ASDEX Upgrade LETTER

Max-Planck-Institut für Plasmaphysik

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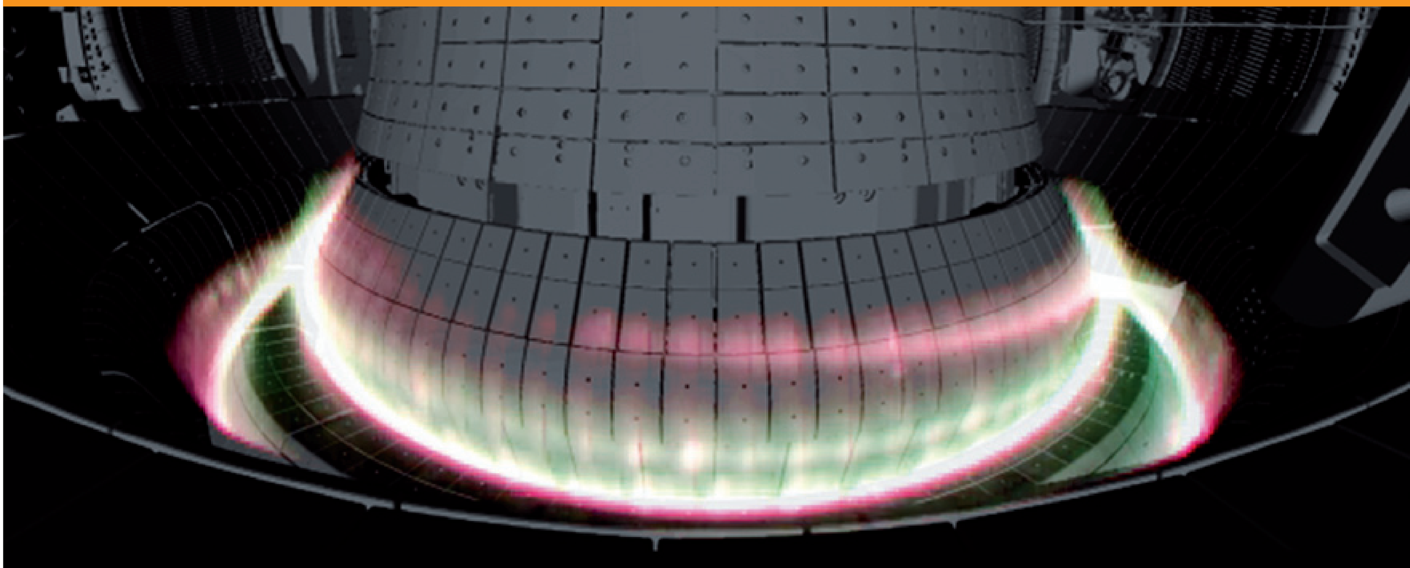
IN GARCHING FOR EUROPE – FUSION RESEARCH WITH THE ASDEX UPGRADE TOKAMAK



Compendium image of ASDEX Upgrade plasma using visible light camera picture, overlaid with CAD drawing of vessel components, of a mitigated ELM in a low-density helium discharge. The lobe structures due to resonant magnetic perturbations are clearly visible on the right. The peripheral pink emission signifies residual hydrogen; the white/green emission is typical of helium.

IMAGE: IPP, T. LUNT

Prof. Dr. Hartmut Zohm
Head of Tokamak Scenario Development division
PHOTO: IPP

EDITORIAL

In keeping with ASDEX Upgrade's mission, research highlights of the 2015/16 campaign presented in this issue, concern preparation of ITER operation and important questions for the step beyond, DEMO. Furthermore, basic elements of fusion-oriented plasma physics are also being studied in order to improve understanding of this exciting nonlinear system. The 2015/16 campaign is the second period in which ASDEX Upgrade is being operated in the Medium-Sized Tokamak Programme (MST) of EUROfusion, the operation time being split roughly 50:50 between the MST and the IPP programmes. This kind of operation is now well established and the results presented here have been obtained in both parts of the programme, which largely complement each other and contribute to the research goals in a coherent manner.

The MST campaign has placed strong emphasis on the start of ITER operation with a non-nuclear phase. The contribution from one of the MST Task Force Leaders in this letter indicates that it is already possible in this phase to study some of the main challenges, such as ELM heat loads and their mitigation. Together with corresponding experiments in TCV, these can make an important contribution to rapid progress with the development of the Q = 10 scenario for ITER. For DEMO, it was possible to demonstrate substantial reduction of tungsten influx from active ICRF antennas by means of a new three-strap antenna design developed in collaboration with ASIPP (China) and ENEA Frascati. This study made use of the unique all-tungsten first-wall environment in ASDEX Upgrade. Finally, it is also shown that 3D structures induced in the scrape-off-layer by applying magnetic perturbations lead to a corresponding 3D heat flux pattern. However, when averaging toroidally, the divertor heat flux profile is similar to the non-perturbed case, this indicating it cannot be substantially broadened with this technique.

These highlights illustrate how the versatile experimental capabilities of ASDEX Upgrade are being used to address various questions in the European and world-wide research programmes. Many other exciting results feature in the 2015/16 campaign, and you are invited to learn more about these in forthcoming conferences and publications.

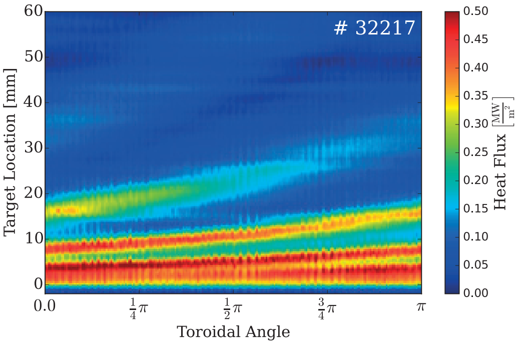
HARTMUT ZOHM

Highlight from a recent ASDEX Upgrade experiment

Power exhaust studies

Divertor heat load with magnetic perturbation

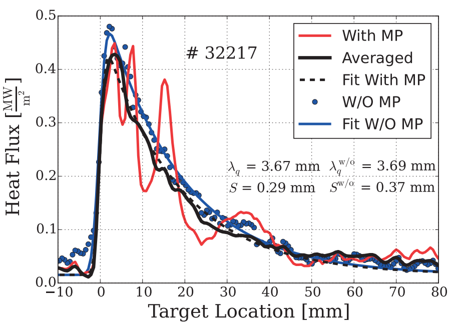
External magnetic perturbation (MP) is one of the techniques considered to be capable of mitigating or suppressing large edge-localized modes (ELMs) in next-step fusion devices such as ITER, where the thermal load due to ELMs might limit the lifetime of the divertor.



2D divertor heat flux profile for ASDEX Upgrade #32217 with rotated MP (n=2, 1 Hz), measured with a new infrared system.

FIGURE: M. FAITSCH

ASDEX Upgrade is equipped with two toroidal rows of eight saddle coils capable of producing a radial perturbation field of the order of 1 per cent of the toroidal field at the outer mid-plane separatrix. The power supply can perform a rigid rotation of a toroidal mode number n = 2 perturbation with an arbitrary phase between the two sets of coils. This allows variation of the alignment of field lines at the plasma edge with respect to the MP and its influence on the heat flux distribution in the divertor can be studied. A slow rotation of ~1 Hz allows the measurement of the complete 2D heat flux structure at the divertor with constant background plasma conditions, using infrared thermography which observes a fixed toroidal position.



Heat flux profile on the outer divertor with MP (red) and without (blue). The toroidally averaged profile in the presence of MP (black) leads to the same distribution as the axisymmetric one.

FIGURE: M. FAITSCH

Stationary low-density L-mode discharges in ASDEX Upgrade were performed. Applying a MP with a phasing aligned to the field lines at the edge (so-called resonant configuration) results in a pronounced change of the heat flux pattern compared to the axisymmetric case without MP. A lobe pattern with a toroidal periodicity of the applied n = 2 perturbation is visible in the first figure. Such discharges were conducted with different phases and also with only one row active at a time. This led to a similar pattern in the 2D profiles but with reduced amplitude of the heat flux variation. Nearly no impact on the heat flux pattern is observed when using a phasing opposite to the resonant configuration (non-resonant configuration). The constant L-mode conditions allow averaging the heat flux in time, corresponding to an average over the whole toroidal circumference of the divertor.

The second figure shows a heat flux profile with resonant MP (red), the toroidally averaged profile (black) as well as a heat flux profile without MP (blue) for ASDEX Upgrade discharge #32217. Fitting the diffusive 1D model (Eich Fit Function) to the axisymmetric and the toroidally averaged profiles reveals that the defining transport qualifiers, viz. the power fall-off length λ_q and the divertor broadening S, do not change with the application of the MP. This holds for all differential phases and different MP strength. No beneficial broadening of the power flux channel in the scrape-off layer with MP application is observed. The helical structure, however, leads to a toroidally asymmetric heat flux distribution with enhanced toroidal peaking of the heat flux in regions further away from the strike line. Hence, rotating the MP is needed to smooth this asymmetry over time, but this causes an unavoidable cyclic variation of the heat flux – in the discharge presented by a factor of two – and thus a cyclic variation of the surface temperature of the divertor target. The benefit of MPs for H-mode discharges in ITER will crucially depend on whether the strong heat load associated with ELMs can be significantly reduced, which is the topic of ongoing investigations on ASDEX Upgrade.

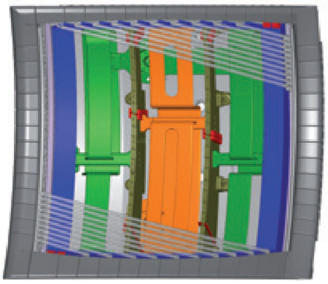
M. FAITSCH

New three-strap antennas

Reduction of ICRF-specific tungsten sources

Four antennas are used to couple the Ion Cyclotron Range of Frequencies (ICRF) power to the plasma in ASDEX Upgrade. After installation of the all-tungsten (W) wall, in particular the W-coated antenna limiters, ICRF-specific W release became a serious problem. In 2012, limiters of two of the antennas were coated with boron (B). The W content in the confined plasma during operation of these B-coated antennas was decreased by a factor of at least 2 in relation to that for the W-coated antennas. Prior to the 2015/16 campaign, the ICRF antennas with the W-coated limiters were replaced by three-strap antennas, with the aim of decreasing the W sources during ICRF operation.

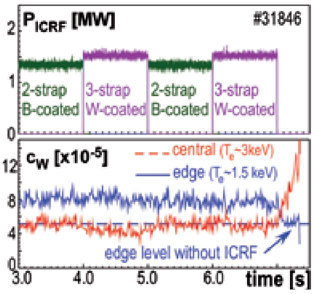
The 3-strap antenna concept is based on minimization of the RF image currents at the antenna frame and reduction of the electric RF fields at the antenna limiters. The antennas were constructed and built in collaboration with colleagues from the Institute of Plasma Physics, Chinese Academy of Sciences (ASIPP, Hefei, China) and the Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA, Frascati, Italy).



Three-strap antenna with tungsten-coated limiters.

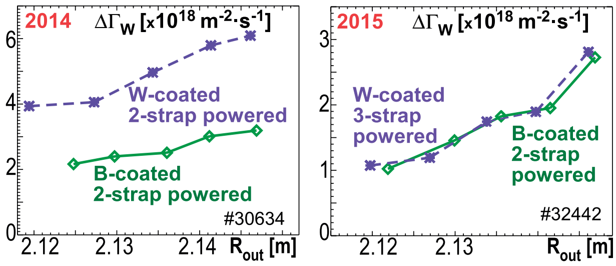
FIGURE: V. BOBKOV

Experiments clearly show that the W concentration, c_W, in the plasma during ICRF with the new W-coated 3-strap antennas decreased substantially, down to that with the B-coated 2-strap antennas. The W-coated antennas can now be routinely used to avoid W accumulation in the plasma centre. The improvement was primarily achieved by reducing the local ICRF-specific W sources at the antenna limiters. This can be seen from comparison of the ICRF-specific W source measured at the limiter of the old 2-strap antenna in 2014 with that at the new 3-strap antenna in 2015, the remote W source during operation of the B-coated antennas being taken as reference.



Comparison of the B-coated 2-strap antennas and the W-coated 3-strap antennas in H-mode with P_{NBI} = 7.2 MW and up to P_{ECRH} =1.3 MW.

FIGURE: V. BOBKOV



ICRF-specific W source at the W-coated antenna side limiter versus the outer plasma position, with the B-coated antennas as reference. P_{ICRF} = 1.2 MW = const.

FIGURE: V. BOBKOV

As predicted by electromagnetic calculations, operation of the three-strap antennas is optimal when the power launched from the central strap is about double the power launched from both outer straps in the dipole strap phasing. Furthermore, the RF currents measured at the limiters behave at least qualitatively as predicted by the calculations when the power ratio between the central and the outer straps is varied. A consequence of the 2:1 optimal ratio is that the RF generator powering the outer straps cannot be used to its maximum power. To allow full-power operation, an additional RF generator (in the past used by the old ASDEX and Wendelstein 7-AS experiments, and recently modified to use a modern tetrode) will be integrated into the circuit of the central strap feeding lines.

An antenna-embedded reflectometer system, provided by ENEA, in cooperation with Instituto Superior Técnico (IST, Lisbon, Portugal), will provide a powerful tool for the antenna characterization.

V. BOBKOV

Computer graphic: The control room for the ITER test reactor.

FIGURE: ITER ORGANIZATION

Cooperation agreement concluded

IPP to develop plasma control system for ITER

The complex software needed to control plasma experiments in ITER in real time will be jointly developed by IPP and the ITER team. The cooperation, scheduled to last about six years, was recently ratified.

Required is a smart system that can quickly react to the fast plasma processes. It must be robust and so flexible that it can be further developed for many years of operation and adapted to changing conditions. Thus, a modular framework structure is desired. The software will be tested on ASDEX Upgrade, which will finally be switched over to the new control system. “As the device will use the same software as ITER, we expect major synergies”, state project heads Gerhard Raupp and Axel Winter. “This gives unique opportunity to prepare control tasks for ITER on ASDEX Upgrade and provide training for future ITER operators at Garching.”

I. MILCH

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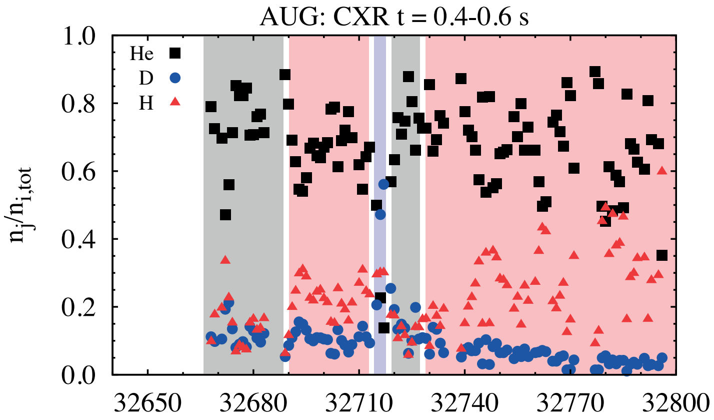
Helping ITER with helium

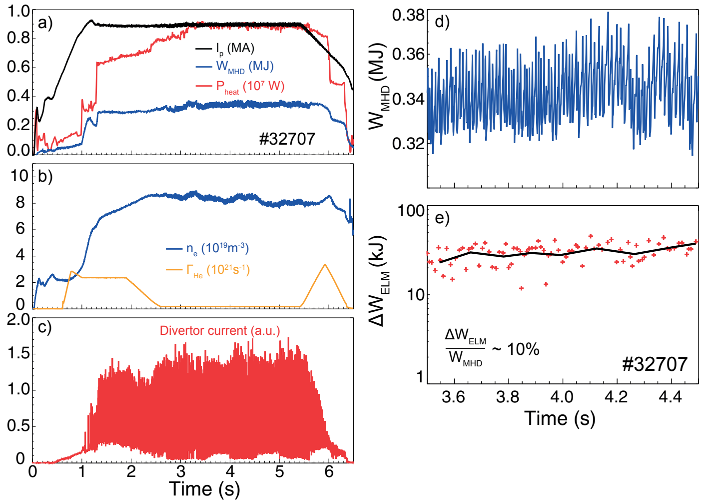
The ITER international experimental reactor will start operation with a non-nuclear phase using either hydrogen (H) or helium (He) as working gas. Operation in He is more likely to allow access to the high-confinement H-mode regime. But, as most tokamaks usually operate either in deuterium (D) or H, little experience with working in He is available, particularly with a tungsten divertor and all-metal walls. H-mode access in the non-nuclear phase of ITER is important for testing the transferability of important aspects such as ELM and disruption mitigation. In particular, plasmas with high He concentration and high pedestal pressure leading to low-frequency type-I ELMs are of interest to ITER. This had not been achieved simultaneously in previous He campaigns on ASDEX Upgrade.



Relative concentration of the main plasma species He (black), D (blue) and H (red) during the 2015 He campaign versus the discharge number.

FIGURE: P. SCHNEIDER

Under the auspices of the EUROfusion MST1 Task Force a dedicated eight-day He campaign was performed on ASDEX Upgrade at the end of 2015. This campaign was longer than previous ones and started with a day of ICRF wall cleaning to study this technique for ITER and help with the isotope exchange. To increase the purity, four neutral beam injection (NBI) sources were converted to work with He, this giving 3 MW of additional heating power to the nearly 7 MW of RF heating (< 4 MW electron cyclotron resonance heating, 3 MW ICRF). The remaining four NBI sources were operated with H to allow ion temperature measurements and high heating power. Argon frosting of the cryogenic pumps, mimicking the carbon coating of the ITER pumps, was used for the first time in plasma operation to allow He pumping and access to low-density operation.



Time traces of an ITER baseline scenario in helium: (a) plasma current, stored energy and heating power, (b) line-averaged density and fuelling rate, (c) divertor current as ELM signature. Zoom of stored energy (d) and ELM energy loss (e).

FIGURE: H. MEYER/T. PÜTTERICH

The result was high He purity. The ICRF wall cleaning increased the He/(D+H+He) ratio from 30 per cent before to 80 per cent. The figure shows that in later discharges purities of up to 90 per cent were achieved.

Experiments in this campaign addressed issues important to ITER, such as pedestal evolution and ELM mitigation, formation and survival of fuzzy structures on the tungsten targets relating to He operation (W-fuzz), disruptions, core tungsten transport, density limits, detachment and divertor asymmetries, as well as more basic plasma science such as L-H transition physics and turbulent transport. For the first time "large" ELMs with $\Delta W_{ELM}/W_{MHD} \sim 10$ per cent were achieved in high-purity He plasmas (see second figure), this facilitating studies of ELM mitigation with RMPs and inter-ELM pedestal evolution. Interestingly, the RMPs affect the ELM energy loss in a collisionality range where no effect has hitherto been observed in D on ASDEX Upgrade, but they required the predicted perturbation alignment. Lobe structures during mitigation as discussed above are observed in the visible emission (see front page). Disruption mitigation behaves similarly to that in D discharges, but the generation of runaway electrons shows differences. The pressure in the divertor was found to be much lower than in D for similar densities, and particle confinement seems to be higher.

H. MEYER

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