X-Ray measurements of MHD activity in shaped TCV plasmas.

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1 . Introduction

The ability of TCV to produce a wide variety of plasma shapes has allowed an investigation of MHD behaviour in a large number of limited ohmic L-mode discharges in which the elongation κ and the triangularity δ have been varied over a wide range: κ=1.1->2.5, δ=-0.3->0.7.

A 200 channel soft X-ray tomography system in conjuction with toroidally spaced soft X-ray diodes has been used to study the structure of internal disruptions and MHD modes. A strong reduction of sawtooth amplitude is observed as the plasma triangularity is decreased together with an increase in mode activity. The reduced sawtooth amplitudes are not correlated with any significant changes of the inversion radius and hence are not simply due to changes in current profiles; the inversion radius however is strongly correlated with the Spitzer conductivity profile and with the edge safety factor.

2 . Diagnostics

The soft X-ray tomography on TCV consists of ten cameras placed in a poloidal plane looking at the plasma through a curved Beryllium filter of 47 μm of thickness; each camera is equipped with a linear array detector of 20 photodiodes providing a total of 200 lines of sight and allowing a spatial resolution of about 3 cm. The acquisition frequency of the system is 10 kHz.

The line integrated signals are tomographically inverted using the Minimum Fisher Information method and the reconstructed poloidal emissivities are analyzed with the help of *Singular Value Decomposition* (SVD), allowing the determination of MHD mode structures and the sawtooth inversion radius [1].

The soft X-ray emissivity from the plasma is also monitored by four silicon photodiodes, equipped with a Beryllium filter of 50 μm thickness, placed at the top of the vessel and equally spaced in the toroidal direction. The viewing lines of these detectors cut the poloidal midplane ≅7 cm from the centre of the vessel in the direction of the major axis. The availability of these 4 photodiodes allows us to distinguish between n=1 or n=3 (by aliasing) and n=2 modes.

3 . MHD and sawtooth behaviour

The most important feature of shape on MHD behaviour is observed as the triangularity is changed. Shots at high triangularity are characterized by large sawtooth amplitude and low level MHD modes; as the triangularity is reduced the sawtooth activity decreases and the MHD modes become persistent (Fig. 1, top).

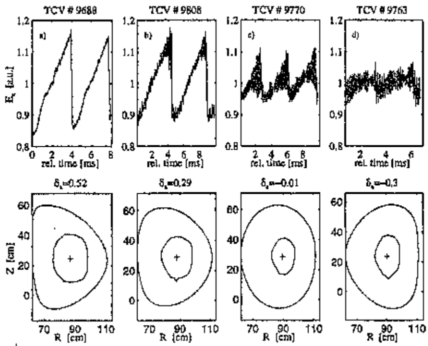

Fig.1. Raw X-Ray signals (top of the figure) with Sawtooth and Mirnov oscillations. Sawtooth inversion radius (bottom of the figure) and LCFS for four different triangularities. All discharges had q_a*=3.5* n_e*=5.0* 10^{19} m^{-3}, κ_a*=1.4.*

The SVD analysis in conjunction with the toroidal Fourier analysis has allowed the identification of MHD mode structures.

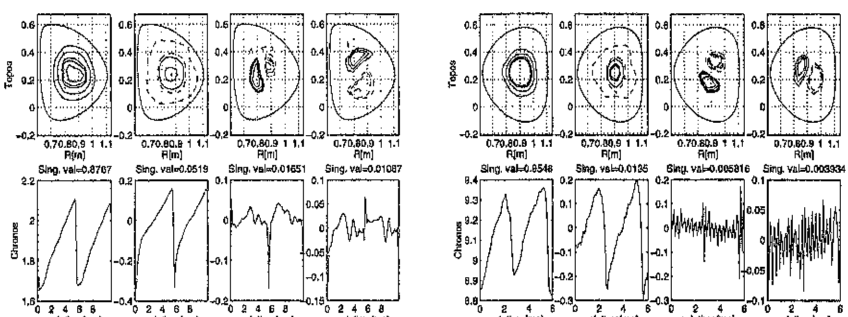

Fig. 2: SVD analysis of the shot 9688 (a) and 9763 (b). Contour plots of the different Topos are shown at the top of the figure with the LCFS; dotted lines correspond to negative value of the Topos. At the bottom the corresponding Chronos normalized to the sawtooth singular value are shown.

As can be seen in Fig. 2, for δ>0 the MHD activity is mainly due to non-axisymmetric modes localized near the q= 1 surface. These modes, presumably tearing modes, are present only as brief precursors or postcursors of the sawtooth crash, being almost absent during the sawtooth ramp. For $\delta<0$ MHD activity becomes continuous and appears as a rotating m=1/n=1 mode. The maximum of the mode amplitude is reached during the sawtooth crash and the rotation is in the direction of the electron diamagnetic drift. At very negative triangularity these modes can lead to a loss of confinement and cause disruptions by mode locking.

As the elongation is increased beyond 2 an m=2/n=2 locked or slowly rotating mode becomes important (Fig. 3), reaching maximum amplitude during the sawtooth crash. The amplitude of these mode increases with the elongation and, at fixed shape, increases as the edge safety factor is reduced. The presence of this mode is consistent with the observation of an m=3, n=2 mode in the soft X-ray emissivity and in the Mirnov probes during major disruptions in TCV [3-4].

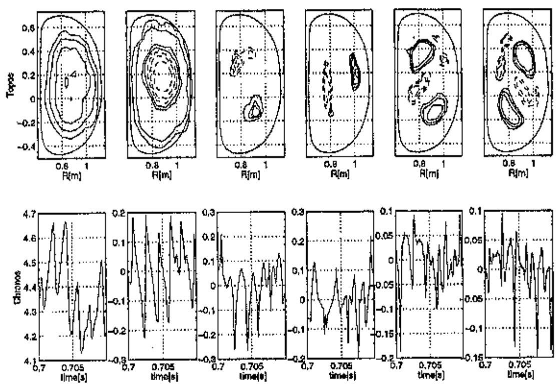

Fig. 3: SVD analysis of TCV SHOT# 11832 at t=0.7-0.71. The shot parameters are:I_p=0.7 MA, κ_{95}=2.38, δ_{95}=0.28. At the top of the figure, the Topos with the LCFS are shown together with the corresponding Chronos (bottom). Topos #3 and #4 show the normal 1/1 activity, while Topos #5 and #6 show the superposed slowly rotating 2/2 mode

The amplitude of the sawtooth crash varies strongly with triangularity, being largest at positive triangularity and sometimes vanishing at negative triangularity [2]. This behaviour can be explained by the fact that any reduction in the ohmic input power, caused either by reduction of current density (high q_a discharges) or by an improvement in energy confinement as observed for $\delta<0$, leads to a reduction of sawtooth reheat power. In Fig. 4 we see that plasmas with highest confinement times have lower ohmic heating power and hence small sawtooth amplitudes.

The sawtooth inversion radius, defined as $\rho_{inv}=(V_{inv}/V)^{1/2}$ where V_{inv} is the plasma volume inside the inversion contour, correlates very well with the cross sectional area averaged current density. This is shown in Fig. 5 where as abscissa we use the non-dimensional average current density $<j>^*=\mu_0 R_0 <j>/B_T$; symbols refer to classes of δ_a showing that there is no intrinsic dependence of the inversion radius on triangularity. This good correlation could be explained by assuming that the effect of sawtoothing is to flatten the current profile inside the inversion radius, preventing the current density from rising to a value higher than that corresponding to q≅1 for $r \leq r_{inv}$.

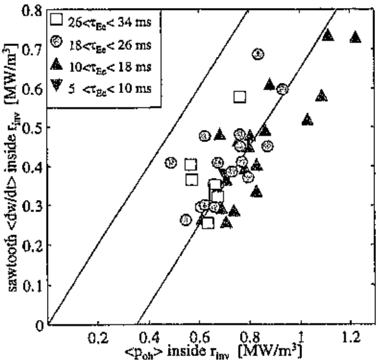

Fig. Sawtooth reheat power versus central ohmic heating power inside inversion radius for $n_e=6.3*10^{-19}\ m^{-3}$. The upper line corresponds to $<dw_0/dt>_{inv}=<p_{oh}>_{inv}$, the lower line to $<dw_0/dt>_{inv}=<p_{oh}>_{inv}-0.35\ MW/m^3$. Symbols refer to classes of confinement time.

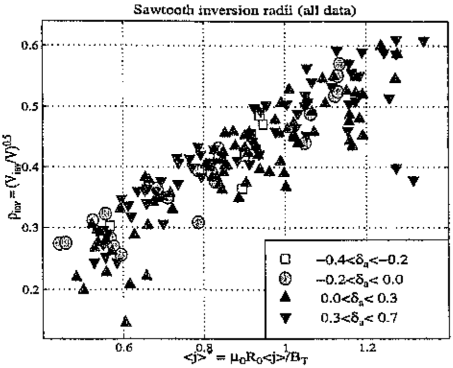

Fig. 5. Normalized sawtooth inversion radius versus non-dimensional average current density. Symbols refer to classes of triangularity.

The reduction of the ohmic input power with δ_a may explain, at least partly, the increase of mode activity. This reduction leads to lower edge electron temperatures [2], which may contribute to destabilizing resistive modes. High amplitude modes are unlikely to develop with Te(0.9a)>200 eV but are frequent at lower temperature. This suggests that the mode observed by X-ray tomography at the q=1 surface may be induced by mode coupling with m>1,n=1 which are destabilized near the plasma edge.

Acknowledgement
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References

[1] M. Anton *et al, Plasma Phy. and Control. Fusion 38, 1849-1878 (1996).*

[2] H. Weisen *et al, Effect of plasma shape on confinement and MHD behaviour in TCV Tokamak* submitted for publication to Nuclear Fusion, available as LRP 571/97.

[3] O. Sauter *et al,* this conf.

[4] F. Hofmann *et al,* this conf.