Temperature and Density Profile Measurements Of Neoclassical Tearing Modes on MAST

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Introduction

Neoclassical tearing modes (NTMs) are frequently observed in MAST. The 2,1 mode is typically the most detrimental and frequently leads to a disruption. A recent upgrade of the MAST Thomson Scattering (TS) system allows the investigation of the NTM structure. Here preliminary results from a series of NTM experiments on MAST are presented.

Experiments

The perturbation of the flux surface due to the presence of the tearing modes can be seen in the electron temperature and density profiles. The evolution of the width (w) of the NTM is given by the generalised Rutherford equation [1,2]

$$\frac{\tau_r}{r}\frac{dw}{dt} = r(\Delta' - \alpha w) + r\beta_p\left[a_{bs}\left(\frac{0.65w}{w^2+w_c^{\,2}} + \frac{0.35w}{w^2+28w_b^{\,2}}\right) - \frac{a_{GGJ}}{\sqrt{w^2+0.2w_c^{\,2}}} - \frac{a_{pol}w}{w^4+w_b^{\,4}}\right], \quad (1)$$

where $r(\Delta'-\alpha w)$ is the tearing mode stability index, a_{bs} is the perturbed bootstrap term, a_{GGJ} represents the stabilising effects of field curvature, which has been found to play a significant role in MAST [3]. Terms w_c, w_b and a_{pol} make the NTM stable at small island sizes and low β_p (poloidal beta; the ratio of plasma pressure and magnetic pressure). These terms represent the stabilising effects of finite transport in the island, incomplete flattening when the island is below the ion banana orbit width and ion polarisation current respectively. The importance of these stability terms is discussed later. This equation leads to a minimum β_p below which the island cannot grow. Experiments on

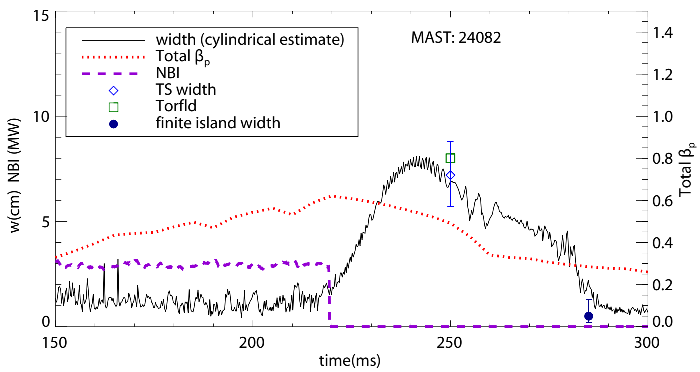

Figure 1: The width of the NTM has been determined using a cylindrical island width formula. Good agreement is found between the TS, cylindrical estimates and 3D field line calculations.

MAST generate high beta plasma within which a NTM is triggered. The β_p was reduced by switching off the beam power, allowing the mode to shrink. The threshold width at which the mode quickly decays is related to the stability mechanisms in equation 1. The TS system is triggered on different amplitudes and phases of the modes. Figure 1 shows the evolution of a 2,1 NTM. The fall in beta is followed by a fall in the mode amplitude. The stabilization of the mode as β_p falls indicates the importance of the $a_{pol,}$ w_b and w_c terms (equation 1) which increase as the mode shrinks. The mode disappears at ~275ms indicating a threshold width of ~3-4cm.

Measuring Magnetic Islands

Magnetic estimates of the island's evolution are determined using 3D field line tracing. TORFLD is used to place a sheet current perturbation representing the island on a given rational surface with a toroidally sinusoidal current variation. The size of the current perturbation is adjusted so that the amplitude of the simulated ΔB is equal to the measured ΔB on the centre column Mirnov array (Figure 2(B)). The equilibrium field has been determined using MSE and kinetically constrained EFIT. Once the amplitude of the flux perturbation has been correctly simulated it can be compared with the perturbation of the temperature profile measured using Thomson scattering.

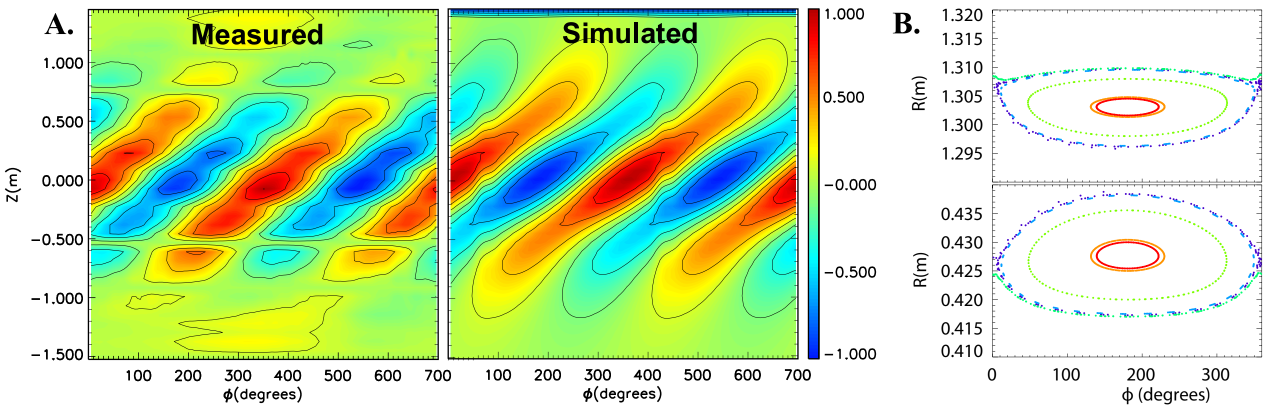

Figure 2. (A) A comparison of the simulated and real ΔB measurements on the vertical Mirnov array. (B) An outboard and inboard magnetic island determined using field line tracing. The size of these islands is determined by the amplitude of the Mirnov signal at the mid-plane (Z=0).

For large islands (>4 cm) this model provides a good quantitative agreement with the observed vertical (Z) variation of the measured fluctuating magnetic field (Figure 2(A)). For smaller islands (<4 cm), the measured fluctuating magnetic field away from the mid-plane (Z=0) does not agree with predictions. This observed discrepancy may imply that smaller islands have a different current distribution, or that the coils response is poorer within the frequency and amplitude ranges of smaller islands. Further modelling is needed to resolve this issue.

Thomson Scattering

The upgraded MAST TS system consists of a 512 point (200 at 50% contrast) dual snap-shot Ruby TS system and a 240Hz Nd:YAG 130 point system [4]. The radial resolution of the Ruby TS system is ~7 mm at 50% contrast and the resolution of the ND: YAG system is ~1 cm.

Both systems can be triggered from the centre column Mirnov coils. An FPGA unit [5] triggers the TS system on the phase and amplitude of the mode in real-time. The eight Nd:YAG lasers are operated in burst mode, with the timing adjusted to measure evolution of the island from x-point to x-point. The electron density profile in H-mode on MAST is typically flat making it difficult to observe the effects of NTMs on the density. Experimental measurements of the flattening of the electron temperature are shown in Figure 3. This data has been remapped to show the evolution of the temperature as a function of the helical angle (ζ) of the mode.

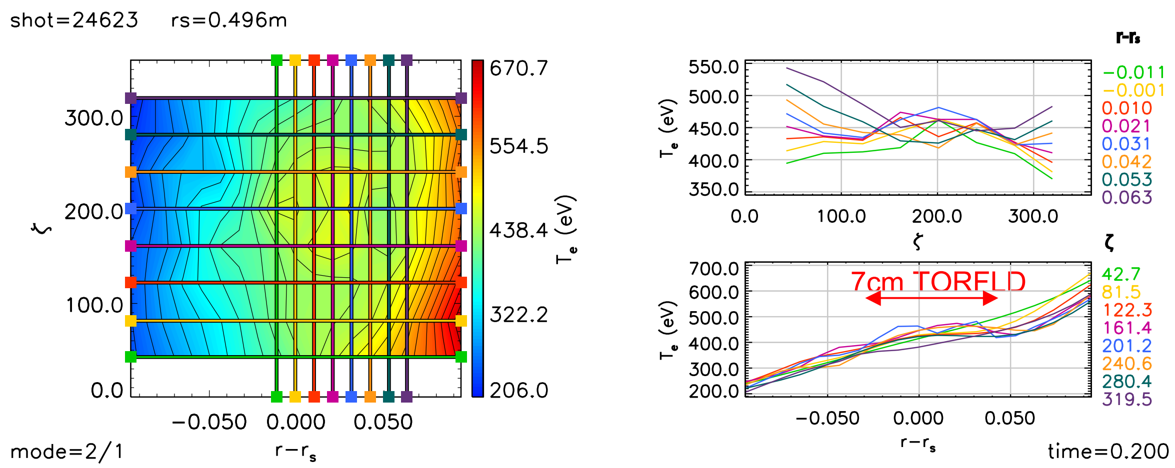

Figure 3: The evolution of the inboard electron temperature profile at the rational surface (r_s) as a function of helical angle (ζ) of the island. Different lasers correspond to different helical angles. The cross section of the island is shown as a function of ζ (top right) and $r-r_s$ (bottom right).

An 'island-like' structure is clearly visible within the contours of the electron temperature (Figure 3). Evidence of peaking of the temperature is visible in the vicinity of the o-point. Density peaking of islands has also been observed. Evidence of peaking and improved transport inside large magnetic islands has been found on other tokamaks, in agreement with these results [2,6].

The Critical Island Width

A critical island width exists below which magnetic islands shrink and disappear. Buttery et al [3] fitted magnetics data from MAST to equation 1 and found that both the ion polarisation and finite transport model can explain the evolution of the magnetic island width on MAST, with similar results on other tokamaks. The finite size island transport model suggests that this critical width is determined by the competition between parallel and perpendicular transport inside an island. Following Fitzpatrick et al [7] it is assumed that there are no sources or sinks of heat and the evolution of the perturbed temperature is defined by

$$\frac{1}{4}\left[\left(\frac{w}{w_c}\right)^2 \sin\xi \frac{\partial}{\partial X} + X\frac{\partial}{\partial \xi}\right]^2 \tilde{T} + \frac{\partial^2 \tilde{T}}{\partial X^2} = 0 \quad (2) \qquad w_c = \sqrt{8}\left(\frac{\kappa_\perp}{\kappa_\parallel}\right)^{\frac{1}{4}} \frac{R_0 r_s}{s_s n} \quad (3)$$

The critical island width (w_c) is given by the ratio of perpendicular ($\kappa_\perp$) to parallel ($\kappa_{||}$) thermal conductivities. The critical island width on MAST is estimated to be ~1 cm. This is a challenging measurement for the TS system. However, if equation 2 is solved numerical and fitted to the electron temperature data, the critical width can be determined as a free parameter in the fit. A preliminary solution to this equation predicts the inboard finite island width of shot 24082 (see Figure 1) to be within the range 0.1-0.85 cm. This is much less than the threshold width (3-4 cm) observed from the magnetic measurements during the β_p scan. These initial results therefore suggest this term is not the dominate stability mechanism.

Conclusions

Detailed measurements of the electron temperature and density profile evolution during NTMs have been performed on MAST. The upgraded TS system can be triggered on the phase and amplitude of NTMs in real time. In addition, a good agreement has been found between the Thomson scattering measurements of island width and magnetic estimates using 3D field line tracing. Preliminary results suggest the finite island width term is not a dominate mechanism in the seeding of the 2,1 mode on MAST. Future work will involve calculation of this term for a larger range of discharges and inclusion of this estimate in the fitting of the Rutherford equation.

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