Closed Orbit Distortion and Correction of the PLS 2 GeV Storage Ring

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Abstract

Closed orbit distortion and correction of the 2 GeV Pohang Light Source (PLS) storage ring are discussed in this paper. For monitoring of the transverse beam position, total nine button-type position monitors are placed per each cell of the storage ring. In total there are 108 monitors distributed around the ring. The correction of the orbit can be done with 94 horizontal and 82 vertical dipole correction magnets. Both global and local orbit correction will be provided. The global orbit correction will be operated with DC utilizing all monitors and correctors. The local orbit correction will be provided only for the beam from insertion devices. It will be operated with a frequency around 25 Hz. In addition, a provision is made for the real-time global harmonic orbit correction using some selected monitors and correctors.

1. INTRODUCTION

A magnet lattice for the third-generation synchrotron radiation source is characterized by a small beam emittance, an order of magnitude smaller than that of the existing light source. Achieving such a small emittance of a beam requires a storage ring operated with very high tune. Subsequently, the lattice becomes very sensitive to magnetic defects, causing large distortion in closed orbit. The closed orbit distortion (COD) depends on three major sources of error; bending magnet field error, quadrupole misalignment error, and bending magnet rotation error.

Direct effect of the COD on the motion of a beam is such that the dynamic aperture is significantly reduced. The lattice for the Pohang Light Source(PLS) storage ring is not an exception. We have studied the sensitivity of the PLS lattice to the various errors that render the COD. The subject of the present paper is to discuss on this. We will first estimate analytically the COD with given sets of *rms* errors. The results obtained there will be compared with the results from the computer calculation. Effects due to the COD will then be described. Our main focus is on the reduction in dynamic aperture as compared with the case for the ideal lattice.

Because of great sensitivity of a lattice to errors, the COD must be corrected by means of a number of correction dipoles that are additionally placed around storage ring. A number of beam position monitors are distributed in the ring in order to accurately measure the COD. Closed orbit correction scheme can then be used to correctly guide a beam within allowable tolerance level. We will also describe various orbit correction schemes that we propose for the PLS lattice.

2. CLOSED ORBIT DISTORTION

In reality the errors in a storage ring are unknown *a priori*. Therefore, a statistical anaylsis can be used with the assumption of the gaussian distribution of the errors. Since all the errors in the ring are uncorrelated, one can then calculate analytically the *rms* distortion of a closed orbit. The results are given by:

$$\bar{x} = \frac{\sqrt{\beta_x}}{2\sqrt{2}\sin\pi\nu_x}\sqrt{\theta_B^2(\frac{\Delta\bar{B}}{B})^2\sum_i\beta_{x_i} + (\Delta\bar{x}_q)^2\sum_i(kl)_i^2\beta_x}$$
$$\bar{y} = \frac{\sqrt{\beta_y}}{2\sqrt{2}\sin\pi\nu_y}\sqrt{\theta_B^2(\Delta\bar{\phi})^2\sum_i\beta_{y_i} + (\Delta\bar{y}_q)^2\sum_i(kl)_i^2\beta_{y_i}}$$

The above results can be applied to the PLS storage ring, where the nominal tunes are $\nu_x = 14.28$, $\nu_y = 8.18$. When doing this we see that the closed orbit distortion is most sensitive to the quadrupole misalignment errors. One can also see that for PLS the vertical closed orbit distortion is larger than the horizontal closed orbit distortion. This is due to the fact that the average β_y is larger than the average β_x and vertical tune is closer to integer than horizontal tune. With the tolerances for PLS, $\Delta\bar{B}/B = 0.1$ %, $\Delta\bar{x}_q = \Delta\bar{y}_q = 0.15$ mm, $\Delta\bar{\phi} = 0.5$ mrad, one obtains $\bar{x} = 4$ mm and $\bar{y} = 9$ mm.

This simple estimation can be more elaborated by using a computer program, such as MAD or RACETRACK. With a given set of *rms* errors and a random number generator, these programs generate the errors in a random way with a gaussian distribution truncated at $\pm n$ *rms* values, where n is a user-given number which we take as 2. By using the program MAD, we have simulated with total 20 different random numbers and their averages are summarized in Table I. Analytical estimation yields larger COD than the computer calculation.

Table I Closed Orbit Distortion averaged over 20 different machines

COD	(mm)
Maximum horizontal COD	8.54
Maximum vertical COD	13.34
rms horizontal COD	3.13
rms vertical COD	6.01

As a result of the COD, the dynamic aperture is reduced. This is due to the fact that the orbit distortion in sextupole results in the change of tune:

$$\Delta\nu = \frac{1}{4\pi}\int_0^{l_s} \beta(s)S(s)\Delta x ds, \quad S(s) = \frac{d^2B_y/dx^2}{B\rho}.$$

Due to rather large strength of the sextupoles for chromaticity correction and the closed orbit distortion Δx for the PLS lattice, one expects large change in tune, a typical feature of a third-generation synchrotron radiation source storage ring.

To calculate the dynamic aperture, we resort to the numerical simulation by RACETRACK. Total 10 different rings were simulated to calculate the dynamic apertures. Fig. 1 shows the average result of this study after tracking a particle up to 300 turns. A significant reduction in dynamic aperture can be seen from the figure.

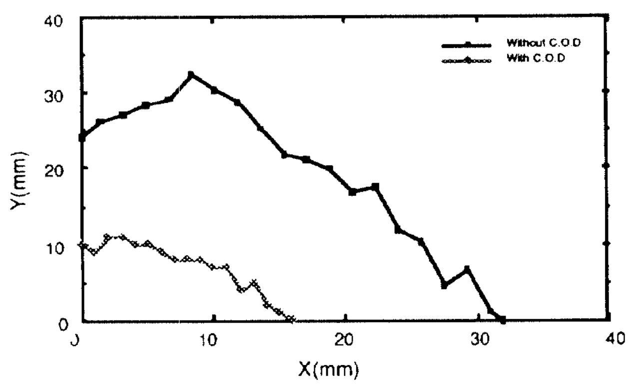

Fig. 1 Dynamic aperture with and without closed orbit distortion.

3. CLOSED ORBIT CORRECTION

Fig. 2 shows a schematic diagram for locations of BPM and correction dipoles in a typical cell of the PLS storage ring. There are per cell total 9 beam position monitors, 8 horizontal correctors and 7 vertical correctors used in our study. In total there are 108 monitors, 94 horizontal correctors, and 82 vertical correctors (*cf.* there are no combined horizontal and vertical correctors in the injection straight because there is no space to place them). All the sextupoles have both horizontal and vertical dipole trim windings. However, we will minimize their use because their presence at sextupoles generates surious random decapole component which can reduce the dynamic aperture. In addition, each bending magnet has horizontal dipole trim winding. Most of the trim windings have not been taken into account in our orbit correction study. They may be utilized for the local steering for the bending magnet beamline at later stage.

In order to see if locations of those correctors and BPMs are reasonable for the orbit correction, we have checked

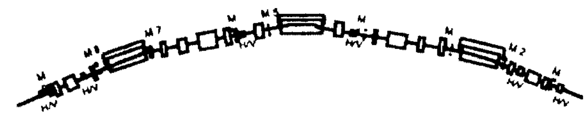

Fig. 2 The position of correctors and monitors in a normal cell

Table II Data for corrected closed orbit using MICADO algorithm. Results are averaged over 20 different machines A: without monitor error B : with monitor error

	A	B
x_{max} after correction (mm)	0.06	0.20
x_{rms} after correction (mm)	0.02	0.05
y_{max} after correction (mm)	0.07	0.21
y_{rms} after correction (mm)	0.02	0.07
Maximum horizontal corrector (mrad)	0.39	0.76
rms horizontal corrector (mrad)	0.13	0.27
Maximum vertical corrector (mrad)	0.28	0.46
rms vertical corrector (mrad)	0.10	0.17

with the MICADO algorithm installed in the program MAD. Table II summarizes the result of this study. In this table, we show averages of simulating 20 different machines. It also compares results with monitor reading errors, which we take as 0.15 mm in *rms*.

So far, we have described the global orbit correction scheme. Though we presented the results with MICADO method for the global orbit correction, we also investigated the correction with other schemes such as the three-bump method and the most effective correcor method installed in the program RACETRACK. Depending on the corrector distribution, some method yields better result than others. Therefore, our plan is to install all three methods mentioned above in our application software and use them during the operation.

Besides the global orbit correction described so far, we have also a provision for the fast local orbit correction. There are many vibration sources which affect the beam in a storage ring. These vibration sources can be conveniently divided into two classes; external source and internal source respectively. External source is the one originated from the outside of the experimental hall building. It includes the ground motion and the traffic. Internal source is the one located inside of the experimental hall. It includes the HVAC equipments, cooling water flow etc.. So far, no measurement has been undertaken for the vibrational characteristics for PLS. Therefore we refer to the results obtained in other laboratories [1,2]. Measurements performed at Intense Pulsed Neuteron Source (IPNS) of Argonne National Laboratory revealed that the cooling water flow inside the storage ring tunnel is not a significant source of vibration. Measurements carried out at

Photon Factory of KEK indicated that the most significant vibrational source is the air-conditioning equipment located inside the storage ring building. The frequency spans wide range and it could be as large as 100 Hz. The result also indicated that most of the frequencies are located below 25 Hz. These fast vibrations result in the effective emittance growth of a beam. At the center of insertion straight for PLS, we have:

$$\epsilon_{n_0} = 12.1 \times 10^{-9}\ m, \quad \beta_x = 10\ m, \quad \beta_y = 4\ m,$$

where ϵ_{n_0} is the nominal natural emittance at 2 GeV. Therefore, assuming 10% emittance coupling between x and y, rms beam sizes and divergences at the center of insertion straight are given by:

$$\sigma_{x_0} = 332\ \mu m \qquad \sigma_{x'_0} = 33.2\ \mu rad$$
$$\sigma_{y_0} = 66.3\ \mu m \qquad \sigma_{y'_0} = 16.6\ \mu rad.$$

If the emittance growth is to be limited to 10%, the closed orbit displacements and angles are:

$$\Delta\sigma_x < 16\ \mu m \qquad \Delta\sigma_{x'} < 1.6\ \mu rad$$
$$\Delta\sigma_y < 3.3\ \mu m \qquad \Delta\sigma_{y'} < 0.8\ \mu rad.$$

These are small fractions of the nominal values of the beam parameters given above.

The most stringent requirement of the orbit control comes from a photon beam from an undulator magnet where the spectral brightness B is important. The spectral brightness is defined as the photon flux per unit solid angle and per unit source area, emitted in a relative bandwidth:

$$B = \frac{d^4N}{dt d\Omega dS(d\lambda/\lambda)},$$

where N is the number of photons, t is time, Ω the solid angle, λ the wavelength, and S the source size. Neglecting the diffraction effects, we have

$$dSd\Omega \sim \epsilon_x \epsilon_y,$$

where ϵ_x and ϵ_y are the horizontal and the vertical emittances, respectively. Therefore, the spectral brightness is directly related with the emittance of a beam.

By measuring a position and an angle of the photon beam downstream, the orbit of an electron beam can be corrected locally:

$$\begin{aligned} \Delta z &= \theta_c \sqrt{\beta_c \beta_s} \sin(\phi_s - \phi_c) \\ \Delta z' &= \theta_c \sqrt{\frac{\beta_c}{\beta_s}} [\cos(\phi_s - \phi_c) - \alpha_c \sin(\phi_s - \phi_c)], \end{aligned}$$

where z denotes either x or y, θ_c the kick given by a corrector, β_c the β-function at the position of a corrector, β_s the β-function at the source point, α_c the value of α at the corrector position, and ϕ is the betatron phase. In order to correct both angle and position of a beam, two corrector magnets are required on the upstream region. Two corrector magnets placed downstream region then restore the orbit to the normal closed orbit. We set the frequency of this feedback to be less than 25 Hz. The vibrational sources which have higher frequencies than 25 Hz should be corrected at the sources themselves or at least minimized by special means [2].

IV. SUMMARY AND CONCLUSION

Errors that make the distortion in closed orbit have been analyzed for PLS lattice. Vertical closed orbit was found to be more distorted than horizontal orbit. Total 108 beam position monitors are allocated to measure the distorted closed orbit. With COD, significant reduction in dynamic aperture is expected. The correction of COD is to be made by two schemes; global correction and local correction. Total 94 horizontal and 82 vertical steering dipoles are distributed around the ring. Among them 90 horizontal and 74 vertical correctors are to be used initially for the global orbit correction. Four horizontal and four vertical correctors are reserved for the local orbit correction for one ID beam and there will be two regions initially that have a capability of the local orbit correction. The global orbit correction scheme for PLS will be a combination of three-bump method and most effective corrector method. It could be operated with DC. We also have a provision such that the global harmonic orbit correction scheme is intalled on a real-time basis [3]. Local orbit correction, on the other hand, requires a fast feedback and the frequency we set is 25 Hz. Sextupoles have dipole trim windings in PLS. The random normal and skew decapoles generated from them are found to be insignificant on the motion of a beam.

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