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Research on European Medium Sized Tokamaks towards ITER and DEMO

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Since 2014 research on three of Europe's medium size tokamaks, ASDEX Upgrade (AUG), MAST-U and TCV, is partly conducted via a single task force (EU-MST). These coordinated studies with joint experiments on all three devices are guided by the European Roadmap to Fusion energy and are focussed answering critical questions for ITER and DEMO to complement the studies on JET. Considerable progress has been accomplished in the field of ELM control using resonant magnetic perturbations (RMPs) and pellets, confinement and divertor physics in seeded scenarios, disruption physics, fast ion physics and the performance of alternative divertor concepts.

To affect ELMs with RMPs at low collisionality the edge peeling response close to the X-point has to be maximised (AUG, MAST) and on MAST also the core kink response at the mid-plane needs to be minimised [1,2]. Profile measurements obtained with rotating fields on AUG show good agreement with the plasma response calculations [3]. Full ELM suppression at low collisionality and high confinement ($H_{H(98,y2)}$=0.95) has now been achieved on AUG, highlighting important aspects of the physics needed to achieve this favourable regime, and ELM control has been ported to He plasmas. A new scaling for the energy fluence ($\epsilon_{\|} \propto p_e^{ped}$) of type-I ELMs onto the divertor targets suggests that mere ELM control may not be sufficient to mitigate the heat loads in the ITER Q_{DT}=10 scenario, though in general it is more favourable for ITER. Large ELMs can lead to flash melting of misaligned W targets on AUG and is observed for the first time in a tokamak. Experiments in He indicate that the role of main chamber W sources may have been underestimated and in ITER net erosion zones may become net deposition zones, thus influencing tritium retention [5]. Further studies concern small ELM scenarios where the role of the density in the scrape-off-layer (SOL) could lead to their applicability for ITER and DEMO despite their existence being limited to high collisionality in present day devices.

The behaviour of a high-density front forming at the high field side (HFSHDF) has been linked to changes in the confinement on AUG by affecting the location of the density pedestal, which moves outward as density in the HFSHDF increases. The measured pedestal performance agrees well with semi-predictive modelling [6] and also the trends of the HFSHDF with fuelling, heating power and impurity seeding have now been successfully modelled using SOLPS5.0 [7].

Stable operation with pronounced detachment has been demonstrated on AUG at ITER relevant P_{sep}/R=12 MW/m (P_{heat}=26 MW) at high radiation fraction (f_{rad} > 0.9) and good confinement using N_2 and Ar seeding. Radiation at the X-point has been identified as a potential observer for detachment control in these scenarios [8]. In L-mode detachment has been studied extensively on TCV in alternative divertor concepts such as Snow Flake, X-point target and Super-X divertors [9,10]. Interestingly the density where detachment starts is not affected by the flux expansion as one might expect, but by the poloidal extension of the divertor leg, both of which significantly change the connection length in the SOL. These results also question simple models projecting the power decay length from the target to the mid-plane. SOLPS5.0 modelling of the closed divertor Super-X configuration on MAST-U, however suggests detachment at lower up-stream density [11]. This will be tested experimentally at the end of 2017.

Routine control of neoclassical tearing modes on AUG and TCV as well as pre-emptive disruption avoidance techniques coupled with simple real time current diffusion calculations has increased the disruption resilience in the EU-MSTs with ECRH. Scenarios with well-controlled runaway electron (RE) current have been established for the first time on AUG and TCV. The RE current can be quenched using massive gas injection (MGI) and also by introducing magnetic perturbations in the pre-disruption phase. First results for the mitigation of disruption forces and thermal loads with MGI have been obtained on TCV extending the large database from AUG, JET and MAST. New MGI studies on AUG concentrated on the minimum quantity of gas needed to mitigate the thermal disruption loads [12].

In the first year of neutral beam injection (NBI) on TCV NBI current drive (NBCD) has been demonstrated [13]. Detailed measurements of on- and off-axis NBCD have been performed on AUG and TCV suggesting near neoclassical fast-ion transport in both cases in these scenarios. The spectral alignment of RMPs also affects the fast ion loss sensitively. Depending on the poloidal spectrum of the applied RMP, an outwards or inwards fast-ion transport can be achieved.

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