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Highlights from the third experiment campaign of MAST Upgrade

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The third experiment campaign of MAST Upgrade (MAST-U) obtained important results for the understanding and operation of current and future fusion devices. The UK's national fusion experiment located at Culham, MAST-U is a medium-sized (R=0.8 m, a=0.6 m) spherical tokamak which operates with toroidal magnetic fields up to 0.72 T, plasma currents up to 1 MA and auxiliary heating provided by on-axis and off-axis neutral beam injectors at up to 3.5 MW of power. The machine is nominally up/down symmetric and standard plasma scenarios utilize a double null divertor configuration with either a conventional divertor (low total flux expansion, low target radius) or a Super-X divertor (high total flux expansion, high target radius) with high divertor closure achieved by strong baffling. The campaign investigated a broad spectrum of topics along integrated scenario development, plasma exhaust, MHD and pedestal, and fast particle themes.

In H mode plasmas with 3 MW of heating power and plasma current Ip = 750 kA, changing the divertor shape from conventional to Super-X was shown to significantly reduce the target heat and particle fluxes [1]. The reduction was greater than that expected from changes in geometry alone, indicating substantial dissipation of power and particles. This increased dissipation does not impact the core and pedestal, which confirms the benefits of the Super-X for scenario integration. Steady state power balance studies in lower single null H mode plasmas did however find that the inner divertor leg heat flux was higher in Super-X than conventional divertors, indicating the importance of double null operation in maximising the effectiveness of the Super-X in low aspect ratio devices [2].

The detachment sensitivity of the Super-X divertor was studied. In L mode plasmas with 1.5 MW of heating power the position of the Fulcher-alpha emission front was used as a marker for the detachment front to assess detachment sensitivity to divertor gas perturbations. The conventional divertor exhibited a very narrow detachment operating window, with small increases in gas puffing leading to immediate detachment and for formation of a MARFE, whereas the Super-X had a much wider detachment control window [3].

Advanced shaping capabilities enabled the development and study of additional divertor configurations, including the X divertor, Snowflake divertor and X point target (XPT) configurations. In H mode, the snowflake divertor showed strong radiative exhaust in the region of low poloidal field around the X points without ELM suppression, and in the XPT configuration power sinks were found to be redistributed among the multiple divertor legs downstream of the secondary X point.

MAST-U H mode plasmas with both on-axis and off-axis NBI heating typically feature a 2/1 tearing mode which degrades confinement by ~30%, and significant effort was devoted to investigating techniques for mitigating or eliminating this mode. Ultimately the mode was found to be very robust and required mitigation by raising the central safety factor (q) to stay above 2 for as long as possible. Flux pumping has been observed in dual-NBI plasmas, leading to a flattening of the current density profile and subsequent rise in minimum q, though the triggers for this appear to be different from those identified on DIII-D and AUG.

The impact of core shaping on the pedestal was studied, and a strong dependence on pedestal stability with plasma squareness was found. High shaping (triangularity and elongation) was found to increase performance – in agreement with peeling-ballooning theory - but excessive shaping led to performance degradation. The first negative triangularity H mode plasma in a spherical tokamak was produced. This exhibited ELM suppression at triangularity d<-0.06 with type-III ELMs sustained at less negative triangularity: a result which differs from ELM-free access conditions on conventional aspect ratio tokamaks [3]. ELM suppression using n=2 resonant magnetic perturbations (RMPs) was studied but the impact was found to be weak due to the significant n=2 error field in MAST-U.

Fast particle-driven Global Alfvén eigenmodes (GAEs) have been observed in NBI-heated plasmas. At low Ip these propagate only in the direction opposite the beam, but at high Ip bi-directional GAEs are observed [4]. The increase in magnetic field in MAST Upgrade leads to the GAEs exhibiting different characteristics to the CAEs identified on pre-upgrade MAST. A novel diamond fusion proton detector [5] has recently been commissioned with better thermal robustness and radiation resilience than conventional Si-based detectors, permitting for the first time energetic proton measurements close to the plasma edge without detector dropouts.

References
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