Sensitivity Analysis of SVD algorithm for real time mode control on FTU

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Abstract

The Singular Value Decomposition (SVD) algorithm behaviour, when applied to a set of Mirnov coils not equispaced and/or in a reduced number, or for a short time sampling window, is studied, with a view to applying it to MHD mode analysis and identification for the Frascati Tokamak Upgrade (FTU) machine, both off line and in real time, aiming at instability control and suppression by EC power injection. Threshold values for proper operation as regards coil number, coil separation and time sampling window length are obtained.

Introduction

SVD [1] is a technique to determine the mode composition of a cyclic instability in tokamaks. Comparing to other postprocessing algorithms, it requires only an extremely short time sampling window (compared to instability period) to determine the toroidal and poloidal mode periodicity and this makes its application of great interest for real time tools. Its implementation for poloidal mode determination purpose has been recently tested on the FTU set of fast sampling (500 kHz for 1.8 s, when a typical MHD mode frequency is 1-15 kHz) Mirnov coils [2].

In FTU Mirnov coils are not disposed uniformly along the poloidal and toroidal direction: the 18 poloidal coils are clustered in 4 groups in a latin-cross-shape, the separation between a coil and its neighbour spanning from 4.5° to 79.6°, while the 8 toroidal coils are disposed in pairs, two pairs on a tile of the toroidal limiter facing the inner limit of the plasma (port 7 and 9) and two pairs on the duck of the port facing the outer (port 1 and 9), thus they do not lie on the same poloidal section and their separation spans from 7° to 98° (Fig.1).

In order to apply the SVD to this non-ideal distribution, we estimate the shortest time sampling window and the minimum number of coils the algorithm needs to correctly determine the mode number, verifying if the coil disposition affects these results. Moreover, to use SVD in cases where two or more modes are present at the same time, we estimate the minimum amplitude and frequency separation that two modes must have to be distinguished by the algorithm.

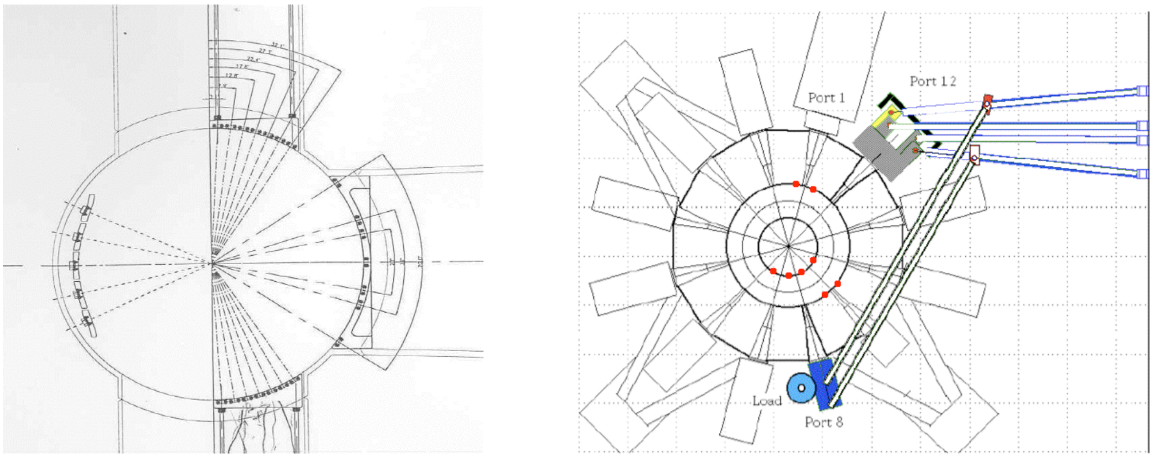

Fig 1: Fast Mirnov coil disposition in FTU: Poroidal (left) and Toloidal (right: red circles) where also the old (port 12) and the new (port 8) EC launcher are shown

Synthetic Signal results

In order to keep the control of all the involved parameters and to know *a priori* the periodicity to be determined, without relying on other diagnostics which might have their own error bars, we performed the test with a synthetic signal, obtained by summing one or more travelling sinusoidal waves with varying frequencies and amplitudes, together with white noise, thus simulating the data collected by a set of Mirnov coils toroidally and poloidally distributed around a torus. As a definition of “successful analysis” the correct determination of the inserted periodicities has been chosen, together with the absence of pathological behaviour, such as Singular Values not decreasing, in the output of the algorithm (Fig2).

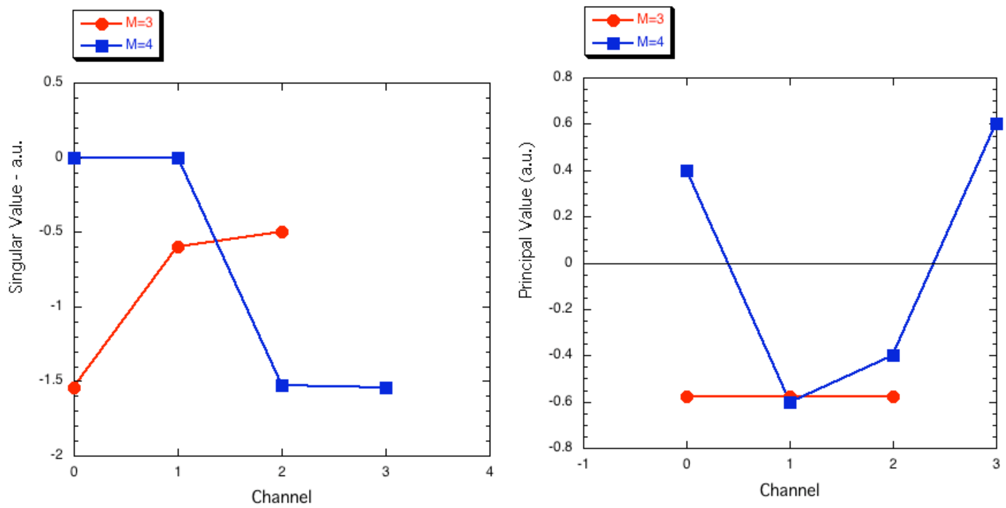

Fig 2: Comparison between “successful” (blue) and “unsuccessful” (red) analysis, in this case due to threshold on coil number M for equispaced coils for a m=1 periodicity. Note the decreasing vs increasing plot of Log(SV) (left) and the correct 2 zero-crossing vs the incorrect no zero-crossing of the PV plot (right).

While the signal has been calculated at high resolution (time resolution of 1ms and space resolution of 2π/1000, for a 20 Hertz frequency and a space periodicity up to m=3), to model the non uniform disposition of the coils an array has been extracted from the synthetic signal, calculating the latter in M different positions which have been made varying throughout the analysis.

The lowest number M of space sampling (*i.e.* of Mirnov coils), for SVD to correctly compute the mode periodicity m, respects the Nyquist criterion: M>2*m+1, although a minimum set of M=5 coils seems necessary for the algorithm to work properly even with low m's (Tab 1, right).

The algorithm does not require *a priori* that coils are uniformly spaced to work properly, but there exist a minimum distance between two "coils" for them to be perceived as distinct and therefore to be both computed as elements of the minimum required set. When the coils are uniformely spaced this threshold is of the order of 1°. If on the contrary coils are clustered in some zones, leaving other zones un-sampled, this threshold results from 14° to 18°.

As regards the time resolution, *i.e.* the smallest time sampling window the algorithm requires to correctly determine the presence and periodicity of the mode, a fraction of the period proved to be enough (4 ms for a mode with T = 50 ms) (Tab 1, left).

Finally, SVD distinguishes the presence and periodicity of two travelling sinusoidal modes if their amplitudes and frequencies differ for at least 5%, and in this case at least a time sampling window of half a mode period is required (32 ms for T = 50 ms).

N	Log(SV)	PA
1024	Ok	Ok
512	Ok	Ok
256	Ok	Ok
128	Ok	Ok
64	~Ok	Ok
32	~ok	Ok
16	~ok	Ok
8	Peaked	Ok
4	Hollow	Ok

M	Log(SV)	PA
8	Plateau	Ok
7	Plateau	Ok
6	Plateau	Ok
5	Plateau	Ok
4	Plateau	Ok
3	Not decreasing	Undetermined

Tab 1: Dependence on time sampling window N (left) and on coil number M (right) for 1 mode, m=1, ν=20Hz: synthetic signal analysis.

Off-line FTU shot analysis

In order to test the behaviour on actual Mirnov coils we examined FTU shots where a MHD mode was present, alone, for a time long with respect to the discharge duration and where its periodicity was determined by other diagnostics such as SXR tomography and/or Mirnov coils FFT analysis. FTU being rather stable with respect to MHD modes, finding a relevant statistics of shots with these characteristics is not straightforward. Moreover, not surprisingly, the actual Mirnov coils signals prove to be far more complex than our synthetic signals, therefore results are still to be considered as preliminary. We focalised on poloidal coils only to avoid for the moment the problem of de-phasing.

The threshold on the minimum number of coils determined by the Nyquist criterion has been confirmed (7 coils for a m=3 mode).

As remarked, FTU poloidal coils are clustered around 0^o, 90^o, 180^o, 270^o (Fig.1) and therefore are never evenly spaced. Despite this, it seems that a separation of 4.5^o is sufficient to SVD to perceiving a coil as distinct from its neighbours.

Conclusions

A sensitivity analysis has been done with the purpose to characterise the algorithm utilisation limit, to determine whether the Mirnov coils in FTU were suitable for mode analysis via SVD and whether the shortest time window the algorithm can successfully analyse was compliant with real time tool requirements. Synthetic signal and poloidal coil results show that at least 7 coils with at least 4.5^o of separation one from the other are required, therefore the 8 FTU toroidal coils, separated by at least 7^o, should work properly, if the dephasing due to the different poloidal position of some of them can be accounted for.

References

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