VALIDATION OF PEP-II RESONANTLY EXCITED TURN-BY-TURN BPM DATA *

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Abstract

For optics measurement and modeling of the PEP-II electron (HER) and position (LER) storage rings, we have been doing well with MIA [1] which requires analyzing turn-by-turn Beam Position Monitor (BPM) data that are resonantly excited at the horizontal, vertical, and longitudinal tunes. However, in anticipation that certain BPM buttons and even pins in the PEP-II IR region would be missing for the run starting in January 2007, we had been developing a data validation process to reduce the effect due to the reduced BPM data accuracy on PEP-II optics measurement and modeling. Besides the routine process for ranking BPM noise level through data correlation among BPMs with a singular-value decomposition (SVD), we could also check BPM data symplecticity by comparing the invariant ratios. Results from PEP-II measurement will be presented.

INTRODUCTION

It is very helpful to have an accurate lattice model in figuring out the best strategy for accelerator optics improvement. Although the ideal lattice may serve such a purpose to some extent, in most cases, real accelerator optics improvement requires accurate measurement of optics parameters. Therefore, it is very desirable to have precision measurements of a complete set of linear orbits from which one can form a linear optics model to match the linear optics of the real machine.

At SLAC, we have a set of MIA programs [1] that have been used for years to obtain the accurate lattice models, the so-called virtual machines, for both PEP-II High-Energy Ring (HER) and Low-Energy Ring (LER). We consider all quadrupole strengths (both normal and skew) and sextupole feed-downs as well as all BPM gains and BPM cross-plane couplings as variables to fit the Local Green's functions [2], the phase advances and the dispersions calculated from a lattice model to those derived from orbit measurement using a model-independent analysis (MIA) [3]. We use an SVD-enhanced Least Square fitting technique [4] that is efficient enough for a system of tens of thousand constraints with thousands of variables. Once the lattice model is fitted to the orbit measurement, we then confirm if it matches the real accelerator in linear optics by checking the coupling Eigen ellipses [5] and/or dimensionless c_{12} [6] between those calculated from the fitted model and those derived from the orbit measurement to see if they are automatically matched at the double-view BPM locations before we call this fitted lattice model the computer virtual accelerator. Once the virtual accelerator is obtained, we may compare it to the ideal lattice model for finding and adjusting special magnets with noticeable differences, although we would most likely search for an easily-approachable better-optics model by pre-selecting and fitting a group of limited number of quadrupole strengths and/or sextupole bumps. The solution is then applied to the real accelerator. This procedure has been successfully applied for numerous PEP-II optics improvements such as fixing the beta beat, bringing LER working tune to near half integer, reducing the linear coupling and dispersion, etc.

To improve the PEP-II luminosity, besides improving the optics, one can also increase currents of both LER and HER. In the 2006 PEP-II run we were able to push the currents to near 3 amperes for the LER and near 2 amperes for the HER and observe a peak luminosity of $1.2e34cm^{-2}s^{-1}$. However, we noticed heating problems, particularly at certain BPM locations. So we decided to take out certain BPM buttons. This weakened the BPM signals; consequently, we had to check the BPM data more carefully to assure that we could still obtain useful virtual machines from MIA.

MIA BPM DATA AND INVARIANTS

The linear geometric optics is determined if one has 4 independent linear orbits. This can be clearly shown by the linear mapping, $Z^b = R^{ab}Z^a$, and so $R^{ab} = Z^bZ^{a-1}$, where the 4-by-4 matrix, $Z^a = [\vec{z}^a_1, \vec{z}^a_2, \vec{z}^a_3, \vec{z}^a_4]$, represents 4 independent linear orbits at location a, and R^{ab} is the linear map from location a to location b. Therefore, a complete geometric-optics set of data must be able to provide the extraction of 4 independent orbits. Since there is radiation damping in the rings, the most economic process for such data acquisition is through two orthogonal resonance excitations, one at the horizontal (Eigen-plane 1) and the other at the vertical (Eigen-plane 2) betatron tunes, and then take and store buffered BPM data. Since a betatron motion has two degrees of freedom (phase and amplitude), each excitation generates a pair of conjugate (cosine- and sine-like) betatron motion orbits from zoomed FFT after removal of non-physical BPM data. Therefore, a complete 4 independent linear (X and Y) orbits can be extracted from the two Eigen-mode excitations.

Since we extract these MIA data at the equilibrium states of the resonance excitation, we expect that the extracted betatron motion orbit will comply with the symplecticity requirement. That is, R^{ab} is a symplectic matrix. Applying

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${R^{ab}}^T S R^{ab} = S$, where

$$S = \begin{pmatrix} 0 & 1 & 0 & 0 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \end{pmatrix},$$

it follows that the anti-symmetric matrix $Q = {Z^b}^T S Z^b = {Z^a}^T S Z^a$ is a constant around the ring. Since a similarity transformation preserves the invariants and the 4 orbits are extracted from two pairs of conjugate Eigen orbits, there are only 2 invariants, Q_{12} and Q_{34} in the constant matrix Q. Each represents how strong the betatron orbit is resonantly excited. Labeling the 4 orbits as (x_1, y_1), (x_2, y_2), (x_3, y_3), (x_4, y_4), the ratio of the two invariants can be derived and is given by

$$Q_{12}/Q_{34} = -(x_1 y_2 - x_2 y_1)/(x_3 y_4 - x_4 y_3), \qquad (1)$$

which is still an invariant under the linear BPM gain and linear BPM cross coupling transformation given by

$$x^m = g_x x + \theta_{xy} y,$$
$$y^m = g_y y + \theta_{yx} x,$$

That is, we can measure the invariant ratio in the BPM measurement frame. Without the need to know the linear BPM gains and the linear BPM cross couplings, all we need to do is to replace the orbits in Equation 1 with the measurement orbit derived directly from BPM readings, i.e.,

$$Q_{12}/Q_{34} = -(x_1^m y_2^m - x_2^m y_1^m)/(x_3^m y_4^m - x_4^m y_3^m). \qquad (2)$$

This is one quantity, which can be measured at each double-view BPM. Therefore, it can be used for checking the BPM data symplecticity, which along with other information, such as BPM noise ranking, can be used for better judgement of valid BPM data.

APPLICATION TO PEP-II BPM DATA VALIDATION

Once the 4 independent orbits, (x_1, y_1), (x_2, y_2), (x_3, y_3), (x_4, y_4) are extracted from the 2 set of resonantly excited BPM buffer data, we first calculate the invariant ratios, Q_{12}/Q_{34} at all BPM locations. Ideally these ratios should be the same at all BPM locations. However, if at a certain BPM location, the machine is not globally coupled, both the nominator and the denominator in Equation 2 can approach 0, causing unreliable invariant ratio calculation for that location. Therefore the invariant ratio is determined by taking the average of those ratios that are well selected through an iterative exclusion process. Once the invariant ratio is determined, we then calculate the standard deviation to select those BPMs with invariant ratio, Q_{12}/Q_{34}, within 3 standard deviations. Shown in Figure 1 is a typical case of the invariant ratio, Q_{12}/Q_{34}, for PEP-II LER MIA data. The plot shows that the majority of the BPM data have an invariant ratio, Q_{12}/Q_{34}, whin 3 standard deviations. They are immediately recognized as good BPM data unless other types of checks show otherwise. For those BPMs with Q_{12}/Q_{34} outside the 3 standard deviation, We have to check further before we can determine whether they are good because of the possible singularity problem as given by Equation 2. For example, if a BPM has an invariant ratio outside the 3 standard deviation range and is identified as a noisy BPM through a correlation check by an SVD process, then we may have to take out that BPM in MIA SVD-enhanced least square fitting.

Shown in Figure 2 is a typical case for PEP-II HER MIA data invariant ratios. That the invariant ratio is about 1 means the two resonance excitations are balanced so that the two invariants, Q_{12} and Q_{34}, are about the same. Again, ratios within 3 standard deviation are considered to be good BPM data while those not within 3 standard deviations requires other checks before one can be sure that they are bad BPM data and thus need to be excluded from MIA enhanced Least-Square fitting.

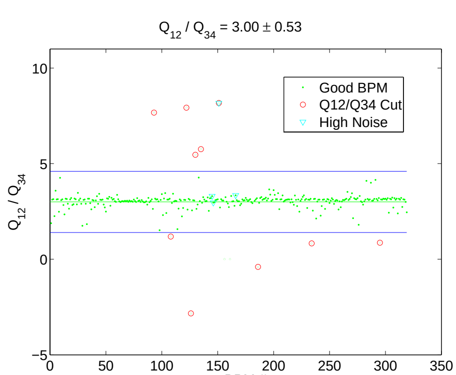

Figure 1: Invariant ratio, Q_{12}/Q_{34}, calculated from the Four independent orbits extracted from PEP-II LER BPM buffer data taken on April 22, 2007. The blue horizontal lines show the 3 standard deviations.

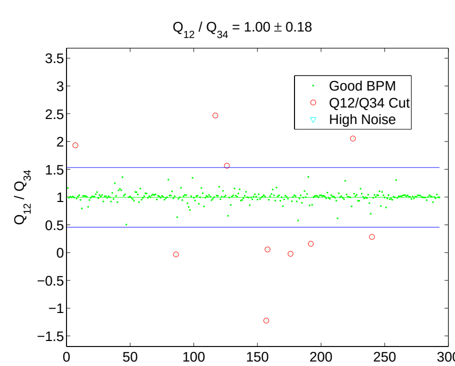

Figure 2: Invariant ratio, Q_{12}/Q_{34}, calculated from the Four independent orbits extracted from PEP-II HER BPM buffer data taken on April 27, 2007. The blue horizontal lines show the 3 standard deviations.

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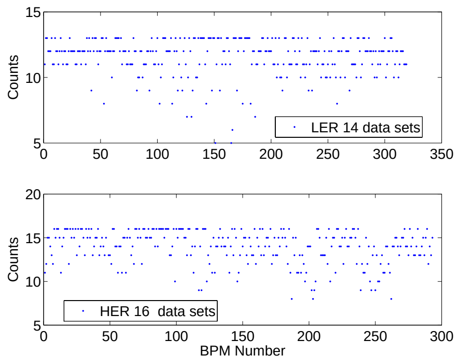

Figure 3: total count of the times for each BPM with invariant ratios, Q_{12}/Q_{34}, falling within 3 standard deviation. The top plot shows the total count for the 14 sets of MIA LER data taken in 2007 while the bottom plot shows the total count for the 16 sets of the MIA HER data taken in 2007.

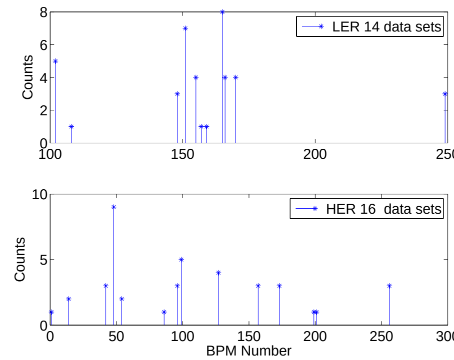

Figure 4: total count of the times for each BPM that does not pass the invariant ratio test and simultaneously have a high rank of noisy level for 14 sets of LER MIA data and 16 sets of HER MIA data. These BPMs are likely to be the trouble BPMs.

PEP-II BPM DATA QUALITY SURVEY FOR 2007 RUN

In order to determine the quality of each BPM and to identify bad BPMs, we surveyed the quality of all the BPM data for all MIA data taken during the 2007 PEP-II run. We surveyed 14 sets of MIA data from the LER and 16 sets of MIA data from the HER. For each BPM, if its invariant ratio was within 3 standard deviations for a given set of MIA data, we gave it one count as a good BPM. As shown in Figure 3, the majority of the BPMs are considered as very good BPMs as they pass the invariant ratio test for near the maximum count (14 for LER and 16 for HER) possible. For example, more than 80% of the LER BPMs have more than 9 out of 14 count while more than 80% of the HER BPMs have more than 10 out of 16 count. Those BPMs with low count would receive our attention in determining if the data should be excluded from MIA fitting each time we have the MIA data. Testing with other criteria such as noise ranking would be required to validate those BPM data.

On the other hand, Figure 4 shows the count for each BPM that does not pass the invariant ratio test and simultaneously has a high rank of noise level from correlation analysis with SVD for the same sets of MIA data. This gives us a clear picture as to which BPMs are most likely trouble BPMs and we need to pay special attention to these BPMs for MIA data exclusion decisions.

SUMMARY

Although MIA has been developed to a mature practical stage for PEP-II LER and HER measurement and modeling, it will not work well without good turn-by-turn BPM data. That MIA could work well in the past shows that PEP-II had a very good BPM system that can take accurate beam orbit data. In the 2007 PEP-II run, we have seen MIA data quality degraded in LER due to missing BPM buttons and even broken pins. However, the data are still useful, but we have to be more careful in excluding the bad BPM data using various data quality test criteria. The most convenient one is the invariant ratio, Q_{12}/Q_{34}, as shown in this paper. Its best advantage is that it does not depend on linear BPM gains and linear BPM cross couplings which cannot be precisely known before MIA fitting. This invariant ratio test works very well for a BPM at a location with strong linear coupling. However, it cannot exclude the singularity problem once a BPM is at a location with no global coupling. Thus, this test can only assure us the good BPM data, leaving those not passing this test as doubtful BPM data which need further testing with other criteria such as noise ranking through SVD analysis.

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