Application of SVD algorithm to a set of Real Time Mirnov coil signals in FTU tokamak

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SVD on a set of Mirnov coils:

The Singular Value Decomposition is an algorithm that, given an array of signals sampled in different places for different time instants, exploiting the phase lag between pairs of samples in different places, calculates the space structure (Principal Axes or PA's) and the time evolution (Principal Components or PC's) of the states in which the physical system spends most of the time in the considered interval (time window), disposing them in decreasing order from the one where the system spends most of the time to the one the system occupies the less [1].

When applied during MHD activity on a set of Mirnov coils distributed along the toroidal and the poloidal direction of a tokamak and sampled at a frequency at least larger than the typical Tearing Mode (TM) one, the space periodicity of the first (i.e. the most important) PA, called PA_0 provides the poloidal *m* and toroidal *n* numbers of the mode. This allows to classify the instabilities as "dangerous" (low *m*, *n* numbers, up to 3 and 2 respectively, for FTU) or "irrelevant" for this kind of mode control (higher mode numbers) and to determine the radial position of the relative magnetic island as the radius *r* for which $q(r)=m/n$ with *q* an estimate of the safety factor [2, 3].

As regards time evolution, during the development of a TM the PC_0 becomes quasi-sinusoidal and therefore its time average is close to zero. Consequently, the condition in which the absolute value of the time average of PC_0 is lower than a proper threshold results a good signature of the presence of the mode. A rough estimate of the mode frequency is also available and it is seen that during mode presence it reaches the typical values (from 3 to 10 kHz) of a FTU TM (Fig. 1).

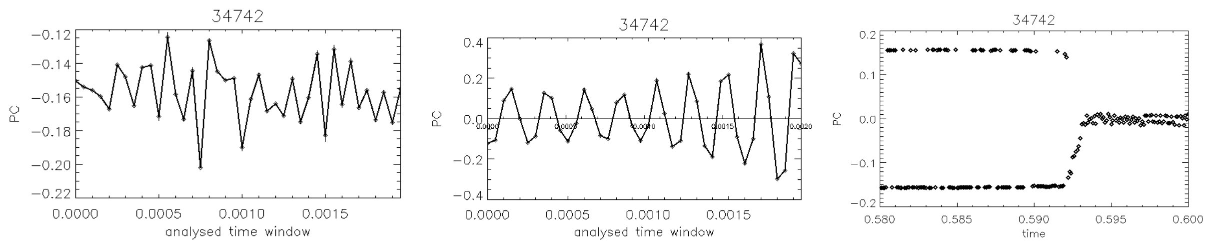

Fig 1: PC_0 out of mode (left) and inside a mode (centre), <PC_0> time evolution during a mode rise (right) of a FTU shot.

Real Time mode controller in FTU:

In the FTU tokamak (major radius R=0.935 m, minor radius r=0.31 m, max toroidal field 8 T, max plasma current 1.6 MA, max flat top pulse duration 1.5 s) is under development a system for Real Time (RT) control of MHD instabilities via ECRH and CD [4] which uses as an actuator a newly installed fast steerable two beams EC launcher [5]. It exploits pre-existing FTU diagnostics and a priori analysis to detect, localise and classify a TM or a sawtooth and to drive the gyrotron switch on-off and the mirror shooting positions accordingly. In this framework, SVD is employed for mode number and presence early detection. The diagnostic acquisition and postprocessing are divided in a fast a slow sets, the first set (ECE, Mirnov and ECH) is acquired at 20 kHz, the second (Plasma current, toroidal field, line-averaged central density and magnetics for the last closed magnetic surface reconstruction) at 2 kHz. The overall response with the settings for the launcher must be given every 1 ms, and SVD time window and execution time must comply with this requirement.

FTU Mirnov coils are not disposed uniformly along the poloidal and toroidal direction, moreover poloidal coils are situated at toroidal angles which can differ by up to 30º while toroidal coils are situated at poloidal angles which can differ by up to 180º.

Previous results [6] showed that SVD algorithm presents the necessary characteristics to exploit FTU magnetic signals in RT.

Results:

SVD has been applied to Mirnov coil sets both acquired @ 500 kHz and then filtered @10 kHz and downsampled @ 20 kHz via software (for instance, Fig. 2, left), and acquired @ 20 kHz with 10 kHz low pass anti-alias filters with a possible RT ADC prototype (for instance, Fig 2, right).

In both cases it has been found time alignment between change on mode periodicity determination, rise of the frequency to TM values and positive value of the mode presence indicator. When applied on toroidal and poloidal sets of the same shot, the behaviours of frequency and mode presence indicator agree. Moreover, SVD appears to detect the mode presence 2 ms before a single Mirnov signal shows the typical mode behaviour (signal rise and sinusoidal time evolution).

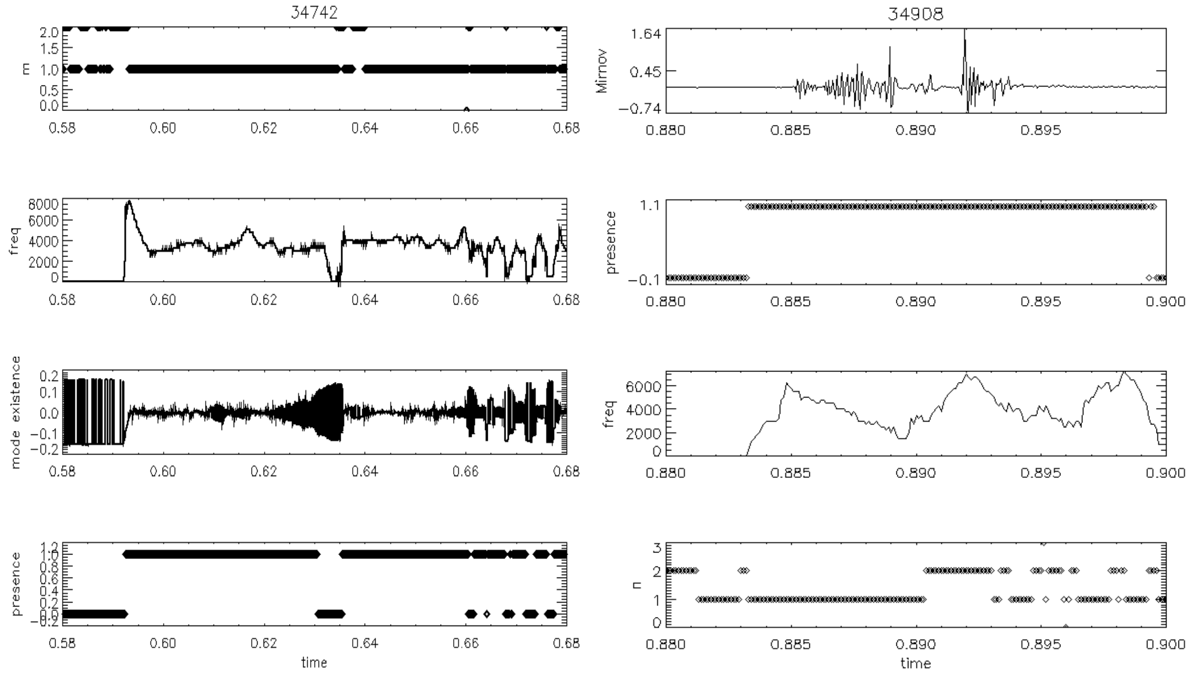

Fig. 2: (left) Time evolutions of poloidal mode number, frequency, PC_0, mode presence indicator for FTU #34742 and (right) of Mirnov coil, mode presence indicator, frequency, toroidal mode number for FTU #34908, around an interval where the mode is present.

Tested off line on a set of shots where MHD activity was present, leading to potentially harmful disruptions, the SVD algorithm proved able to detect the presence of the mode in a time instant which differs from the one determined by observing the behaviour of a selected Mirnov coils by typically the order of ms (Tab 1).

FTU Shot	Mode Start time (SVD)	Mode Start time (Mirnov)	Δt
34769	0.884 s	0.886 s	0.002 s
34784	0.845 s	0.855 s	0.010 s
32712	0.135 s	0.127 s	0.008 s
32476	0.821 s	0.823 s	0.002 s
32710	0.910 s	0.930 s	0.020 s

Tab 1: Mode start time determination by SVD and by a Mirnov coil.

In order to measure the performance of the algorithm, it has been checked against the correlations between fluctuations sensed by ECE and Mirnov diagnostics. A change of sign between cross-correlations of two adjacent channels with a Mirnov signal is associated to the presence of an island if its amplitude overcomes a given threshold [7]. SVD and ECE-Mirnov cross-correlations indicate quite contemporarily the presence of MHD activities (Fig. 3).

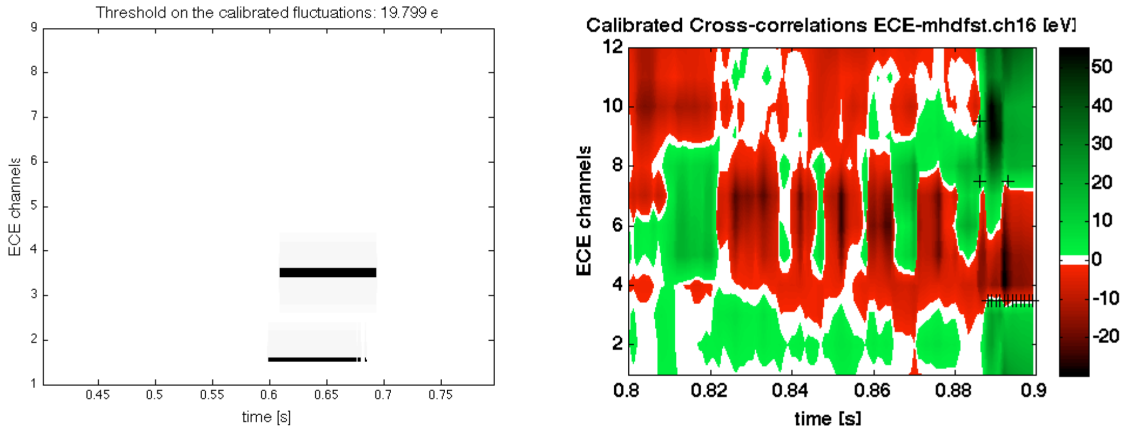

Fig 3:

(left) boolean outputs (one for each pair of adjacent ECE channels) of ECE-Mirnov cross-correlation for shot #34742,

(right) ECE-Mirnov cross-correlations profile for shot #34908, black crosses indicate the presence of an island.

This application of SVD algorithm has been developed and tested in IDL and then implemented in C++ into the open-source framework MARTe (Multi-threaded Application Real-Time executor) on Linux/RTAI real-time operating system. Preliminary timing results show an execution time of 287us for a 40x7 array, compliant with the RT requirements [8].

Conclusions:

SVD early mode detection via post processing of the most significant PC (PC_0) proved able to detect the presence of the mode as compared to Mirnov signal and these results are confirmed by ECE-Mirnov cross-correlation. The C++ version of the algorithm on MARTe runs in an execution time consistent with RT requirements. Toroidal and poloidal mode number determination is still to be compared with mode location by q-profile reconstruction.

Acknowledgements:

Useful discussions with Dr D. Del Sarto and Dr A. Moro are gratefully acknowledged.

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