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Overview of first physics results from MAST Upgrade

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MAST Upgrade is scheduled to start operating in October 2020 followed by the start of the first experimental campaign in December. Experiments will emphasise addressing key physics issues for ITER and the design of future fusion reactors [b] by leveraging the unique capabilities of this new device. The main aims of the early experimental campaigns will be to study the benefits of alternative divertor configurations to support the development of exhaust solutions for DEMO and future reactor concepts, develop integrated scenarios to support the experimental programme and exploring fast ion confinement with on and off axis neutral beam injectors. Integrated commissioning of the solenoid, toroidal field and main chamber poloidal field coils and their power supplies, operated by the Plasma Control System, have been completed to meet the requirements of the experimental campaign, as shown in Figure 1. Commissioning of the remaining poloidal field coils in the divertors is expected to be completed by October to enable production of the first plasma. The results from the initial plasma commissioning phase and physics results from the first campaign will be presented.

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The uniquely flexible divertors will enable physics studies to better understand plasma exhaust in tightly baffled, up-down symmetric divertors with extensive diagnostics and unprecedented flexibility to vary the outer divertor leg length and strike point major radius, in single and double null, whilst preserving the shape of the core plasma. On and off axis neutral beam injection will be applied to tailor the fast ion distribution and q profile to avoid performance limiting instabilities and confined and lost fast particles will be comprehensively diagnosed. A new solenoid will increase the maximum plasma current and pulse length to 2 MA and 5 s respectively, compared with 1.3 MA and 0.7 s with the original MAST. The maximum toroidal field at the magnetic axis will be 0.8 T, 50% higher than MAST, that are predicted to improve confinement and contribute to physics understanding.

The rapid development of robust, high performance scenarios, underpinned by detailed physics studies, is a high priority in preparation for the operation of upcoming devices, e.g. ITER and JT-60SA, including MAST Upgrade. Several actuators will be available on MAST Upgrade to optimise scenario performance, including: the balance of on and off-axis heating (influencing the q profile and fast ion profile), fuelling location and divertor closure (modifying H-mode access and edge collisionality) and divertor configuration (affecting fuelling, H-mode access and quality and separatrix parameters). The impact of these on core performance will be evaluated with detailed numerical modelling and an extensive suite of highly resolved diagnostics, including Thomson scattering, Beam Emission Spectroscopy and Charge Exchange Recombination Spectroscopy.

Finding a solution to handling power and particle exhaust is of paramount importance for the operation of ITER and the design of future devices. The steady-state divertor loads can be mitigated by using detachment to dissipate the plasma heat flux and MAST-U will be an excellent facility for understanding detachment onset and control. The impact of the target major radius on access to detachment has been studied in SOLPS simulations of MAST-U, predicting the upstream density needed to reach detachment will be 2.4x lower in the Super-X configuration compared with a conventional divertor with 50% lower target major radius [c]. Analytic modelling of the variations in upstream density, power crossing the separatrix and divertor impurity concentration to transition from detachment onset to an X-point MARFE [4] indicate that the Super-X gives a significantly expanded operating window for detachment compared with conventional divertors. These predictions will be tested against experiments to study detachment onset and controllability in conventional and Super-X divertor configurations and the role of filamentary transport (i.e. if turbulence is affected by divertor configuration), atomic and molecular processes such as radiation and volumetric recombination and impurity transport.

The higher toroidal field and neutral compression in MAST Upgrade will extend studies of pedestal physics and ELM control to lower collisionality and more reactor relevant regimes. Two rows of in-vessel coils, situated above and below the mid-plane, enable the application of resonant magnetic perturbations with toroidal mode number, n, of n = 2 and n = 4 respectively for ELM control and error field correction. Transport across the pedestal will be characterised by two toroidally separated Doppler Backscattering systems. The highly flexible magnetic geometry in the divertors will enable detailed studies of the impact of alternative divertor configurations and divertor state (e.g. attached or detached) on H-mode access and quality.

Studies of MHD stability will concentrate on performance limiting instabilities and their avoidance, such as optimising error field correction to expand the operational space to lower density and collisionality and tailoring the q profile during the ramp-up phase and flat-top. Active MHD spectroscopy and stability calculations will be used to detect the proximity to stability limits and predict the onset of disruptions.

A package of EUROfusion co-funded enhancements are being developed, including upgraded diagnostics such as new fast imaging cameras, IR cameras, bolometry and a Thomson scattering system viewing the lower X-point. A cryoplant, to serve the existing divertor cryopumps, is being installed. 5 MW of additional neutral beam heating is also under development, extending on and off-axis heating and current drive capabilities.

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References

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