Developing understanding of spherical tokamaks with MAST Upgrade

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MAST Upgrade (MAST-U) is a new low aspect ratio device (R/a = 0.85/0.65 ~ 1.3) based on the MAST tokamak that started plasma operations in October 2020. It has substantial new capabilities compared with the original MAST device, with 19 new poloidal field coils (14 of which are within the vacuum vessel) and new, closed, up-down symmetric divertors with Super-X capability. MAST-U is designed to operate at higher toroidal field (0.585 T to 0.8 T at full current), the new solenoid nearly doubles the inductive flux from 0.9Vs to 1.7Vs, allowing for the maximum plasma current and pulse length to be 2MA and 5s respectively and a combination of on and off-axis neutral beam heating and current drive. In the first physics campaign the operational envelope is slightly reduced compared to the full design with pulses at up to 1 MA for 2 seconds duration, 0.65 T toroidal field at R=0.7 m, but with the full on and off axis beam power at ~1.7 MW per beam line, for a total of 3.5 MW of injected power for 1 second.

As power exhaust is a key challenge facing for future, high power fusion reactors, a key physics mission for MAST-U is to explore the benefits of alternative divertor configurations, especially the Super-X [1], that offer substantially reduced power loads in steady-state [2, 3]. This is due to a longer field line length from the outer mid-plane to divertor target and larger strike point major radius in the Super-X configuration compared with a conventional. Improved control of the detachment front position is expected due to the magnetic field being significantly higher at the x-point compared with the divertor strike point in low aspect ratio devices, leading to commensurate gradients in the parallel heat flux [4]. Initial results from MAST Upgrade indicate the detachment threshold based on the core line-average density is up to 50% lower in the Super-X configuration compared to the conventional divertor, which is in reasonable agreement with predictive modelling predictions [5]. Strong divertor heat flux mitigation in the Super-X configuration has been observed in ohmic and strongly NBI heated L-mode discharges. Detailed characterisation of the mechanisms governing the onset and evolution of detachment suggest a complex interplay between plasma-molecule interactions and volumetric ionization and recombination processes.

Substantial progress has been made towards developing robust, high performance plasma scenarios with on- and off-axis neutral beam (NBI) heating. In 750 kA discharges with NBI heating exceeding 3.0 MW, pedestal top temperatures of up to 400 eV and stored energy of 100 kJ have been obtained, with the pedestal reaching the peeling stability limit (compared with the ballooning limit previously observed on MAST). Good performance has been obtained in strongly shaped plasmas with relatively high elongation, κ, of ~2.2 with good vertical stability. Optimisation of the plasma breakdown and early Ip ramp was performed using a semi-empirical model [6] to ensure robust, repeatable breakdown and minimal solenoid flux consumption. The on- and off-axis neutral beams allow for careful tailoring of the equilibrium q profile to avoid deleterious MHD instabilities and gradients in the fast ion pressure that give rise to fast particle modes that degrade fast ion confinement. Results from initial studies of the impact of on- and off-axis NBI heating in these respects, and on the performance of the overall plasma scenario, will be presented.

References

[1] P. M. Valanju, M. Kotschenreuther, S. M. Mahajan, J. Canik, Phys. Plasmas 16, 056110 (2009)
[2] E. Havlíčková et al Plasma Phys. Control. Fusion 56 075008 (2014)
[3] E. Havlíčková et al Plasma Phys. Control. Fusion 57 115001 (2015)
[4] B. Lipschultz et al Nucl. Fusion 56 056007 (2016)
[5] D. Moulton et al 2017 Proc. 44th EPS Conf. (Belfast, UK, 2017)
[6] D.J. Battaglia et al Nucl. Fusion 59 126016 (2019)