# ANALYSIS OF THE LOADING RESISTANCE FOR ICRF HEATING EXPERIMENTS IN ASDEX

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## Introduction

Long-pulse high-power ICRF heating experiments have been conducted in the H-minority (10% H, $f$=33.5$MHz$) and second harmonic ($2\Omega_{CH}$,$f$=67$MHz$) regimes with two low-field-side antennas, in combination with NI and repetitive pellet refueling [1]. In three particular cases the loading resistance has been compared with theory, using a global wave code with a slab geometry [2]. 1) In H-minority heating experiments, H-phases lasting for up to 0.5 sec have been achieved in combination with NI. At the L-H transition the loading resistance decreases sharply. But, during the H-phase, the increasing density induces a variation of the loading resistance. Due to the presence of eigenmodes the pre-transition value can be recovered. 2) In long pulse $2\Omega_{CH}$ heating experiments, a slowly changing isotope concentration (H concentration; from 70% to 85%) is accompanied by a gradual decrease of the loading resistance. 3) In $2\Omega_{CH}$ heating experiments with repetitive pellet refueling, in which two confinement phases have been identified, it has been observed that the temporal behaviour of the loading resistance is also quite different for the two phases.

## II. H-Minority Heating Experiments

In H-minority (10% H) heating experiments, H-phases lasting for up to have been achieved in combination with NI. The L-H transition induces a sudden decrease of the loading resistance (Fig. 1), which corresponds to a decrease of the density in the SoL. However, the loading resistance does not stay at the reduced level during the H-phase, but changes on a long time scale (0.2 sec) with many spikes due to ELMs. The slow variation is not correlated with the plasma position. Despite the fact that the density rises monotonically during the H-phase, the loading resistance has revealed maximum/minimum values. This is interpreted in terms of eigenmode effects.

Indeed, to understand this slow variation during the H-phase, we have calculated the loading resistance summed up for various toroidal mode numbers $n(=k_{\parallel}R_0)$ with the global wave code, as a function of density (Fig. 2). Peaks of the loading resistance correspond to eigenmodes standing between two cut-off layers of the fast wave (i.e., at the two-ion hybrid layer and at the plasma edge). The experimental loading resistance [3] during the H-phase is also plotted as a function of the density. The spacing of the peaks and the amplitude of the variation are in agreement with the loading resistance calculated for $n \geqq 16$. Therefore, we conclude that the slow variation of the loading resistance during the H-phase indicates the existence of the eigenmode. This is the first clear evidence of eigenmodes in ASDEX. Note that the theory predicts the disappearance of the eigenmode, if the percentage of hydrogen is reduced below 5%.

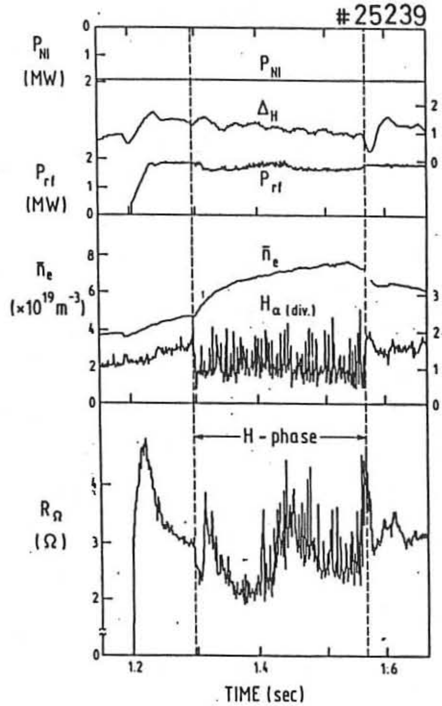


Fig. 1 H-mode discharge in 10% H-minority heating experiments.

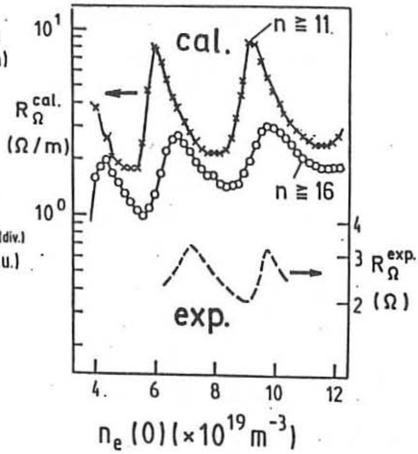


Fig. 2 The loading resistance calculated with a global wave code is plotted as a function of the central density $n_e(0)$ for various sums of the toroidal mode numbers $n(=k_{\parallel}R_0)$. The experimental data shown in Fig. 1 are also plotted.

## III. Second Harmonic Heating Experiments

### III.1 Long pulse discharge

Figure 3 shows a typical long pulse discharge for $2\Omega_{CH}$ heating experiments, where NI was used only at the beginning of the ICRF pulse. Let us first discuss the beneficial role of the NI( either $H^0$ or $D^0$). The loading resistance has been calculated as a function of the hydrogen temperature $T_H(0)$. The loading resistance increases monotonically with $T_H(0)$ below 1 $keV$, and saturates at $T_H(0)>1\ keV$. Since the ion temperature in the ohmic phase is 0.6-0.7 $keV$ in ASDEX plasmas and increases with NI pre-heating above 1 $keV$, the achieved better loading could be one reason why NI at the beginning of the rf pulse is beneficial for rf operation.

After the turn-off of NI, the gradual decrease of the loading resistance has been observed on a long time scale (1 sec), accompanied by a slowly changing isotope concentration ( the H concentration increases from 70% to 85%). Other parameters are constant. From the computer code we found indeed that, as the H concentration is increased from 50% to 100%, the loading resistance decreases slightly, in agreement with the experimental observations. This can be understood in terms of the difference in the cut-off density for the fast wave between deuterium D and hydrogen H; i.e., $n_H(cut\text{-}off)/n_D(cut\text{-}off)=(\omega+\Omega_{CH})/(\omega+\Omega_{CD})=1.2$ for all various toroidal mode numbers $n(=k_{\parallel}R_0)$. Figure 4 shows the positions of the cut-off for H and D ions. When D is replaced by H, the position of the cut-off for the fast wave moves about 0.33 cm away from the antenna, giving a slight deterioration of the antenna-plasma coupling.

The gradual decrease of the loading resistance experimentally observed could thus be explained by the increase of the cut-off density for H enriched plasmas, although the role of eigenmodes or changes in the SoL can not be excluded.

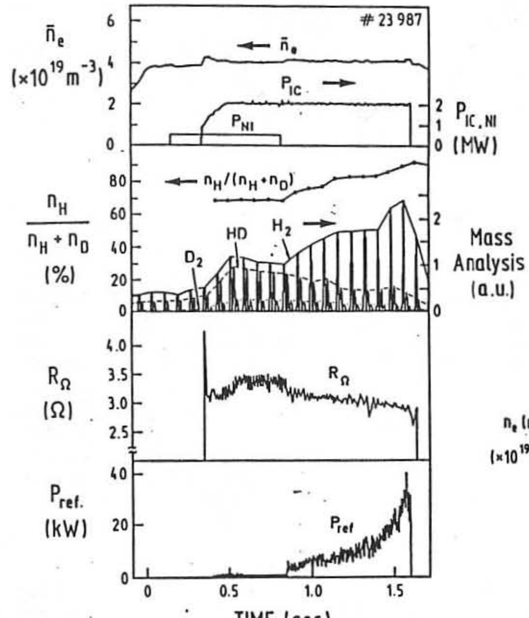


Fig. 3 Long pulse discharge for $2\Omega_{CH}$ heating, with the help of the NI at the beginning of the rf pulse.

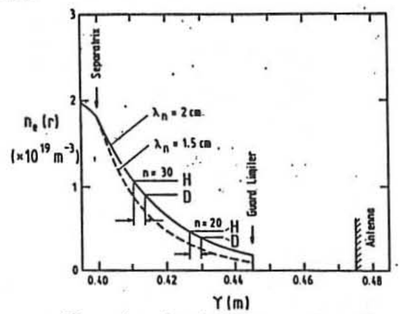


Fig. 4 Positions of the cut-off densities for the fast wave at the SoL for H and D ions.

## III.2 Repetitive Pellet Refueling

In $2\Omega_{CH}$ heating experiment refueled by repetitive pellet injection, two confinement phases (phase I and II) have been observed [1]. The improved confinement phase (phase II) is characterized by a peaked density profile, accompanied by a deeper penetration of the pellet. Figure 5 shows the

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loading resistance of the two antennas (called SO and NW) for the two phases. Synchronized to the pellet injection, a large positive spike has been observed clearly only on the signal of the SO antenna in phase I. Since the pellet injector is toroidally only 45° away from the SO antenna, but 135° from the NW antenna, this spike could be an indication of a strong perturbation transiently produced rather locally by the pellet in the boundary.

The temporal behaviour of the loading resistance after the pellet injection is quite different for the two phases. In phase I, the signal is characterized by a quick recovery(~15ms) followed by a gradual decrease, and in phase II the loading resistance is staying at the reduced level for a relatively long time. The plasma position seems to bear no clear correlation with it, as shown in Fig. 5. The time scales of these gradual changes seem to be corresponding not to those of SoL parameters, but to those of the bulk plasma(e.g., the changes of the density profile, H temperature and its high energy tail, and so on). Further work is in progress.

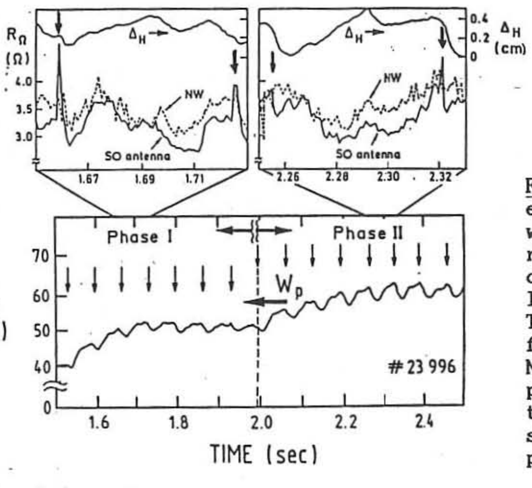


Fig. 5 $2\Omega_{CH}$ heating experiment in combination with repetitive pellet refueling, where two confinement phases (I and II) have been identified. The loading resistance for two antennas (SO and NW) and the plasma position $\Delta_H$ are shown for the two phases. Arrows show the times at which pellets are injected.

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