Statistical Study of TCV disruptivity and H-mode Accessibility

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INTRODUCTION

Optimising tokamak operation consists of finding a path, in a multidimensional parameter space, which leads to the desired plasma characteristics and avoids hazardous regions. Typically the desirable regions are the domain where an L-mode to H-mode transition can occur, and then, in the H-mode, where ELMs and the required high density can be maintained. The regions to avoid are those with a high rate of disruptivity. On TCV, learning the safe and successful paths is achieved empirically. This will no longer be possible in a machine like ITER, since only a small percentage of disrupted discharges will be tolerable. An *a priori* knowledge of the hazardous regions in ITER is therefore mandatory. This paper presents the results of a statistical analysis of the occurrence of disruptions in TCV.

For the H-mode accessibility, it is usually admitted that a minimum auxiliary power is required, and that this power threshold depends on some plasma parameters. On TCV, since the H-mode was achieved with Ohmic heating only, such a power threshold can not be determined. Plasma shape, current and densities as well as the vacuum vessel conditioning are known to play a role in the H-mode accessibility. Discriminant analysis, a powerful statistical method, has been used to estimate a probability of being close to an L-mode to H-mode (LH) transition, which could be used to guide the plasma discharge towards the LH transition, with the help of an advanced and intelligent control system.

PLASMA DISRUPTIVITY IN TCV

In order to quantify the disruption rate in TCV, we have defined the disruptivity as the number of disruptions observed in a multidimensional cell of the operational domain, divided by the total plasma operation time spent in that cell. This latter time is provided by a database containing time slices taken every 50 ms in every plasma discharges produced over more than two years of operation, a total of over 60'000 time slices. The disruptions have been visually classified according to their operational context, such as during an L-mode or H-mode phase or in the presence of locking modes, etc. This allows us to analyse the disruptivity in different contexts separately and also to remove disruptions provoked by technical failures or feedback control experiments, which have nothing to do with the underlying physics of disruptions. The aim of such an approach is to identify the high disruptivity zones without *a priori* knowledge. For instance, the q=2 limit naturally emerges from the analysis as a hard limit, with only a slight increase in disruptivity for 2<q<3.

To answer the question whether the Greenwald density limit is a strong limit or not, we plot the disruptivity in the Greenwald diagram for 4 different contexts (fig 1). In the stationary case, in L-mode or H-mode or soon after a HL transition, the Greenwald limit (G=1) is not exceeded. However, the disruptivity does not increase with the Greenwald parameter (G). This limit then appears like a soft limit for the low currents in L-mode, in the sense that the plasma itself avoids going to higher density, but without disrupting. For higher plasma current values, the disruptivity simply increases with the plasma density, not with G. In H-mode plasmas, the disruptivity also increases with the density with only a weak dependence on the Greenwald parameter (Ip/a^2). During the current decay phase, the limit is exceeded, but with a high disruptivity. In this case the Greenwald density limit appears as a strong limit.

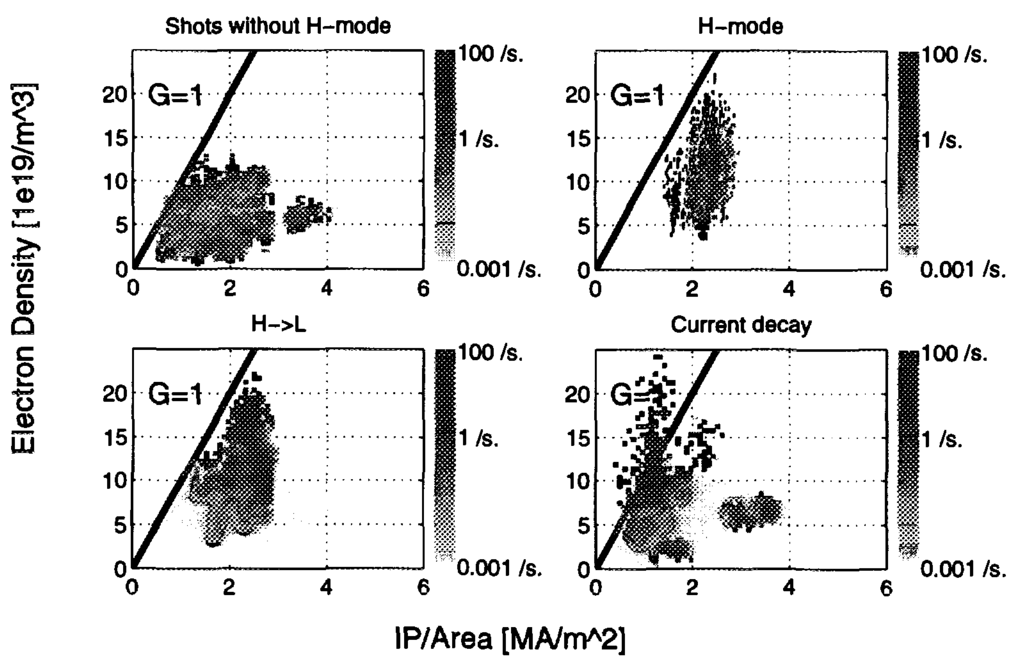

Fig 1: Disruptivity at the Greenwald density limit in different contexts

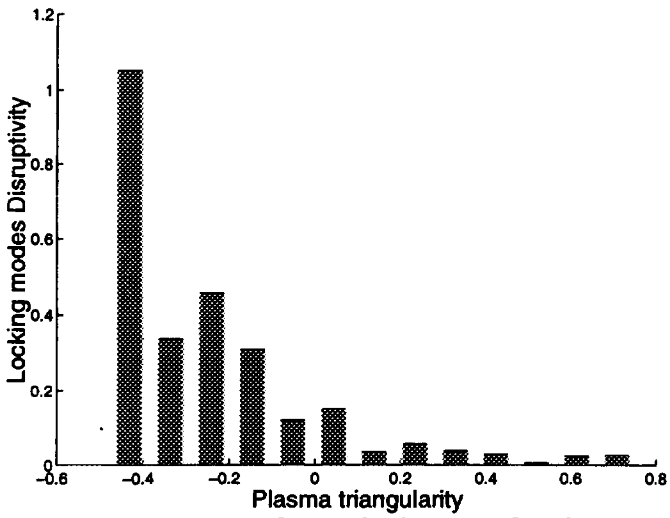

Fig 2: Disruptivity due to locking modes decreases with the triangularity

Although no clear dependence on the plasma shape is observed when all disruptions are taken together, either in a Hugill or li:q diagram, the disruptions due to locking modes are found to occur mainly at low triangularity, as shown in Fig. 2. This decrease of disruptivity at high positive triangularity is commonly used on TCV to cross q=3. For instance, even if the desired final plasma has a negative triangularity, its formation goes through a high triangularity phase (δ>0.2). With such a formation path, we performed 180 similar shots, one every morning, with a disruption rate lower than 1 %.

H-MODE ACCESSIBILITY

L-mode to H-mode transitions have been observed in TCV in a wide variety of ohmically heated plasma configurations (limited, single null, double null), plasma shapes (triagularity, elongation, gaps, ...), plasma currents, plasma densities and magnetic fields. Initially, the vacuum vessel conditioning appeared to play an important role in the reproducibility of the H-mode access. Since physics explanations of the effect of the conditioning remain unclear, a statistical approach, discriminant analysis, has been chosen, with the aim of extracting those parameters which are important for characterising the closeness to the LH transition.

Discriminant analysis consists of a multidimensional (R^n) coordinate transformation which minimises the intercorrelation between data groups while maximising the intracorrelation within a data group. In the case of a discrimination between two groups of data, only one variable, called the classification variable, is necessary to reveal the separation, if any. From that new variable, we define a probability of belonging to one or to the other of the two groups.

We calculated the classification variable, as well as the associated probability for two groups of data. One contains the time slices in L-mode before the transition and the other contains the time slices taken right at the LH transition. In a first step, the input parameters were the plasma shape, current and density. This set of input parameters did not lead to a clear classification variable. We had to include the Ohmic power, the plasma temperature and a measure of the gas flux inside the machine to obtain a good enough classification variable, as shown in Fig. 3. The necessity of using this latter variable indicates the importance of the recycling on the H-mode accessibility.

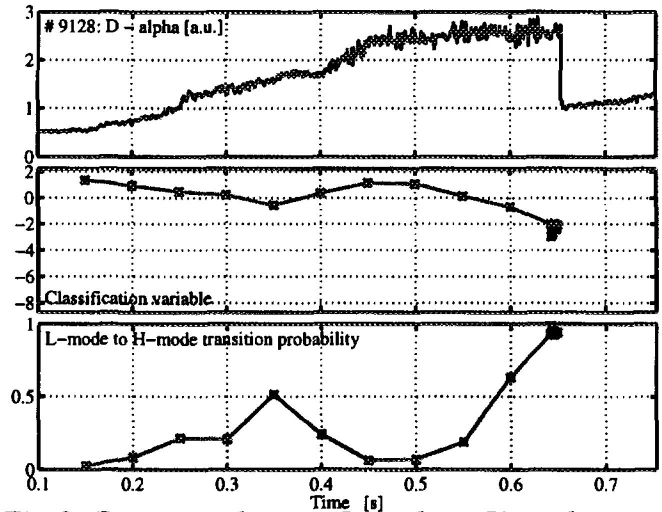

Fig 3: Dα trace shows a L-mode to H-mode transition, the discriminant variable and the associated probability reveals the imminence of the transition by the increase of the transition probability

Figure 4 shows the discriminant analysis results between L-mode and ELM free H-mode time slices, with the same input parameters. The probability curve clearly shows that a predictor can be easily calculated in this case.

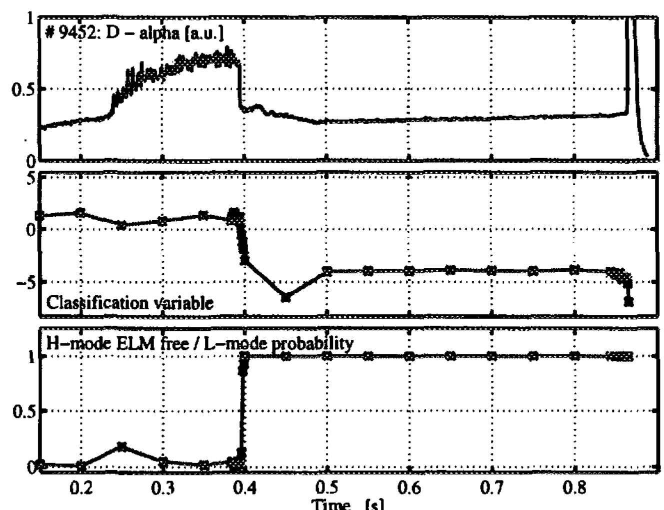

Fig 4: Dα trace of a typical TCV H-mode plasma, the discriminant variable and the associated probability showing the prediction to be in the H-mode

CONCLUSIONS

The disruptivity analysis reveals the importance of the plasma shaping during its formation in order to avoid disruptions due to locking modes. The Greenwald limit does not appear as a strong limit during the stationary phases.

Resulting from a discriminant analysis, a linear combination of plasma parameters, including information about the wall recycling, gives a probability of LH transition which is verified to increase and reach unity as the transition is approached.

ACKNOWLEDGEMENT

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