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Phase tracking with Hilbert transform and nonlinear wave-wave coupling analysis on the HL-2A tokamak

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Routinely, bi-spectral analysis is applied to detect the nonlinear interaction [1]. However, a number of statistical ensembles are necessary for the bi-spectral analysis. The Hilbert transform [2] analysis does not need ensembles. It has already been applied for nonlinear mode coupling analysis on the camera data in the linear magnetized device PANTA [3]. A phase tracking method based on Hilbert transform algorithm is applied to the nonlinear wave-wave coupling analysis on HL-2A tokamak. Synthetic signal analysis shows the principle of phase analysis for the detection of nonlinear coupling. If the phase difference between two coherent modes is synchronized with the phase of a third mode, the three modes are nonlinearly coupled, vice versa. The time evolution of the phase of a coherent mode could be computed with Hilbert transform for experimental data. A phase tracking flowchart is summarized in figure 1.

Figure 1. Phase tracking flowchart of a mode with Hilbert transform

On HL-2A tokamak, in discharge number 26121 the 136-141 kHz Alfvén modes AM1, 126-132 kHz Alfvén modes AM2 and 7-12 kHz tearing mode TM are shown in figure 2(a). The nonlinear coupling among AM1, AM2 and TM has been confirmed with FFT bicoherence analysis, as shown in figure 2(b).

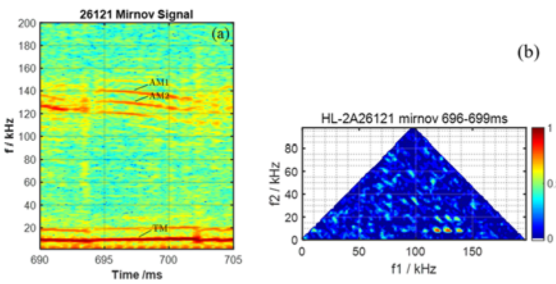

Figure 2. Data analysis results of a mirnov coil signal in discharge number 26121: (a) The power spectrogram; (b)The FFT bicoherence spectrogram during 696-699ms.

All the phases are calculated with the flowchart in figure 1. θ_{AM1}, θ_{AM2} and θ_{TM} stand for the instantaneous phases of AM1, AM2 and TM, respectively. In figure 3(a), the blue curve is the phase delay between AM1 and AM2, i.e. $\Delta\theta_{12} = \theta_{AM1}-\theta_{AM2}$, and the red curve is θ_{TM}. We could observe that $\Delta\theta_{12}$ and θ_{TM} are roughly synchronized with each other, and the maximum value of cross-correlation coefficient between $\Delta\theta_{12}$ and θ_{TM} $r(\Delta\theta_{12}, \theta_{TM})$ reaches 0.82, as shown in figure 3(b). An alternative to the cross-correlation method to check the synchronization is to observe the time evolution of the difference between $\Delta\theta_{12}$ and θ_{TM}, i.e. $\Delta\theta_{12}-\theta_{TM}$. If $\Delta\theta_{12}-\theta_{TM}$ varies smoothly and stays in a small range, $\Delta\theta_{12}$ and θ_{TM} are locked and nonlinear coupling exists among the three modes. If the time evolution of $\Delta\theta_{12}-\theta_{TM}$ is not a simple steady process but a kind of intermittent one, the phases are unlocked and nonlinear coupling does not exist among the three modes. Figure 3(c) shows the time evolution of $\Delta\theta_{12}-\theta_{TM}$ for the case when nonlinear coupling exists. $\Delta\theta_{12}-\theta_{TM}$ varies smoothly for the case that nonlinear coupling exists, and the histogram in figure 3(d) is peaking near $(\Delta\theta_{12}-\theta_{TM})/\pi = 1/2$.

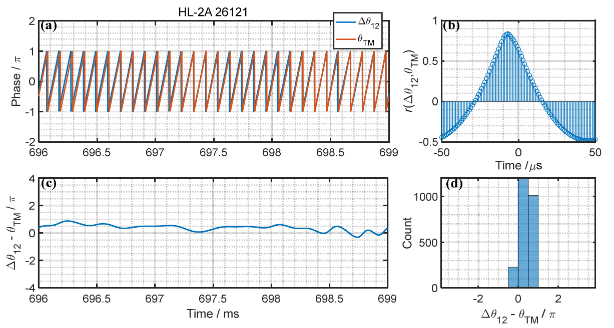

Figure 3. (a) The blue curve is the time evolution of $\Delta\theta_{12}$, and the red curve is the time evolution of θ_{TM}. (b) The time evolution of $r(\Delta\theta_{12}, \theta_{TM})$ during [-50μs, 50μs]. The maximum value of $r(\Delta\theta_{12}, \theta_{TM})$ reaches 0.82. (c) The time evolution of $\Delta\theta_{12}-\theta_{TM}$ for the case when nonlinear coupling exists. (d) The histogram of the curve in figure 3(a).

References

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