

INITIAL RESULTS FROM MODEL INDEPENDENT ANALYSIS OF THE KEK ATF*

A. Wolski[†], LBNL, Berkeley, CA 94720, USA
 M.C. Ross, M.D. Woodley, J. Nelson, SLAC, Menlo Park, CA 94025, USA

Abstract

Model Independent Analysis (MIA) has shown the potential to be a useful tool for diagnostics and optics verification. The Accelerator Test Facility (ATF) prototype damping ring at KEK has a diagnostic system with the ability to collect data allowing the application of MIA for analysis of the injection stability, and the storage ring optics and diagnostics. Understanding of all these issues will be important for improving the operational performance of a damping ring. We report here the results of a first attempt to apply MIA to the ATF.

1 MODEL INDEPENDENT ANALYSIS

The basic technique of Model Independent Analysis [1] is a decomposition of a matrix constructed from BPM readings, which reveals correlations between the signals at the various BPMs. A set of signals from all the BPMs in a given beamline over a number of bunch passages will have correlated components arising, for example, from betatron motion of the bunch, variations in bunch charge, and energy errors; and uncorrelated components arising, for example, from BPM noise.

An “orbit vector” may be constructed from the BPM signals taken during a single bunch passage. Horizontal and vertical data are combined into a single vector; other variables possibly correlated to the BPM signals, such as the bunch charge, may be added as additional components. We may then construct a matrix M with rows composed of orbit vectors from a number of successive bunch passages. Singular value decomposition (SVD) of this matrix provides us with matrices u , w , and v such that:

$$M = u^T \cdot w \cdot v$$

where

$$u \cdot u^T = v \cdot v^T = I$$

I is the identity matrix, and w is diagonal. We refer to the elements of w as the eigenvalues of M , and to rows of v as “modes”. The matrix v contains correlations between different components of the orbit vectors, in that any orbit vector may be reconstructed by a linear superposition of the modes.

The power of MIA lies in the ability to reveal correlations between BPM signals, and in this respect, nothing needs to be known about the optical properties of the beamline. However, the technique may be extended to verify the beamline optics, since a large number of

orbits will allow a very precise determination of the betatron and dispersion modes.

2 KEK ATF

The Accelerator Test Facility (ATF) at KEK is a prototype damping ring for future linear colliders. The storage ring is a racetrack lattice, with circumference 139 m and nominal energy 1.54 GeV. One of the objectives of the ATF is to demonstrate the performance that will be required of damping rings for a future linear collider, in terms of low emittance and injection efficiency. To achieve these goals, a good understanding of the diagnostics system, injection errors and the condition of the storage ring lattice will be crucial, and MIA has the potential to provide important relevant information. For the present investigation, we collected data from 7000 orbits, over a period of four hours during a shift in December 2001. Ultimately, we hope to use MIA to perform detailed checks of the optics, but our initial goals were simply to verify the technique in identifying the betatron and dispersion modes, and estimating the BPM noise.

There are 96 BPMs throughout the storage ring, each capable of reading the horizontal and vertical offset of a bunch on a single pass, with a resolution of the order of 20 μm . A bunch with a charge of the order 10^{10} particles may be injected, damped and extracted with a repetition rate of up to 3 Hz. The orbit can be recorded on any given turn after injection, and the required data for MIA is thus readily acquired.

Sextupoles are used to correct the chromaticity in the lattice, but they cause nonlinear orbit oscillations that complicate the analysis, and were therefore turned off for the present studies. In this configuration, the injection efficiency is poor. Radiation from the injection losses adversely affects the BPM system, and it was therefore necessary to record orbits after a few hundred turns. The relatively low remaining bunch charge (of the order 30% of nominal) degrades the BPM resolution.

3 DATA ANALYSIS

Orbit vectors were constructed with the first 96 components containing the horizontal BPM readings, the next 96 components containing the vertical BPM readings, and the final component containing the bunch charge. Note that we subtracted the mean orbit vector from each vector in the data set of 7000 orbits, before performing the decomposition. The eigenvalues produced by SVD are shown in Figure 1. The largest four values are associated with the principal betatron modes (note one

*Work supported by the US DOE under contract DE-AC03-76SF00098
[†]awolski@lbl.gov

eigenvalue above 60000). The next two modes are associated with energy and bunch charge variations. There are several modes with eigenvalues around 10000, corresponding to particularly noisy BPMs, and then a large number of modes close to the “noise floor” with eigenvalues a little over 2000. Finally, there are a number of zero eigenvalues, associated with broken BPMs, which were simply returning zero values.

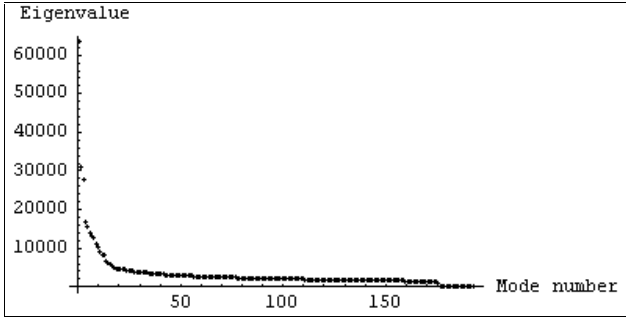


Figure 1: Eigenvalues from SVD of 7000 orbit vectors.

3.1 Betatron Modes

The modes corresponding to the first two eigenvalues are shown in Figures 2 and 3.

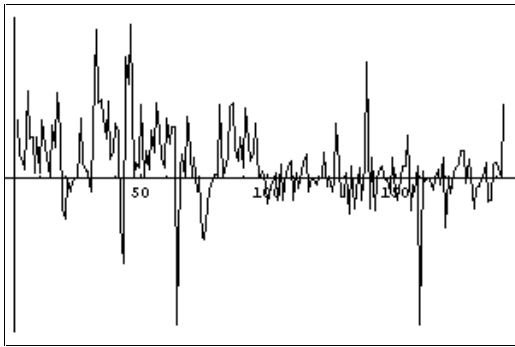


Figure 2: Mode corresponding to first eigenvalue.

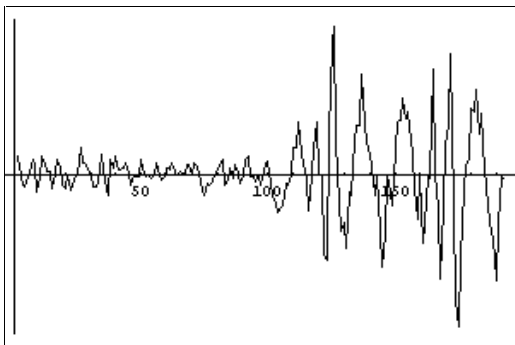


Figure 3: Mode corresponding to second eigenvalue.

The first mode appears to be principally horizontal, while the second is principally vertical, but the presence of correlations between horizontal and vertical motion indicates a significant amount of coupling. Large components in the vertical part of the “horizontal” mode correspond to noisy BPMs.

3.2 Estimates of BPM Resolution

As we mentioned above, we expect the noise on the signals from different BPMs to be uncorrelated. The “independence” of a particular component of an orbit vector may be characterized by the relative contributions from different modes required to construct a vector with only the component of interest taking a non-zero value. The contribution of the i th mode to a vector with the j th component equal to one, and all other components zero, is just v_{ij} . For the j th BPM, we can plot $|v_{ij}|^2$ for the full range of i . We do this for BPM 20 in Figure 4. Only a small number of modes, with relatively large eigenvalues, contribute, showing that BPM 20 has a significant variation independent of other variables. In fact, it is known that BPM 20 has a different construction from other BPMs in the ring, because of the local beam-pipe geometry, and has a poorer resolution. Compare Figure 4 with Figure 5, which shows the corresponding plot for BPM 4. Independent variations in the signal from BPM 4 are relatively weak, and are peaked at very small eigenvalues, indicating that BPM 4 has a good resolution.

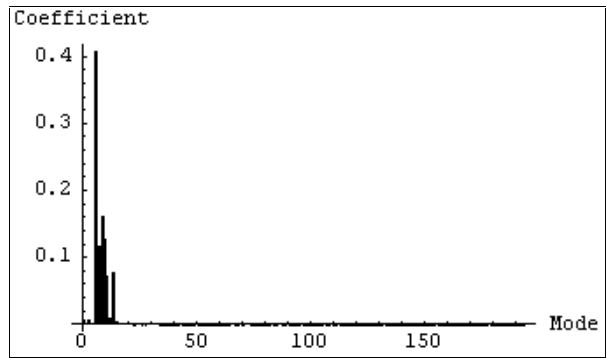


Figure 4: Contributions of different modes to independent variations of BPM 20 signal.

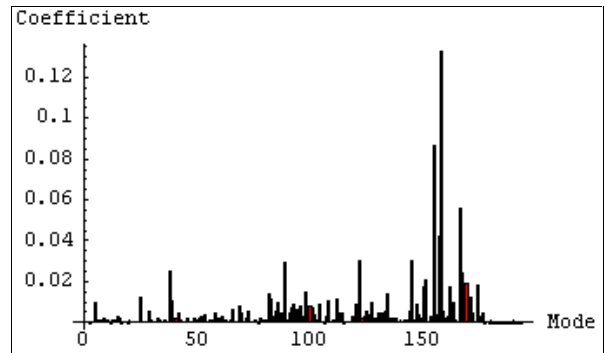


Figure 5: Contributions of different modes to independent variations of BPM 4 signal.

The resolution of individual BPMs may be found from:

$$\sigma_i^2 = \sum_j w_j v_{ji}^2$$

The results for the horizontal plane are shown in Figure 6; results in the vertical plane are similar. The zero values correspond to the broken BPMs that are consistently returning zero. The resolutions found in this way are

consistent with sets of BPM readings taken for a damped beam under stable conditions, indicating that the reduced bunch charge in the MIA data did not seriously degrade the BPM resolution.

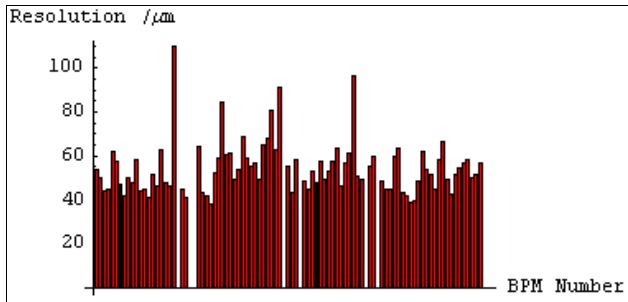


Figure 6: BPM resolution determined by MIA.

3.3 Optics Verification

Comparing the principal betatron modes obtained by the SVD of the orbit data, with orbits generated from a lattice model, allows a simple test of the optics in the storage ring. A typical fit, for the vertical plane, is shown in Figure 7. The quality of the fit is good, despite the fact that no attempt has been made to adjust parameters in the model (quadrupole strengths, BPM gains and rotations etc.) to generate a better fit. We intend to investigate the best fit that may be achieved through variation of these parameters; this could yield useful information on coupling, optical and diagnostics errors [2].

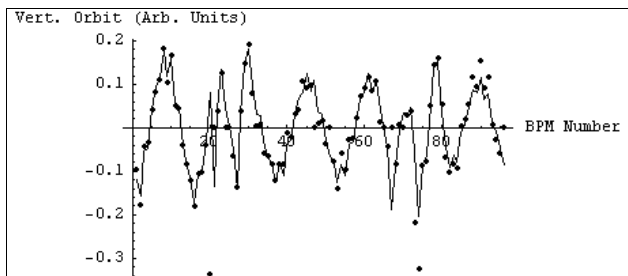


Figure 7: Vertical orbit fit from lattice model (line) to second MIA vertical betatron mode (points).

3.4 Injection Jitter

The comparison between MIA modes and orbits generated from a lattice model suggests that the lattice itself is well tuned. Furthermore, the MIA modes allow the reduction of noise in the data for any particular orbit, by a reconstruction the orbit using just the first five modes (corresponding to energy offset and betatron oscillations) with appropriate amplitudes. Fitting an orbit in the lattice model to the noise-reduced orbit allows an accurate determination of the energy deviation and transverse phase-space co-ordinates of the injected bunch. Since the mean BPM readings are subtracted from the data before carrying out the SVD, we cannot determine the mean offset from the target injection point, but we can estimate the fluctuations.

The energy jitter is shown in Figure 8, and the horizontal jitter in Figure 9. Note that the transverse jitter is specified by variations in the action; for the ATF lattice,

the lattice functions at the injection point are such that a 1 nm-rad variation in the action corresponds to a 54 μm horizontal offset. The vertical stability is much better than the horizontal, as may be expected since the injection kickers operate horizontally.

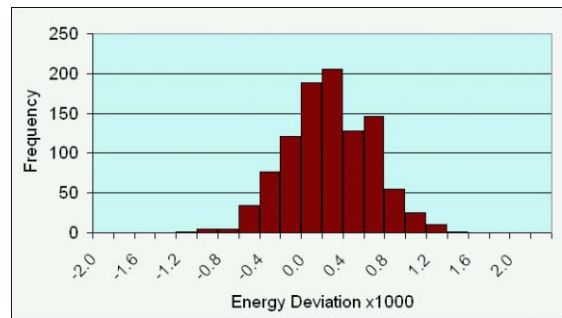


Figure 8: Injection energy jitter.

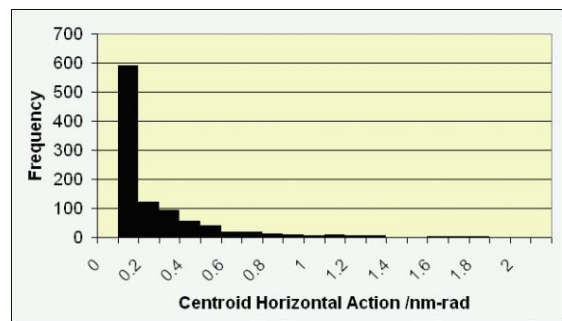


Figure 9: Injection horizontal jitter.

It is also possible to study the correlation between injection energy error and horizontal and vertical offset, to estimate any dispersion mismatch between the injection line and the storage ring lattice. In the horizontal, the mismatch is of the order 10 mm, and about 5 mm in the vertical.

4 FUTURE WORK

We hope to extend the work to allow verification of the storage ring optics. The dispersion information contained in the modes is potentially extremely valuable for tuning the ring for low vertical emittance. If MIA can be shown to provide a fast, non-invasive technique for accurate measurement of the vertical dispersion, this has significant benefits for damping ring operation.

5 ACKNOWLEDGEMENTS

The authors would like to thank John Irwin and Yiton Yan for useful discussions, and the staff at the ATF for assistance in obtaining the data.

6 REFERENCES

- [1] J. Irwin, C.X. Wang, Y. Yan et al, "Model Independent Beam Dynamics Analysis", Phys.Rev.Lett. 82 (1999).
- [2] J. Irwin, Y. Yan, "Beamline Model Verification Using Model Independent Analysis," proceedings EPAC 2000, June 2000.