INDEPENDENT COMPONENT ANALYSIS FOR THE TURN BY TURN BEAM POSITION MEASUREMENT IN THE TLS

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Abstract

New BPM system for the Taiwan Light Source (TLS) have been deployed recently, it would support functionality of turn-by-turn data which can be applied in independent component analysis (ICA). This data analysis method is a special case of blind source separation to separate multivariable signal and additive noise and shown to be a useful diagnostic tool in acceleration application. In this paper, we use the ICA method to analyze experimental BPM turn by turn data of the TLS storage ring, measure betatron, dispersion function, and identify abnormal BPM signals. Other possible applications have been also further studied continuously.

INTRODUCTION

Independent component analysis [1] has been applied extensively for various fields of science such as signal processing, medical imaging, telecommunications and etc. In the last several years, its application for accelerators has also been emerged and initiated by the team of S.Y. Lee [2][3].

The Taiwan Light Source has 59 beam position monitors (BPMs) installed in the storage ring. The BPM electronics Libera Brilliance [4] provides functionality to enable simultaneously recording vertical and horizontal beam oscillations up to 30000 turns to be acquired through EPICS channel access [4]. The data resolution in turn by turn mode is within 10 µm down to 30 mA. These precise measured data can be applied for ICA.

Assume that there are recorded data with m BPM sources and n turns, it can be represented as Eq. 1 and 2 ,

$$X = \left[X_1 \ X_2 \ \dots \ X_m\right]^T \tag{1}$$

$$X_i = \left[X_i(1) \ X_i(2) \ \dots \ X_i(n)\right] \tag{2}$$

where χ_i is the i^{th} BPM waveform and **X** is the matrix of the measured signal of the dimension $m \times n$. In the ICA model, X can be observed as the sum of sources and noise as Eq. 3,

$$X = AX + N \tag{3}$$

where A is some unknown matrix, N is stationary noise vector, S are nongaussian source signal. ICA technique can estimated the mixing matrix A and S. Since source signals are independent, we can get Eq. 4,

$$C_S(\tau) = < S(t)S(t-\tau)^T > = D(\tau) \tag{4}$$

The covariance matrix $C_X = XX^T$ can be diagonalized via singular value decomposition (See Eq. 5).

$$C_X = U * W * U^T = AC_S A^T \tag{5}$$

To produce the covariance matrix $C_X = 1$, performing Eq. 6 and get Eq. 7.

$$S_O = QX \tag{6}$$

$$Q = W^{-1}U^T \tag{7}$$

Then it infers that A is pseudo-inverse of the matrix Q.

APPICATION OF ICA FOR TLS TURN-BY-TURN DATA

BPM Turn-By-Turn Data and Spectrum

Fig. 1 shows the typical turn-by-turn data of one BPM R6BPM7. The beam motions including betatron motion, synchrotron motion, orbit drift, bpm noise and etc are coupled to each other. In its spectrum as Fig 2, we observe the betatron mode easily while other mode could be buried in the strong betatron motion.

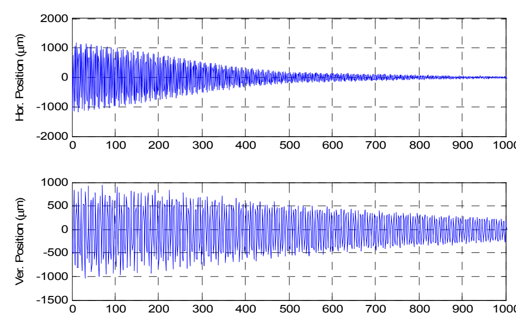

Figure 1: Betatron oscillation excited by kicker. Synchrotron oscillation excited by positive longitudinal feedback. It is R6BPM7 turn-by-turn data.

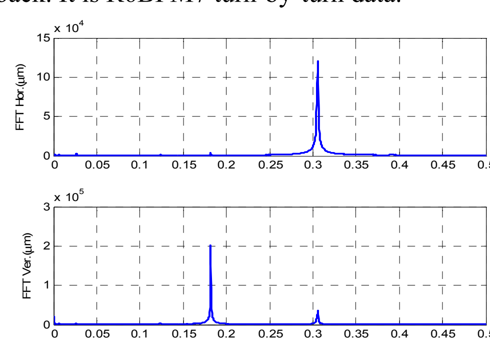

Figure 2: Spectrum of the above turn-by-turn data. Horizontal betatron tune is around 0.295 Vertical is 0.1817. Synchrotron tune is 0.0133

ICA Decomposition Results

The temporal function of ICA decomposition of the horizontal turn-by-turn data is shown as Fig. 3 S1-S2 are related to betatron oscillation; S4-S5 are vertical betatron motion coupled to the horizontal plane. S3 are low frequency synchrotron mode with orbit drift caused by kicker/septum field leakage due to eddy current.

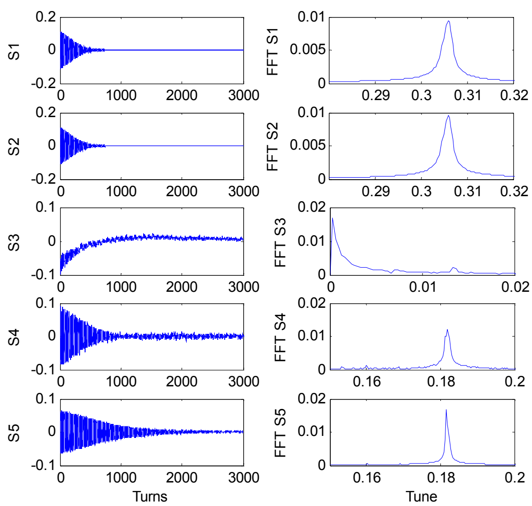

Figure 3: The temporal function of ICA decomposition and their spectrum in the horizontal plane.

Betatron Function and Phase Advance Calculated From Spatial Function

The betatron function and phase advance can be derived from spatial function as Eq. 8 and 9.

$$\beta = a\left(A_{S1}^2 + A_{S2}^2\right) \tag{8}$$

$$\varphi = \tan^{-1}\left(\frac{A_{S1}}{A_{S2}}\right) \tag{9}$$

Fig. 4 and Fig. 5 show betatron function and phase advance calculated from ICA spatial function and the provided the accelerator model.

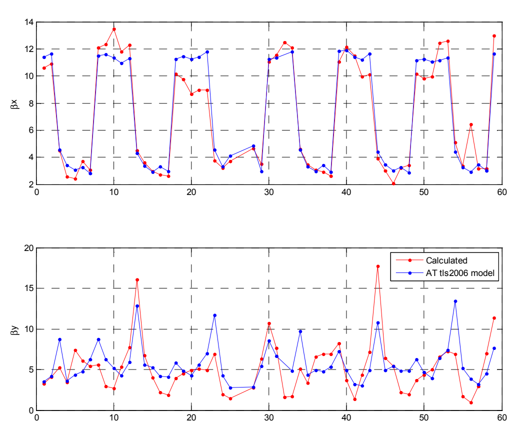

Figure 4: Betatron function comparison between ICA evaluation and Accelerator toolbox model.

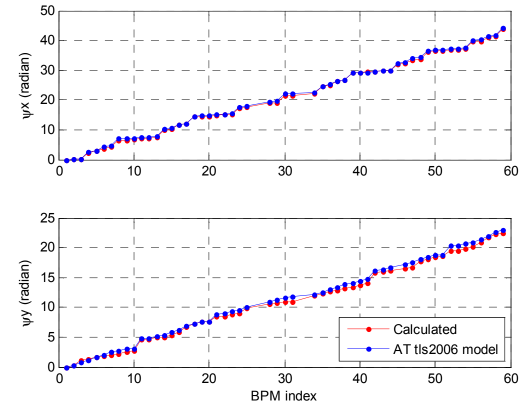

Figure 5: Phase advance between ICA evaluation and Accelerator toolbox model.

Synchrotron Oscillation Mode

In Fig. 3, synchrotron mode is coupled with low frequency orbit distortion caused by magnetic field leakage therefore we turn off septum and acquire another data operated in short-bunch low current. The result of ICA decomposition shows that S1-S2 are still related to strong betatron oscillation and S3-S4, as Fig. 6, is the synchrotron mode and clearly separated. Nevertheless, its spatial function, shown in Fig. 7, does not resemble dispersion function and is even cross zero in some locations. This may result from non single bunch experiment or other unknown reasons but consequently lead phase inconsistency. It requires further study to clarify.

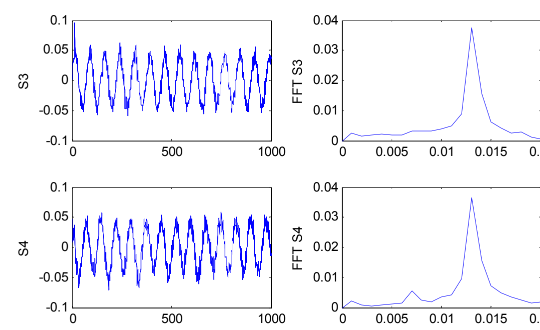

Figure 6: ICA decomposition S3-S4 modes (synchrotron mode) and its spectra in low frequency. The synchrotron tune is around 0.0133.

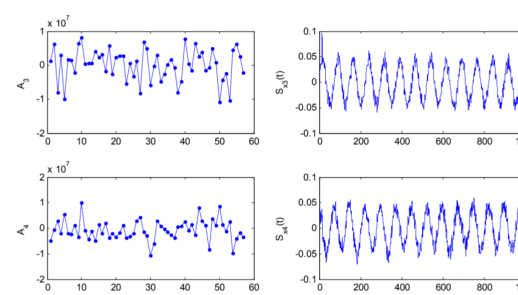

Figure 7: Synchrotron mode's spatial (left) and temporal function (right).

ICA APPLICATION TO IDENTIFY MISBEHAVIOR DBPM

The quasi-crossbar switching should be turned off for high precision turn-by-turn position measurement. The R3BPM7 quasi-crossbar switching is still turned on for the data acquisition due to improper initialization. It will introduce 13 kHz switching spike in turn-by-turn reading for both of the horizontal and vertical planes of this BPM. Figure 8 shows its ICA decomposition result for vertical mode S1 and S3. Mode S1 and S2 are related to betatron modes. Mode S3 spatial function reveals R3BPM7 (BPM index 29) has a switching signal at 13 kHz (~ 190 turns).

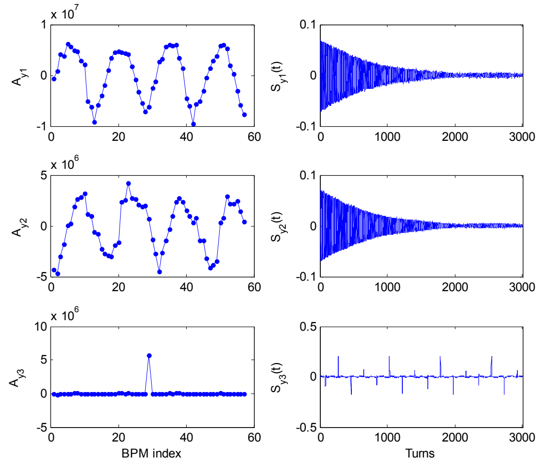

Figure 8: ICA decomposition for vertical S1-S3 modes.

In the horizontal plane, S1 and S2 are still related to betatron modes, BPM noise mode is shifted to S4 and orbit distortion caused by eddy current induced by the leakage field of the injection septum is S3 with larger spatial quantity than S4. Inherently, orbit excursion is much more severe in the horizontal plane than vertical. The data was taken in injection instance.

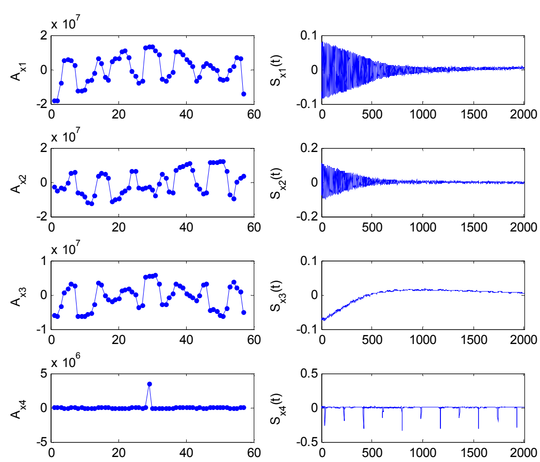

Figure 9: ICA decomposition for horizontal S1-S4 modes.

The above experiment validates the capability of ICA to identify ill behaviour BPM and it will be useful to confirm initial configurations of Libera and further examine abnormal units rather than the others.

SUMMARY

Preliminary analyses of the turn-by-turn data by ICA method have been done. This report demonstrates applicability of the ICA for the TLS data. The preliminary results show that ICA can be a useful tools to extract accelerator related information and diagnostic for improper configuration or bad BPM.

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