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Snake-like structures after pellet injection in the T-10 tokamak

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Introduction

A formation of snake-like structures was observed after a pellet injection in the tokamaks many years ago [1]. It was shown in [1-4] that a pellet ablation near a rational q surface can trigger a creation of a magnetic island followed by its fast growth. Such a rotating island was clearly identified on the T-10 tokamak using both fast bolometric and SXR detectors in the case of high-Z impurity pellet injection (titanium).

The aim of this work is to demonstrate a possibility to estimate properties of the created structures such as their position, width, poloidal rotation frequency, but also the shape and rotation direction from the measured data. In usual case, either the quality of the data or a limited number of detectors does not allow to make a clear tomographic reconstruction. The data are smoothed in time or space, noisy, there is an overlapping of more plasma features or the number of projections is insufficient to see a complex structure of the physical image. Then, a combination of the singular value decomposition (SVD) [5], the cross-correlation analysis, the asymmetric Abel inversion and simple simulations is the best option to reach the desirable information.

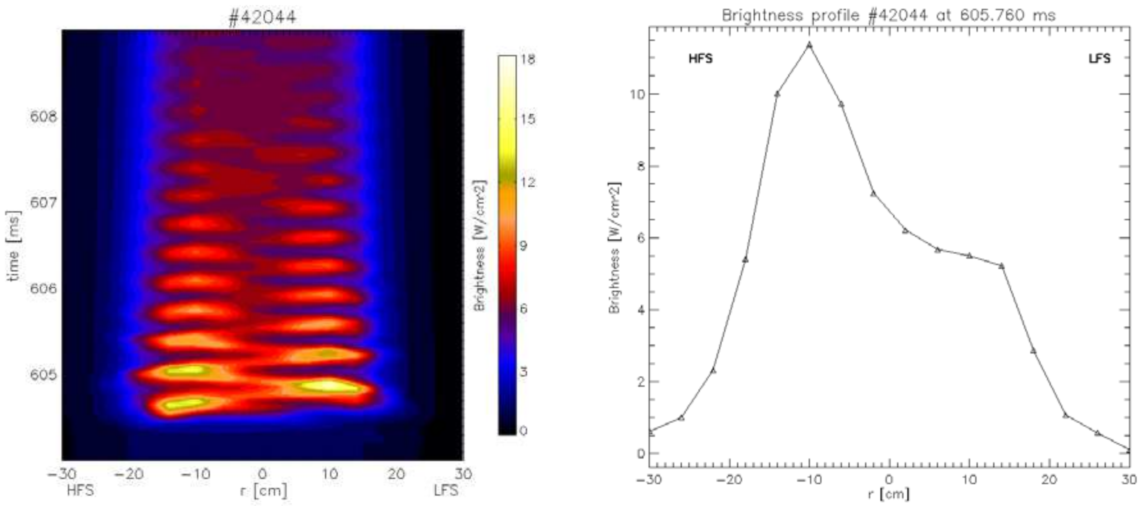

Fig.1: A snake-like structure visible on raw AXUV signals several milliseconds after the Ti pellet injection: contour plot (left) and the brightness profile at the selected time (right).

Experimental setup

The experiments were performed on the T-10 tokamak (R = 150 cm, a_L~30 cm). The poloidal plasma cross-section is circular, given by a movable rail limiter. In the studied shot #42044 (L-mode, OH regime, I_p~200 kA, B_T~2.4 T, n_e~$2.5*10^{19}$ m^{-3}), a pellet injection (Ti) at 600 ms was realized. The experimental set-up was similar to [2]. The total radiated power is monitored by the fast AXUV-based bolometers. Both one 16-channel bolometric array with a spatial resolution of 4 cm and one array of 64-channel SXR detectors with a spatial resolution of 1 cm were located close to each other inside the same bottom diagnostic port. A pellet injector leads from the top into a diagnostic port localized on the toroidally opposite side of the tokamak chamber. The fast bolometers reached the temporal resolution of 32 μs and looked at the plasma column through the aperture slit (pinhole camera) causing fan-like chords. A similar setup was used for the SXR array operating only at 64 μs sampling rate.

Measurements and observations

A formation of snake-like structures was observed by both bolometric and SXR detectors few milliseconds after a titanium pellet injection at t_0=600 ms in the shot #42044, see Fig.1. The pellet material evaporation caused a gradual increase of the soft X-ray intensity and a very fast growth of the total radiated power together with a shrinking of the profile, all visible from t_1=604.5 ms. However, the signal behavior of SXR and bolometers differs in time-scales. The total radiated power peak occurs about half a millisecond after t_1 and decay exponentially to its original state with a decay constant of 1 ms order. Oscillations on chords crossing radii up to 20 cm, interpreted as a formation of rotating island with poloidal mode number m=2, are present immediately after the increase of the bolometric signals and persist for next 5 ms. The SXR peak occurs later, about 30 ms after t_1 and decays exponentially with a constant ~60-80 ms comparable with the particle confinement time. Oscillations on chords crossing radii up to 10 cm, interpreted as a formation of snake-like structure localized at q=1 surface, are present immediately after the increase of the bolometric signals and persist only for next 3 ms.

Data analysis and simulations

As first, the measured AXUV and SXR data were fitted to find evolution of the total radiation, radiation peak position (shift), radiation FWHM and the brightness profile. Afterwards, the data were separated into spatio-temporal components by SVD [5] to distinguish the main plasma profile (k=1), sawtooth (k=2 for long period τ>>5ms of SXR data) and finally island radiation (k=2 for short period of AXUV and SXR data). A high contrast between k=1 component and higher ones and their complexity showed that a better way than to use a higher number of SVD components is to take only first two for suitably chosen time period. From the k=2 components, the sawtooth inversion radius (used for estimation of the q=1 surface position), island evolution, position, its radiating width and poloidal rotation frequency were computed.

The island shape itself had to be deduced by another way. The obtained island parameters were used in simple simulations to compute a response of the detectors on a rotating object. Such simulations also included a plasma background profile corresponding to the k=1 component and a noise (k>>1). More efficient than to compare measured and computed emissivity directly was to compare their cross-correlation functions.

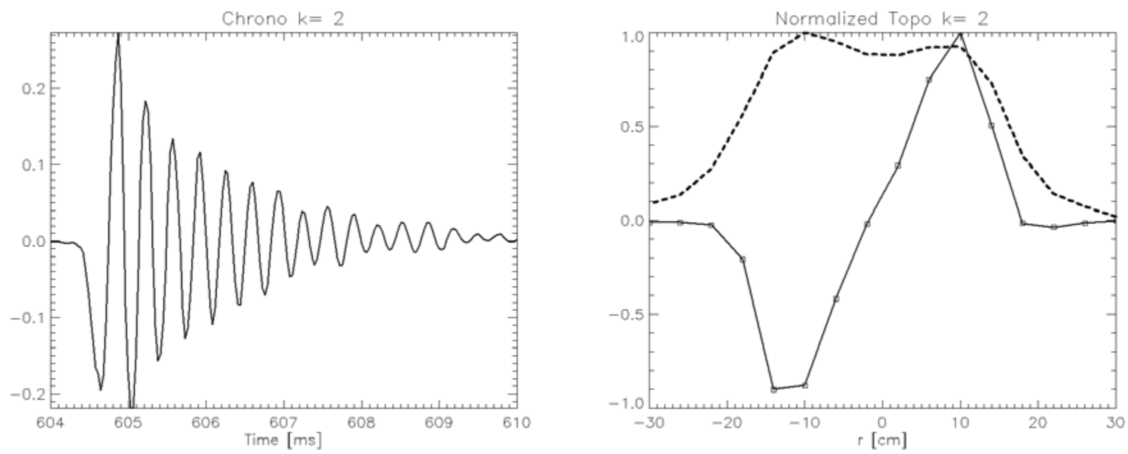

Fig.2: SVD of AXUV data. Chrono and topo of the k=2 component corresponding to the island rotation. The dashed line represents the main plasma profile (k=1).

The rotating island observed by the SXR array is localized at the sawtooth inversion radius (q=1) of 6.5 cm and its poloidal rotation frequency is 2.86 kHz. The amplitude, derived from SVD, grows exponentially with a time constant 1.7 ms till the collapse after t_2=606.4 ms. Its width derived from the simulations is 5 cm. The island amplitude quickly decays poloidally that significantly contributes to about 180°. The rotating island observed by the AXUV array is localized more outside (probably m=2) at 11-13 cm and its poloidal rotation frequency is the same as for SXR between t_1 and t_2, then the frequency increases to 3.1 kHz. The amplitude, derived from SVD, decays exponentially with a time constant 1.1 ms, after t_2 with 1.3 ms. Its width derived from the simulations is about 10-14 cm. It seems there is a coupling between m=1 and m=2 magnetic islands.

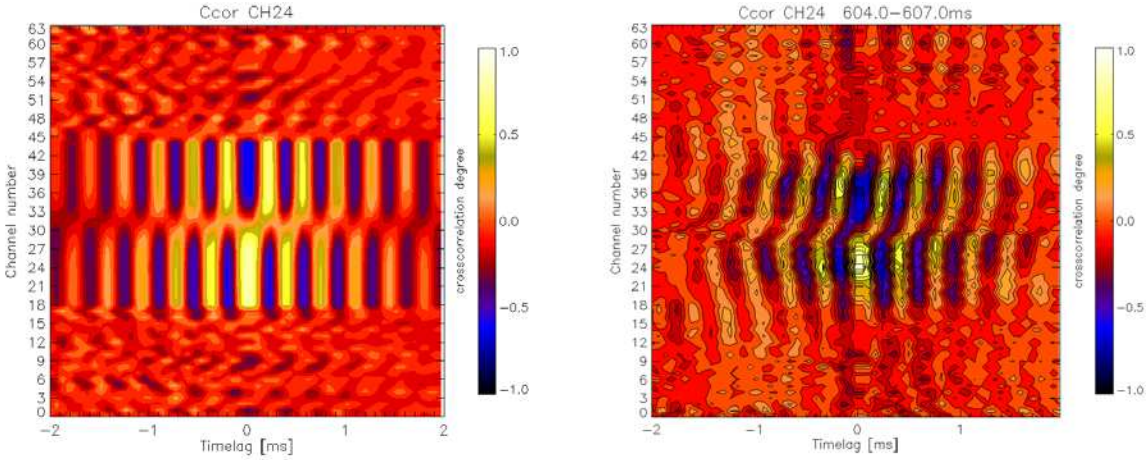

Fig.3: Comparison of cross-correlation contours for an artificial case of a rotating island (left) and k>1 components of the SXR data (right). The channel 24 is reference.

Conclusions

Fast events like a formation of snake-like structures observed after a pellet injection can be easily described using a combination of the advanced method of data analysis like SVD or cross-correlation on spectroscopic signals. Such information is crucial for the understanding of the underlying physics of the energy and particle transport phenomena during fast MHD events and events themselves. The T-10 data collected in both OH and ECRH regimes with a pellet injection (D, C, KCl, Ti) are under evaluation. The data processing routines and all new results will be reachable at http://server.ipp.cas.cz/~vwei/

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