REFLECTOMETER MEASUREMENT OF DEFORMATION OF THE PLASMA BOUNDARY BY M.H.D. MODES, IN THE MAST TOKAMAK

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Abstract

The MAST H mode plasma typically has a high and steep density pedestal, with the result that reflectometry is of limited utility for measuring the profile, but is very effective in measuring small movements in the pedestal position. The paper describes high resolution measurements made using fast narrow band FMCW reflectometry, the signals being analysed by comparing the phase in successive sweeps. This technique gives improved resolution over the usual frequency demodulation method, and more importantly is effectively immune from the Doppler effect [1]. It is found that displacements due to internal low frequency MHD modes can be reconciled with magnetic measurements of the mode amplitude by assuming that $\Delta R = \Delta B_z . \frac{\partial R}{\partial B_z}$.

Introduction

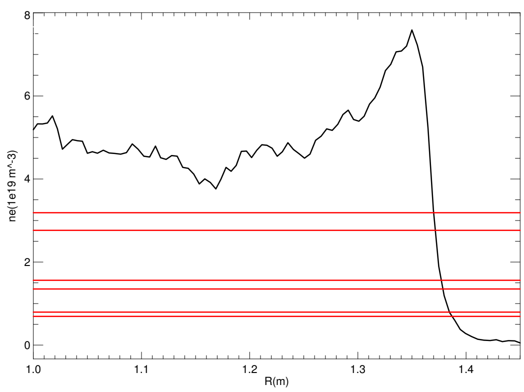

Figure 1. Typical MAST H mode density profile, measured by Thomson scattering.

Figure 1 shows a typical density profile for a MAST H mode plasma during an ELM-free period. The O mode cutoff density for the 3 channels of the MAST reflectometer are also shown. Under these conditions it is sometimes found that the raw FMCW reflectometer signals show a high degree of coherence from sweep to sweep, over extended periods, figure 2. By calculating the relative phase of the fringes in consecutive sweeps, it is possible to measure movement in the reflecting layer with a resolution which is a small fraction of the probing wavelength.

If the reflecting layer happens to be oscillating with, say, an amplitude of A=1mm and a frequency of f_m=5kHz, then there will be a Doppler shift in the frequency of the returning wave amounting to $\Delta f = A.2\pi.f_m.2.\frac{F}{c} \approx$ 10kHz. Compare this with the change in the beat frequency arising from the frequency modulation of the source, for a displacement of 1mm, $\Delta f = \frac{\partial F}{\partial t}.\frac{2A}{c} \approx$ 4kHz. Thus even for a relatively low

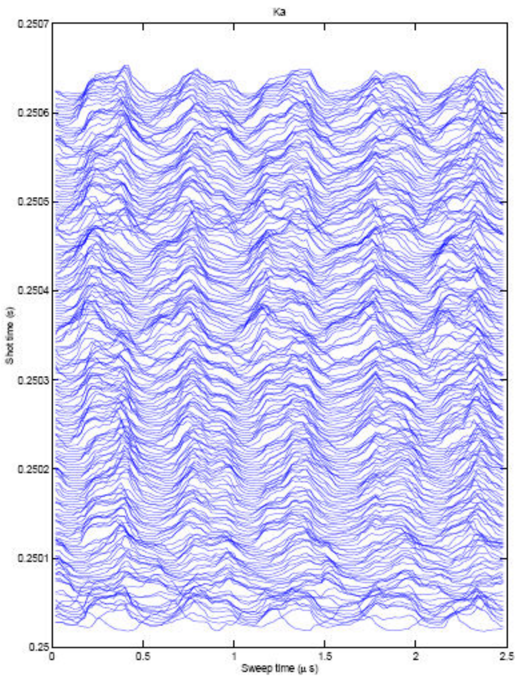

Figure 2. Raw signal from the Ka band channel, central frequency=49GHz sweep rate=0.6 GHz per µs, sweep period=2.5 µs

frequency modulation of the reflecting layer, the observed beat frequency will be dominated by Doppler effect. On the other hand, if the FMCW signal is demodulated by comparing the sweep to sweep phase change, as described above, then the influence of the Doppler effect is largely absent and the resulting measurement is much less ambiguous.

Observations on low frequency MHD modes.

Figure 3 (left) shows the absolute phase from the U band reflectometer together with the signal from a Mirnov coil during an ELM-free H mode phase. Two modes, one at about 6kHz and the other at about 50kHz are clearly apparent on both signals. The Mirnov signal corresponds to an amplitude in B_Z of 0.24 mT for the 6kHz mode, while that for the reflectometer phase is 1.2 cycles. To compare these amplitudes we need to extrapolate the magnetic signal back to the plasma boundary, and this is most easily done using a model representation of the mode. This mode has *m/n = 2/1* and is probably an island at the q=2 surface, so the model comprises a current sheet at that position with a sinusoidally distributed current. According to this model, 0.24mT at the Mirnov probe position of R=1.8m would correspond to 0.76mT at the plasma boundary, R=1.4m. We also use EFIT to calculate $\frac{dB_z}{dR}$ at the plasma boundary, which gives a value of 0.43 Tm^{-1}, however this value depends critically on J_φ at the edge and also varies strongly with R; it is likely that the 49GHz cut-off layer is actually about 20mm inside the LCFS, which would reduce this value to about 0.3 Tm^{-1}. Thus according to the simple model that $\Delta R = \Delta B_z.\frac{dR}{dB_z}$, we get a mode amplitude of 1.8 to 2.5 mm. In comparison, the mean reflectometer probing frequency was 48.9GHz, so the observed

1.2 cycles corresponds to a displacement of $\frac{1.2\times 3.10^{8}}{48.9\times 10^{9}\times 2}=3.7\text{mm}$. Given the uncertainty in the analysis this is reasonable agreement.

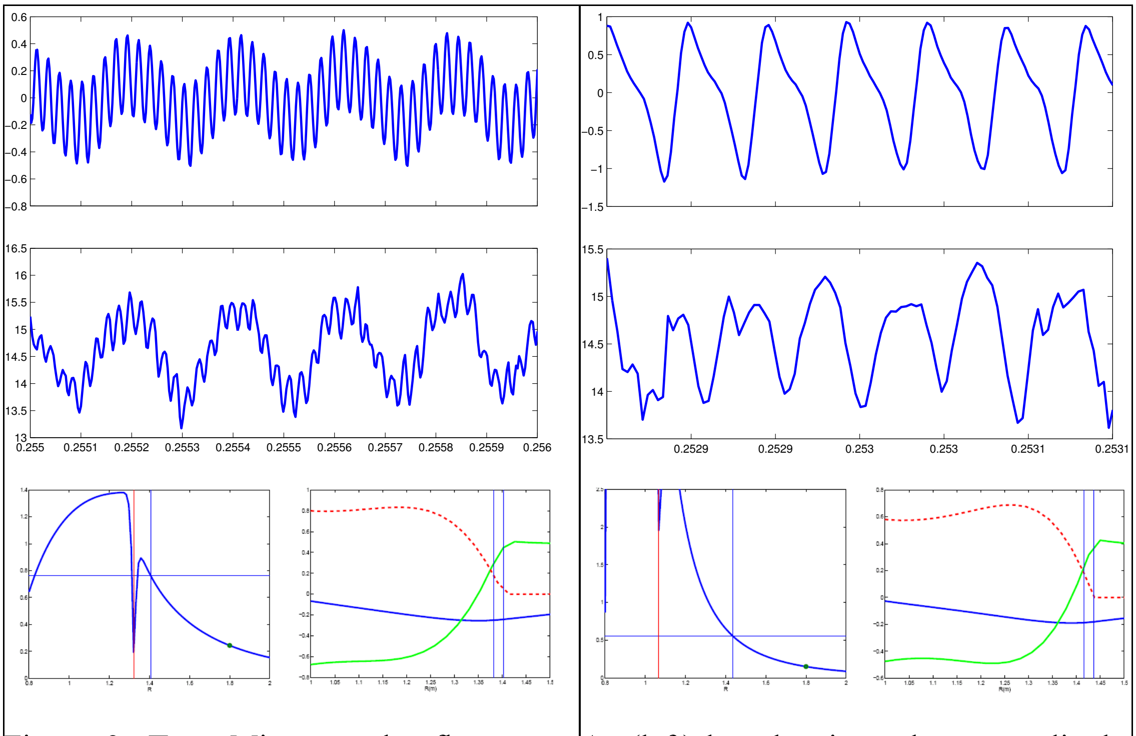

Figure 3. **Top**: Mirnov and reflectometer phase signals showing 2 distinct MHD modes. **Lower left**: Bz(mT) for the model mode. Vertical bars correspond to the q=2 surface (red) and the plasma edge (blue). **Lower right**: equilibrium Bz(blue), dBz/dR (green) and Jφ(red).

As (left) but showing a lower amplitude, higher frequency mode with non-sinusoidal character.

In figure 3 (right) we see a similar analysis of a 1/1 mode which is thought to have a kink-like structure and gives a non-sinusoidal signal in both dB/dt and the plasma edge displacement. In this case the Mirnov signal indicates an amplitude at the probe of 0.15mT at 21kHz which extrapolates to 0.55mT at the plasma edge, implying the displacement amplitude is 1.5mm. In comparison the Ka band reflectometer phase modulation is 0.5 cycles, equivalent to 2.4mm, and again there is reasonable agreement. Consistency with this simple interpretation, which implies that there is no plasma response to the perturbation, is also consistent with observations using applied error fields [2], except that in the present case the perturbing field is predominantly poloidal and radial, whereas in [2] it was predominantly toroidal and radial.

Observations on a high n edge mode.

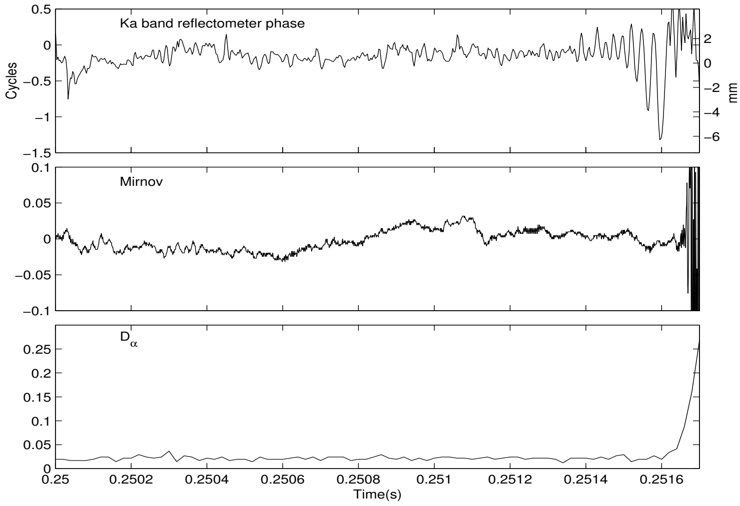

Figure 4. Reflectometer, Mirnov and Dα signals between ELMs.

Figure 4 shows measurements made using the same technique between ELMs in a lower density discharge. The level of perturbation is generally low (<1mm), but there is a mode at about 40kHz growing prior to the ELM onset, which appears to have no magnetic signature. However, if this mode can be identified as a peeling or ballooning mode in the plasma edge, it will probably have a mode number in the region 10-20 so any magnetic fluctuation will fall rapidly with distance from the plasma and may not be detected. The displacement due to the mode reaches an amplitude of about 4mm before the ELM explodes, and calculations are in progress using the BOUT++ 3D non-linear MHD code to determine whether this is consistent with the stability limit for the H mode pedestal.

Conclusions

It has been shown that use of fast narrow-band sweeping, combined with phase demodulation, can yield precise measurements of small movements of the density pedestal in H mode plasmas, free from ambiguity due to Doppler effect.

References and acknowledgements

[1]Cunningham. *Use of the absolute phase in frequency modulated continuous wave plasma reflectometry.* Rev. Sci. Inst. **79.8** (2008)

[2]Chapman et. al. *Perturbation of tokamak magnetic surfaces by applied toroidally asymmetric magnetic fields*. Nucl. Fusion **47** (2007) L36-L40

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