29th EPS Conference on Plasma Phys. and Contr. Fusion Montreux, 17-21 June 2002 ECA Vol. ***26B****, P-2.080 (2002)*

MHD Instabilities during Current Ramp Up as a Function of Plasma Shape in the TCV Tokamak

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The beneficial effect of plasma shaping during the initial current ramp up of L-mode ohmic discharges was noticed and regularly used early in TCV (*Tokamak à Configuration Variable)* operation as a way to reduce or suppress MHD activity or disruptions [1]. The details of the phenomena are studied in this paper.

The typical evolution of a disruptive discharge is shown in fig.1. The safety factor values q_{edge} and q_{95} are decreasing during the current rise while the plasma shape (κ =1.3, δ =0.2) is kept constant. An MHD mode of dominant toroidal number n=1 starts at t = 0.351 s, typically when the q=3 rational surface is entering the edge region of the last 5% of the flux as seen in fig.2. The mode rotates in the electron diamagnetic drift direction with a frequency of about 7 kHz. During this initial stage, the dominant poloidal number m is 3, therefore the instability is located on the q=3 rational flux surface at the plasma edge. When the mode has reached high amplitude, at 0.388 s, the dominant poloidal number m changes to 2. Figure 3 illustrates this transition that suggests a destabilizing interaction between the external kink mode [2] and a mode localized on q=2. The frequency and the amplitude of the mode are modulated by the sawtooth crashes visible in the central soft x-ray signal at the bottom of fig.1, probably caused by a magnetic coupling with the sawteeth precursor. At 0.372 s, the amplitude begins to grow linearly while the frequency slows down. This is due to the interaction of the mode with the resistive metallic walls [3] that drags the magnetic island created by the instability.

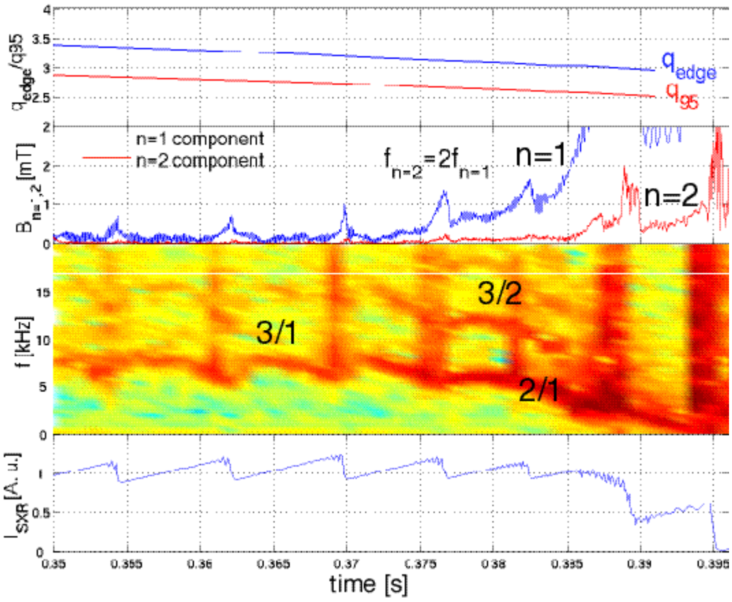

Fig.1. *Summary of the shot 21400*

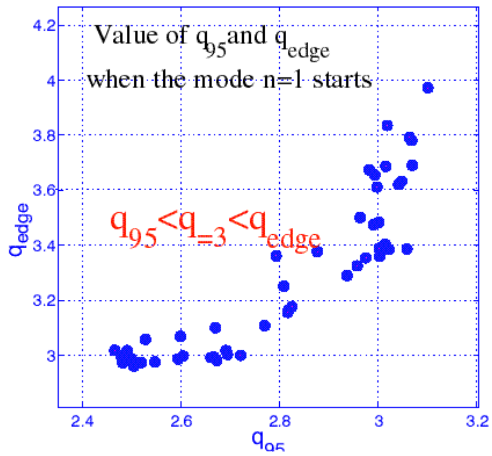

Fig. 2. *Value of q_{edge} and q_{95} at the triggering of the n=1 mode*

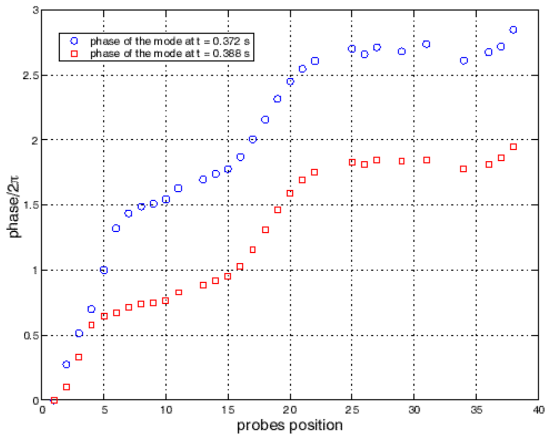

Fig. 3. *Phase variation of the magnetic signal from the Mirnov coils along a full turn of the poloidal direction at t=0.372 and t=0.388 s.*

At 0.374 s an m/n=3/2 mode is triggered with $f_{n=2} = 2 f_{n=1}$ indicating coupling between the different resonant surfaces. The triggering of this mode can be explained by the nonlinear modification of the current profile due to the presence of the 2/1 and 1/1 islands [4].

The coherent poloidal magnetic structure is extracted from the Mirnov coils using the Singular Value Decomposition method. It has been compared with a model for the reconstruction of magnetic islands [5] before the disruption at 0.388 s. Figure 4 shows a good agreement between the experiment and the model using two islands on the q=2 and q=1.5 rational surfaces identifying therefore the instabilities as the tearing modes. It should be noted that no good agreement with the island model could be found for the dominant 3/1 mode probably due to the distortion from the external kink. Using the cylindrical approximation in [6] the estimated maximum island sizes reached before the disruption are of 7 and 5 cm for the 2/1 and 3/2 mode respectively. Although these values are unrealistic, considering that the resonant surfaces are only 3-4 cm apart, they point to the possibility of strong interactions between the islands or the vacuum vessel leading to the disruption. The presence of a central MHD mode can be inferred from the Fourier analysis of the line integrated soft x-ray

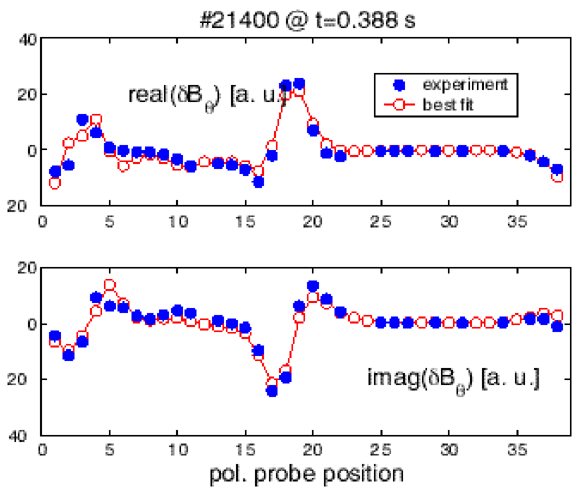

Fig.4. *Comparison of the poloidal mode structure from SVD analysis and the island model*

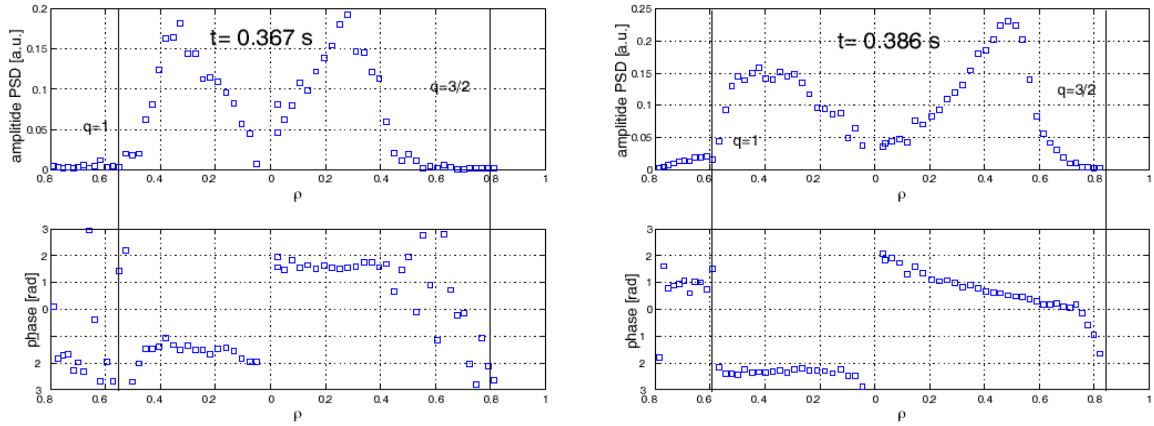

Fig. 5. *Left: amplitude and phase of the sawteeth precursor from SXR at t=0.367 s. Right: amplitude and phase of the central mode at t=0.386 s.*

emissivity shown in fig. 5, during the sawteeth precursor activity at t = 0.367 s and later at t = 0.386 s when the mode becomes continuous. Clearly the high and low field side oscillations are in opposite phase revealing a dominant m=1 poloidal mode number while the amplitude has two peaks inside the q=1 surface. The mode structure at 0.386 s, although similar to the sawtooth precursors is modified by the presence of the outer modes. It is interesting to note that the frequency of the oscillation always matches, inside the error bars, the frequency of the edge magnetic signal, as can be seen in fig. 6, suggesting a strong interaction between the 2/1, 3/2 and 1/1 islands that all rotate at the same speed.

Figure 7 schematizes the influence of shape on the MHD stability dividing the $\kappa-\delta$ space in disruptive and non-disruptive regions together with the mode numbers of the dominant instability. We firstly note the absence of disruptions for κ >1.4, δ <-0.4 and δ >0.2. A detailed analysis of the database reveals that for these ranges of parameters the 3/2 mode was never triggered and there was no continuous transition between the 3/1 and the 2/1 mode. The 2/1 mode which can be detected in very few shots, is rotating at low saturated amplitude with a different frequency or simply it is not present simultaneously with the 3/1 mode. Figure 8 summarizes cylindrical tearing stability index (Δ') calculations performed for several shots in the database using the experimental profiles. It shows the 2/1 tearing mode to be marginally stable for this scenario but no clear shape dependence of the Δ' is visible, leaving the shape stabilization unexplained. On the

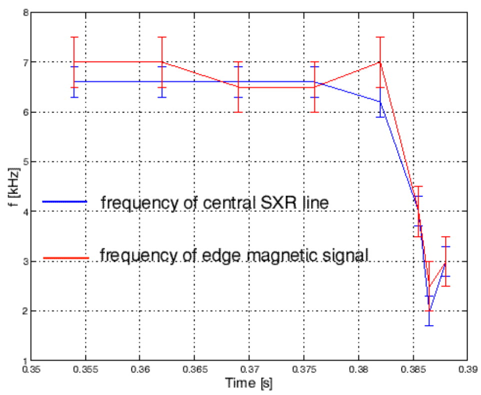

Fig 6. *Frequency of the edge magnetic (red) and central SXR (blue) perturbation*

other hand the current rise could lead to high edge current gradients generated by skin effect

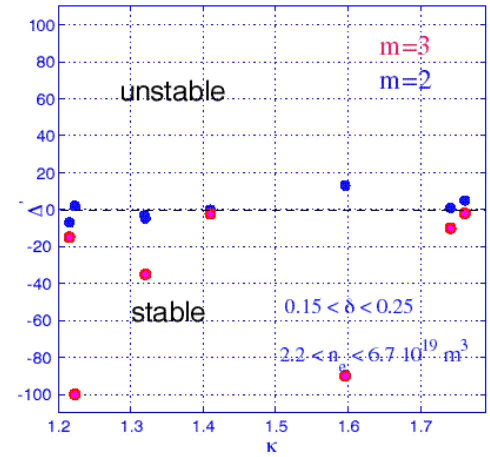

Fig. 8. *Cylindrical stability index Δ' for 2/1 (blue) and 3/1 (red) for different* κ

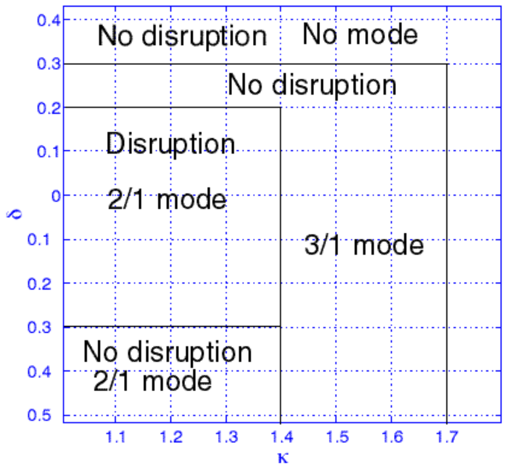

Fig. 7. *Disruption events in $\kappa - \delta$ plane and main mode*

leading to unstable profiles. Although in these experiments the rate of the current rise is too low, 500-800 kA/s, for producing any appreciable effect on the current profile. This hypothesis has been confirmed using the transport code PRETOR [7] to simulate this non-stationary condition. These calculations point out the difficulties of explaining the evolution of this instability only in terms of current profile. Besides the data analysis shows the mode coupling between the tearing modes and the external kink to be a key element of the dynamic.

This experimental conclusion is supported by the theoretical analysis presented in [8]. In this work the stability of the so called "fully reconnected" solution of the tearing dispersion relation is studied with a Δ' shooting code solving ideal MHD equations. Toroidal and shape coupling are retained within the code. When using circular cross section a strong destabilizing effect of the 2/1 tearing is clearly seen while q_{edge} approaches the value of 3 due to the toroidal coupling with the 3/1 external kink. If the plasma shaping parameters, κ or δ, are taken into account, other rational surfaces are coupled resulting in a complete stabilization of the mode even for modest κ or δ values, consistently with the observations presented here.

This work was partially supported by the Swiss National Science Foundation

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