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MHD marking using the MSE polarimeter optics in ILW JET plasmas [a)]

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In this communication we propose a novel diagnostic technique, which use the collection optics of the JET Motional Stark Effect (MSE) diagnostic, to perform polarimetry marking of observed MHD in high temperature plasma regimes. To introduce the technique, first we will present measurements of the coherence between MSE polarimeter, Electron Cyclotron Emission (ECE) and Mirnov coil signals aiming to show the feasibility of the method. The next step consist to measure the amplitude fluctuation of the raw MSE polarimeter signals, for each MSE channel, following carefully the MHD frequency on Mirnov coil data spectrograms. A variety of experimental examples in JET ITER-Like Wall (ILW) plasmas are presented, providing an adequate picture and interpretation for the MSE optics polarimeter technique.

I. INTRODUCTION

The Motional Stark Effect diagnostic at JET [1], [2] has 25 lines of sight, probing the light emitted by neutral deuterium from JET octant 4 neutral beam injector, covering a plasma region ranging from 2.68 m to 3.88 m, with spatial resolution within 0.05 m to 0.07 m. The imaging optics was designed to collect the Stark multiplet from the Deuterium-α ($n = 3 \rightarrow 2$) transition. The MSE polarimeter consist of two photo elastic modulators (PEMs), working at 20 kHz and 23 kHz in tandem, with their fast axis oriented at 45° to each other and a linear polarizer working as an analyzer. Light from the output of the polarimeter is optically coupled to a set of interference optical filters with 0.4 nm bandpass, which are tuned to the $+\pi$ line of the Stark pattern. Data acquisition is performed at 250 kHz. Fourier analysis of the raw data from the JET MSE diagnostic, have revealed MHD signatures on the respective spectrograms, with unprecedented clarity, not seen before the new ITER-Like Wall at JET [3]. It is important to note, that those spectrograms does not show the full MHD pattern, as one could observe on Mirnov coil data spectrograms for instance. In JET hybrid or baseline ILW operational scenarios, it is often found $n > 1$ tearing activity, which can degrade plasma performance and is closely related with high Z impurities, accumulated at the plasma center [4], [5]. An example of those observations is depicted in figure 1, in JET hybrid plasma regimes for JET pulse #83533 ($P_{NBI} = 22.5$ MW, $I_P = 2.0$ MA, $B_T = 2.3$ T), where a $n = 1$ MHD can be observed on spectrograms from MSE channel 17 (figure 1a), with plasma location close to 3.128 m, and Mirnov coil data (figure 1 b). Also it is possible to observe on the MSE spectrogram, a MHD reflection around 23 kHz. Similar phenomena has been reported from DIII-D tokamak [6]. The signature of MHD activity from MSE data, has also been reported from JT-60 tokamak [7]. In both reports, the analysis uses the MHD fluctuation as a perturbation, to the conventional MSE signals, i.e. data coming directly from the Stark emission of the dedicated MSE neutral beam injector.

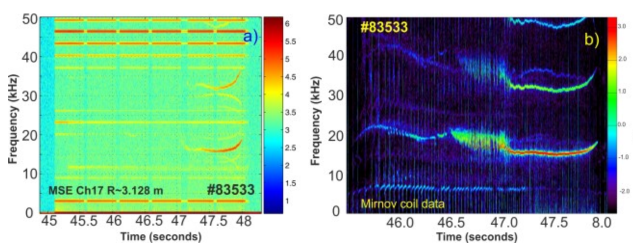

FIG. 1. MHD spectrograms for JET shot #83533 from a) MSE polarimeter and b) Mirnov coil data.

In this communication we will present a novel technique, which measures the amplitude of the fluctuations on the raw MSE signal, for each MSE channel, following carefully the frequency of the observed MHD on Mirnov spectrograms or by choosing a defined frequency bandwidth. The proposed technique, can be used whether the dedicated MSE neutral beam injector is firing or not. In this sense, this method it is not a conventional MSE measurement. Note that in figure 1a) the MSE injector is firing, where the horizontal bars corresponds to the fundamental PEMs frequencies, higher harmonics and beatings. To introduce this diagnostic technique, first we will present in section II, detailed measurements of the coherence between MSE polarimeter, Electron Cyclotron Emission (ECE) and Mirnov coil signals respectively, aiming to show the feasibility of the

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measuring technique. Finally, in section III will be presented a variety of experimental examples, for this technique in JET ILW plasmas. From these examples, will be highlighted experimental results, performed during q_{95} scan experiments in hybrid regimes, which allows the observation by the MSE polarimeter, of fluctuations on the Bremsstrahlung emission induced by tearing activity [8].

II. COHERENCE BETWEEN MSE, ECE AND MIRNOV COIL SIGNALS

The observation of the marking of MHD events on MSE, ECE and Mirnov coil data, has suggested to further investigate coherence between those signals in a variety of configurations, such MSE single channel and all ECE channels or all MSE channels with a single magnetic probe, in order to measure the degree of linear dependence between those signals at similar frequency. Coherence between two signals can be defined as:

$$C(\omega) = \frac{\left\langle X(\omega)Y^{*}(\omega)\right\rangle}{\left\langle X(\omega)X^{*}(\omega)\right\rangle^{\frac{1}{2}}\left\langle Y(\omega)Y^{*}(\omega)\right\rangle^{\frac{1}{2}}} \quad , \qquad (1)$$

Where $X(\omega)$ and $Y(\omega)$ are the Fourier transform of the measured signals. Results of the analysis are plotted in figure 2 for JET pulse #83533, where the coherence between the raw signal coming from MSE channel 17 close to the plasma core and all available ECE channels, has been computed for time slices when the n = 1 is absent (figure 2a) or is present (figure 2b). A significant coherence, can be observed for MSE channel 17 and ECE channels 54 to 60. The same method has been used for a single Mirnov coil and all MSE channels giving similar results.

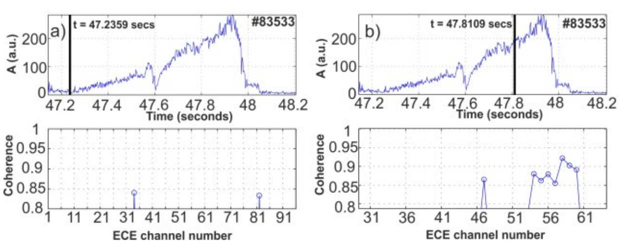

FIG. 2. Coherence between MSE channel 17 and all available ECE channels outside of the MHD a) and inside of the MHD b). Top traces shows the amplitude of the used magnetic probe.

In order to test the method, ECE channel 57 data (R_{maj} = 3.14 m), which is one exhibiting a high degree of coherence and similar plasma location with MSE channel 17, has been Fourier analyzed to retrieve the respective spectrogram (see figure 3).

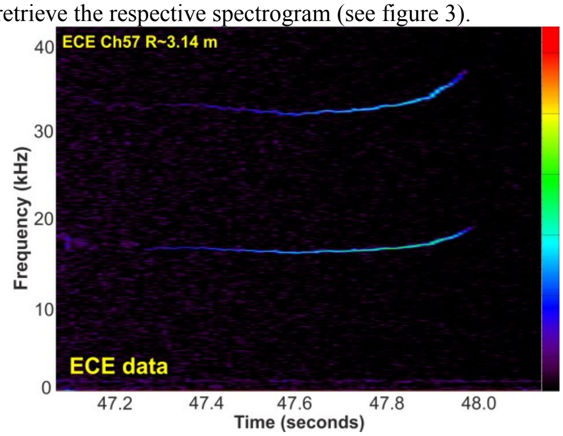

FIG. 3. Spectrogram from ECE channel 57 data.

III. EXAMPLES OF THE TECHNIQUE IN JET ILW PLASMAS

The technique has been used in several JET ILW operational scenarios. The first example is in hybrid development experiments. A very common feature of those plasmas, is the occurrence of an internal kink-like n = 1, m = 1 in its initial phase, which shortly develops to tearing activity, as is the case of shot #82722 [4]. The behavior of this MHD is closely related with impurity peaking at the plasma center, mainly tungsten in JET ILW plasmas. The MSE raw signal data has been used to retrieve the MHD spectrogram which is presented in figure 4a). Here is possible to observe the MHD, where the dashed circle points to its relationship with the impurity accumulation observed in figure 4b) from Soft-X Ray (SXR) diagnostic. The impurity peaking is followed by T_e sawteeth (ST) flushing out the accumulated impurity. The ST signature it is also marked on the SXR data.

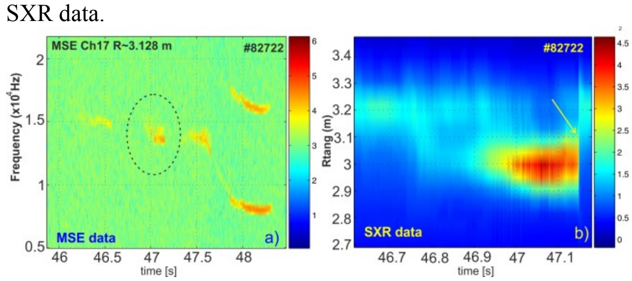

FIG. 4. MSE spectrogram a) and SXR data plot b) shows that possibly both diagnostics are observing the same event.

The related phenomenology is described in figure 5. Here the impurity flush out is clearly linked to the ST as observed in figure 5a), where the gradient of the electron temperature (grad(T_e)) has been computed, marking the ST signature. Remarkably, the ST observed on the ECE data, is clearly signed on the MSE data, as can be observed in figure 5b) for a radial location from 3.1 m to 3.45 m.

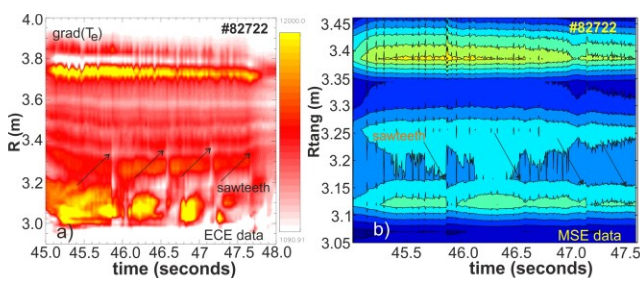

FIG. 5. Observation of the ST signature by a) the gradient of T_e and b) the MSE polarimeter

Another example on the application of the technique, can be found in the so called baseline ELMy-H mode scenario, presented in figure 6 for JET pulse #83400. The MSE signals have been used to observe in figure 6a) the establishment of the Edge Transport Barrier (ETB) and its dynamics. Furthermore, a strong m/n = 3/2 MHD closely related with impurity peaking is present, In figure 6b) the grad(T_e) criteria has been used, showing consistency with the MSE polarimeter technique.

Finally, the technique has been applied in JET hybrid ILW plasmas, during q_{95} scan experiments for JET pulses #84667 and #84669 where the q_{95} parameter has been varied from 4.0 to 3.0.

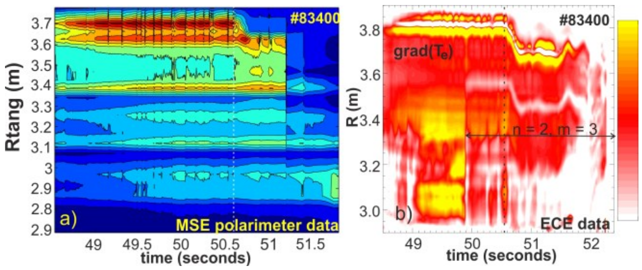

FIG. 6. ETB as observed by a) MSE polarimeter and b) ECE

During the discharges, m/n = 3/2 and 4/3 tearing activity is observed. Amplitude fluctuations on the MSE polarimeter signals has been scanned at very low frequency (typically 400 Hz to 50 Hz bandwidth). The result of the analysis is presented in figure 7a) and b) for the 2 JET pulses respectively. Where strong structures are observed close to the plasma center.

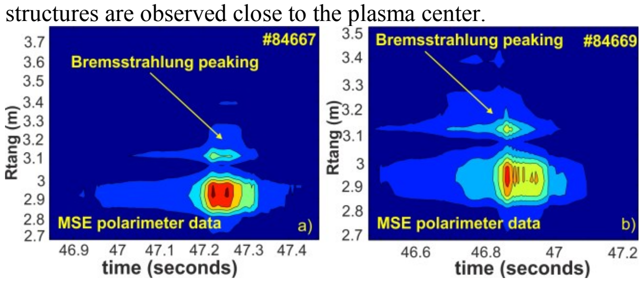

FIG. 7. MSE polarimeter results for shots a) 84667 and b) 84669

Careful comparison of the peaking time of those structures, with the peaking time of the Bremsstrahlung emission, as measured by the visible spectrometer diagnostic (see figure 8a), allows to conclude that both diagnostics have an exact match, pointing to the conclusion that they are probing the same event. In figure 8b) is plotted the spectrogram for JET pulse #84667, where a low frequency, n = 1, MHD during plasma landing is encircled, corresponding to the event signed by the MSE polarimeter data.

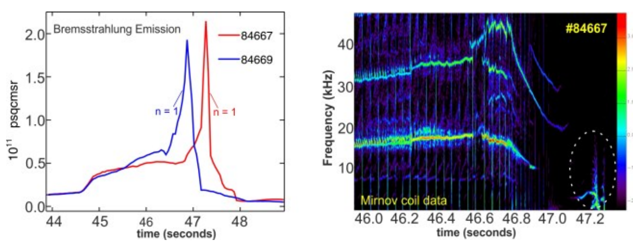

FIG. 8. a) Bremsstrahlung emission from visible spectrometer, dashed vertical lines points, to the time when the event is signed by MSE data. b) Pick-up coils spectrogram, showing the MHD event signed by the MSE polarimeter.

This result can be interpreted by considering the perturbation on the bremsstrahlung emission by the tearing [8]. The visible broadband bremsstrahlung emission is given as:

$$\frac{dI_B}{d\lambda} = 2.27\times10^{-14}\frac{n_e^2 Z_{eff}}{\lambda T_e^{1/2}} e^{-hc/\lambda T_e} \quad , \qquad (2)$$

While the fluctuation on the bremsstrahlung emission induced by the tearing activity, can be written as:

$$\tilde{I}_B \propto \xi \nabla I_B \qquad (3)$$

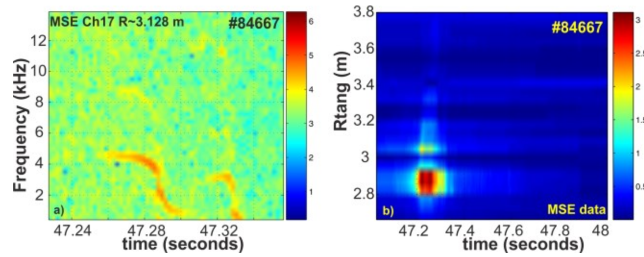

FIG. 9. Detail of the observed MHD by the MSE polarimeter.

With ξ the radial displacement of the MHD. Regarding to equation (2), the dependence of the emitted light on n_e^2, the fluctuation on the bremsstrahlung emission is a measure of density fluctuations, induced by the tearing. From these considerations, we can conclude that the optics of the MSE polarimeter is likely measuring density fluctuations. The light source for the MSE polarimeter is broadband visible bremsstrahlung. It is worth noting, that no NBI heating is present at the time of measurements. The detail of the MHD observed by the MSE polarimeter is represented in figure 9 a) by the MSE spectrogram and b) the 2D plot of the raw MSE signal amplitude fluctuation, showing the structure at the plasma center and its impact across the plasma radial direction.

IV. CONCLUSIONS

The question of MHD observation through Fourier analysis of the MSE polarimeter data has been addressed. Measurement of the coherence between MSE polarimeter signals, ECE and Mirnov coil data gives confidence to go further on the use of this novel technique in JET ILW experiments. Results from q_{95} scan experiments in hybrid scenarios, have shown that the light source for the MSE polarimeter is broadband bremsstrahlung emission. Future work should include, studies for cases where the MSE injector is firing. In principle, it would be possible to separate the intensity of the MSE polarized light, from the intensity of the bremsstrahlung polarized light by using the total polarized light received by the polarimeter. Interferometry data shows the same MHD signatures marked by the MSE polarimeter signals. Efforts are under the way to develop comparative studies between reflectometry data and MSE polarimeter analysis in JET ILW plasmas. Finally, the underlying physical mechanism, for the polarization of visible Bremsstrahlung emission, needs to be assessed.

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