# Towards q-profile reconstruction through fast-MHD analysis on TCV

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## 1) Abstract

The TCV tokamak has developed steady-state fully non-inductive scenarios with internal transport barriers, high bootstrap fraction and reversed magnetic shear profiles. However no direct measurements of the current density profile are available. Therefore it is proposed to use the fast diagnostics and tomographic systems available to measure and identify MHD modes and islands in order to constrain the reconstructed or simulated current density profile in discharges where MHD modes are observed. This requires a detailed characterization of the properties of the measurements, experimental analysis and comparison with theoretical predictions. This work will also provide key information on the modes limiting the plasma performance in advanced scenarios and their role in the barrier formation.

The extensive set of fast, spatially well resolved diagnostics available to study MHD modes in TCV is ideal for the purpose of constraining the q-profile. In this paper we focus on MHD observed in discharges (if any) exhibiting a large slow oscillation of the core plasma parameters.

## 2) Oscillations of electron temperature in ITB discharges:

Oscillations of the electron temperature and plasma current have been previously studied in other tokamak [1] and are observed in TCV low-density, on-axis counter-ECCD and fully non inductive ECCD discharges [2]. These strong, slow oscillations (<100Hz), are not direct manifestation of MHD instabilities, although they generally coexist with helical rotating modes. These oscillations have many characteristics of the oscillations of the central electron temperature observed in low-loop voltage or LHCD fully non-inductive plasmas with reversed central magnetic shear on Tore Supra. There, it has been proposed that the origin of the oscillation is linked to the interplay between the current density profile and electron heat transport. On TCV, however, the whole plasma appears to be involved, judging from the experimental data acquired with SXR cameras, DMPX, and ECE diagnostic. The common feature of these oscillations is the presence of MHD.

## 3) Experimental data: magnetic analysis

Three discharges, amongst those obtained during the experimental campaign, have been analyzed in details regarding the MHD behavior.

The FFT over magnetic data clearly displays the slow oscillations together with the SXR core trace, (fig.1). From this, one can recognize the time at which ECCD is applied (*t=0.5s*), followed by a slowly frequency rising mode (from *f*=11kHz at *t*=~0.6s to *f*=17kHz at *t*=~1s. At this point in time the frequency has a very fast increase and the mode becomes less recognizable, until at *t*=1.3s when it reappears at *f*=15kHz. During the slow *Te* oscillations the mode sweeps form 10kHz to 20kHz, being always stronger during the descending phase of the temperature oscillation. By using SVD (Singular Value Decomposition) analysis technique, it is possible to infer the character of the instability and the toroidal periodicity of the mode with little uncertainties. Because of the vessel geometry and the tokamak plasma topology, the poloidal mode number is more difficult to discriminate, as only few (typically 5-6) LFS probes and a couple of HFS probes (among the full poloidal Mirnov coil set, made of 36 coils) acquire a signal strong enough for mode analysis. The character of the instability also changes during the different phases of the discharges with an initial phase that is more ideal-like (short lasting bursts, like incomplete crashes) and a magnetic island that is visible in the strongest part of the mode. This is reported in fig.2 where the raw integrated Mirnov toroidal signal (blue) is compared to the eigenvectors-couple energy for the rotating mode. This

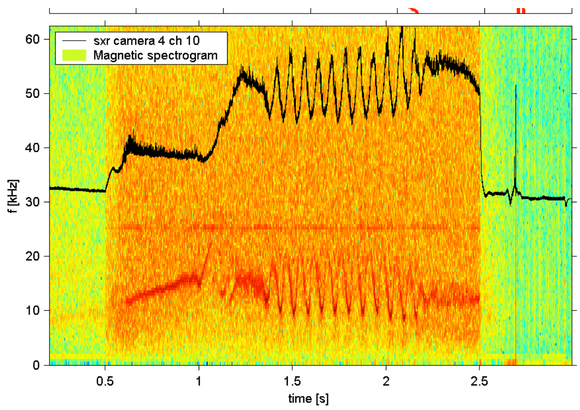


Fig. 1: FFT of magnetic toroidal coil, for discharge 31891, with superposed SXR core trace

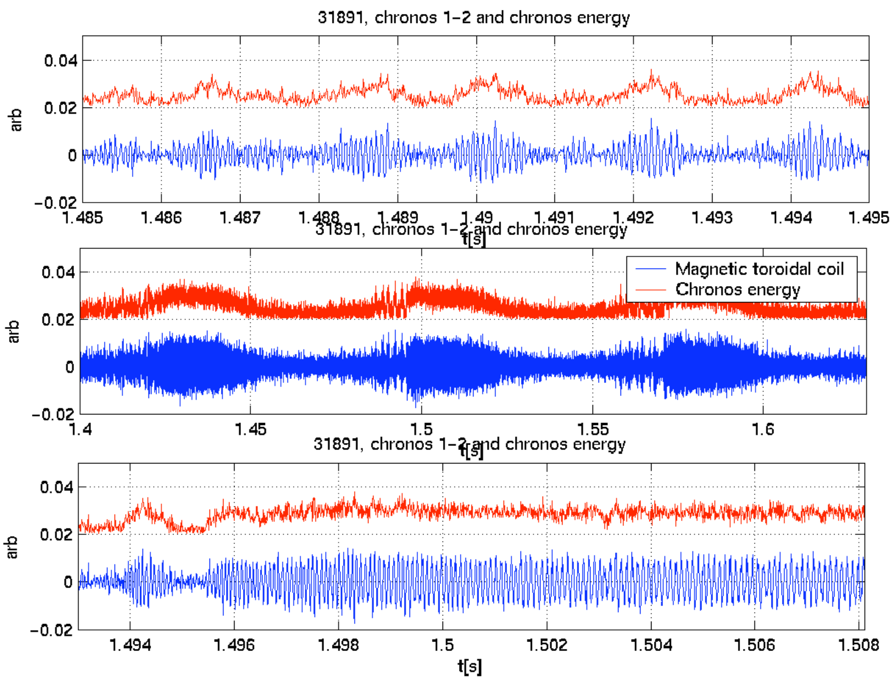


Fig. 2: Magnetic raw signal (blue) and chronos energy, showing three slow oscillations (middle) the initial incomplete reconnection (top) and the magnetic island (bottom).

pattern is repeated throughout the whole slow evolution of the plasma, until a change is applied (for instance Ohmic contribution to the current density). Mapping the phase of the perturbation against the poloidal and toroidal location of the coils, it is possible to estimate the periodicities, which turns out to be (discharges 31891 and 31892) $m/n$=3/1 for the main component. Discharge 32022, which displays a different MHD character, is found to have a main $m/n$=2/1 periodicity. This is due to the ECH current injection strategy (counter ECCD), which peaks the current lowering q-min, hence the mode is on q=2.

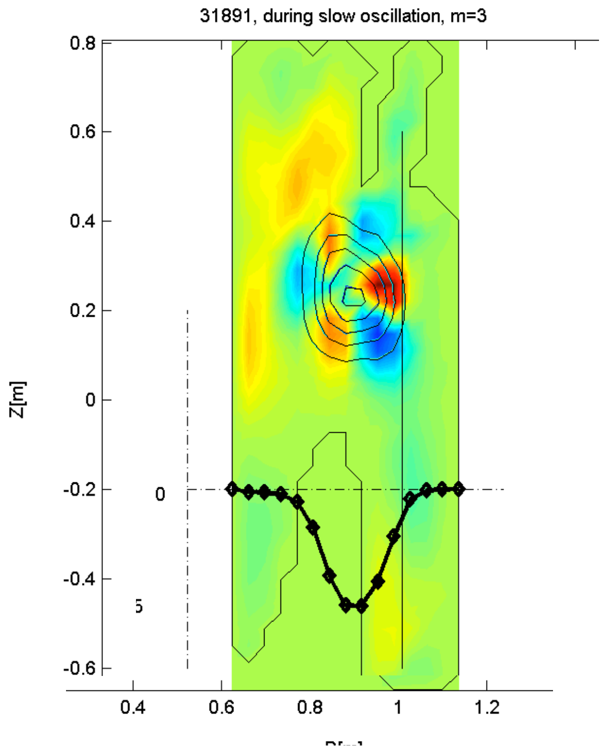


Fig. 3: SXR tomography of the plasma during the oscillations. A clear mode $m$=3 is visible

**4) Soft X-Ray (SXR) diagnostics:**

The analysis has been re-done for the same discharges with the aim of the SXR *conventional* array (XTOMO, [3]), while the newer SXR wire chamber (DMPX,[4]) has been used for discharge 32022. Despite of the integrated nature of the signal, inversion techniques allow the reconstruction of the local SXR emission. Bi-orthogonal decomposition is used during a second phase to underline the existence of rotating mode in the plasma, by identifying couples of degenerate eigenvectors which represent the topological (*topos*) and chronological (*chronos*) character of the mode. The decomposition can be attempted on a long timescale, as the SVD is capable of extrapolating single modes from the rest of the evolution. The result can be affected by the varying frequency of the analyzed modes. Hence, the analysis has been repeated for testing the consistency on the full discharge and on short phases where the mode is more evident. XTOMO, fig. 3, clearly shows the presence of an $m$=3 mode with the same frequency of the mode identified by magnetics (mirrored against the Nyquist limit, as SXR was acquired at 10kHz during these experiments). Figure 4 shows a time-comparison of the magnetics (green traces) SXR eigenvectors energy (blue trace) and SXR raw signal (black trace). Thus, the mode is mainly an $m/n$=3/1 mode (for 31891 and 31892). Discharge 32022 shows the same agreement between SXR and magnetics, with the main periodicity being

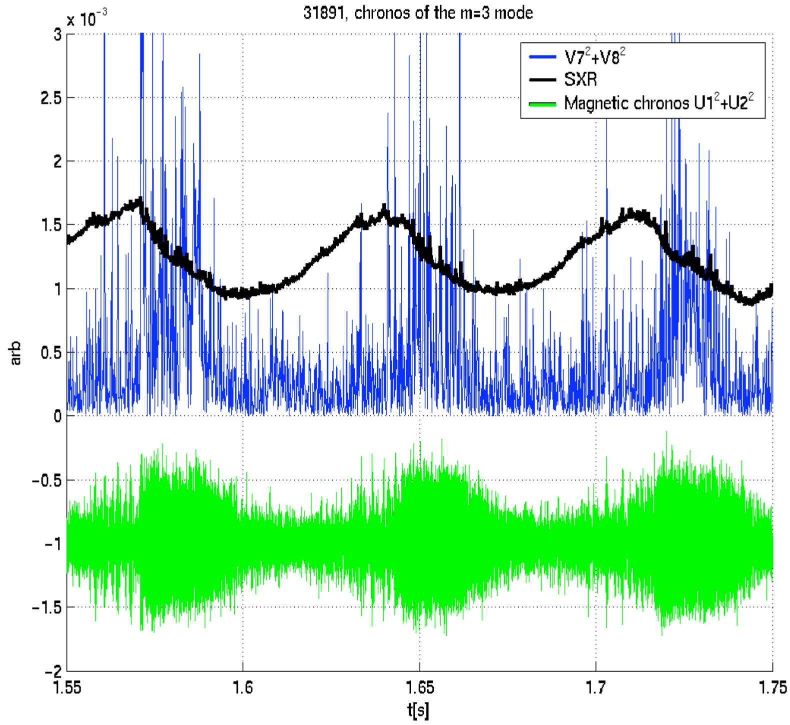


Fig. 4: Comparison of the SXR raw trace (black), the SXR chronos energy (Blue) and magnetic chronos energy (green). The mode is the same one, $m/n$=3/1.

$m/n$=2/1. DMPX can be used for gathering highly resolved spatial-temporal evolution of the location of the mode, hence becoming a tool for improving the reconstruction made by LIUQE.

**5) Comparison of LIUQE reconstruction and experimental data**

In Figure 3, below the tomographic data, the curve of the global SXR emission is shown (topos U=1), together with the emission line at 20% of the maximum SXR radiation, indicating that most of the mode is likely to be within the strong SXR emitting region (ITB region). The mode exists after the oscillations, although it is more visible from magnetics. Interestingly, at this later time, the mode seems to extend slightly beyond the region of strong SXR emission, when the ITB is still present in the plasma. This requires further modeling and investigation to be understood. For discharge 31891 the location of the q=3 surface is between $\psi_N$=0.25 and $\psi_N$=0.51, with the strongest mode signal at $\psi_N$=0.37. Through LIUQE reconstruction q=3 is found at $\psi_N$=0.59, in disagreement with our analysis. Furthermore, the edges of the reconstructed flux surfaces do not match the location of the topos, indicating a wrong reconstruction, as expected since the reconstructed q profile is monotonic by construction. It is the main purpose of this tool to provide constraints to improve the equilibrium code reconstruction.

[1] G. Giruzzi *et al.*, Phys. Rev. Lett. 91, 135001 (2003)

[2] G. Zhuang *et al*, 31st EPS. London, 28 June - 2 July 2004 ECA Vol.**28G**, P-2.143 (2004)

[3] M Anton *et al* 1996 Plasma Phys. Control. Fusion 38 1849-1878

[4] A. Sushkov *et al* 29th EPS. Montreux, 17-21 June 2002 ECA Vol. 26B, P-4.118 (2002)