontal axis 30 cm below the midplane) density measurement, depending on the pitch of the magnetic field lines (the magnetic field direction and the q value). Different values of the plasma density is the edge/SOL were obtained by operating at different plasma currents (resulting in different SOL density gradient length at the separatrix), and different operating conditions (gas puffing, CDH mode). By activating the antenna, the influence of the RF on the density in the region between the separatrix and the antenna and in the region beyond the antenna limiter can be determined. The ICRF power was in the range of 500 kW to 1 MW per antenna.

For different combinations of B_t and I_p (Table 1), using the actual magnetic configuration, as reconstructed from the magnetic measurements, the antennas were mapped along field lines to the location of the Li beam. Two examples are shown schematically in Fig1 a,b. Which antennas map to the location of the Li beam for the other combinations is shown in the table.

shot nr	B_t (T)	Ip (MA)	q	antennas mapping to Li beam location	frequencies
8116	-2.5	1	3.9	1,2,4	38 MHz (1)
6167	+2.1	1	3.2	3,4	30 MHz (1,4) 31.6MHz (2,3)
6501	-2.1	0.6	5	1,2,4	id.
6499	-2.5	1	3.9	1,2,4	id.
6492	-2.1	1	3.2	1,4	id.
6504	-2.1	1.2	2.6	1	id.

Table 1. Conditions for the different discharges.

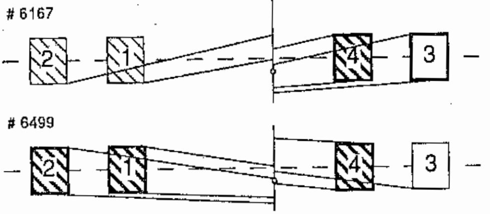

Fig. 1. Schematic view of how the antennas map along field lines to the location of the Li beam measurement (indicated by the small circle). The antennas in bold are connected, the others not. Antennas 1,2,4 have a Faraday screen (pitch w.r.to B indicated, value 15°).

RESULTS

Fig 2. shows the edge/SOL density at the location of the Li beam for the discharges of Table 1. The high density discharge, the low density discharge and the discharges in the middle range of densities behave differently. The discharges in the middle range of the densities (# 6167, 6592, 6499, 6501) have 3 x 10^{18} m^{-3} at the antenna, and 1 x 10^{18} m^{-3} at 1 cm behind the antenna. The time traces for #6167 in Fig. 3 (see the emission of the Li resonance line at R = 2.075 m) show clearly that the density changes suddenly at turn-on and turn-off of *those* antennas (3, 4) that map to the location of the Li beam measurement. The density at 2 cm behind the antenna decreases strongly. The density profiles (plotted in Fig. 4a for specific times) indicate that the decrease of the plasma density is essentially in the region beyond the antenna limiters and only for those antennas that are connected to the location of the Li beam density measurement along field lines. All other parameters are constant. Note that the difference in resonance position between antennas 3 (center + 2 cm) and 4 (+11 cm) does not play a role, nor the fact that antenna 4 has a Faraday screen and antenna 3 none.

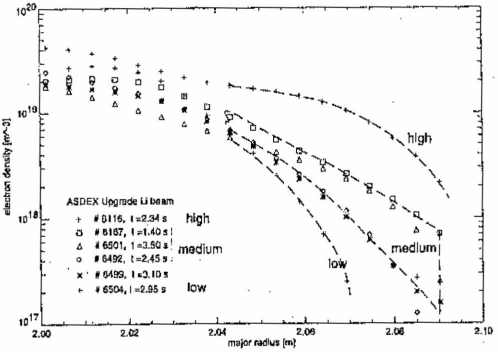

Fig.2 Density profile at the location of the Li beam density measurement

At - 2.5 T (#6499), the resonance position for both frequencies are off-axis (1,4 at +33 cm and 2,3 at +44 cm). The density in the shadow of the antenna limiter decreases for antenna 1 and 4, and increases for antenna 2. Those antennas all map to the Li beam measurement. The density is not affected, at the location of the measurement, by antenna 3 which does not map to this location (Fig. 4b). Similar results are obtained for the other combinations at the average densities. The distinct behaviour of antenna 2 for this series is probably related to a difference in the electrical connection of the antenna limiters (see discussion), rather than to the variation in resonance position.

At the higher current and lower q value of # 6504, the steeper density gradient results in a lower density in the shadow of the antenna limiter. Under this conditions the density still decreases, but is less affected as shown in Fig 4c.

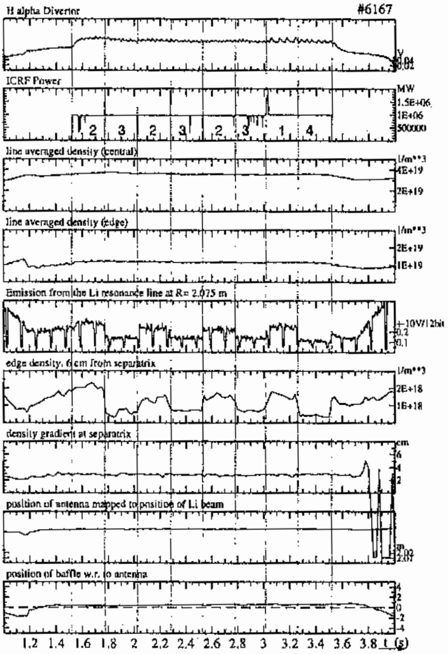

Fig. 3. Time traces of the discharge # 6167.

In the completely detached H-mode (#8816), the density near the antenna is a factor 10 higher (Fig. 4d) than for the cases above (and is much higher than one would estimate from a simple exponential decay of the density at the separatrix). The effect of the RF is a slight increase of the density in the shadow of the antenna.

DISCUSSION

The effect of the RF on the SOL/edge density profile is essentially restricted to the region beyond the antenna limiters on field lines connected to an active antenna.

Between separatrix and front of the antenna, the changes are small so that the RF itself does not change the normal coupling resistance of the antenna (this is in contrast to Lower Hybrid which produces its own plasma in front of the coupler).

The change of the density in the region beyond the antenna limiters, along field lines connected an active antenna, is a direct indication of edge plasma/antenna interaction due to the RF. With the FELICE code, we calculated that the RF fields due to ICRF are *not* restriced (toroidally nor poloidally) to field lines connected to the antenna. However, where those field lines intersect the antenna, sheaths will develop. The density on the field lines can then decrease, either if the

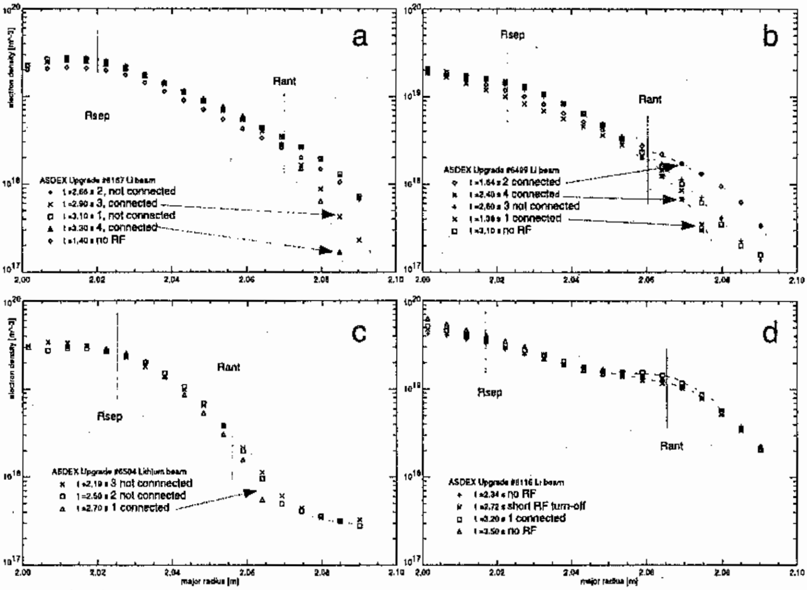

Fig 4. Edge density profiles, and their changes during the RF.

parallel transport is increased or if the perpendicular transport is decreased. The *parallel transport* can be increased if heating of the ions increases their sound velocity. The *perpendicular transport* in the edge is due to turbulent diffusion in convective cells which extend along field lines. Radial electric fields (a consequence of the sheaths) at the ICRF limiter can affect those convective cells [3]. The radial electric fields depend on electrical properties and connections of the antenna limiters. This was different for antenna 2 and could be the reason for its peculiar behaviour.

Note that what happens on field lines connected to the antenna can partly be seen as a model of what happens, for an antenna without Faraday screen, to a possible plasma density inside the antenna. Because of the different connection lengths (shorter in the antenna) and different strength of the RF fields (stronger inside) a decrease of density outside the antenna is sufficient to conclude that a decrease will also occur in the antenna. On the other hand, when no decrease occurs in the shadow, no immediate conclusion is possible for the effect in the antenna. For medium to low density, the density decreases. This is consistent with a decrease of the parasitic loading observed at low power on other machines, when high power (> 100 kW) is applied. The inferred reduction of the density is also favourable for the voltage stand-off of the antenna. It remains to be investigated to what extent the conditions of much higher density lead to parasitic loading and reduced voltage stand-off.

REFERENCES

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