Detection of Regime Changes in the Dynamics of Thermonuclear Plasmas for the Disruptions Prediction Improvement

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Abstract. A series of time series analysis methods is deployed to determine when the plasma dynamics of the tokamak configuration varies, indicating the onset of drifts towards a form of collapse called disruption. The analysis of a representative set of plasma discharges shows that the information for disruptions prediction is available in the diagnostic signals 300 ms before the beginning of the collapse, a time interval which allows mitigation actions.

Introduction

In particular circumstances, nonlinear systems can collapse suddenly and abruptly. Anomalous detection is therefore an important task. Unfortunately, many phenomena occurring in complex systems out of equilibrium, such as disruptions in tokamak thermonuclear plasmas, cannot be modelled from first principles in real time compatible form and therefore data driven, machine learning techniques are often deployed. A typical issue, for training these tools, is the choice of the most adequate examples. Determining the intervals, in which the anomalous behaviours manifest themselves, is consequently a challenging but essential objective.

Results and discussion

A series of methods is deployed to determine when the plasma dynamics of the tokamak configuration varies, indicating the onset of drifts towards a form of collapse called disruption. The techniques rely on changes in various quantities derived from the time series of the main signals: from the embedding dimensions [1] to recurrence plots measures for assessing the similarity of the evolution of different time series [2-3] and to indicators of transition to a chaotic regime [3]. The methods, being mathematically completely independent, provide quite robust indications about the intervals, in which the various signals manifest a pre-disruptive behaviour.

The analysis of several discharges in different experiments reveals that the first signs of an approaching disruption are present in the plasma current and locked mode amplitude signals about 300 ms before the beginning of the collapse. Earlier warning or alarms, launched by predictors using the signals considered in the present work, should therefore be considered false alarms. However, 300 ms are a comfortable time interval to undertake mitigation actions. The techniques presented should therefore allow building a significantly more reliable training sets for the predictors already providing quite satisfactory performance.

Unfortunately, most of the analysis techniques deployed are quite demanding in terms of computational resources. The only fast one is the 0-1 chaos test. On usual computers, the routine, provided by the *DynamicalSystems.jl* software package [5], written in Julia language, runs in about 1.2 ms, already compatible with real time applications (on JET the cycle time of the real time network is 2 ms). All the other methods require from about 500 ms to 1 second to run. The potential of acceleration measures and implementation using GPUs will be a matter of future investigations.

With regard to the plasma dynamics, very interesting new information has emerged. The signal processing techniques has revealed that the plasma evolution leading to disruptions typically consists of two phases. First the dynamics becomes more chaotic or at least less coherent, for a couple of hundreds of ms. Then, in the interval closer to the beginning of the collapse, the signal become again more coherent and less chaotic. This behaviour should be further investigated also because it shows analogies with other anomalous events namely the onset of epilepsy.

References

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