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Automatic Location of Disruption Times in JET

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ABSTRACT

The loss of stability and confinement in tokamak plasmas can induce critical events known as disruptions. Disruptions produce strong electromagnetic forces and thermal loads which can damage fundamental components of the devices. Determining the disruption time is extremely important for various disruption studies: theoretical models, physics-driven models or disruption predictors. In JET, during the experimental campaigns with the JET-C (Carbon Fiber Composite) wall, a common criterion to determine the disruption time consisted of locating the time of the thermal quench. However, with the metallic ITER-like wall (JET-ILW), this criterion is usually not valid. Several thermal quenches may occur previous to the current quench but the temperature recovers. Therefore, a new criterion has to be defined. A possibility is to use the start of the current quench as disruption time. This work describes the implementation of an automatic data processing method to estimate the disruption time according to this new definition. This automatic determination allows both reducing human efforts to locate the disruption times and standardizing the estimates (with the benefit of being less vulnerable to human errors).

1. INTRODUCTION

In JET experiments, the stability and confinement of the plasma can be lost in a few hundred microseconds [1, 2]. The electromagnetic forces and thermal loads produced by disruptions can damage the components of the devices. Disruptions are difficult to understand from a theoretical point of view due to: event complexity, highly nonlinear interactions and diversity of causes. Furthermore many different behaviors and current quench scenarios are possible in disruptions [3]. Because of this, these events have been the subject of several studies along the years, where the causes and consequences have been analyzed [1-4].

The importance of disruptions entails the need of efficient predictors to carry out mitigation actions and avoid damages in the devices. Many studies have tried to achieve an efficient predictor mainly using support vector machines (SVM), neural networks, genetic algorithms and various other techniques and theories [5-8]. The disruption time is very important for the development of theoretical models, physics driven systems and disruption predictors, but its location is a hard task if we look at the behavior of disruptive discharges in Carbon Fiber Composite (JET-C) campaigns and with the metallic ITER-like wall (JET-ILW). The purpose of this paper is to provide an analysis tool to locate the disruption time defining a new criterion.

This article explains briefly about the disruptions in JET with the JET-ILW in section 2. Section 3 shows an overview of wavelets theory, which has been used to develop the analysis tool. After that, section 4 explains the automatic location of disruption times. Finally section 4 contains the results obtained and conclusions are the subject of section 5.

2. DISRUPTIONS DURING OPERATION WITH THE JET-ILW

In the past JET-C campaigns, disruptions were identified as the fast decay of the plasma current (typically called “current quench”) produced by the increase in plasma resistivity that thermal quench cooling generated [3, 9] (Figure 1).

However, disruptions at experiments with the JET-ILW show a different behaviour. It is not unusual for these plasmas to present several thermal quenches previous and after the current quench. In many instances the temperature recovers and the plasma survives until the next thermal quench (Figure 2).

Therefore, the criterion used during the JET-C experiments is usually not valid and therefore, a new one has to be defined. A possibility is to use the start of the current quench as disruption time, since around this time the plasma looses completely its stability, becomes uncontrollable and ends abruptly.

2. REVIEW OF WAVELETS THEORY

Wavelets are basis functions which can be used to approximate a signal or extract information from data. They are similar to Fourier transforms but wavelets are able to represent a signal in the time and frequency. The discrete wavelet transforms (DWT), proposed by Mallat (1989), is an efficient algorithm for calculating the wavelet coefficients of a discrete series. The idea is to filter the series, using the high and low pass filters associated with the wavelet basis to obtain the wavelet coefficients. In DWT, the signal is convolved and decimated. Therefore, a modified version of the traditional wavelet transform DWT has been used in this study. Non-Decimated Wavelet Transform (NDWT) or stationary wavelet transform, has no subsampling step so, it keeps the same number of coefficients of each level.

The basis or family functions chosen in this study is the Haar wavelet. A Haar wavelet is the simplest type of wavelet, a sequence of rescaled “square-shaped” functions. As a special case of the Daubechies wavelet, the Haar wavelet is also known as D2. The main disadvantage of this family is that it is not continuous and not differentiable; but this is an advantage for the analysis of signals with sudden transitions.

3. DISRUPTION LOCATION

The data processing algorithm is based on following the temporal evolution of the plasma current time derivative during the last 3 seconds of the discharge before the plasma current crosses the value of 50kA. To this end, its evolution is analyzed through a multilevel non decimated wavelet decomposition looking for the temporal location of the components that determine the current quench.

Two sets of coefficients are provided: detail and approximation. The analysis has been done using both coefficients but the best results have been obtained with the approximation coefficients. Therefore, the location is carried out with the coefficients of the approximation of level L. This latter signal shows large-scale featuresat the current quench times. To discriminate these features from others, due to phenomena different from disruptions, it is necessary to identify an appropriate threshold. This threshold allows selecting only the main peaks that correspond to the biggest changes in plasma evolution. It is defined by the bounds of the band $[\overline{W}_L - k \cdot \sigma_W, \overline{W}_L + k \cdot \sigma_W]$, where $\overline{W}_L$ and sW are the mean value and the standard deviation of the approximation coefficients obtained after applying non decimated wavelet of level L to current time derivative respectively, and k is a small positive integer.

With regard to the developed interface and create the ground truth, the user can select the discharge to analyze; the program will show the plasma current, the time derivative of plasma current and the approximation coefficients with the threshold. The possible disruption times are shown and the user chooses the point that best represent the beginning of the disruption (Figure 3).

4. RESULTS

Very promising results are obtained from the final analysis of the disruption database; which is formed by 256 non intentional and intentional disruptions from 2011-2012 JET-ILW campaigns. The discharges have been analyzed with different values of levels for non decimated wavelet (Levels 1 to 6) and threshold (values of k from 1 to 6). Summarizing, the best results are obtained for levels 1, 2, 3 and 4 with sigma k = 1 (Table 1). A window of 16 ms around the current quench provides a success rate of 100% and a window of 8ms around the current quench shows a success rate of 99.61% (only 1 discharge is outside the window of 8ms).

CONCLUSIONS

Taking into account that many disruptions occur during JET experiments and that analysis and estimation of disruption times are also carried out manually, it is not unusual to find human errors when a big database is analyzed. The proposed automatic data processing algorithm allows both reducing human efforts to locate the disruption times and standardizing the estimations (with the benefit of being less vulnerable to human errors).

Locating disruption times, minimizing human errors and establishing a general criterion, are important issues which must be addressed. Actually, disruption predictors are developed using the disruption time to characterize the disruptive features of the training samples. Accordingly, enhancing, the importance of the precise estimation of disruption times. If the disruption time is not estimated correctly, the samples that define the disruptive behavior could be confusing and provide false information to classifiers.

This article shows a possible way to generalize and calculate the time of disruptions, which could help in different studies: benchmarking of theoretical models, development of physics-driven models and training of disruption predictors.

After numerous simulations with different values of the parameters, the best results shown in section 4 provides a success rate of 100% in a window of 16ms around the current quench and 99.61% in a window of 8ms. Disruption location is sometimes confused so, user selection lets determine which point corresponds better to the beginning of disruption.

Future works could include other signals and parameters to define deeply disruption time, as electron temperature, radiated power, loop voltage. Furthermore, it could be studied whether including the time derivative of the plasma current in a classifier can provide useful information about disruptions.

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Level (L)	Sigma (k)	Window 16ms	Window 8ms
1	1	100% (256/256)	99.61% (255/256)
2	1	100% (256/256)	99.61% (255/256)
3	1	100% (256/256)	99.61% (255/256)
4	1	100% (256/256)	99.61% (255/256)

Table 1: Values of levels for non decimated wavelet and threshold provide the best results.

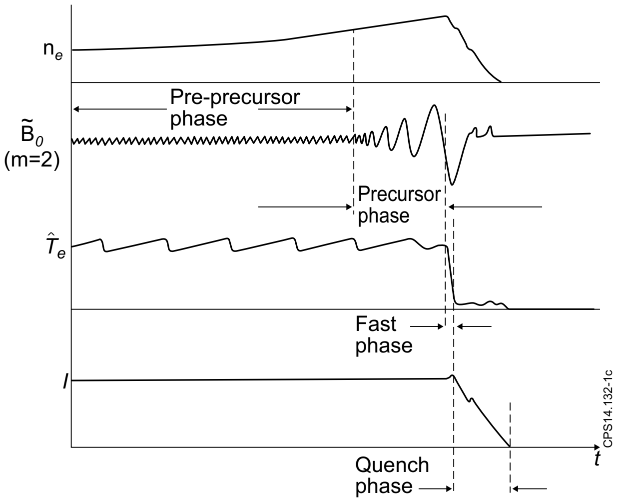


Figure 1: Example of a disruption during campaigns with the JET-C wall [9].

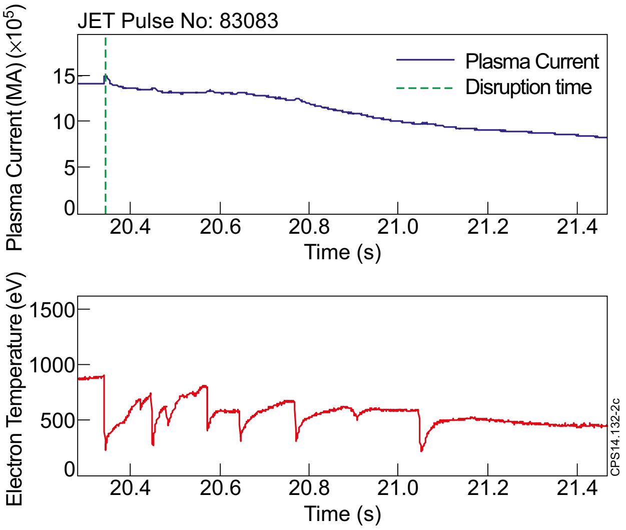
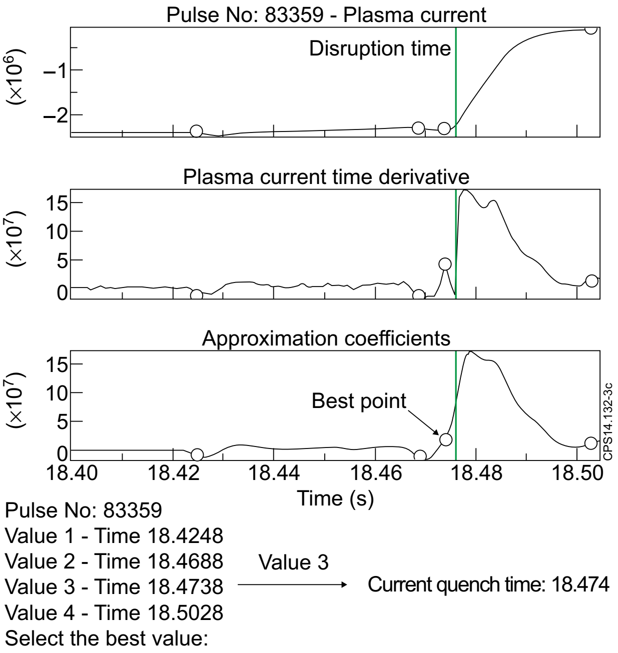


Figure 2: Disruption from JET-ILW experiments. It can be seen several thermal quenches and how the temperature recovers.



```
Pulse No: 83359
Value 1 - Time 18.4248
Value 2 - Time 18.4688
Value 3 - Time 18.4738
Value 4 - Time 18.5028
Select the best value:
```

Figure 3: Process of the data processing algorithm. The program shows the best options under the parameters selected (in this case a level of 3 and for sigma, k=1) and, user selects the proper time. In this example the difference between the current quench time estimated and the disruption time is 1ms.