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An Example of a New Approach for the Development of Disruption Protection Tools for JET: The Mode-Lock Disruption Class

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** See annex of M.L. Watkins et al, “Overview of JET Results ”,*
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ABSTRACT

The paper presents a new approach based on the discrete Fourier transform to improve the performance of the mode lock disruption protection system at JET. With this algorithm, not only the amplitude but also the dynamic of a mode lock event is taken into consideration. This allows improving the performance of the present disruption protection system at JET.

1. INTRODUCTION

Studies based on a first-principles physics approach have produced a wider understanding of JET disruptions [1] and [2].

The paper presents a new approach for the detection of disruptions in a tokamak. The general purpose of this approach is to study the techniques that can be applied to anticipate the occurrence of a disruption, starting from the physical analysis of the different classes of disruptions.

The first type of disruption studied in this work has been the locked mode. On JET, protection against locked mode disruptions already exists and uses the mode amplitude as a threshold. The current mode-lock signal presents, however, an offset that has a non-linear dependence on currents circulating in the poloidal field circuit. Hence, to avoid the effect of spurious trips in this signal, the trigger level used to request the pulse termination is set to a rather high value. This procedure has the clear drawback of delaying the request to safely shut down the plasma even when, by monitoring the signal itself, the presence of a mode lock could have been predicted earlier.

Different algorithms have been tested for minimising the effect of this offset so as to provide an earlier alarm than the current mode lock protection system.

This paper focus on the discrete frequency spectrum of the locked mode signal calculated using the Discrete Fourier Transform (DFT), which gives the best performance.

2. PHYSICAL BASED APPROACH

The physical mechanism responsible for mode locking is the braking effect of error fields or MHD modes (such as resistive wall modes) that slow down and ultimately stop the plasma rotation.

In a mode lock event, the mode amplitude grows during the slowing down of the plasma rotation: the resulting high amplitude mode degrades the plasma confinement and can subsequently lead to a disruption.

As locked modes are experienced during the final stage in almost all the disruptions, at JET, as in other machines, the protection against this event exists and it is performed by the Poloidal Field Protection System. This system uses the mode lock amplitude to detect the precursor of a mode lock disruption. The mode lock amplitude is normalized to the plasma current and compared to a user-defined threshold. If the normalised signal exceeds the threshold a pulse termination request is issued via Pulse Termination Network.

However, the actual mode lock signal shows a considerable offset even during experiments without a locked mode. This offset is not constant and has a non-linear dependency on the current in the poloidal field circuit.

This phenomenon is clearly illustrated in fig.1 for a dry run (i.e. pulse without plasma), where the blow-up shows the mode lock signal to be initially higher than the Poloidal Vertical Field Current, while it behaves the opposite way during the second phase of the pulse.

The existence of this offset delays raising the alarm until the last phase of the disruption, even if, by examining a-posteriori the signal itself, the mode lock could have been detected earlier.

3. APPLICATION OF THE PHYSICS BASED MODEL

This algorithm has been developed to use all the information present in the signal, such as the amplitude and the dynamic of a mode lock event. The DFT has been applied to the mode lock signal to highlight the rapid variations of the signal. The signal considered has a sampling rate of 0.4ms: the DFT is applied to a 20ms moving window, so that the window of observation is composed by 50 samples. Every 0.4ms a new DFT of the mode lock signal is calculated using the 50 previous samples, the DC component is removed, and the sum of all the other frequencies present in the spectrum is used to recognize rapid signal variations. Figure 2 shows an example of the performance of this new algorithm, as applied to the disrupted pulse #63101. In this case the DFT signal (blue line) triggers the alarm 106ms before the current mode lock signal (green line).

4. RESULTS

The DFT algorithm has been benchmarked on a database of 106 disrupted pulses, which were divided in two different groups. The first group is composed of disruptions that have not been recognised by the current mode lock system: this set contains 39 disruptions, 37 of which would have caused the DFT algorithm to trigger a request for termination of the pulse. For 28 of these pulses the termination request would have been raised in average 200ms before the occurrence of the disruption.

The second group lists 67 disrupted pulses that did trigger a mode lock alarm. For 50 of these pulses the DFT algorithm would have triggered the alarm in average 75ms before the current mode lock protection. However, in 17 pulses the mode lock protection raises the alarm before the DFT algorithm would have done. These 17 pulses have a slowly increasing locked mode signal amplitude, not picked up by the DFT algorithm. Figure 3 shows an example of this phenomenon. For this case the mode locks about 500ms before the disruption, but the mode amplitude increases so slowly that it is not picked-up by the DFT signal. All these 17 cases are characterised by this phenomenon: the mode lock system trigger the alarm more than 300ms before the disruption. By analysing the database it has been concluded that using this technique together with the present protection system, the performance increases from 63% of pulses correctly predicted to 90%. Moreover this technique anticipates the alarm for 77% of the considered pulses.

5. CONCLUSIONS

Starting from the identification of the physical mechanisms driving the disruption, different algorithms can be developed to protect tokamaks against such events.

This paper presents, as a first example, an improvement of the performances of the mode lock protection system currently in used at JET, using a simple algorithm.

Further studies are ongoing to apply the same methodology to others types of disruption.

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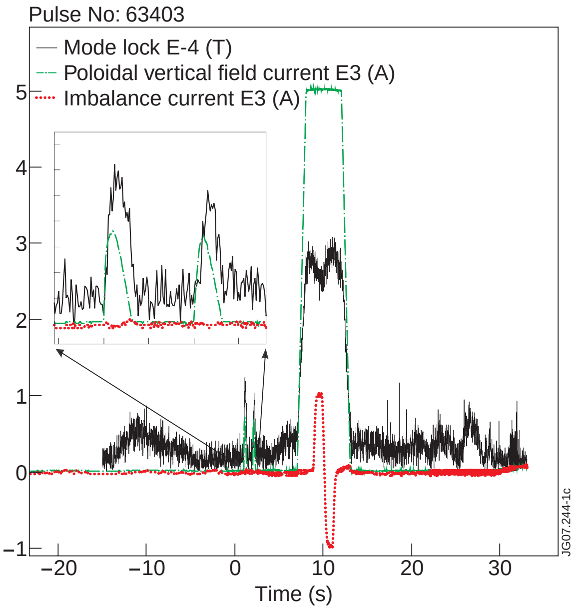

Figure 1: Dry run pulse example (Pulse No: 63403).

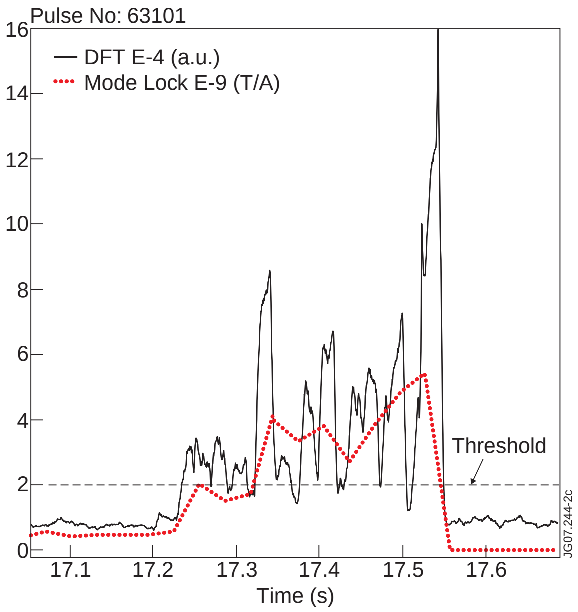

Figure 2: Example of the DFT signal for the Pulse No: 63101.

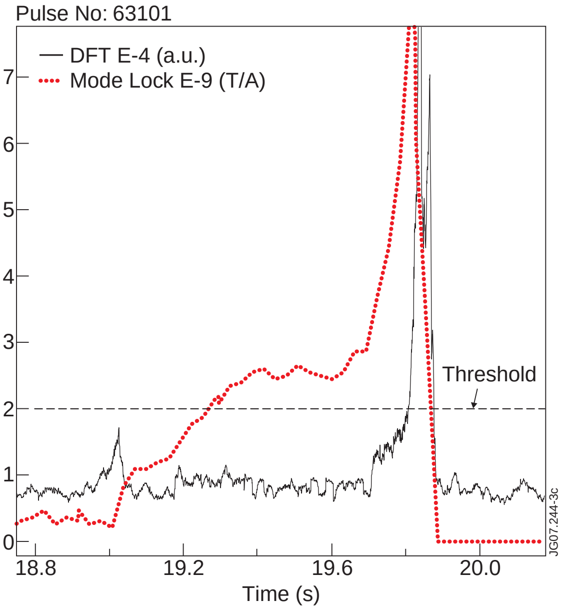

Figure 3: Example of the DFT signal for the Pulse No: 62124.