CLOSED ORBIT CORRECTION OF TPS STORAGE RING

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Abstract

A 3 GeV synchrotron storage ring is proposed in Taiwan to serve the synchrotron light users, especially for the x-ray community. The ring consists of 24 double-bend cells with 6-fold symmetry and the circumference is 518.4 m. The designed natural emittance with slightly positive dispersion in the straight sections is less than 2 nm-rad. This low emittance lattice structure needs strong quadrupoles and sextupoles and the closed orbit distortions are sensitive to the alignment errors in the quadrupoles and sextupoles as well. The closed orbit distortions due to tolerable magnetic errors are simulated and the correction scheme is proposed. Using singular value decomposition method, the closed orbit distortions are corrected and corrector strengths as well as the residual closed orbit distortions are obtained.

INTRODUCTION

The lattice design TPS24P18K1 [1] of Taiwan Photon Source (TPS), which consists of 24 double-bend cells with 6-fold symmetry and a circumference of 518.4 m, is shown in Figure 1. The designed natural emittance with slightly positive dispersion in the straight sections is less than 2 nm-rad. It is designed with a very small beam emittance to produce very high brilliance beams of synchrotron radiation. This low emittance lattice structure has strong quadrupoles and sexturpoles, Therefore, the magnet alignment errors will introduce large closed orbit distortion (COD) which induces unwanted side effects. Firstly, it excites the non-linear effect and leads to the decrease of beam lifetime and dynamic apecture. Secondly, it changes the position of synchrotron light at front-end of the beam-line, which reduces the brightness at experiment station. In order to correct the orbit distortion, the Beam Position Monitors (BPMs) and dipole correctors must be installed.

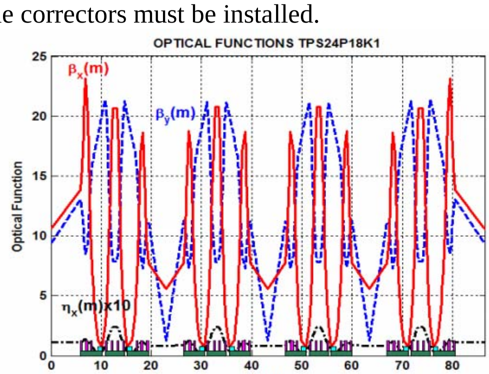

Figure 1: Optical functions of the TPS superperiod (distributed dispersion type, 24P18K1).

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In this report, the number and position of correcotors and BPMs will be discussed. A popular method, the singular value decomposition (SVD) algorithem, is employed in the simulations. The results of the orbit correction are given in different number of correctors and eigenvalues, which include the maximun of orbit distortion in BPMs, maximun of corrector strength in use and mean of corrector strength.

ERROR SOURCES OF CLOSED ORBIT DISTORTIONS

The closed orbit distortion due to imperfections of magnetic field and misalignment of magnets is an important issue in the lattice design. In dipole angular kick form, we can express the closed orbit due to errors in a circular machine as: [2]

$$y_{co}(s) = \frac{\sqrt{\beta(s)}}{2\sin\pi\nu}\sum_{i=1}^{N}\theta_i\sqrt{\beta(s_i)}\cos(\pi\nu - |\psi(s)-\psi(s_i)|)$$

where $\theta_i = \frac{\Delta B(s_i)}{B\rho}ds_i$ is the kick angle from the linear dipole field errors, quadrupole misalignments Δx and Δx, N is the number of kick elements, and the feed-down of the misaligned sextupoles, etc. One can estimate the rms closed orbit with the random distribution of the errors as:

$$y^{co}_{rms}(s) = \frac{\sqrt{\beta(s)\bar{\beta}}}{2\sqrt{2}\,|\sin\pi\nu|}\sqrt{N}\theta_{rms},$$

where $\bar{\beta}$ is the average of the betatron functions in kick elements, θ_{rms} is the rms kick strength for each element. The kick strengths include the quadrupole misalignments in both plane $kl\Delta x, y$, dipole rotation errors $\alpha\Delta\phi$ in vertical plane and dipole fiels errors $\alpha\Delta B/B$ in horizintal plane, where α is bending angle. The amplification factor of quadrupole misalignment errors is defined as $A_{x,y} = y^{co}_{x(rms),y(rms)}/\Delta x, y$. Note that the relative field error due to such a roll angle of dipole is given by $\Delta B/B_0 = \Delta\phi$. The amplification factor for dipole is defined as $A_{x,y} = y^{co}_{x(rms),y(rms)}/(\Delta B/B_0)$. In the third generation synchrotron light sources, the machines are designed with strong focusing strengths in order to obtain small emittance. Therefore the amplification factors are usually as high as 50 or more. The amplifications of dipole and quadrupoles are shown in Figure 2.

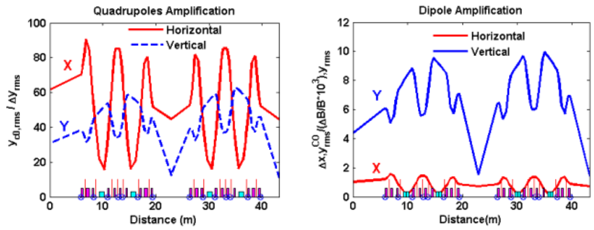

Figure 2 : The amplification of dipole and quadrupoles.

Hence, serious efforts are needed to reduce the alignment errors of the magnets. The preliminary design of girder support system in TPS design is show in Figure 3. Girder support can reduce both the alignment errors and the amplification factors.

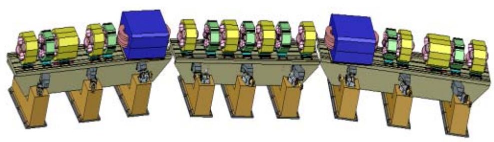

Figure 3: Girder support in one unit cell.

The typical tolerances for the alignment and field error of a high performance synchrotron light source are:

- Girder transverse displacement error: 0.1 mm (rms).
- Girder roll error: 0.1 mrad (rms).
- Quadurpole and sextupole transverse displacement error with respect to girder: 0.03 mm (rms).
- Dipole transverse displacement error with respect to girder: 0.5 mm (rms).
- Dipole roll error with respect to girder: 0.1 mrad (rms).
- Dipole field error : 0.001 (rms).

Using simulation codes [3,4,5], we calculate the closed orbit with the above input errors. Figure 4 displays the rms COD calculated in a half super-period. The rms value of the whole ring for 200 sampling machines is 3.66 mm and 2.28 mm in the horizontal and vertical plane, respectively.

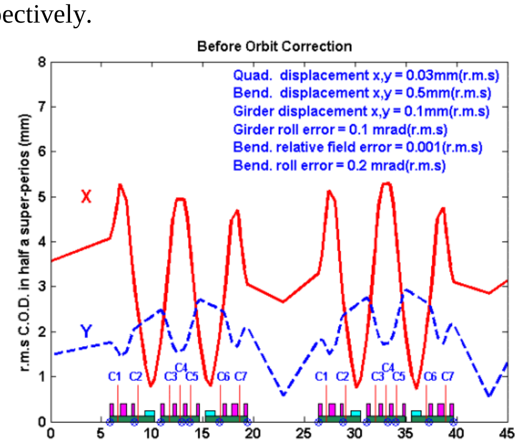

Figure 4: Simulated TPS closed orbit distortions for 200 sampling machines with the errors.

CLOSED ORBIT CORRECTION METHOD

The orbit change at the BPM position s_j due to the corrector kick θ_i at s_i can be written as [2]

$$\Delta y_{co}(s_j) = \frac{\sqrt{\beta(s_j)}}{2\sin\pi\nu}\sum_{i=1}^{N}\theta_i\sqrt{\beta(s_i)}\cos(\pi\nu - |\psi(s_j)-\psi(s_i)|).$$

This can be expressed in a matrix equation $\Delta\vec{y}_m = A\vec{\theta}_n$, where $\Delta\vec{y}_m$ is the vector formed by different orbits of m BPMs and $\vec{\theta}_n$ is the vector formed by n correctors. A is the response matrix with

$$A_{ji} = \frac{\sqrt{\beta(s_j)}}{2\sin\pi\nu}\sqrt{\beta(s_i)}\cos(\pi\nu - |\psi(s_j)-\psi(s_i)|).$$

The distorted orbit can be minimized at the location of BPMs to the desired value so that $\Delta\vec{y}_{co,m} \approx -\Delta\vec{u}_{co,m}$, where $\Delta\vec{u}_{co,m}$ is the difference between the measured orbit and the reference orbit with the following expression $\vec{\theta}_n = A^{-1}\Delta\vec{y}_{co,m}$.

Using SVD we can solves the least-squares problems to avoid the unnecessary large strengths in correctors.

NUMBER AND LOCATION OF BPMS AND CORRECTORS

The locations BPMs need to be selected carefully. In principle, BPMs should be placed close to the quadrupoles to reduce the COD or close to the sextupoles to reduce the feed-down effects including COD, coupling and tune shifts. They should also be placed at both ends of each straight section to have better control of the stable light sources from insertion devices. In the preliminary design [1], each superperiod contains 28 BPMs (7 per cell), corresponding to a total of 168 for the machine. Their positions are indicated in Figure 4.

The correctors are located within the sextupoles with additional coils. There are 7 possible correctors in one cell and 168 possible correctors for the whole ring. Figure 5 show the eigenvalues in SVD method, descending order when all BPMs and correctors are used. In the horizontal plane, the large decrease at n=72, indicates that 48 of the correctors are redundant and, therefore, do not contribute effectively to orbit correction. The same remark is made for the vertical plane, where the first large decrease is at n=48, followed by n=72 and n=96, combining the information from the phase advance and the values of β_x and β_y functions. After a systematic study, Table 1 summarizes the results of the closed orbit correction calculation using the SVD method. The corrector strengths and residual COD obtained by the 200 different CODs generated by magnetic random errors are shown in rms values. We choose 72 correctors in each horizontal and vertical planes and shown in Figure 5.

Table 1 :The number of correctors, the corrector strength and the residual COD at BPMs in the COD correction.

	Correctors Used	Number of eigenvalues used	Mean of <|cor. Strength|> (mrad)	Max of <|cor. Strength|> (mrad)	Max of <|res. C.O. at BPM|> (mm)	Max of <|res. C.O. at Sexts> (mm)
Horizontal	(1,4,7)	72	5.9116E-02	3.3003E-01	1.9442E-01	1.8889E-01
	168, (C1-C7)x24	72	2.6916E-02	2.2188E-01	1.3792E-01	2.2460E-01
		96	3.3339E-02	2.1320E-01	7.7583E-02	1.8839E-01
		144	3.7189E-02	2.7428E-01	5.4999E-02	2.1880E-01
Vertical	(2,6)	48	3.7422E-02	2.4469E-01	3.1127E-01	2.8970E-01
	(2,4,6)	72	4.1858E-02	2.6460E-01	2.6994E-01	3.0295E-01
	168, (C1-C7)x24	48	1.2129E-02	1.1048E-01	2.2614E-01	1.9396E-01
		72	1.4808E-02	1.2938E-01	1.4466E-01	1.4856E-01
		96	1.7434E-02	1.7030E-01	1.3340E-01	1.5415E-01
		144	2.1954E-02	1.9875E-01	9.7587E-02	1.6399E-01

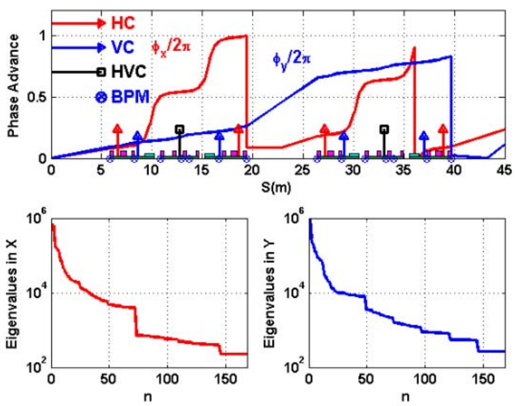

Figure 5: The position of BPMs and correctors and the eigenvalues of the response matrix *A*.

SIMULATION RESULT

Figure 6 shows that the COD before correction is 3.66 mm (rms) in the horizontal plane and 2.28 mm (rms) in the vertical plane, and 0.0587 mm (rms) in the horizontal plane and 0.0446 mm (rms) in the vertical plane after correction. The maximun corrector strength is 0.33 mrad and 0.26 mrad in the horizontal and vertical plane respectively. Figure 7 shows that the dispersion before and after correction in the both plane.

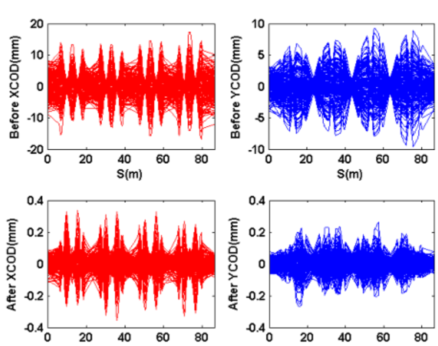

Figure 6: COD before and after correction in one superperiod in the TPS for 200 different scheme of errors.

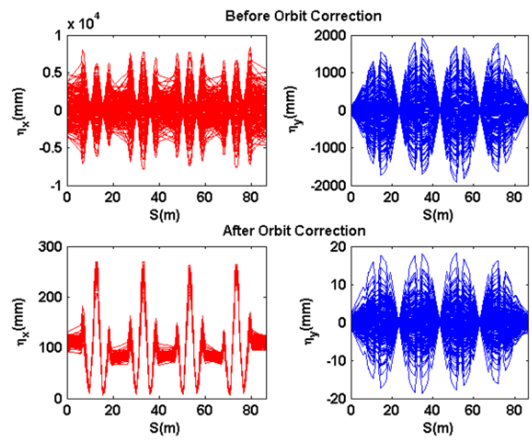

Figure 7: Dispersion before and after correction in one superperiod in the TPS for 200 different scheme of errors.

CONCLUSION

Estimation of the COD from various error sources are investigated. Based on the engineering achievable tolerance level, the simulated COD are presented. We propose a COD correction scheme with 168 BPMs and 72 correctors in the whole ring. Using orbit response matrix and SVD methods, we can correct COD down to 50 microns level. The corrector strengths are reasonably small for the sampling machines with the errors as listed in Table 1.

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