Assessing the Power Balance through Infrared Thermography from Diverted Plasmas in MAST

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1. Introduction

A commercial scale tokamak is likely to suffer from unacceptable heat loads in its exhaust region. This heat flux originates in the plasma core, then escapes into the scrape-off-layer (SOL) of the tokamak, which is the region outside the last closed flux surface or separatrix. The flux travels through the SOL, past the X-point, and onto the plates.

Recent research suggests that the SOL width remains constant as the machine size is increased [2]. This means power handling quickly becomes a problem on larger machines, probably leading to heat fluxes higher than 100 MW m^{-2} in DEMO, and at least 15 MW m^{-2} in a mitigated case [3].

Understanding how the power leaving the plasma is dissipated is key for future devices. In this work, the power balance is assessed in MAST (fig 1, left). This detailed understanding will then be applied to MAST-U (fig 1, right), particularly the case of the new Super-X divertor.

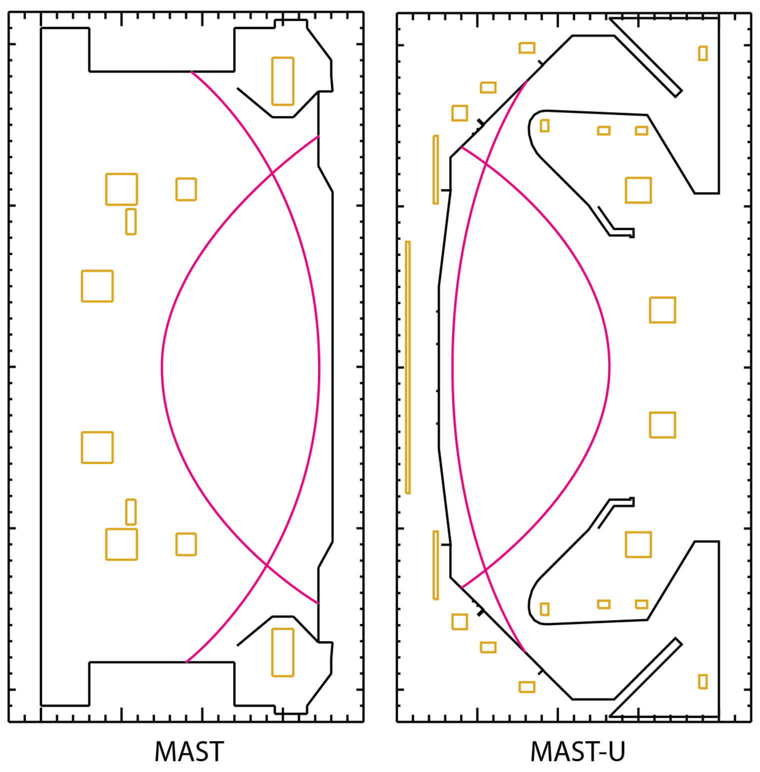

Figure 1: A Diagram showing the vessel and coils of MAST, and how they compare to MAST-U

2. Super-X Divertor

The super-X divertor [4] (figure 2b) is proposed as a way to reduce the heat flux onto the divertor plates of future tokamaks, and has three main advantages:

- Total flux expansion, which lowers the magnetic field strength and spreads the power across the divertor
- Long connection length, which increases the interaction volume between plasma and neutrals
- Large strike point radius which increases the area over which the power is deposited

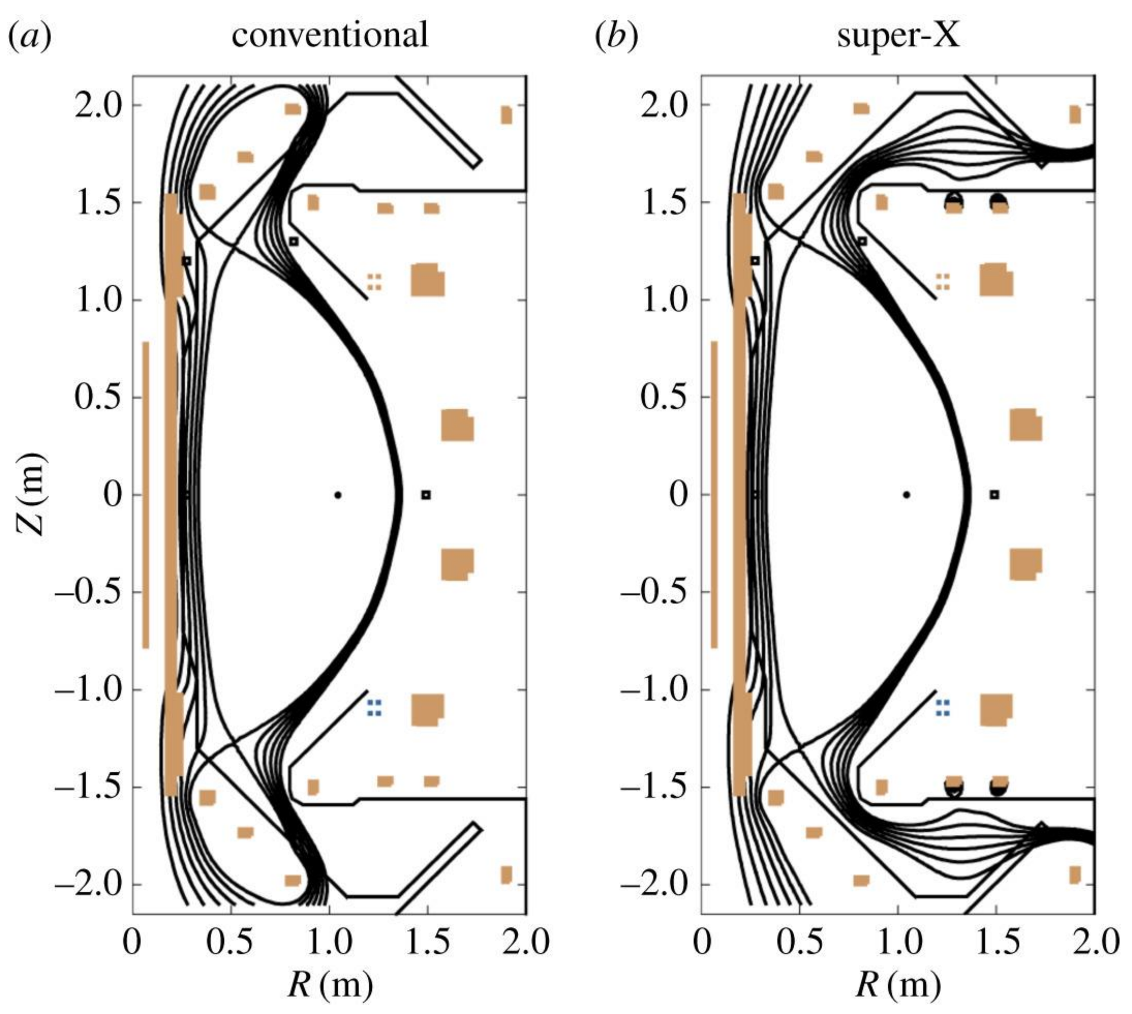

Figure 2: A Diagram showing the Super-X divertor configuration next to a conventional divertor

3. Power Balance

Power balance is concerned with accounting for all fluxes of heat into and out of the plasma, ensuring they balance to zero. The relevant fluxes for a steady state L mode plasma are shown in figure 3.

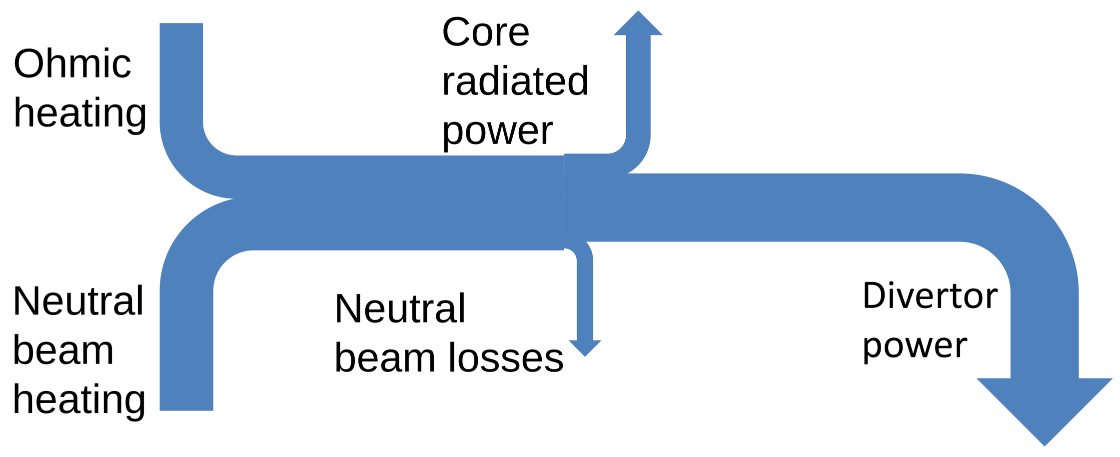

Figure 3: A flow diagram of the power going into and out of the tokamak

These measurements rely on a variety of diagnostics, such as those shown in fig. 4. This includes bolometry for core radiation, flux loops for ohmic heating, beam diagnostics for beam heating and IR cameras for thermography.

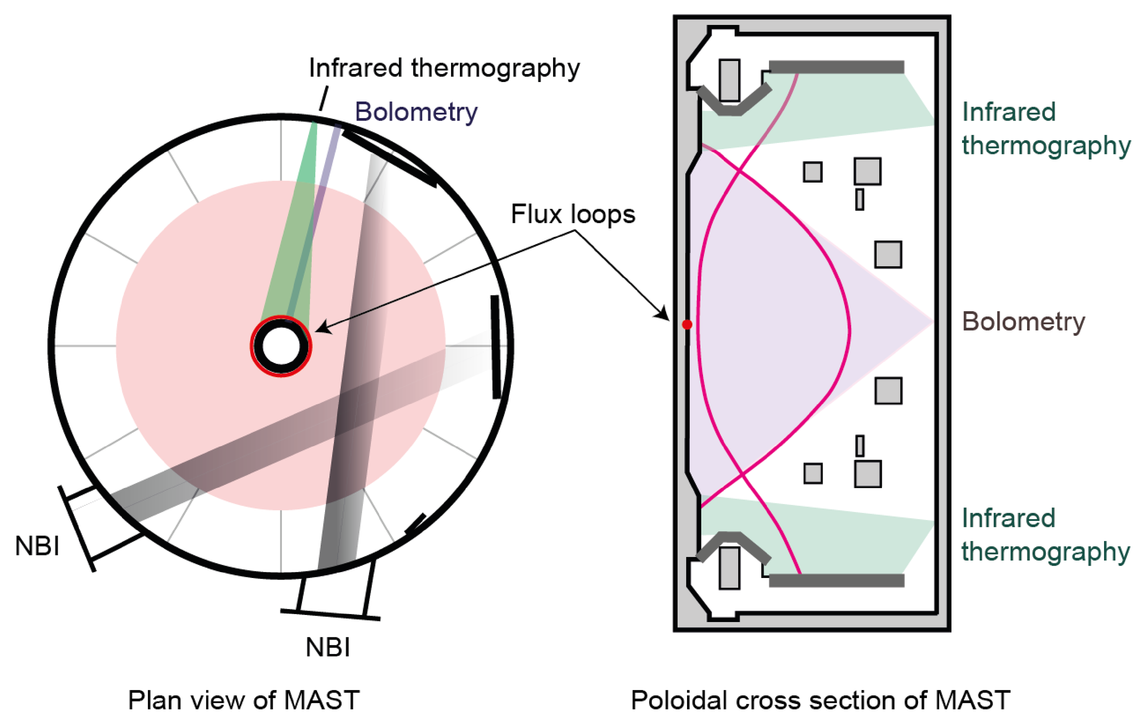

Figure 4: The location of the relevant diagnostics in MAST, shown both from above and as a cross-section

4. Infrared Thermography

Infrared thermography is the use of IR cameras to measure the surface temperature of a material to infer the heat flux. This technique is used to measure the heat deposited on a tokamak divertor surface [5].

The spatial and temporal surface temperature evolution is inferred by assuming the surface is a blackbody radiator. Then the inverse heat conduction equation can be solved to calculate the heat flux from the temperature change.

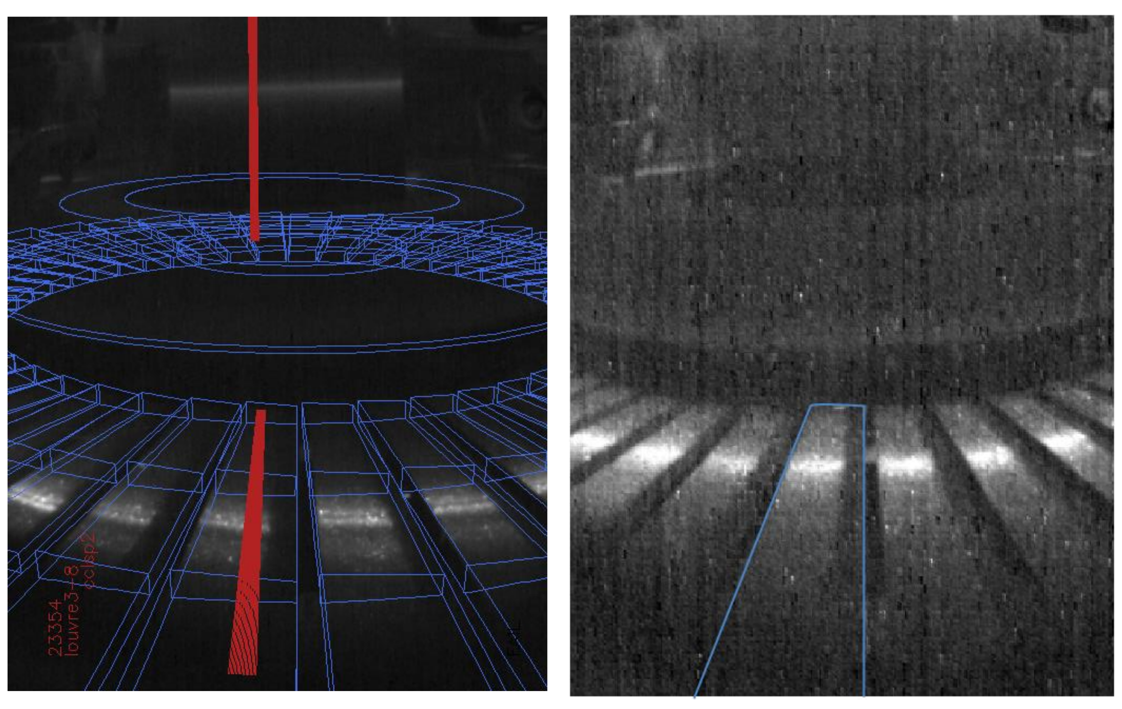

Figure 5: Left – an image of divertor tiles overlaid with the 3D computer model used to map these 2D images
Right - an infrared image showing the fraction of tile area which is wetted, with the dark vertical stripes being the shaded areas.

5. Power Balance on MAST

Previous analysis of data from MAST shows that about 85% of the energy recorded entering the plasma is recorded leaving it [5]. There are two more factors to address in this calculation; these are the wetted area and beam power absorption.

Previously, it has been assumed that 100% of the tile is wetted. Shadowed regions in fig. 5 show that it is closer to 65%. This means that the area over which heat is deposited is smaller, resulting in a lower deposited energy being calculated to arrive at the tile. Accounting for this leads to an imbalance between the power leaving the plasma and that entering it, with more power entering than leaving it. The unaccounted for power will be investigated as part of this work.

6. Beam Power Absorption

Some of the power from the neutral beam injectors is not absorbed into the plasma as intended, but lost either by shine through or first orbit loss. This results in an discrepancy between the energy leaving the beam injectors and entering the plasma.

There is no reliable experimental way to measure the absorbed fraction of power into the plasma, and so it must be determined by simulations.

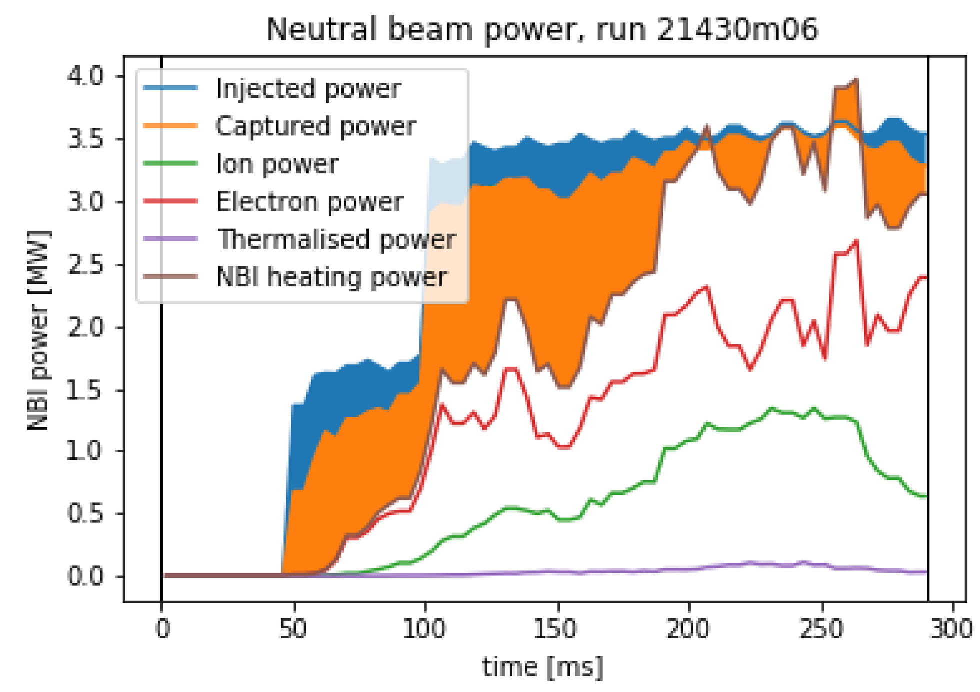

Figure 6: A graph showing the fraction of neutral beam power which is not absorbed into the plasma, shinethrough in blue and first orbit loss in orange

Figure 6 shows results from a TRANSP [6] simulation of MAST shot 21430. The shaded areas show that a significant fraction of power leaving the neutral beams does not actually heat the plasma. This has been overlooked in the past, and work is ongoing to estimate the size of this effect.

7. Next Steps

New analysis of data has begun, and accounting for the wetted area worsens the power balance to 67%. The unaccounted power could be due to overestimation of the amount of absorbed beam power; further work will provide a rigorous assessment of the amount of power that is lost.

Experimental work will begin once MAST-U comes online in the near future. This will require a range of diagnostics, such as IR and bolometry.

This will experimentally and quantitatively assess the effect of flux expansion, connection length, divertor closure, detachment on the distribution of power loss in the plasma.

References

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