A comparative multivariate analysis of disruption classes between JET and AUG

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I. Introduction

Disruptive events still represent one of the main concerns for safe operation of large size tokamak devices, in particular in relation to the preservation of the structural integrity of the machine. This aspect plays a key role in the design and running of the next step experimental devices as ITER and motivates the need of developing methods and techniques aimed to minimize both the number and the severity of disruptions. Furthermore, when a disruption occurs it would be particularly important to be able to distinguish among its different types to improve avoidance and mitigation schemes. In order to extrapolate results from existing devices to the next step ones, it is crucial to interpret the multi-machine plasma confined experiments data with a firm physical basis. The definition of common basis and criteria for cross-machine analysis would facilitate the development of portable systems for disruption prediction and classification, which is becoming of increasingly importance for the real-time plasma control and operation.

Recently, criteria for manual disruption classification have been proposed both for JET [1] and AUG [2]. It has been noted that several physics instabilities in AUG [2] are also usual disruption precursors in JET [1]. In this paper, two data bases have been used containing 116 flat-top disruptions occurred at JET with ITER Like Wall (ILW) from 2011 to 2012 and 102 flat-top disruptions occurred at ASDEX Upgrade (AUG) from 2011 to 2014. A manual classification of disruptions has been done for the AUG database. In particular, the analyzed AUG discharges have been clustered in different classes following the chain of events as proposed in [1] for JET. The manual classification for JET was already available [3]. The distribution of the disrupted pulses in the classes is very similar in the two machines, even if the relative percentage of each class of disruption is strongly influenced by the scientific program and/or by the number of sessions devoted to a given program. A smaller percentage of disruptions during impurity accumulation (RPK) has been found in AUG with respect to

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* See the Appendix of F. Romanelli et al., Proceedings of the 25th IAEA Fusion Energy Conference 2014, Saint Petersburg, Russia.

** See http://www.euro-fusionscipub.org/mst1.

JET; this reflects the capability of this device to centrally heat the plasma with ECRH in most of the experimental scenarios [2].

The availability of common disruption classes for the two machines allows us to perform an analysis aiming to identify a robust set of dimensionless parameters, with particular reference to basic quantities available in real-time in different machines. The raw signals have been processed in the time and frequency domains in order to synthesize non-dimensional indicators fitting both the considered devices. In this paper, the procedure followed to build such indicators has been shown with reference to the locked mode (LM) signal. The validity of the proposed indicator has been assessed by using it as disruption predictor. Its performance has been compared with that of the LM raw signal, which is commonly used both at AUG and JET to trigger the mitigation system.

II. Physics-based indicators

An indicator can synthesize more signals in order to describe a complex phenomenology, or can be based on a single signal when the signal itself is intrinsically representative of a disruptive behaviour, as for example in the case of the locked mode. In most of the cases, in order to maximize the information content in the signal, it could be required to remove noise or unwanted spikes, or simply to extract the trend of the signal filtering transient phenomena. After the signal-processing step, in order to allow an eventual comparison among different machines it is required to find suitable scaling factors and to normalize the signal.

Even if the amplitude of the LM signal scales with several quantities, in this work the normalization has been done with respect to the amplitude of the plasma current. To remove the trend and the offset from this signal (sampling frequency of 10 kHz), its maximum deviation from the mean over a sliding window of 3.2 ms is evaluated (Fig. 1c). Moreover, a FFT of the normalized LM signal is performed over a sliding window of 51.2 ms, and the DC component is removed. Then, the standard deviation of the FFT (Fig. 1d) and the sum of the FFT components, weighted with respect to the frequencies themselves (Fig. 1e), are evaluated. The final indicator obtained multiplying these three signals has been plotted in logarithmic scale to better visualize its behaviour (Fig. 1f). In order to statistically assess its effectiveness, such indicator has been tested as a disruption predictor both on the considered JET and AUG databases and its performance have been compared to those ones obtained with the simple raw signal. In both the cases, the probability density function of the indicator for samples belonging to the safe and the disruptive phases of a subset of discharge (training set) have been compared in order to identify a range of values that potentially discriminate the two phases. In that range, a threshold has been optimized maximizing the successful prediction rate on the training set, and then a test over a separated set of discharges (test set) has been performed. Testing the indicator on both JET and AUG, a significant improvement of about 10% of the successful predictions on the test sets is achieved, passing from 69% to 77% at JET and from 65% to 74% at AUG. A disruption is considered successfully predicted when triggered between 1.5 s and 10 ms before the disruption time for JET, and between 500 ms and 2 ms before the disruption time for AUG.

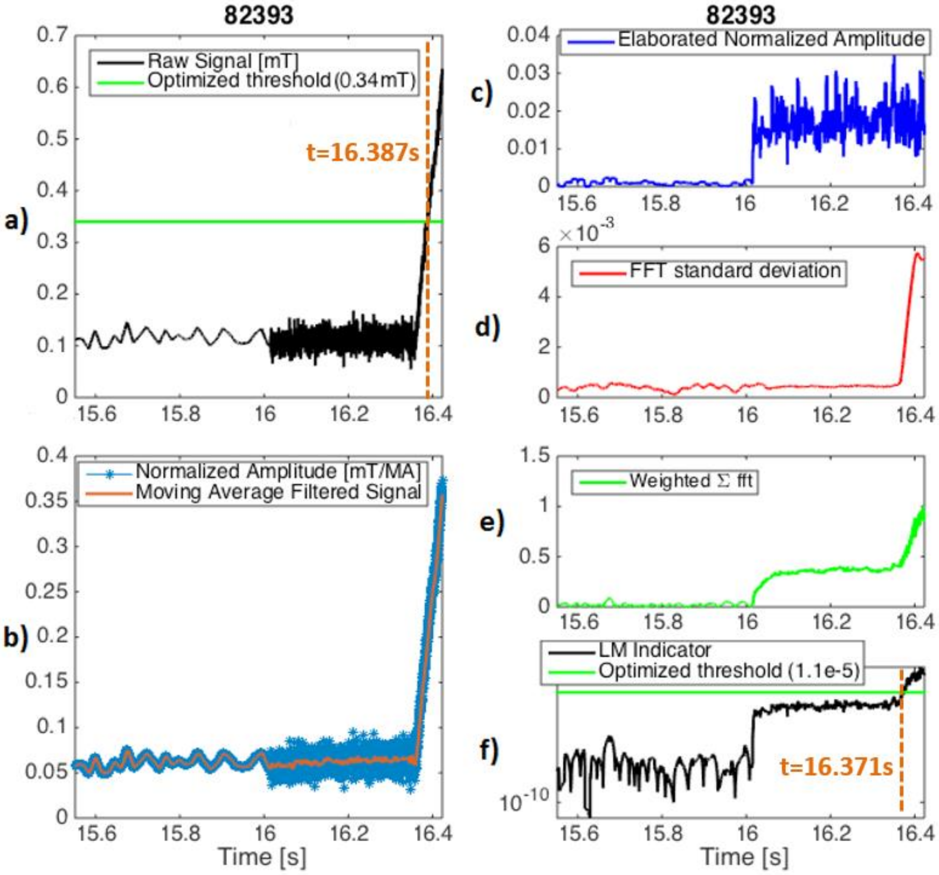

Figure 1: Construction of the Locked Mode indicator for JET

As it has been introduced before, an indicator can be built not only from a single signal, but also properly combining information and sequence of events described by more signals. In Fig. 2, a set of dimensionless parameters is reported which represents some of the most relevant quantities describing the accumulation of high-Z impurities. Depending on the plasma underlying conditions, the accumulation of high-Z impurities can lead to disruption both in JET and in AUG. Even if the time scales are different, a robust calculation of some peaking factors of basic quantities, as radiation and temperature profile, can be well correlated with the slow impurity profile peaking, as well as the final reduction or even suppression of the sawtooth activity, followed by the onset of strong tearing modes up to the final mode locking.

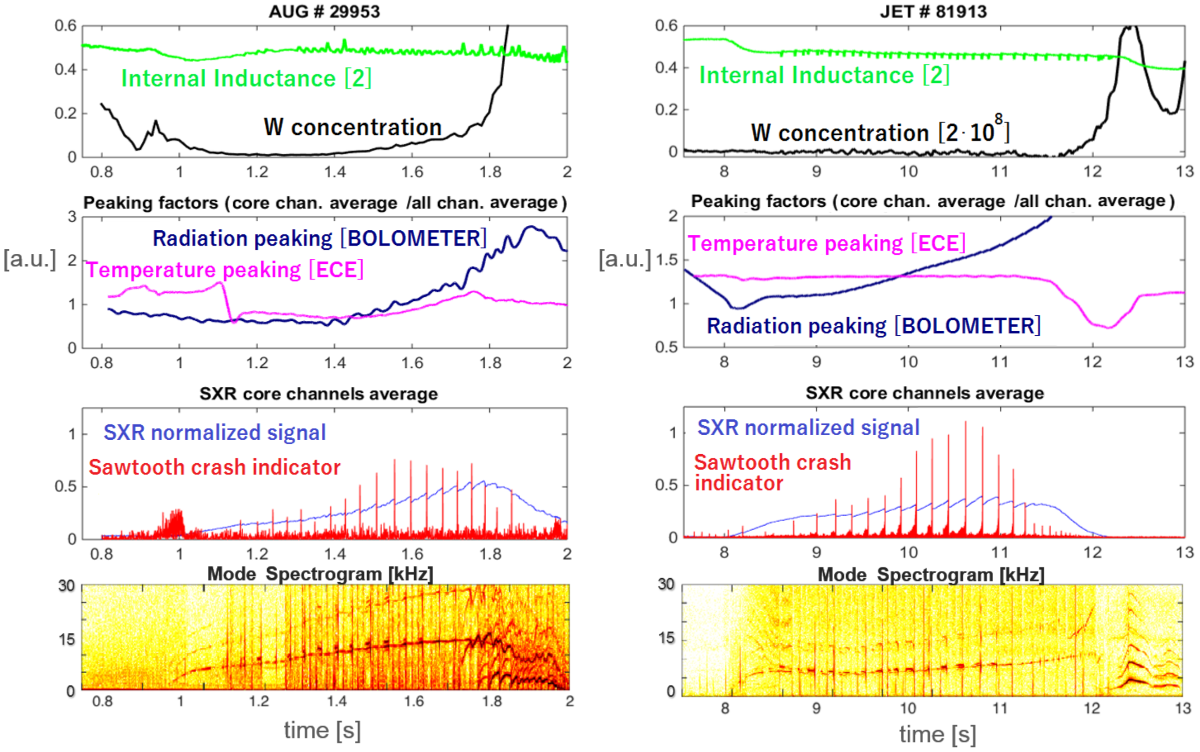

Figure 2: Dimensionless parameters describing impurity accumulation on AUG and JET.

III. Conclusions

In order to get reliable and comparable dimensionless parameters, the steps of signal processing and feature extraction are of primary importance as well as the investigation of suitable scaling factors for normalization. This requires an extensive modelling of past experiments, concerning in particular the definition of thresholds for the obtained indicators, and a connection to the operational space where the plasma is evolving. This link can be provided in real-time through mapping by means of manifold learning techniques, as described in [4].

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