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** See annex of M.L. Watkins et al, "Overview of JET Results ",*
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## 1. INTRODUCTION

The Motional Stark Effect (MSE) diagnostic is widely applied to determine the current distribution in high temperature plasmas. The MSE measurement is based on the detection of the polarised Balmer-a light, emitted by the NBI (hydrogen or deuterium) atoms, which is related to the direction of the magnetic field in the plasma. The 25 channels MSE diagnostic on JET [1-3] covers the center and outer side of the plasma (major radius 2.68-3.88m) with a spatial resolution of 0.05-0.07m and channel-to-channel separation of ~0.05m. The safety factor, q, is determined from the most Doppler shifted $\pi^+$ component (selected by interference filters with ~0.4 nm bandpass) measured with avalanche photo diodes. The detection of the polarisation of the measured light is made by two photo-elastic modulators and a linear polariser. The measured light is analysed using a Stokes vector (derived from the amplitudes of the APD harmonics): the total intensity (FDC), two linearly polarised light components (40kHz, 46kHz) and a circular component (23kHz).

The q-profile on JET is reconstructed with the EFIT equilibrium reconstruction code [4]. EFIT solves the Grad-Shafranov equation using as constraints measurements (external magnetic probes, external poloidal flux loops, polarimetry and MSE) and searches for the minimum least-square solution.

During H-mode operation the plasma is affected by Edge Localized Mode (ELM) instabilities. The ELMs appear as intense light flashes from the $D_\alpha$ radiation. Their influence on the MSE measurements can extend across the full field of view of the MSE diagnostic. In most of the discharges with the ELMs the light components detected by the MSE diagnostic show periodic disturbances, which are correlated in time with the ELM bursts appearing at the plasma edge. This behaviour of the MSE data prompts the question about the impact of the disturbances on the polarisation angle measurement and thus on the reconstruction of the q-profile using EFIT. Furthermore it is important to understand whether the MSE data during the ELM can be included in the analysis, for example to investigate whether the ELM actually causes loss of current and a new equilibrium as has been suggested by Solano et al. [5].

To be able to use the MSE data for more timeslices in discharges where ELMs are present we have constructed a new numerical method (ELM filter). This paper will discuss the effectiveness and limitations of the technique and address the effects of the ELMs on the measured q-profile. The analysis in this paper is done at the moment of an ELM and compared with analysis before or after the ELM. The first results using this technique show that the MSE data can be used reliably for q-profile reconstruction for time slices which would otherwise have not been usable. The results show that these ELM filtered data lead to q-profiles which are consistent with data analysed either before or after the ELM.

Another approach of ELM filtering [6] based on the data captured before the ELM has been presented with the goal of real time plasma control using the MSE data.

## 2. ELM FILTER

The ELM filter exploits the transient nature of ELMs, by linear interpolation between the unperturbed time points prior to and after the ELM events in all resolved polarisation components of the measured light. The technique is limited to well separated ELMs. The beginning and the end of the ELM influence on the MSE data is defined when the MSE signal intensity derivative exceeds a certain threshold. In most of the analysed cases this threshold is set at 47.5 $V{\cdot}s^{-1}$ to effectively filter all the affected channels. The data analysis becomes troublesome when compound ELMs appear in the plasma or the frequency is too high since the MSE signals do not recover between the ELMs. The disturbances in the MSE polarised light components are observed also during periods when the PINI1 injector is off (Figure 1), which might be an indication that the optical filter rejection of background $D_{\alpha}$ light is inadequate. Figure 1 shows an example of the effect of the applied ELM filter (shot 70229, channels 11 and 21).

## 3. RESULTS

The MSE data were analysed during discharges with ELMs of different frequency (~6-160Hz) and different intensity ELMs ($D_{\alpha}$ emissivity vertical l.o.s. 0.1-1.5×$10^{15}$ [$s^{-1}cm^{-2}sr^{-1}$]). The calculation of the polarisation angle (γ) has been performed at the moment of the ELM as well as before or after ELM events, Figure 2a.

The MSE data are digitized at 250kHz, and usually for the analysis an averaging is done over 20ms (shorter integration times leading to increased noise). When the ELM filter is applied the channel-to-channel scatter in g is reduced. For the analysed cases all the 25 channels are influenced by the ELM's. Even with the ELM filter applied many channels are still distorted and manualy excluded from the further analysis (eg 13 channels excluded in Figure 2a), but the number of reliable channels increases. There is no clear trend or systematics for which channels are most influenced by the ELMs. Figure 2a shows the profile of measured polarisation angle. The points correspond to the polarisation angle calculated from the measured data, solid lines show the polarisation angle calculated by EFIT, constrained by the MSE data. The error bars contain an allowance for an estimated systematic error of $0.2^{o}$ in addition to the statistical errors calculated from the signal strengths.

Data taken during an ELM (red curve, Figure 2a), and then filtered (blue), are consistent with data taken just before the ELM (green). Corresponding q-profiles derived from the data are shown in Figure 2b. As a consequence of applying the ELM filter the safety factor at the axis ($q_0$) increases (Table 1). The ELM filtered $q_0$ value calculated at the moment of the ELM is very similar to the $q_0$ value calculated before the ELM.

Table 1: Examples of differences between ELM filtered/non filtered safety factor at the axis ($q_0$) calculated at the moment of, before or after an ELM appears in the plasma. Calculations are done for MSE data averaged over 20 ms. All reconstructed profiles are smooth and monotonic or 'near' monotonic as shown in Figure 2b. $c^2$ is calculated for all the measurements used by EFIT, including both magnetics and MSE measurements.

## CONCLUSIONS

Bursts of radiation caused by ELMs affect the MSE measurement on JET, therefore a method of eliminating the ELM influence has been proposed (ELM filter). This technique extends the scope of timeslices amenable to MSE analysis allowing data to be analysed which would otherwise have been rejected. The scatter of the polarisation angle data, which increases with decreasing averaging time, is reduced using the ELM filter. With the ELM filter applied MSE channels can still be distorted by the ELMs and have to be manually excluded from the analysis, but the number of reliable channels increases. q-profiles reconstructed with EFIT using the ELM filter for the MSE data at the ELM time give comparable values to the q-profiles from the pre- or after ELM phases of the discharge. Within the error bars of the polarisation angle measurements we can not detect a change in the q-profile caused by the ELMs for the monotonic (non-reversed) q-profiles studied in this work.

## REFERENCES


[1]. N.C. Hawkes et al., Rev. Sci. Instrum. **70**, 894 (1999)

[2]. B.C. Stratton et al., Rev. Sci. Instrum. **70**, 898 (1999)

[3]. N. C. Hawkes et al., Rev. Sci. Instrum. **77**, 10E509 (2006)

[4]. L.L. Lao et al., Nucl.Fus. **25**, 1611 (1985)

[5]. Emilia R. Solano et al., J. Nucl. Mat. **337-339**, 747 (2005)

[6]. D. Alves et al., 33rd EPS Conference on Plasma Phys. Rome, 19-23 June 2006 ECA 30I, P-1.068 (2006)


| Pulse No: | Time (s) | $q_0$ | Total $\chi^2$ | $q_0$ | Total $\chi^2$ of MSE fit | Time (s) | $q_0$ (no ELM) | Total $\chi^2$ of MSE fit |
|---|---|---|---|---|---|---|---|---|
| 70016 | 28.664 | 0.7 | 154.4 | 0.8 | 76.8 | 28.89 | 0.9 | 47.2 |
| 70221 | 20.9005 | 0.6 | 102.2 | 0.7 | 33.3 | 20.858 | 0.8 | 33.7 |
| | 20.9695 | 0.6 | 120.1 | 0.8 | 46.5 | 20.858 | 0.8 | 33.7 |
| | 20.9755 | 0.6 | 128.4 | 0.8 | 63.7 | 20.858 | 0.8 | 33.7 |
| | 21.0075 | 0.8 | 58.4 | 0.8 | 42.3 | 20.858 | 0.8 | 33.7 |
| | 21.320 | 0.6 | 151.6 | 0.8 | 66.3 | 21.078 | 0.8 | 71.6 |
| | 21.329 | 0.6 | 215.3 | 0.7 | 70.1 | 21.078 | 0.8 | 71.6 |
| 70222 | 21.410 | 0.6 | 11.1 | 0.7 | 26.0 | 21.400 | 0.7 | 46 |
| 70229 | 21.776 | 0.7 | 31.7 | 1.0 | 22.4 | 21.737 | 1.0 | 6.4 |

*Table 1: Examples of differences between ELM filtered/non filtered safety factor at the axis ($q_0$) calculated at the moment of, before or after an ELM appears in the plasma. Calculations are done for MSE data averaged over 20ms. All reconstructed profiles are smooth and monotonic or 'near' monotonic as shown in Figure 2b. $\chi^2$ is calculated for all the measurements used by EFIT, including both magnetics and MSE measurements.*

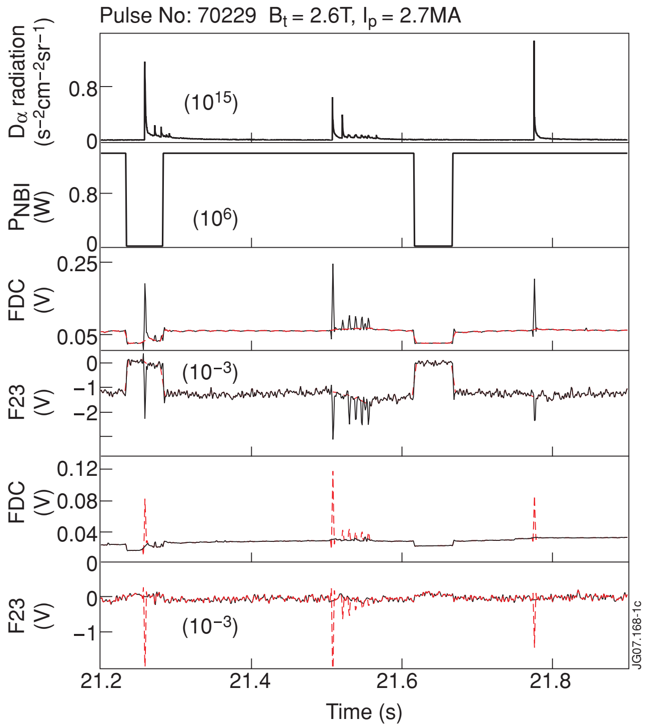


*Figure 1: From top to bottom: D-a radiation, NBI power, total intensity (FDC) channel 11, circular component (23 kHz) channel 11, total intensity (FDC) channel 21 and circular component (23 kHz) channel 21, MSE signals with and without the ELM filter applied.*

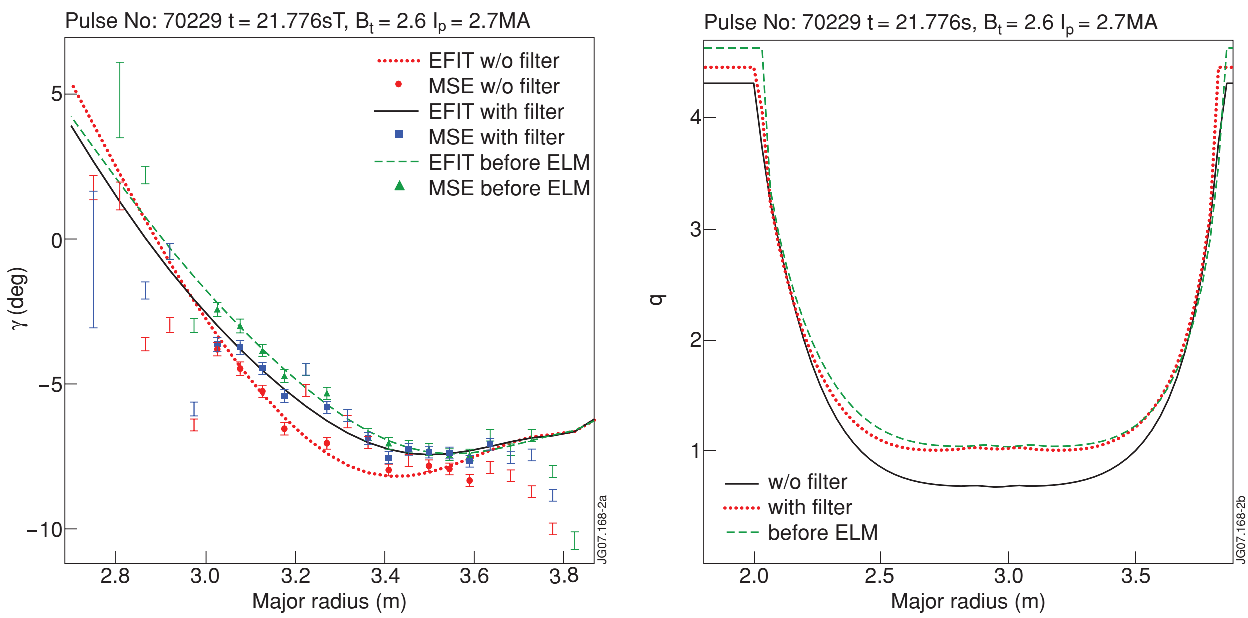


*Figure 2: (a) Polarisation angle (g), the points symbolized with full circles represent the MSE channels included in the EFIT analysis (only 9 of the 25 channels are included in analysis without the filter and 12 of the 25 in analysis with the filter). 23 of the 25 channels are shown within the displayed polarisation angle scale. The solid line (blue with filter, red without filter and green before ELM) represent the fit to the data. b) The reconstructed q-profile with (blue), without (red) and before (green) the ELM filter applied to the MSE data.*