BEAM-OPTICS ANALYSIS AND PERIODICITY RESTORATION IN THE STORAGE RING OF THE POHANG LIGHT SOURCE

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Abstract

In this paper, we examine numerically and experimentally the linear beam optics distortion in the storage ring of the Pohang Light Source (PLS), and the correction of optics using a number of quadrupole magnets installed in the storage ring. The measured orbit-response matrices were fitted to the model-response matrices to obtain beta and dispersion functions in storage ring. From new quadrupole strengths determined in fitting process of response matrix, dynamic aperture was also calculated. By readjusting currents of quadrupole-magnet power supplies, optics parameters were successfully restored to the values very close to the design ones. After the optics correction, it is expected that the performance of the storage ring is better than the present one.

INTRODUCTION

During the design stage of a storage ring for synchrotron-radiation source, considerable efforts to optimize the ring parameters such as operating tunes, chromaticities, natural beam emittance, dynamic aperture, etc. are made. In actual operation, however, there are a number of reasons that these parameters deviate from the design values. It is therefore very important to measure beam-optics parameters and restore design parameters to assure successful operation of a ring. For linear optics investigation in storage ring, one possible method is to utilize corrector magnets and beam-position monitors (BPMs) [1, 2]. In this method, each corrector magnet is excited one by one by a small amount and the resulting orbit changes at all BPMs are recorded. Then a M by N orbit-response matrix for a given plane can be obtained, where M is the number of BPMs and N is the number of correctors. This procedure is repeated in the other plane, and as a result both horizontal and vertical response matrices can be obtained. Since response matrices contain an information related with focusing errors of quadrupole magnets, analysis of orbit-response matrices makes it possible to identify the current performance of a storage ring and to cure the periodicity breaking if any. This method has been successfully applied to the storage ring of the Pohang Light Source (PLS) [3, 4, 5] and it is the subject of this paper to describe the procedure and the results obtained experimentally. In PLS ring, a computer program LOCO (Linear Optics from Closed Orbits)~\cite{r4} was implemented to analyze a measured orbit-response matrix. The LOCO program not only identifies the focusing errors of quadrupoles, but also finds the BPM and corrector gains.

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In this paper, we describe the results of studies for linear optics and restoration of periodicity with particular emphasis on the PLS storage ring. In section 2, the current performance of the PLS ring with the help of the LOCO program is described and section 3 describes the restoration of design periodicity. Finally, in section 4, a summary and conclusion is given.

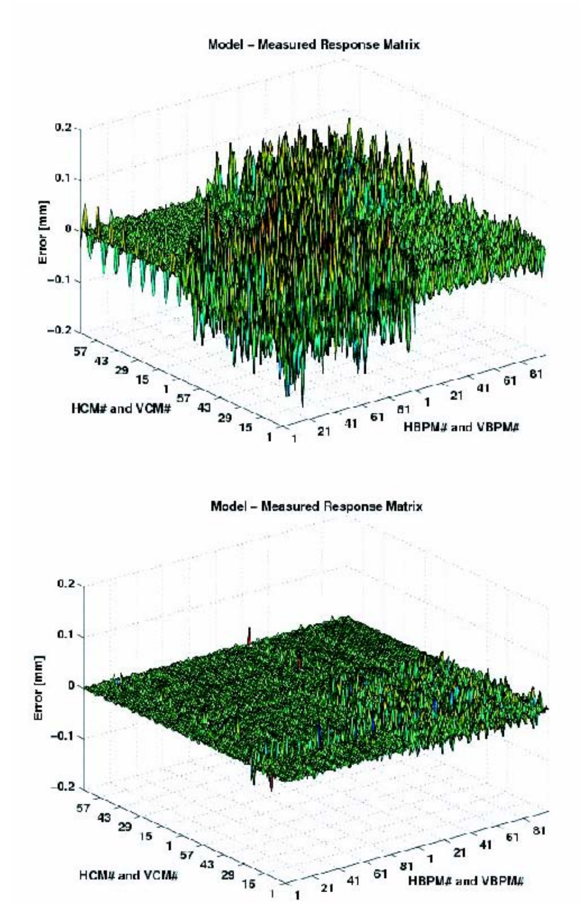

Figure 1: (a) Difference between the measured response matrix and the model response matrix before correction (upper plot). (b) Difference between the measured response matrix and the model response matrix after correction (lower plot).

LINEAR OPTICS ANALYSIS

The magnet-gradient distribution can be determined by analyzing the measured orbit-response matrices, M_{meas}. In reality, the measured orbit-response matrix differs from the the model orbit-response matrix M_{mod} for the reason described before. That it is so is clearly shown in

Fig. 1 (a), where the model-response matrix was calculated theoretically. This figure depicts the difference between the model and the measured response matrix elements, and ideally they should be zero. Using the computer program LOCO, the actual gradient distribution in the ring can be determined by adjusting the quadrupole gradient in the model to minimize χ^2 between M_{meas} and M_{mod}

$$\chi^2 = \sum_{i,j} \frac{(M_{\mathrm{mod}i,j} - M_{\mathrm{meas}i,j})^2}{\sigma_i^2}, \qquad (1)$$

where σ_i in the denominator is the measured rms noise of the i^{th} BPM. In Eq. (1) the double summation runs over all BPMs and correctors.

In addition to the quadrupole gradient, other parameters including BPM gains, corrector-magnet gains, roll errors, and energy shifts associated with changes in corrector magnet are also used to minimize the deviation between M_{meas} and M_{mod}. Since the fitting method of LOCO has been described elsewhere [1], we will not go into further detail here.

ANALYSIS OF FOCUSING ERRORS

Data for LOCO analysis were obtained on December 20, 2005. The resolution of each BPM was estimated by weighting the fit in the LOCO analysis. Dispersion functions were also measured for LOCO input. The orbit-response matrix was measured with all the sextupole magnets on, because the PLS ring could not be operated at more than 100 mA without sextupole magnets. Figure 1 (b) shows the difference between the measured response matrix and the model-response matrix after minimizing the difference by quadrupole-strength readjustment. Compared with Fig. 1 (a) which exhibits the case before the fit, Fig. 1 (b) clearly shows that the difference between the measured response matrix and the model-response matrix after the fit is reduced by a factor of 24.

The PLS storage ring has six families of quadrupoles labeled Q1, Q2, Q3, Q4, Q5, and Q6. Each family consists of 24 quadrupole magnets, and therefore there are in total 144 quadrupole magnets in the ring. These magnets are powered by 39 power supplies. Among 39 power supplies, Q1, Q2 and Q3 families are powered by 36 power supplies, 12 for each. The remaining Q4, Q5 and Q6 magnets are then powered by three supplies, one for each family, and therefore all 24 magnets in each of these families are connected in series, driven by a single power supply. Hence, there are in total 39 parameters for the focusing errors to fit.

In electron-storage ring, equilibrium beam parameters such as natural emittance, natural bunch length and damping times are determined by the balance between the synchrotron radiation and the quantum excitation. Those parameters can be expressed by the synchrotron-radiation integrals through Twiss parameters. Since Twiss parameters can be calculated from fitted quadrupole strengths with the LOCO program, current beam properties in the PLS storage ring can be estimated. The comparison of beam parameters between design values and the current operating values is shown in Table 1.

Table 1: Major storage ring parameters

Parameter	Design value	Before correction
$(\eta_x)_{\max}$	0.456 m	0.470 m
$(\eta_x)_{\min}$	0 m	-0.01 m
σ_ε	0.00085	0.00086
Natural Emittance	18.9 nm	20.3 nm
Natural Chromaticity h	-23.36	-22.89
Natural Chromaticity v	-18.19	-18.34

From new quadrupole strengths determined in fitting process of response matrix, dynamic aperture was also calculated. Compared with design dynamic aperture, the dynamic aperture for the current storage ring in PLS is much shrunk as shown in Fig. 2.

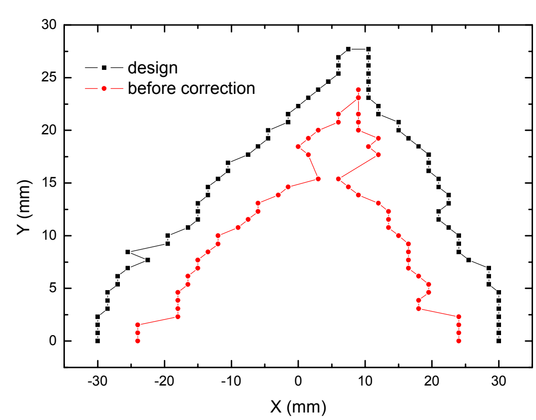

Figure 2: Error free dynamic aperture for on momentum particles.

OPTICS CORRECTION

Restoration of lattice function to the design periodicity assures the beam stability in a ring. By doing so the ring is under well-controlled mode of operation. When a need to change beam parameters occurs, one can always change quadrupole currents to desired values to modify the optics. Restoration of the beta functions to the designed values in the PLS ring was thus performed. Focusing errors obtained from the LOCO fitting were applied to correct the preset strengths of quadrupoles.

Fig. 3 shows beta functions before and after the correction. The horizontal and vertical rms differences of beta function from design value are 0.41 m and 0.90 m before correction but reduce to 0.08 m and 0.03 m after the correction respectively.

Fig. 4 shows tune values measured by spectrum analyzer. This figure also depicts all resonances up to the fifth order with 12-fold periodicity. Comparing with the tunes before correction, the beam optics correction successfully restores the tunes to designed values (14.28, 8.18).

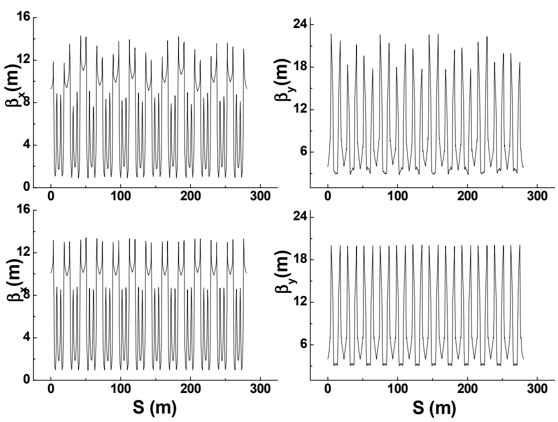

Figure 3: Predicted beta functions before (top plot) and after correction (bottom plot). It is seen that after correction beta functions became very close to the designed values and near twelve-fold symmetry of the ring was restored.

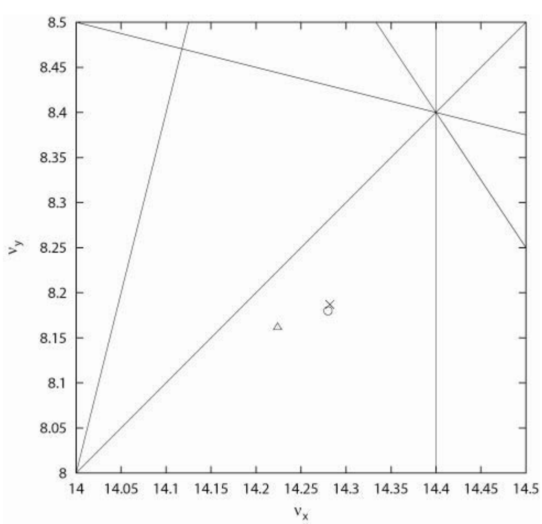

Figure 4: Measured tune values and resonance diagram. Allowed resonances up to the 5th order are shown as solid lines. A circle mark indicates the design tunes (14.28, 8.18), the triangle mark shows the tunes before correction and the cross mark indicates the tunes after correction.

CONCLUSION

So far, we have described the measurement and the analysis of the beam-optics distortion and subsequent correction in the PLS storage ring. Although the measured beta functions are not significantly deviated from the design values, it is found that after optics correction Q1 and Q6 quadrupoles are significantly deviated from set currents, probably because of their small magnetic length. After optics correction, beta functions are very close to designed values. As a result of this study, the storage-ring operation becomes under well-controlled mode.

ACKNOWLEDGMENTS

We thank Greg Portmann at Lawrence Berkeley National Laboratory for his support during the installation of the middleware at the Pohang Accelerator Laboratory. This work was supported by the Ministry of Science and Technology.

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