ASDEX Upgrade Letter

No. 10/Jan 2008

Foreword

With the 2007 experimental campaign, an exciting and challenging phase for the ASDEX Upgrade experiment has been concluded. The start-up of the machine with un-boronised, fully tungsten coated walls and with flywheel generator EZ4 out of operation, gave tough boundary conditions for the operations team. While the establishment of 'normal' operation (limitations of flux swing, plasma current and heating power will remain till the restart of EZ4 this autumn) took a few weeks, at the end of a learning curve a 'milestone pulse' was achieved six weeks after the first plasma attempt. In fact, after understanding some differences of the wall behaviour with uncoated tungsten, we feel confident enough to start the next campaign without boronisation again in order to obtain reference pulses for improved H-mode conditions with a pure tungsten wall.

The 2007 campaign with fully tungsten-coated plasma facing components set a milestone in the ASDEX Upgrade programme – so now is the time to look a little ahead. In fact, the preparation of the next major hardware extensions are well under way: The installation of a very flexible and versatile system of active coils, to be combined later with a conducting wall structure will open up the experimental road for active ELM control and resistive wall mode stabilisation. Since the acceptable ELM size in ITER is currently a decreasing number, all means of active ELM control are hot topics in the development of the fusion programme. Combining various elements of future tokamak operation with tungsten plasma facing components will guarantee exciting times around ASDEX Upgrade for the next half-decade at least.

A. Kallenbach

Highlights
from recent ASDEX Upgrade experiments

Experience in 2007 with a full tungsten device

Starting the 2007 campaign with full tungsten (W) walls was the final step on the long path ASDEX Upgrade (AUG) entered in 1999 when installing the first square meter of tungsten coated plasma facing components (PFCs) in the main chamber. The first experiments with tungsten concluded in 1996 when a tungsten divertor was used. At that time however, it became evident that the PFCs in the main chamber were a strong carbon source which led to thick C deposits covering the strike point zone of the inner divertor. From this observation it became clear that these sources must be removed first before using a W divertor again.

When restarting AUG in 2007 it was the first time that a full tungsten divertor tokamak went into operation. To ensure operating with W surfaces, we removed layers from old boronisations or deposited C on the W PFCs which had been installed earlier. Moreover, no boronisations were performed throughout the entire campaign.

Only two out of three flywheel generators were operational in 2007 to supply magnetic field coils and additional heating systems. This constraint did not considerably hamper AUG operation in 2007, because the use of the remaining generators has been significantly optimized.

Under these boundary conditions it was of course more difficult to restart the machine. Not so much because of the missing oxygen getter, but more because one had to learn to operate AUG with two generators only. Nonetheless, we achieved H-modes soon after applying additional heating power. Within the restricted operational space, we reached similar confinement (H ~ 1) as in earlier H-mode discharges with boronisation (see fig. 1).

Comparing the W concentrations, no strong increase was observed after the installation of the W divertor. This underlines the fact that the divertor W source has only a minor influence on the main plasma W content, which has now been proven by detailed measurements of the local influx at the divertor, the low field side limiters and the central column. Figure 2 shows the temporal evolution of the W influx at different locations together with the reaction of the W edge concentration to changes in the ICRH antenna power at different gaps to the low field side antenna limiters. It can be seen that there is a strong increase of the (local) W influx when the ICRF is switched on. Although ICRH was found to be beneficial for the suppression of W accumulation in earlier campaigns, it turned out that under the unboronised conditions the impact of the induced large W influx was much larger than this beneficial effect and therefore the use of ICRH had to be restricted to high edge densities. With full W PFCs it was much more efficient to use ECRH for central heating to control the central W concentration.

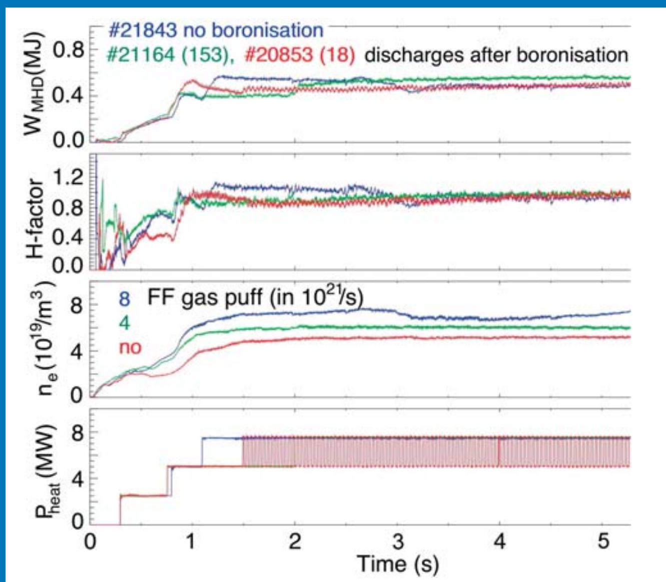


Fig.1: Comparison of an H-mode discharge (#21843, full tungsten walls, no boronisation, in blue) at I_p=0.8MA in the full tungsten AUG with similar ones of previous campaigns under different wall conditions (C-divertor, #21164, #20853, 153 and 18 days after a boronisation, respectively). In the flattop between 2s - 5s at least the same H-factor is reached in the 2007 pulse as in the previous ones.

Surprisingly, the carbon concentration in the plasma was only marginally reduced. Although being already rather small (typically 0.5%) it was expected that without primary sources it should decrease further. The reason for this behaviour is not yet clear, but it seems to be related to the strong recycling character of C. In contrary to the C concentration in the plasma, the net C deposition in the inner divertor was strongly reduced according to very recent post mortem surface analyses (see fig. 3).

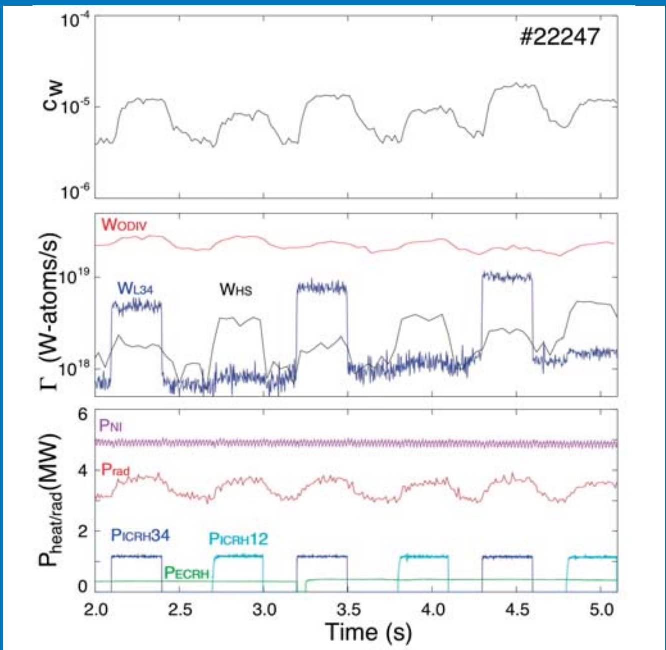
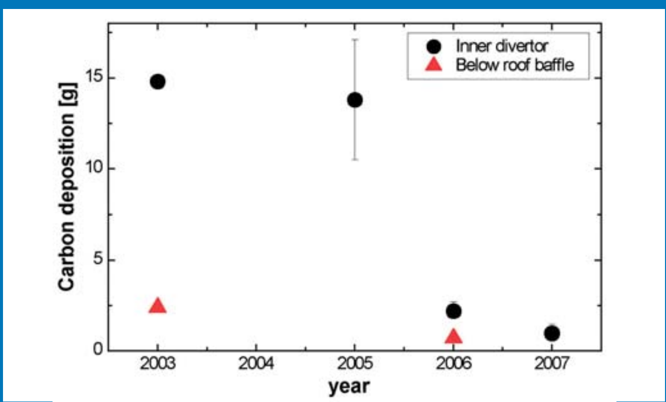


Fig. 2: Influence of ICRH (time-traces for power on ICRH antenna pairs 1+2 and 3+4, respectively, in the lowest panel together with total radiation P_{rad} and NBI & ECRH heating power) on tungsten influx Γ at the antenna limiter (L34), the central column (HS), and in the outer divertor (ODIV). In addition, the central W-concentration c_W is shown in the upper most panel. In the presented time window the plasma is slowly shifted by 2cm closer to the LFS antenna limiters, which leads to an increase of both W-influx as well as central W-concentration.

In summary, the first campaign with a full W AUG was very successful and we are looking forward to explore the W behaviour in the entire operational space of AUG. Such an extension of the operational space will be possible already for the beginning of the 2008 campaign, because the power limit of the EZ3 generator has been increased by ~30%. Having more heating power available, studies at higher plasma current are feasible at the very start of the 2008 campaign. The restart is planned to be conducted again without using boronisations. Thus, it will be possible to study the compatibility of advanced scenarios, e.g. improved H-modes (1 MA, 10 MW), with full W PFCs.

Fig.3: Evolution of the carbon deposition normalized to 3000s of plasma during campaigns 2003 (carbon dominated machine) until 2007 (full tungsten machine). dots: deposition on the tiles of the inner divertor; triangles: deposition below the roof baffle.



The 2008 Campaign

In response to the call for participation in the 2008 AUG campaign 171 experimental proposals have been submitted by 84 scientists. Almost 50% of them are non-IPP scientists. Besides several proposals from GA (DIII-D) the majority of external proposals originates from 14 different EU Associations. In total the execution of more than 1400 discharges has been requested.

The AUG Programme Committee met in December and approved a prioritized programme of roughly 800 shots. As in previous years the programme will be organised under four Task Forces (TF). Their management is now in the hands of J. Schweinzer, E. Wolfrum, A Kirk and M. Maraschek. Andrew Kirk, the leader of the AUG TF III "SOL & Divertor Physics and First Wall Materials" is a scientist from the MAST team. With this step the tradition of having an external Task Force Leader at AUG has been prolonged. Based on the experience with his predecessors, mutual benefit for the programmes of MAST and AUG can be expected.

The execution of the physics programme will start in February with two operational flywheel generators only. However, in comparison to the 2007 campaign the power limit of the EZ3 generator has been increased by ~30%, which extends the AUG operational window.

At the end of 2008 we expect to get EZ4 flywheel back into operation. This will, together with the experience gained in 2006/7, boost AUG operation into new dimensions allowing shaped plasmas with currents of up to 1.4MA and more than 20MW of additional heating at pulse lengths of around 10s.

AUG enhancement with active in-vessel coils for ELM suppression and MHD control

Edge Localised Modes (ELMs) remain a critical issue for ITER because they cause a large peak heat load to the main chamber wall and divertor, which impacts materials lifetime and can cause co-deposition of tritium with eroded carbon. Therefore, small and no ELM regimes are intensively studied in AUG. Recent experiments in DIII-D and JET have demonstrated that non-axisymmetric error fields can be used to suppress ELMs while maintaining high edge pedestal pressure and thus good high-confinement mode performance. Though it is believed that ergodisation of the plasma edge plays a key role for ELM suppression, there is no explanation to date for the observed effects on edge profiles. Installation of additional error field coils or ferritic inserts for ITER, however, presents a significant technical challenge and it is therefore highly desirable to assess the necessary field configurations in present experiments. In particular, the role of a magnetic resonance of the field perturbation with the edge pedestal plasma needs to be investigated.

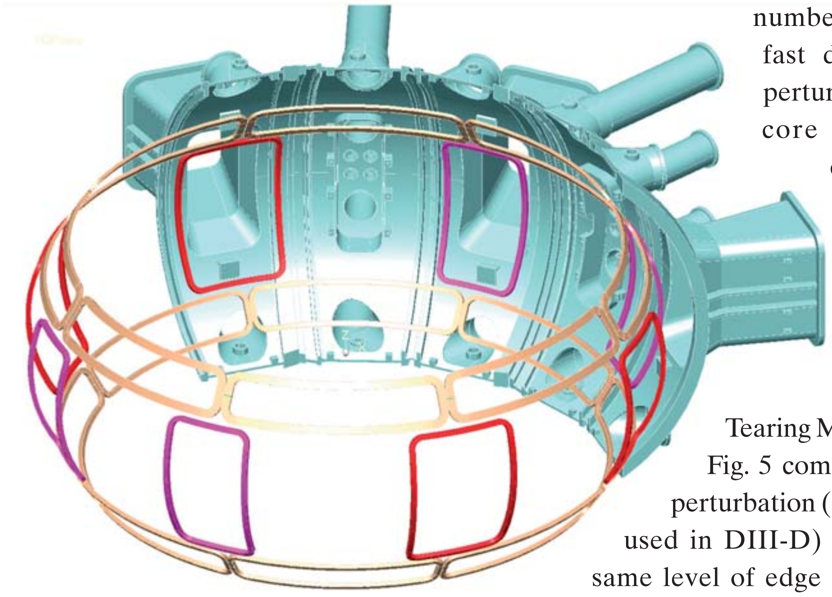


Fig. 4: 3D view of 24 in-vessel coils with 5 segments of the vacuum vessel.

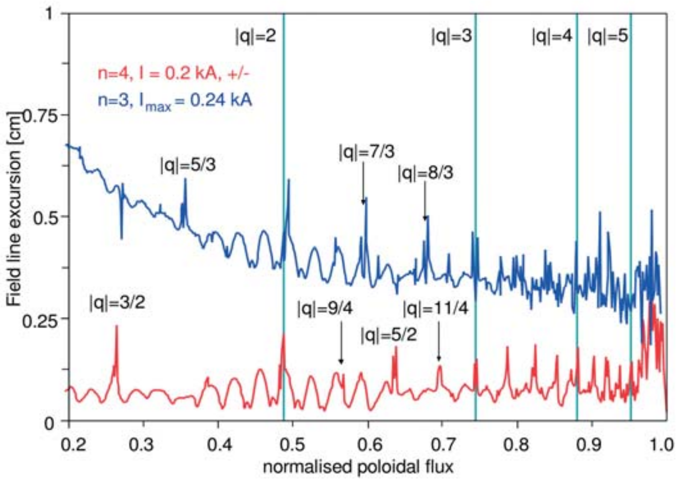


Fig. 5: Comparison of field line excursion (island half-width) for n=3 and n=4 vacuum error field (assuming no plasma rotation). Parasitic islands at rational surfaces for n=4 are small and below the seed island width (~1 cm) of NTMs.

It is planned in AUG to install a highly flexible set of 3x8 in-vessel saddle coils (fig. 4) which can produce perturbations with toroidal mode numbers up to n=4. The high mode number leads to a fast decay of the perturbation in the core plasma and causes smaller parasitic islands, reducing the potential drive of Neoclassical Tearing Modes (NTM). Fig. 5 compares an n=3 perturbation (similar to that used in DIII-D) with n=4 for same level of edge ergodisation.

The AUG enhancement will be carried out in several consecutive steps, starting with sixteen upper and lower coils powered by an existing DC converter, followed by eight midplane coils and independent AC power supplies. Ultimately, a conducting wall structure will be added between the two branches of the existing passive stabilising loop (PSL) in order to reduce the growth rate of resistive wall modes (RWM) and allow active stabilisation in advanced scenarios. The enhancements are done in collaboration with three EU Associations ENEA (Consorzio RFX, Padova), VR (KTH Stockholm) and FZ Jülich – an efficient combination of expertise on fast coil technology, edge plasma effects and MHD feedback control.

ASDEX Upgrade Letter
published by
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