ASDEX Upgrade Letter

No. 6/April 2004

Foreword

With the start of the 2004 ASDEX Upgrade experimental campaign, we have again increased the W-coverage of the first wall, thus progressing further towards a C-free environment. First results look promising, but detailed analysis will have to be done before more definitive conclusions can be drawn. The so far very promising results with tungsten should form a basis to start a discussion with the ITER team about a road map for decisions on first wall materials.

The present campaign has already generated exciting results in as different areas of ELM control (see the corresponding research highlight in this issue) or extension of the operational space for the hybrid scenario. The physics programme on ASDEX Upgrade also benefits from new diagnostics developments such as the new T_i measurements or the enhanced capabilities of the fast MHD diagnostics, both of them discussed in this issue.

Last but not least, collaboration within the EU, but also on a worldwide level, continues to generate additional value for both our work and that of our partners. In 2003, we were pleased to welcome the Hungarian Association as our 10^{th} EU member of the ASDEX Upgrade Programme Committee. In an environment preparing for a worldwide experiment, this is a reassuring fact that benefits not only our daily scientific life, but also the credibility of our programme as a whole.

Besides experiments on ASDEX Upgrade itself the ASDEX Upgrade team is strongly engaged in collaboration with other facilities. The export of findings from one experiment and the validation on others with the same relative geometrical dimensions improves considerably the basis for ITER. ASDEX Upgrade together especially with JET form a "ladder" which allows a sound extrapolation to ITER. The smaller experiments are more flexible and are therefore predestined for exploration. This will become in the future an important backbone for preparation of the operation of ITER.

M. Kaufmann

Highlights

from recent ASDEX Upgrade experiments

ELM pace making and mitigation by pellets

Operating ITER in the type-I ELMy H-Mode regime may create a severe dilemma. Natural ELM frequencies expected for conditions necessary to obtain sufficient confinement may result in unacceptable high thermal loads on first wall elements. A possible solution to this dilemma currently under investigation is the technique to increase the ELM frequency by external means without deteriorating the energy confinement. Several methods aiming to trigger ELMs by manipulating the pressure gradient or the current profile in the edge gradient region have been developed successfully at ASDEX Upgrade (AUG). These methods apply either rapid vertical movements of the plasma, localised gas jets, application of ECCD at the plasma edge, or the injection of carbon micro-pellets or of small, cryogenic deuterium pellets. The latter method is the most advanced technique at AUG and all basic properties required to be met simultaneously by an ELM control approach have been fulfilled:

- external ELM control, enhancing the ELM frequency f_{ELM} beyond the intrinsic or 'natural' value f^0_{ELM}
- keeping the plasma particle and energy confinement high
- reducing the power load P_{ELM} of in-vessel components during a single ELM

An example of a discharge including a pellet sequence is displayed in fig. 1, clearly showing a transient enhancement of f_{ELM}. Data derived from a set of experiments performed with different pellet rates f_{pel} revealed a rather modest impact on the confinement. Increasing f_{ELM} by using pellets results in significantly less plasma energy reduction than in a reference discharge where f_{ELM} was increased by a gas puff ramp (see full line in fig. 1, right).

Comparison of a pellet controlled discharge with a similar gas puffed one at matched plasma conditions (i.e. global parameters as well as edge n_e and T_e profiles are the same) demonstrated that the intrinsic ELM frequency could be increased by a factor 1.6 with this pellet approach. Thus also the average energy loss per ELM event is reduced considerably. Further enhancement of f_{ELM} is limited by the repetition rate of the present pellet injector.

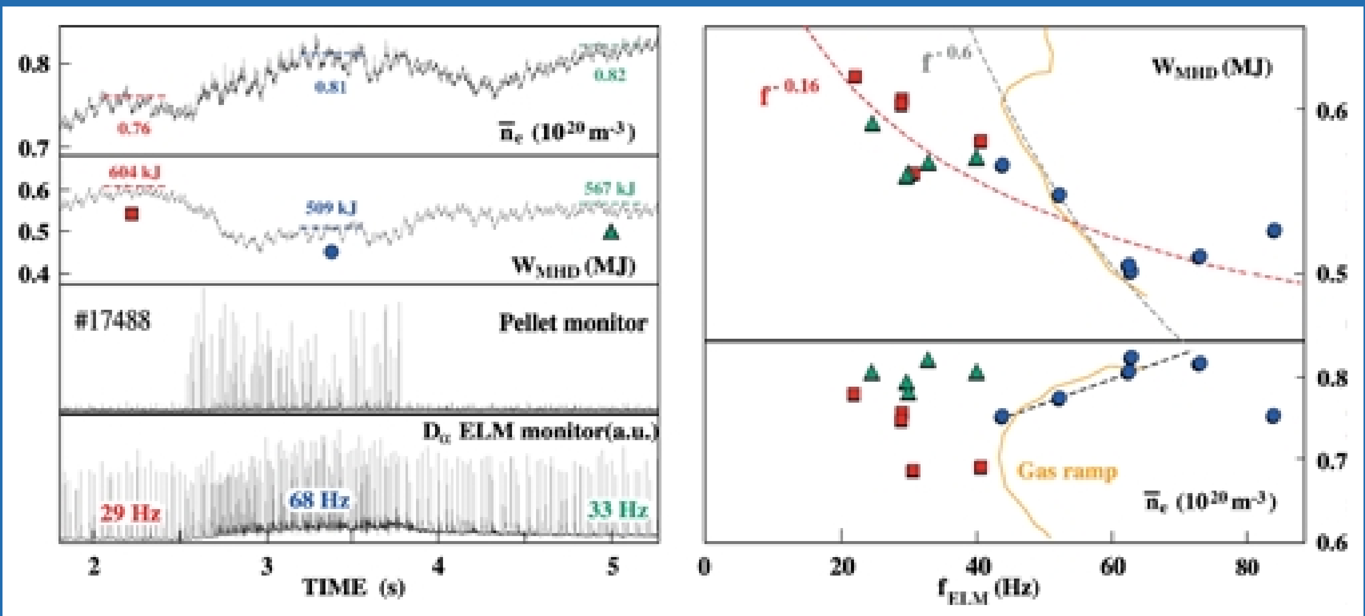

Fig. 1 : Left: Temporal evolution of line averaged density n_e, energy content W_{MHD}, pellet and ELM monitor signals in a type I ELMy H-mode discharge including a phase of pellet controlled ELM frequency. Right: Data derived from pellet (blue) and reference phases (red: unfuelled, green: pellet equivalent gas puff) of a f_{pel} scan show modest impact on confinement (W_{MHD}) and n_e by pellet ELM control. For comparison the much stronger confinement degradation by a gas puff ramp is given (full line).

There are hints that drastically smaller pellets (mass reduction by factor 10 - 100) will still be able to provoke ELMs and will then exhibit even less confinement degradation and fuelling. Once such pellet injectors (small pellet mass, high repetition rate) are available, this technique can be applied as a tool for scenario development using the ELM frequency as an almost free parameter. Moreover, dedicated studies on the ELMs underlying physics will become possible in a wide range of edge parameters.

For ITER a much lower intrinsic ELM frequency is expected than in AUG. Therefore it seems possible to meet particle refuelling and ELM pace making requirements simultaneously using an accordingly adapted pellet injection system delivering pellets at a frequency of about 4 Hz.

Ion temperature edge measurements

Electron density and temperature profiles are measured routinely at AUG with high temporal and spatial resolution. Corresponding profiles of the ion channel have been available in the past only in the core of the plasma. Recently, edge ion temperature T_i profiles have become available by means of charge exchange spectroscopy on a fast diagnostic lithium beam (50 keV, 3 mA neutral equivalent current). The measurement is based on the charge exchange process of doubly charged helium ions He^{2+} with lithium beam atoms and the subsequent HeII (n=4 → n=3) line emission which is Doppler broadened and thus allows the derivation of the local He^{2+} temperature. Although this approach has, in principal, been established for many years, the practical realisation at AUG turned out to be difficult due to a low signal to background light ratio. Despite recent diagnostic improvements T_i profiles can only be obtained under favourable plasma conditions in quasi-stationary phases of a couple of 100 ms with low density and modest heating power.

In addition, in ELMy H-modes the ELM frequency has to be well below 60 Hz in order to allow the proper removal of CCD frames with ELM events from the evaluation. Such ELM events disturb the technique to distinguish between background and active signal. Therefore only inter-ELM edge T_i profiles can be derived. In fig. 2 such T_i profiles are compared with the fit to the electron temperature T_e profile for both L- and H-mode phases. In addition, the outermost points of the core ion temperature measurements are given. In the L-mode case both measurements overlap and show an excellent agreement. The T_i values in the edge are above T_e. Especially the T_i values at the separatrix position are considerably higher than the ones for the electrons (L-mode, n_e(separatrix) = $0.8 \cdot 10^{19}$ m^{-3}).

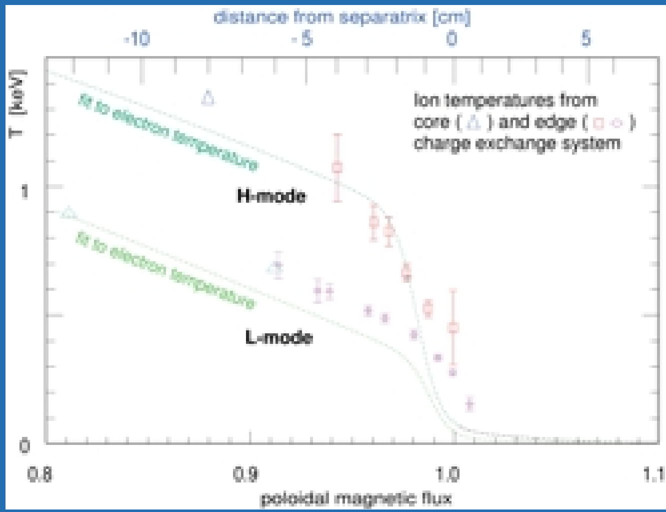

Fig. 2: Ion temperature profiles for L- and H-mode phases compared with corresponding profiles of electrons.

The H-mode (n_e(pedesdal) = $5.0 \cdot 10^{19}$ m^{-3}) T_i profile is found to be similar to the electron temperature with about a factor of two higher sepraratrix ion temperature. These new diagnostic data represents a further milestone in the characterisation of the AUG edge plasma and will serve as an input for MHD stability analysis and for SOL power balance as well as for transport studies in the near future.

Upgrade of magnetic measurements

A significant upgrade has been made to the magnetic measurements at AUG. 16 channels of the magnetic measurements are now routinely sampled with a time resolution of 2 MHz (0.5 µs) and an amplitude resolution of 14 bit for the entire pulse length of up to 10 s. The measured digitized data is directly stored into the memory of a UNIX workstation. The system can be easily extended with respect to duration and channel number by increasing the memory of the workstation. Due to this architecture full real time capabilities on the workstation for online calculations and experiment control is available. Within a new planned advanced control system such capabilities are foreseen for all diagnostics.

Presently, two conventional Mirnov coils and all radial field coils close to the separatrix at the low field side are connected to this improved system. With the radial field coils full quantification of local low field side poloidal mode numbers and toroidal mode numbers is possible up to the Nyquist frequency of 1 MHz. This is of special interest for ELM related MHD and for edge localized MHD in general. With this upgraded diagnostic high frequency magnetic oscillations have been discovered in quiescent H-modes (see AUG Letter No. 4 / May 2003).

Status Report on current ASDEX Upgrade campaign

In January 2004 AUG started a new experimental campaign after a five month shutdown. The following hardware upgrades have been implemented during this shutdown:

The next step towards a carbon-free machine – around 70 % of first wall are now covered with tungsten (see fig. 3) – was taken. The upper divertor has tungsten tiles, while the lower is still on carbon. The tungsten coverage of all relevant structures has the highest priority in the present AUG hardware extension programme. All plasma scenarios are still accessible.

Steerable mirrors for a new 4 MW ECRH system have been installed in the torus (see fig. 4). These mirrors can be rotated around a horizontal axis. Thus the toroidal component of the microwave beam can be changed in order to optimise the current drive efficiency. This motion is slow and therefore changes can be done in-between shots only. The poloidal steering of the beam is fast and is designed for feedback control of the power deposition in experiments dedicated to stabilising neoclassical tearing modes as well as sawteeth. The delivery of the first of two new gyrotrons (104 / 140 GHz, 10 s) is anticipated for summer 2004.

The 2004 campaign was planned at the annual AUG programme seminar together with scientists from EU Associates which responded to the last Call for Participation. The scientific programme has been approved in December 2003 by the international AUG Programme Committee and is now executed in co-operation with 14 EU Associates. Main emphasis is given to:

- Improved H-mode studies (q-scan, dimensionless scaling of confinement and maximum stable β, increase of ICRH heating)
- Impact of tungsten surface enlargement on all AUG scenarios
- NBCD physics and efficiency
- ELM control applying various techniques
- NTM control (avoidance of seed islands, FIR modes, stabilisation by local ECCD)
- Disruption avoidance and mitigation
- ELM-free operation in QH modes

More than 70 experimental days are planned for the 2004 campaign. A one week opening of the vessel became necessary at the end of March to work on sparking problems in the region of the upper passive stabilizing loop and in the lower divertor. A significant reduction of experimental time throughout 2004 is not anticipated by this short maintenance shutdown.

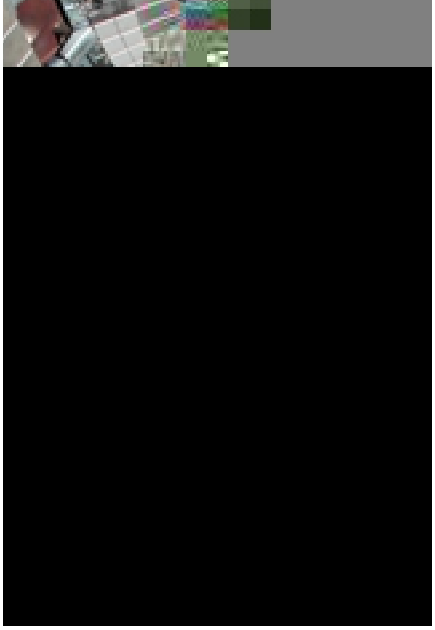

Fig. 3: View of the interior of the AUG vessel with indication of tungsten surfaces.

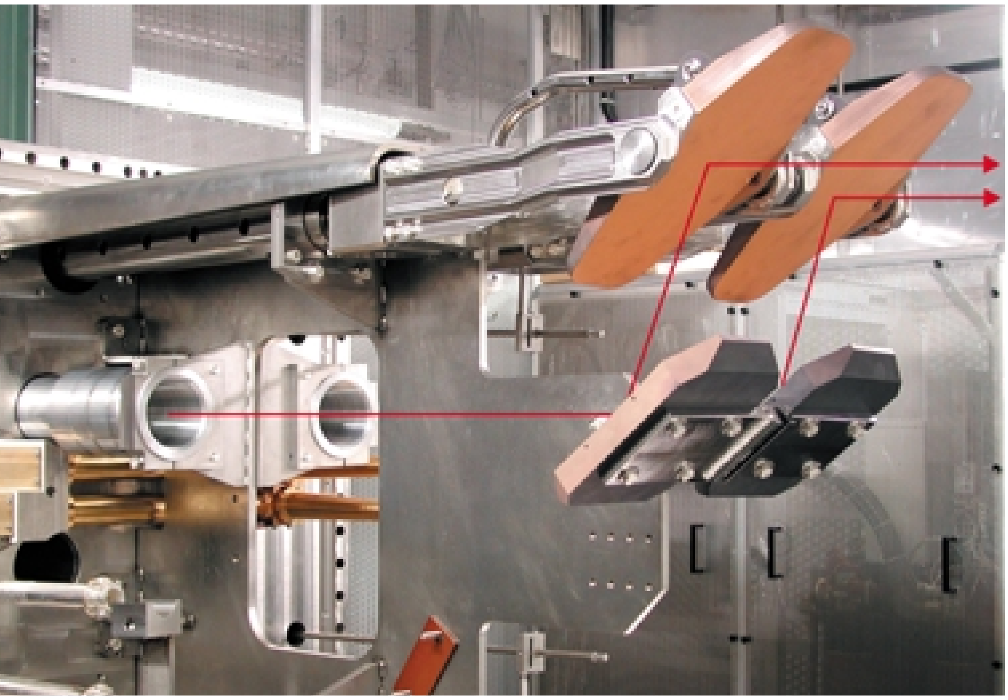

Fig. 4: View of the plug-in unit with two installed ECRH launchers. The microwave beams are indicated with arrows.

ASDEX Upgrade Letter
published by
Max-Planck-Institut für Plasmaphysik
Association Euratom-IPP
Boltzmannstraße 2
D-85748 Garching
www.ipp.mpg.de

Coordination Prof. Dr. Hartmut Zohm
Contact Dr. Josef Schweinzer
Phone +49/89/3299-2205
Fax +49/89/3299-2580
E-Mail josef.schweinzer@ipp.mpg.de