*34th EPS Conference on Plasma Phys. Warsaw, 2 - 6 July 2007 ECA Vol.**31F**, P-5.138 (2007)*

First experiments with the extended ECRH system on ASDEX Upgrade

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Introduction

Experiments on ASDEX Upgrade in the ongoing campaign are focused on the operation of the tokamak as a full tungsten device [1]. In the previous opening W-covered tiles have also been installed in the divertor and previously installed W-covered tiles in the main chamber have been cleaned. The machine has been started-up without using boronisation. The ECRH has proven to be essential to operate low density high performance plasmas. Some of these plasmas show the typical features of the improved H-mode scenario. These aspects of low-density tungsten operation are discussed in the next section.

The ECRH system of ASDEX Upgrade consists of the first system with four units delivering each 0.4 MW to the plasma for 2 s and the new second system actually under construction. In its final stage it will consist of 4 multi-frequency units of up to 1 MW for 10 seconds each. The first unit is now in operation at 105 GHz and 140 GHz and, at 140 GHz, delivers more than 800 kW to the plasma [2]. The total amount of ECRH power available for heating of ASDEX Upgrade is currently 2.5 MW. The launchers of the new system are steerable poloidally also during discharges allowing to vary the location of power deposition during the discharge. The final goal is to manipulate MHD instabilities such as neoclassical tearing modes (NTMs) and sawteeth by feedback-control of the ECRH deposition in analogy to the functionality of the ECRH-system foreseen for ITER. First feed-forward mirror movements have been performed and effects on MHD and impurity control have been observed as reported in the last section.

Low density H-mode operation in a full tungsten device

H-mode operation with low or no additional gas puff at low values of q_{95} has become increasingly difficult at ASDEX Upgrade as the first-wall W-coverage increased during the last years such that low n_e, high T_e edge conditions lead to increased W-influx. The general observation for discharges heated with NBI only is a central accumulation of heavy impurities eventually leading to a reduction of the core temperature due to radiation. For some years it is known that central heating with ICRH or ECRH can counteract such accumulations [3]. Especially the powerful ($>$ 5 MW) multi-frequency ICRH system, capable to cope with type-I ELMs due to the use of 3dB-couplers, was used for this purpose at several values of B_t. As the limiters close to the ICRH were covered with tungsten it turned out that ICRH operation released additional W from the limiters, especially in the presence of light impurities [4]. Therefore, H-mode operation with small gas puff was preferentially performed at a few operational days after a boronisation. ECRH was proven to be very effective in reducing central accumulation, but was limited in length and power, especially with one of the four gyrotrons of the old system out of operation since 2005[1].

In the new campaign with the fully tungsten covered plasma facing components no boronisation was used so far. Operation started with high gas-puff, high q_{95} plasmas. As expected from previous experience, operation at low gas puff shows central accumulation when using NBI only. ICRH can still be used, but only with strong gas puff [1]. Experiments with low gas puff have therefore been done with ECRH. Fig. 1 shows time traces of a pair of discharges with moderate gas puff with and without ECRH. With ECRH a quasi steady-state situation is achieved whereas without ECRH central accumulation occurs accompanied by a reduction of confinement. Due to the reduced confinement the accumulated impurities can escape and the plasma consequently recovers, leading to an oscillatory behaviour. Encouraged by these results the gas puff was switched-off completely. H-factors IPB98(y,2) of 1.1 were reached transiently, but (3,2)- or (2,1)-NTMs set in reducing the confinement. The NTMs could be prevented by delaying the third NBI beam as shown in figure 2. This is typical for the improved H-mode scenario in ASDEX Upgrade, which allows to reach high β-values only if the current profile is given time to equilibrate after having entered the type-I H-mode [5]. During the ECRH phase fishbone-MHD-modes are observed, as they occur in the best performing improved H-modes [6]. In the discharge shown in figure 2 a maximum value of β_N=2.2 was obtained (H-factor 1.2). An increase of the NBI heating is foreseen in the ongoing campaign. Figure 2 also shows that the central tungsten concentration remains at an acceptable level, although in a small zone of a few cm width (probably inside the ECRH deposition) the concentration reaches the 10^{-4} level. These results indicate that sufficient ECRH allows improved H-mode operation in a fully tungsten covered machine. Still we note that $q_{95} = 5.5$ is still high. As long as the ECR power

[1]The broken gyrotron has been replaced by a similar gyrotron from W7-AS. In total 2 gyrotrons from W7-AS are now in use as replacements in the old ASDEX Upgrade system.

is mainly available at 140 GHz this can be achieved only by increasing the plasma current. Experiments at 1.0 MA have just started and will allow to compare to previous data for the improved H-mode scenario. On a longer time scale we can make use of the three multi-frequency gyrotrons to be installed from late 2007 to 2009. These gyrotrons will have 2 intermediate frequencies at 117 GHz and 127 GHz allowing to reduce B_t and thereby q_{95}. In summary we note that the extended ECRH system helps to extend the operational range of the full tungsten device towards low density and high β, i.e. high edge-temperature.

First experiments with the steerable launcher

As mentioned above the last mirror of the new launcher can be moved around one axis during the discharge. Conceptually this movement corresponds to a poloidal movement of the beam, whereas the other axis (usually generating toroidal movements) has to be set on a shot-by-shot basis. A first feed-forward programmed movement has been successfully performed, such that the beam crosses the $q = 1$ surface towards the plasma centre. A negative toroidal angle of 6 degrees is used such that some co-current drive (ECCD) is expected. Figure 3 shows the equilibrium, five lines-of-sight of the soft X-ray diagnostic and the position of the ECR heating at different time points. Figure 4 shows time traces of the discharge. The central radiation strongly increases as the NBI heating is doubled. The accumulation of radiating impurities only stops 0.6 sec later. We ascribe this to the location of the ECRH deposition, since we know that central ECRH leads to an immediate effect ($<$ 100 ms) on central impurity accumulation (see also figure 2). As can be seen in figure 4, a mode sets in close to the maximum of the central radiation. It shows up in channels 50 to 58 of the respective SXR-camera (figure 3). Analysis shows that this is a (1,1)-mode. We therefore assume that the lines-of-sight of channel 50 and 58 are about tangential to the $q = 1$-surface. The mode disappears approximately 60ms after the ECRH is switched off. In summary these data indicate that the region to be heated with the ECRH for impurity control is highly localised in the core. Additionally we are able to affect MHD modes with our movable launcher. Although the simultaneous occurrence of the (1,1)-mode and the reduction of the radiation peaking is tempting we do not speculate about any correlation. In fact, most discharges with central ECRH do not show a (1,1)-mode and we suspect that its occurrence is related to the applied ECCD. Obviously, further experiments moving the mirror back and forth are planed to broaden these initial results.

References

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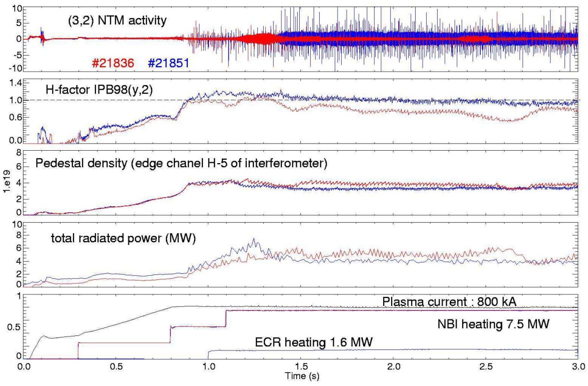

Figure 1: Comparison of discharges with and without ECRH at a moderate gas puff rate of $4\times10^{21}/s$. B_t*=2.4 T,* $q_{95} = 5.5$*, average triangularity at the separatix is 0.2.*

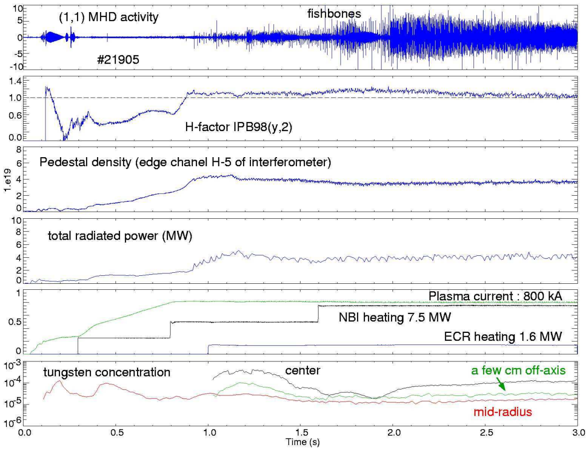

Figure 2: Similar discharge as #21851 in figure 1, but with no gas puff and the third NBI source delayed. No NTMs are observed.

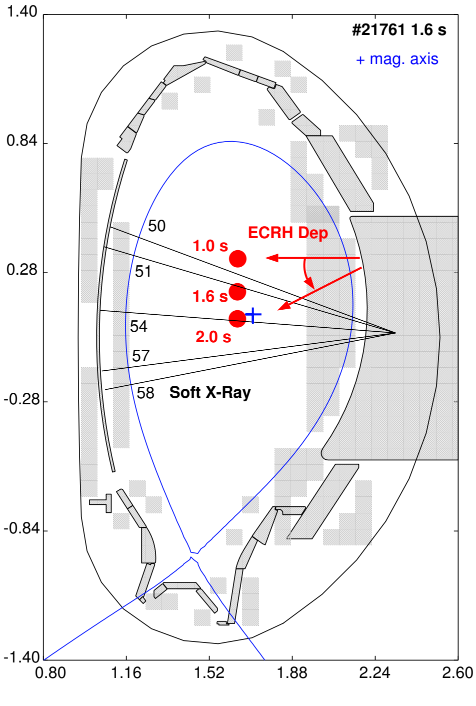

Figure 3: Geometrical setup of 21761: separatrix shape, magnetic axis, ECRH deposition (varying due to mirror movement) and selected SXR lines-of-sight used in figure 4.

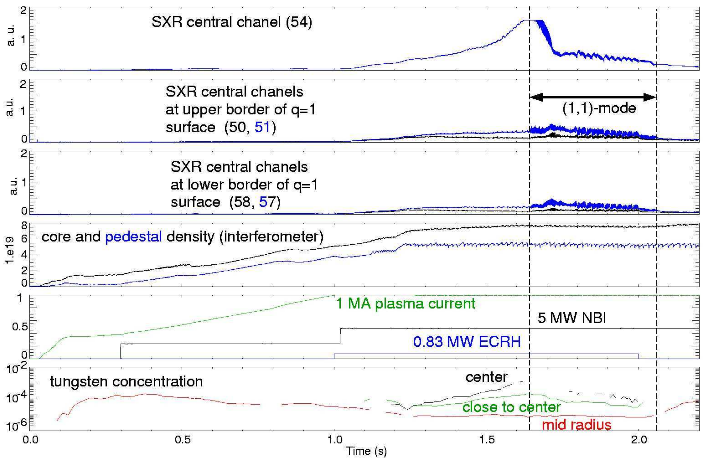

Figure 4: Evolution of the central radiation, tungsten concentration and MHD activity during an ECRH mirror movement as shown in figure 3. The ECRH is injected with a toroidal angle of -6 degree. The plasma current is 1 MA.