Preliminary application of turn-by-turn data analysis to the SSRF storage ring*

CHEN Jian-Hui(陈建辉)[1,2] ZHAO Zhen-Tang(赵振堂)[1;1)]

1 (Shanghai Institute of Applied Physics, Chinese Academy of Sciences, Shanghai 201800, China)

2 (Graduate University of Chinese Academy of Sciences, Beijing 100049, China)

Abstract There is growing interest in utilizing the beam position monitor turn-by-turn (TBT) data to debug accelerators. TBT data can be used to determine the linear optics, coupled optics and nonlinear behaviors of the storage ring lattice. This is not only a useful complement to other methods of determining the linear optics such as LOCO, but also provides a possibility to uncover more hidden phenomena. In this paper, a preliminary application of a β function measurement to the SSRF storage ring is presented.

Key words beam position monitor, turn-by-turn, model independent analysis, principal component analysis, independent component analysis

PACS 29.20.Dh, 29.27.Bd

1 Introduction

A beam position monitor (BPM), as an indispensable diagnostic tool, plays an important role in each phase of accelerator commissioning, operation and performance upgrades. The convenience of having BPM turn-by-turn (TBT) data has significantly aided in the commissioning of the storage ring as well as a day-to-day diagnostic for instabilities, injection problems, and tune measurement. Recently, techniques such as principal component analysis (PCA)[1, 2] and independent component analysis (ICA)[3, 4] have been developed to extract uncoupled and even coupled lattice functions from TBT data. There is also increasing interest in nonlinear beam dynamics studies[5, 6], for example, resonance driving term measurement and nonlinear optics modeling, complementary to orbit response matrix analysis[7, 8].

The Shanghai Synchrotron Radiation Facility (SSRF) is an intermediate energy synchrotron light source now being commissioned[9]. The SSRF storage ring is equipped with a full compliment of 140 Libera electron beam position processors from I-Tech (EBPPs)[10]. The EBPPs are capable of measuring beam position data at TBT rates and have long history buffers. In this paper, preliminary applications of TBT BPM data analysis based on the model independent analysis (MIA) algorithm to the SSRF storage ring, i.e. the β function measurement, is presented.

2 Principles of MIA

In recent years, MIA emerged as a new approach to study beam dynamics by analyzing simultaneously recorded beam histories at a large number of BPMs, as shown in Fig. 1 with 140 BPMs of 2048

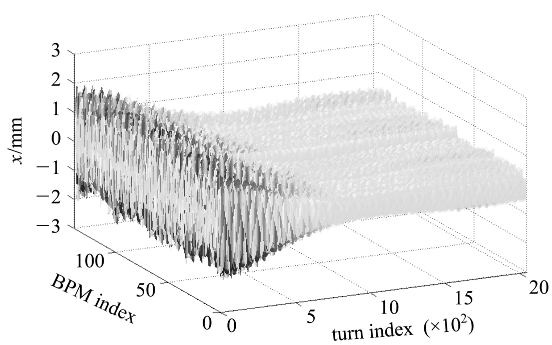

Fig. 1. Typical raw BPM history data after a horizontal kick from an injection kicker.

Received 27 October 2008

* Supported by SSRF project

1) E-mail: zhaozt@ssrc.ac.cn

turns recorded. Letting b_p^m represent the measurement at the m^{th} monitor for the p^{th} pulse or turn, beam history matrix $B_{P\times M}=(b_p^m)$ can be easily constructed. It has been widely used in storage rings as well as linacs for the study of beam dynamics. Two major techniques, principal component analysis (PCA) and independant component analysis (ICA), have been developed to extract physical modes.

2.1 PCA

PCA finds a small number of uncorrelated principal components that can account for the maximum amount of observed variances and covariances in the data. Each principal component is a linear combination of the observed signals and retains the maximum variance along its direction. PCA can be achieved by an singular value decomposition (SVD) of the data matrix B as,

$$B=USV^{\mathrm{T}}=\sum_{\text{modes}}\sigma_i u_i v_i^{\mathrm{T}}\,, \tag{1}$$

where $U_{P\times P}=[u_1,\cdots,u_P]$ and $V_{M\times M}=[v_1,\cdots,v_M]$ are orthonormal matrices comprising the temporal and spatial eigenvectors, and $S_{P\times M}$ is a rectangular matrix with non-negative singular values σ_i along the upper diagonal. A pair of spatial and temporal vectors characterizes an eigenmode and the corresponding singular value specifies the overall amplitude of the eigenmode.

2.2 ICA

If the modes are strongly mixed, the SVD based PCA method might be not applicable anymore. ICA attempts to reconstruct the source signals based on the assumption that they are mutually independent and non-Gaussian. Like PCA, ICA assumes mutual uncorrelatedness since it is a necessary condition for independence. For non-Gaussian signals, independence requires more than uncorrelativeness and thus provides extra conditions for determining the source signals.

3 Preliminary applications of MIA

3.1 BPM system and performance

The SSRF storage ring consists of 20 identical cells with 4 super-periods. A schematic view of one cell is shown in Fig. 2, where BPM locations are displayed. Each cell accommodates 7 BPMs, 2 of which are supported with invar materials of low thermal conductivity.

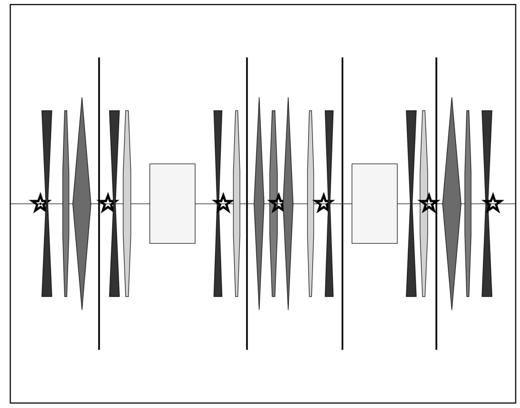

Fig. 2. BPMs (★) of one cell of the SSRF storage ring.

The BPM performance is characterized during the first phase commissioning of the storage ring[11], as shown in Table 1.

Table 1. BPM performance.

type	rate	bandwidth	H/μm	V/μm
SA	10 Hz	4 Hz	0.1	0.1
FA	10 kHz	2 kHz	<2	<2
TBT	694 kHz	347 kHz	<5	<5

For TBT data to be useful the BPMs have to be synchronised to catch the same turn. As shown in Fig. 2, the synchronization is very good[11].

3.2 Spatial-temporal mode observation

The beam was excited using the storage ring injection kickers up to an amplitude of 3 mm, as shown in Fig. 2, in the horizontal plane and using a vertical kicker in the vertical plane.

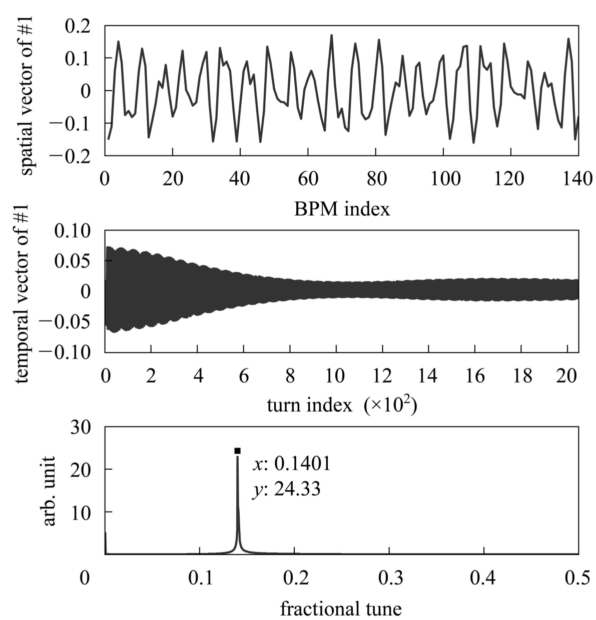

Fig. 3. Horizontal spatial-temporal observation.

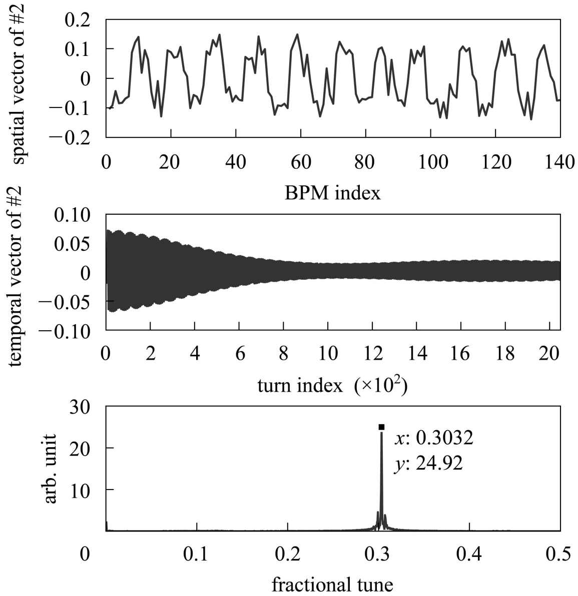

Fig. 4. Vertical spatial-temporal observation.

As explained in the MIA part, spatial and temporal modes can be easily gained with a simple SVD technique. As an example, the spatial and temporal behaviors of the first mode of the horizontal plane and the second mode of the vertical plane are shown in Fig. 3 and Fig. 4, respectively, where the peak of the fourier transformation of the temporal vector indicates the tune of each plane.

3.3 β function measurements

As shown in Fig. 3 and Fig. 4, beam motions after both injection kick excitation and vertical kicker are dominated by betatron oscillations. There are two orthogonal eigenmodes corresponding to the normal coordinates that are normally used to describe the betatron motion[2], as shown in Fig. 5.

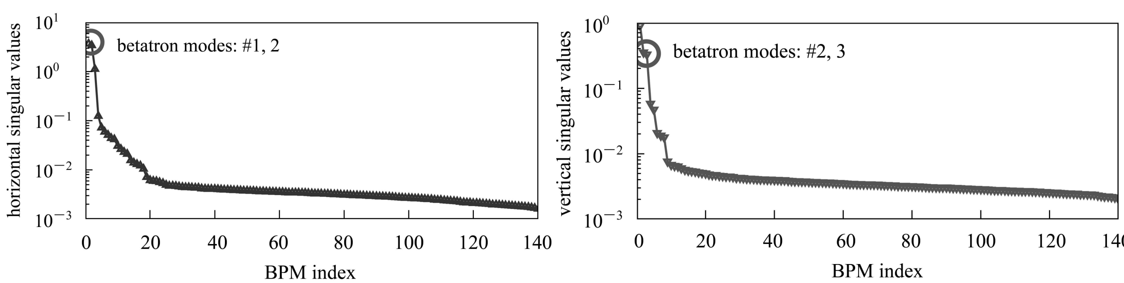

Fig. 5. Singular value spectra.

From these two betatron modes, the β function can be derived with good accuracy.

For the SVD based PCA method, the β function is determined as[2],

$$\beta=\langle J\rangle^{-1}(\lambda_+ v_+^2+\lambda_- v_-^2), \tag{2}$$

where λ_+ and λ_- are the upper and lower singular values of the two betatron modes, and v_+ and v_- are the corresponding spatial vectors, respectively. $\langle J\rangle^{-1}$ is the scaling factor.

For the ICA method case, the β function is determined as[3],

$$\beta=a(A_{b1}^2+A_{b2}^2), \tag{3}$$

where A_{b1} and A_{b2} are the two spatial vectors of betatron modes, and again a is the scaling factor.

In this paper, an easy-to-use Matlab software package called FastICA[12] is used to extract spatial and temporal functions. Comparisons of β function derived from both methods calibrated with the model and from LOCO with the model one are shown in Fig. 6.

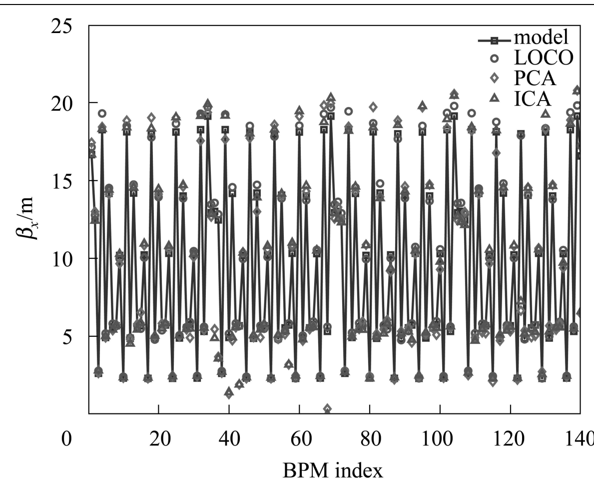

Fig. 6. Comparison of horizontal β functions.

4 Concluding remarks

Both PCA and ICA based MIA have been applied to determine the β functions of the SSRF storage ring and the results agree well with LOCO output. Although calibration of the scaling factor is needed, it serves as a fast and accurate approach to β function measurement.

We would like to thank Leng Yongbin and Yan Yingbing of the diagnostics group of the SSRF project for their kind help with the BPM configuration and data acquisition. Many thanks also go to Eugene Tan from the Australian Synchrotron Project for introducing is to the FastICA algorithm and implementation.

References

1 Irwin J, WANG C X, YAN Y T et al. Phys. Rev. Lett., 1999, **82**: 1684

2 WANG C X, Sajaev V, YAO C Y. Phys. Rev. ST Accel. Beams, 2003, **6**: 104001

3 HUANG X, Lee S Y, Prebys E et al. Phys. Rev. ST Accel. Beams, 2005, **8**: 064001

4 WANG F, Lee S Y. Phys. Rev. ST Accel. Beams, 2008, **11**: 050701

5 Bartolini R. Proceedings of ICAP 2006. Chamonix, France

6 Nonlinear Beam Dynamics Workshop. Grenoble, 26—28 May 2008

7 Safranek J. Nucl. Instrum. Methods Phys. Res. A, 1997, **388**: 27

8 ICFA Beam Dynamics Newsletter. No. 44, December 2007

9 ZHAO Z T, XU H J, DING H. Proceedings of 2008 European Particle Accelerator Conference. Genoa, Italy

10 Kosicek A. Proceedings of 2005 Particle Accelerator Conference. Knoxville, Tennessee

11 YAN Y B, CHEN Y Z, LENG Y B et al. Proceedings of 2008 European Particle Accelerator Conference. Genoa, Italy

12 Gavert H et al. FastICA package version 2.5, published on 19-10-2005