IMPACT OF TRANSIENT HEAT LOADS ON THE DETACHED MAST UPGRADE SUPER-X DIVERTOR

[1]R.Scannell, [2]J. Flanagan, [1]Z. Huang, [1]J. Harrison, [1]S. Silburn, [1]D. Moulton, [1]S. Leigh, [1]S. Mijin and the MAST-U Team

[1]United Kingdom Atomic Energy Authority, Culham Campus, Abingdon, OX14 3DB, United Kingdom
[2]University of Liverpool, Department of Physics, Liverpool, L697ZE, United Kingdom

Email: rory.scannell@ukaea.uk

Future Tokamaks are required to protect plasma facing components (PFCs) from plasma exhaust. This is achieved by building up a region of cold neutral gas close to where the open field lines intersect with the divertor, a phenomenon know as detachment. This has been shown to work in existing devices with conventional divertors [1] and the MAST-U super-X divertor [2][3] which creates ideal conditions for detachment with a long connection length and high neutral pressure in the divertor region compared to the main chamber. Previous investigations into detachment in the MAST-U super-X divertor have been performed in steady state conditions looking at detachment over timescales covering several confinement times [4] and during >1ms transients created by z-shifts [5]. This paper investigates the impact of fast transients, <1ms timescale, which cause an increase in power to the scrape off layer beyond the steady state "P_{sol}", this increase may burn through detached divertors which represents a risk to PFCs. The transients can result from a number of different plasma phenomena such as sawteeth, ELMs, H-L transitions and internal reconnection events. ELMs are convenient phenomena to study transients as they are repetitive and cover a wide variety of energy losses (ΔW). Although ELMs are not permissible on reactors, the data from them is directly relevant for events that cannot be prevented, such as H-L back transition. The reduction of the energy reaching the target below the total released plasma energy is known as 'buffering' and where transients go fully through the detachment front to the PFCs, they are said to have 'burned through'. Buffering and burn through are studied in the MAST-U Super-X divertor as well as their variation with energy release and divertor neutral pressure. Two key diagnostics are used in this study are the divertor Thomson scattering (DTS) [6] which measures T_e right to the target and the ultra-fast divertor spectroscopy which measures at >500kHz bandwidth allowing diagnosis of the detachment front location during the transient event.

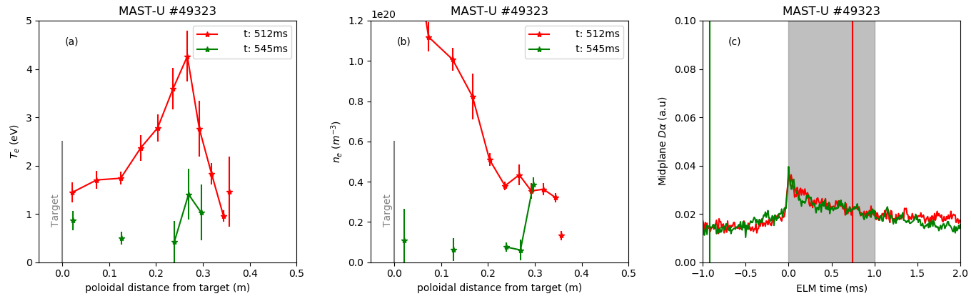

Figure 1 – Divertor parameters as measured by Thomson scattering for MAST pulse 49323 for two timeslices showing (a) T_e (b) n_e and (c) timing of measured pulses relative to mid-plane D-alpha emission.

Fig 1 shows two sets of profiles which are typical of measurements during the inter-ELM and ELM respectively. The profile in green taken ~1ms before the ELM shows little measureable plasma near the target, this indicates that either T_e<1eV or n_e <~10^{18} m^{-3} or both. Observations from the Multi Wavelength Imaging (MWI) [7] correspondingly show that the detachment front is far from the target at 1ms before the ELM. The timing of this measurement relative to the ELM event is shown by the D_α emission from fig 1c, the inter-ELM profile is taken almost 1ms before the ELM event. The red profile ~0.7ms after an ELM event shows greatly elevated T_e and n_e right up to the divertor target plate, indicating burn through has taken place. A systematic study from a range of ELM transients has shown greatly elevated temperature and density in an ~1ms window after the ELM event. This corresponds well in terms of magnitude of temperature and duration of reconnection with T_i measurements taken from a retarding field energy analyser [8].

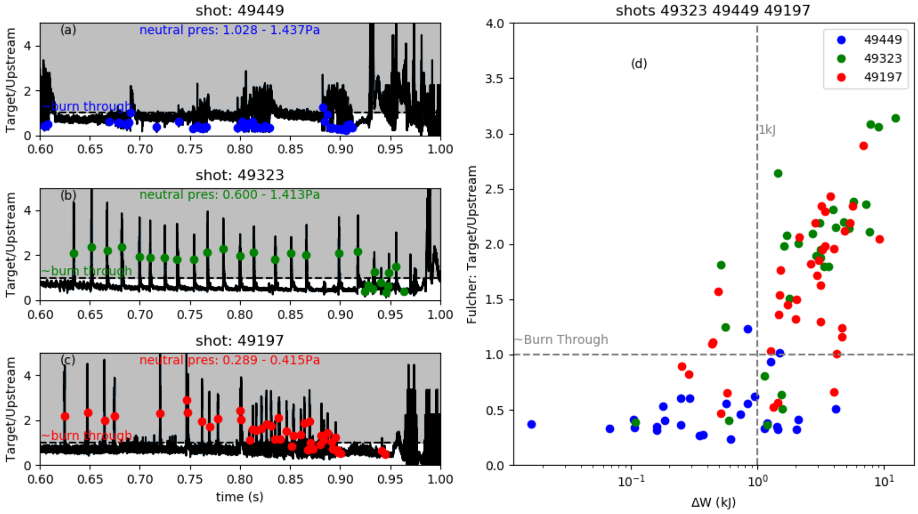

Figure 2 – Three pulses on this plot show (a,b,c) show the ratio of target/upstream Fulcher emission. (d) The averaged ratio of target/upstream Fulcher emission in the 1ms window after the ELMs versus ELM energy

The data from the DTS illustrate what happens during ELMs, but the number of events captured is somewhat limited as it requires the overlap of the laser firing with the ELM event. To further our understanding for next step machines we probe variation of transient behaviour with neutral pressure and ELM energy. This is achieved by the UFDS diagnostic, data from which are shown in fig 2. Here three pulses are examined at a range of divertor pressure and for a range of ELM energy loss(fig 2d). To determine what happens during an individual ELM, the ratio of the target over upstream Fulcher emission is examined as the Fulcher emission has been shown to be a proxy for detachment front location [9]. The continuous Fulcher emission ratio is shown in fig 2a,b,c, the averaged ratio in the 1ms window after the ELM event is shown in fig 2d. For large ΔW ELMs, the Fulcher emission at the target increases above the upstream Fulcher emission leading to a large ratio. For small ΔW ELMs, the Fulcher emission upstream increases, but the ELM is effectively buffered and the target emission does not increase leading to a small Target/Upstream ratio. For ELMs which just marginally re-attach, there is an effectively flat Fulcher emission along the strike from upstream to target and a ratio of Target/Upstream ~1. Fig 2d shows the ratio versus ELM energy, it shows that on MAST Upgrade ELMs which are >1kJ typically will burn through the detachment front which is remarkably similar to a simple calculation based on neutral pressure, divertor volume and ionisation and dissociation energies. Further to the data shown, in the paper the required neutral pressure to buffer ELMs of a certain size is inferred. This UFDS and DTS data are also related to the IR camera data which provide a direct measurement of ELM power at the target, which may then be used to infer the fraction of energy buffered by the super-X. Improved buffering when there are impurities in the plasma is also investigated. The data obtained will be compared with models and in particular the ReMKiT1D[10] code. This work aims to deepen our understanding of how transient heat fluxes affect the MAST-U Super-X divertor and hence the possibility of alternative divertor configurations to effectively withstand these events.

ACKNOWLEDGEMENTS This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission.

[1] Leonard, A. W, Plasma Phys. Control. Fusion 60 (2018) 044001
[2] Havlickova E., et al (2015) *Plasma Phys. Control. Fusion* **57** 115001
[3] J.R. Harrison et al 2024 Nucl. Fusion 64 112017
[4] K. Verhaegh et al (2023) Nucl. Fusion 63 016014
[5] S.S. Henderson et al, Nuclear Materials and Energy, Volume 41, 2024, 101765, ISSN 2352-1791, https://doi.org/10.1016/j.nme.2024.101765
[6] Clark, J. G. et al, First divertor Thomson scattering measurements on MAST-U, Rev. Sci. Instrum. 93, 103534 (2022)
[7] Feng, X. et al, Rev. Sci. Instrum. 92, 063510 (2021)
[8] Damizia, Y. et al, arXiv:2411.07881
[9] Osborne, N. et al, Phys. Control. Fusion 66 (2024) 025008
[10] Mijin, S. et al, Computer Physics Communications, 300 (2024) 109195