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First multi-chord MSE measurements on MAST

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After a successful single-chord, proof-of-principle pilot-system[1], a multi-chord Motional Stark Effect (MSE) diagnostic has recently been installed on MAST. The low magnetic field in a spherical tokamak (ST) like MAST causes a strong overlap of the π and σ-lines in the Stark spectrum. This reduces the fraction of polarised light within the spectrum and causes the influence of the finite collection volume and the beam velocity distribution on the polarisation angle to become more significant[2]. To assess the expected performance of the system and to aid the design, a code was written that simulates the MAST MSE spectrum[2]. The same code was also used to calculate the Stark spectrum of the ITER DNB[3].

The MSE diagnostic has 35 spatial channels with a resolution of ~ 2.5 *cm*. They cover a range in major radius from 0.7 *m* to 1.5 *m* which corresponds to a normalised minor radius from approximately -0.1 to 1.0. Five additional channels look beyond the tangency point of the neutral beam. They are intended as spare channels, but are also used to verify the simulation code because the finite volume effects are most significant for these channels[2]. The MSE diagnostic on MAST is similar to MSE systems on other tokamaks[4–6]: photo elastic modulators (PEMs) encode the polarisation state of the beam emission into a modulated intensity signal while interference filters select the π or σ-dominated part of the MSE spectrum. Due to the small Stark splitting, very narrowband filters are needed: FWHM= 1.2 Å. A commonly used technique for tuning the central wavelength (CWL) of interference filters is tilting them. Unfortunately this leads to a rapid increase of the bandwidth and is therefore unsuitable for the MAST MSE system. Currently for a given neutral beam voltage (i.e. Doppler shift) the best matched 35 filters out of an available set of 42 are selected. A thermal tuning approach is foreseen in the future.

Because the CWL of the filters cannot be tuned, a spectrum of polarisation angle γ and fraction was obtained by a scan of the neutral beam voltage. This measurement was compared with the calculation of the MSE simulation code[2] as shown in figure 1(a). Assuming a statistical population of the upper Stark levels, the code predicts a higher linear polarisation fraction on σ than observed. At the plasma densities typical for MAST discharges, however, the upper Stark levels are not expected to be statistically populated, resulting in a higher intensity of the π-emission, integrated over the whole spectrum[7;8]. This π-dominance was also measured directly by using a 10 Å wide bandpass filter that integrates over the whole MSE spectrum. A net linear polarisation fraction of $\sim 7\%$ is typically observed, with a corresponding π-polarisation angle – see figure 1(b). Using the relative intensities given in[7;8] for a typical plasma density of

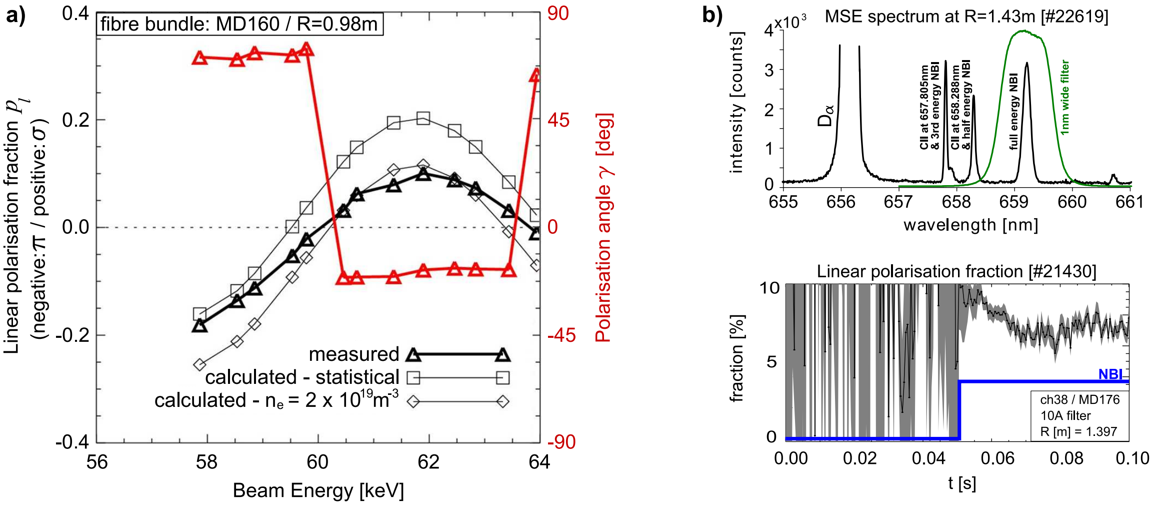

Figure 1: (a) Comparison of MSE spectrum simulation with beam voltage scan measurements. (b) Measured polarisation fraction of 7% remains when integrating over the whole spectrum using a 10 Å wide filter.

$n_e = 2 \times 10^{19} m^{-3}$, better agreement with the σ-polarisation fraction is obtained, however the predicted π-polarisation fraction is higher than the measured one. Further investigation of this discrepancy is under way. The polarisation angle γ, most important for a MSE system, is not directly affected by these atomic physics effects.

In figure 2 a contour plot of a typical MSE measurement of the polarisation angle γ in MAST is shown. The time resolution is 0.5 ms (1 kHz demodulation bandwidth) with – for this discharge – 32 active channels. The RMS error is lower than 0.5° on 14 channels and lower than 1.0° on all 28 plasma channels (the outer 4 channels were looking beyond the LCFS for this particular discharge). One observes the growth of the plasma, a steepening of the γ-profile just before $t = 0.190$ s (red and blue dashed lines), an internal reconnection event at $t = 0.257$ s after which the plasma starts sawtoothing (green dashed line) and the vacuum field measurement after the disruption at $t = 0.340$ s. A contour plot of the $q-$profile is also shown, as calculated by MSE-constrained EFIT. The evolution of the minimum $q-$value and the q-value on the magnetic axis (q_0) is plotted as well. Finally, on the contour plot of the measured γ, the position of the magnetic axis – as calculated by EFIT – is indicated by the black dotted line. Because in double null divertor (DND) plasmas the MAST MSE system's geometry is such that $\gamma \propto \gamma_m$, with $\gamma_m = \arctan(B_\theta/B_\phi)$ the magnetic pitch angle, the magnetic axis corresponds with the position where $\gamma = 0°$ [1].

At $t = 0.180$ s the γ-contours in figure 2, around the position of the magnetic axis, are further apart than at $t = 0.190$ s. This means the gradient of the γ-profile – and hence the gradient of the γ_m-profile – is smaller at $t = 0.180$ s than at $t = 0.190$ s. This is also shown in the top left plot of figure 3, where profiles of γ, q, pressure (p) and j_ϕ are shown for $t = 0.180$ s and $t = 0.190$ s (corresponding to the red and blue dashed lines in figure 2). Because j_ϕ at the magnetic axis is proportional to the gradient in γ_m, this corresponds to a lower (hollow)

[1]For single null plasmas (SND) γ is no longer proportional to γ_m. In such a case $\gamma = 0°$ indicates the 'top' or 'bottom' of the flux surface: $B_Z = 0$ T.

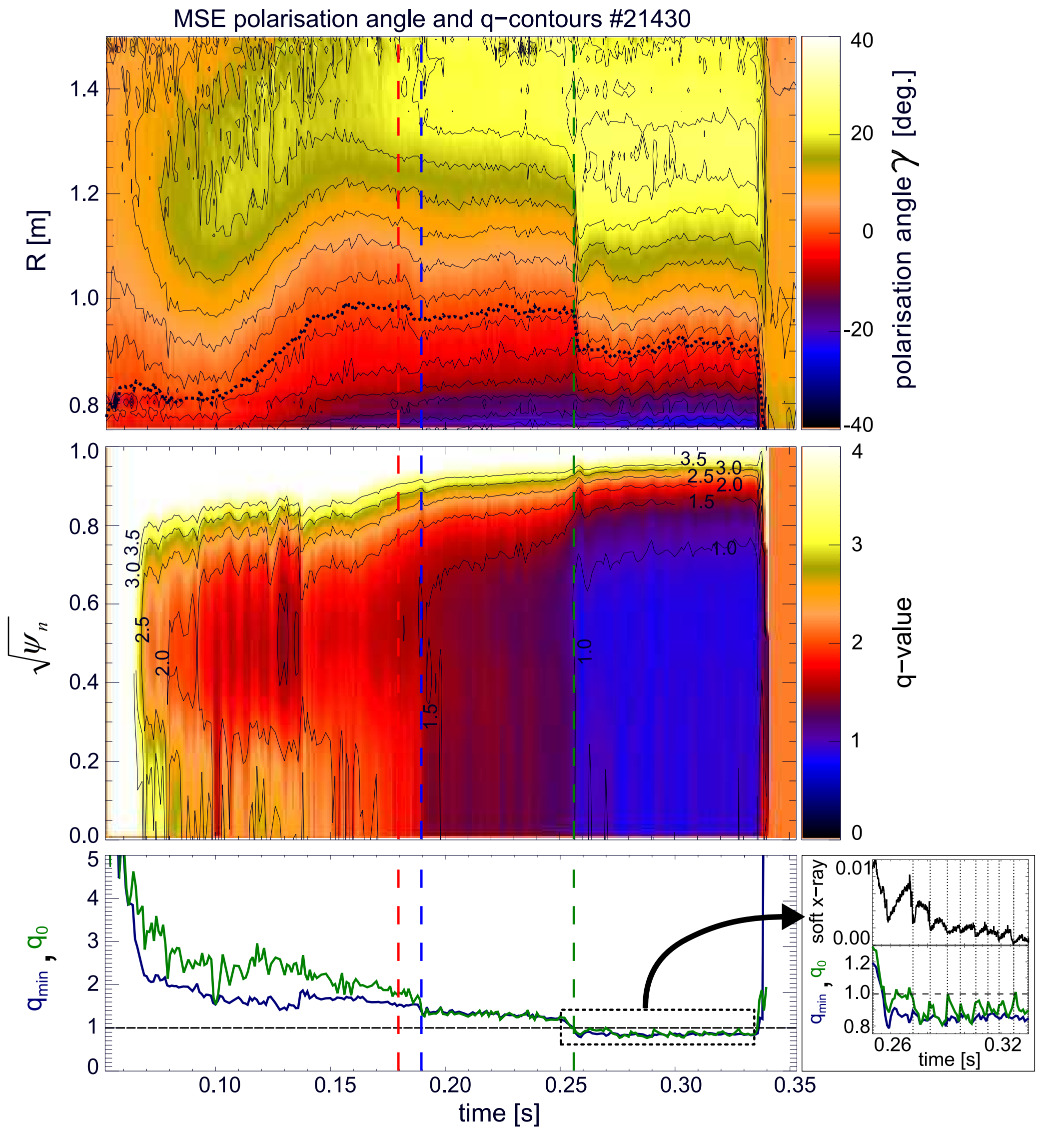

Figure 2: Contour plot of the polarisation angle γ measured by MSE and the $q-$profile calculated using MSE-constrained EFIT. (MAST discharge #21430).

j_ϕ-profile around the magnetic axis at $t = 0.180\ s$ and a higher (flat) j_ϕ-profile at $t = 0.190\ s$ (figure 3, lower right plot). The corresponding reversed and monotonic $q-$profiles are shown in the lower left plot of figure 3. The transition from reversed to monotonic q-profiles is also seen in the $q-$profile contour plot and the q_{min} and q_0 traces of figure 2 ($q_0 > q_{min}$ for reversed, $q_0 = q_{min}$ for monotonic). Apart from the result of the MSE-constrained EFIT calculation, figure 3 also shows the measured γ and p data. One observes that the calculated γ is indeed well constrained to the γ measurement from MSE. The p-profile has been estimated using Thomson scattering (TS) data (setting $p = 2p_e$). EFIT was not constrained to pressure and returns a pressure that is clearly higher than that derived from the TS measurement. This is entirely reasonable, because in the presence of 2 neutral beams a significant fast ion content is expected.

The IRE occurs at the time that the $q = 1$ surface enters the plasma. This can be seen on both the q-contour plot and the q_{min} and q_0 traces in figure 2. Once q_0 (and q_{min}) are below 1 the plasma starts sawtoothing. The inset in figure 2 suggests that q_0 jumps briefly back to 1 (or close to 1) after a sawtooth crash. However, q_{min} remains constant at 0.85. This would mean

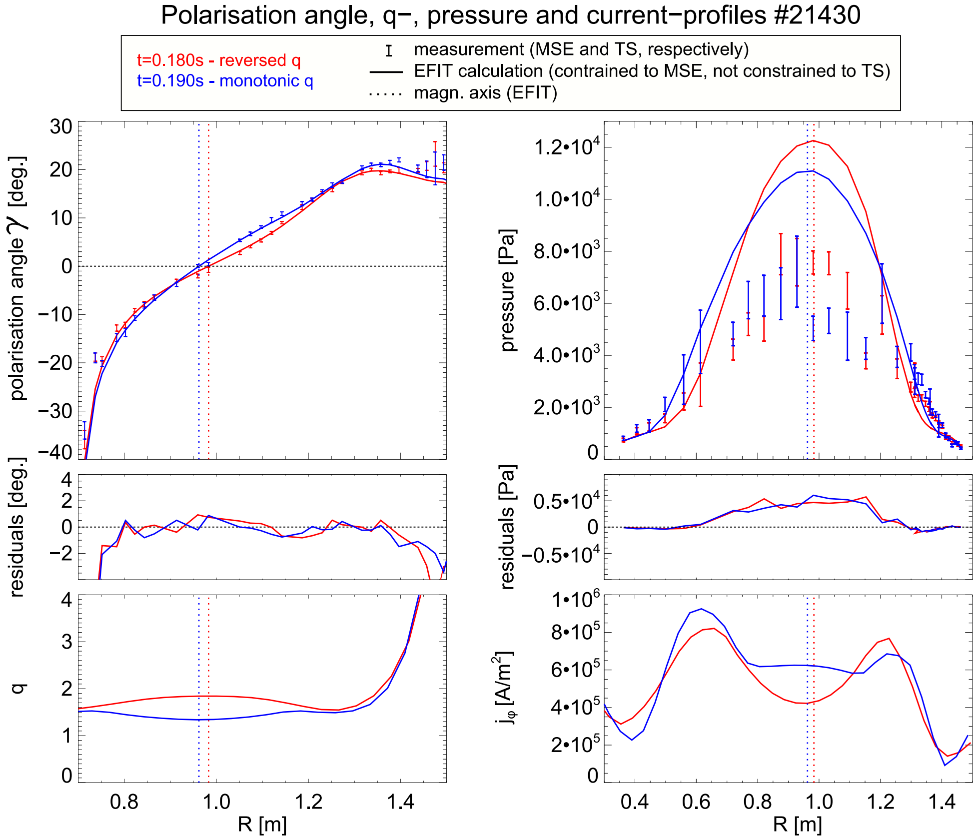

Figure 3: Profiles of γ, q, p and j_ϕ at $t = 0.180\ s$ (reversed q) and $t = 0.190\ s$.

the q-profile becomes slightly reversed after a sawtooth crash. The jump in q_0 is however very small and could possibly be an artefact of the EFIT equilibrium reconstruction.

The MSE diagnostic on MAST is currently operating routinely. It delivers measurements of the polarisation angle γ on 36 spatial channels (final number of channels will be 40) with a spatial resolution of 2.5 cm and a typical RMS error of 0.5° at 0.5 ms time resolution. Its data are used extensively to provide accurate reconstruction of the q and j_ϕ-profiles using MSE-constrained EFIT; e.g. for experiments studying off-axis neutral beam current drive[9] and sawtooth control[10]. Future improvements include increasing the demodulation bandwidth to 3 kHz, which will allow investigation of slow magnetic fluctuations, and possibly thermal tuning of the CWL of the filters in order to optimise the signal-to-noise ratio for all channels.

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References

[1] M. Kuldkepp *et al*, Review of Scientific Instruments **77**, 10E905 (2006).
[2] M. F. M. de Bock *et al*, Review of Scientific Instruments **79**, 10F524 (2008).
[3] N. C. Hawkes *et al*, ITER-CXRS-CORE-UKAEA-Memo-0006 (2009).
[4] F. M. Levinton *et al*, Review of Scientific Instruments **79**, 10F522 (2008).
[5] F. M. Levinton *et al*, Review of Scientific Instruments **61**, 2914 (1990).
[6] N. C. Hawkes *et al*, Review of Scientific Instruments **70**, 894 (1999).
[7] A. Boileau *et al*, Journal of Physics B **22**, L145–L152 (1989).
[8] M. F. Gu *et al*, Journal of Physics B **41**, 095701 (2008).
[9] M. R. Turnyanskiy *et al*, 36th EPS Conference on Controlled Fusion and Plasma Physics O4.029 (2009).
[10] I. Chapman *et al*, submitted to Physics of Plasmas (2009).