CLOSED ORBIT CORRECTION AND ORBIT STABILIZATION CONTROL FOR TPS STORAGE RING

H.J. Tsai, H.P. Chang, C.C. Kuo, P.J. Chou, W.T. Liu, H.J. Chao, J.W. Tsai, and K.T. Hsue
National Synchrotron Radiation Research Center
101 Hsin-Ann Road, Hsinchu Science Park, Hsinchu, Taiwan

Abstract

Taiwan Photon Source (TPS) is a 3 GeV synchrotron storage ring proposed in Taiwan. The designed natural emittance with slightly positive dispersion in the straight sections is less than 2 nm-rad and emittance ratio is 1%. The beam sizes in horizontal and vertical plane are 165/120(LS/SS) , 10/5 (LS/SS) μm in the long and short straight sections. The beam position stability requirements are 8-16/6-12 (LS/SS), 0.5-1/0.25-0.5(LS/SS) μm in both planes. The closed orbit distortions due to magnetic errors are simulated. The tolerances of orbit stability and alignment errors and vibration in quadrupoles for slow and fast orbit movement are discussed in this paper. The distribution of beam position monitors and the location of slow and fast correctors are reported. Estimation of the efficiency of the fast orbit correction scheme is presented.

INTRODUCTION

The lattice consists of 24 double-bend cells with 6-fold symmetry and has circumference of 518.4 m, as shown in Figure 1. The designed natural emittance with slightly positive dispersion in straight sections is less than 2 nm-rad. It is designed with a very small beam emittance to produce very high brilliance of synchrotron radiation. This low emittance lattice structure has strong quadrupoles and sexturpoles. Therefore, the magnet misalignment will introduce large closed orbit distortions (COD) which induce unwanted side effects. In section 2, the closed orbit distortions due to magnetic errors are simulated and the efficiency of correction scheme is proposed.

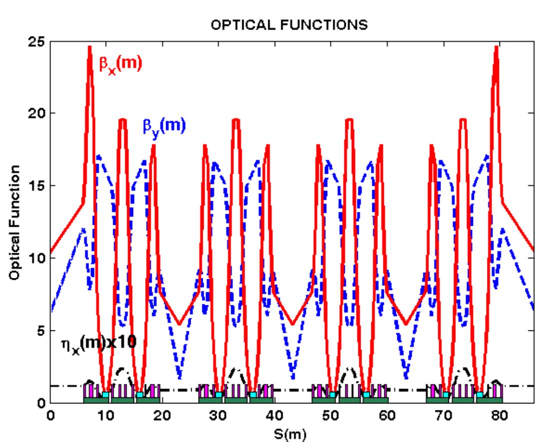

Figure 1: Optical functions of the TPS superperiod (distributed dispersion type).

TPS storage ring is designed to achieve very small vertical electron beam size with 1% emittance ratio. The horizontal beam size is 165 μm and 10 μm in the long and short straight section respectively, whereas vertical beam size is 10 μm and 5 μm. Orbit stability tolerances are usually specified as 5% to 10% of the electron beam transverse dimensions both in position and divergence. So the orbit stability requirement are 8-16/6-12(LS/SS) in horizontal plane and 0.5-1/0.25-0.5 (LS/SS) μm in vertical plane. In section 3, the tolerance of orbit stability with 5% electron beam transverse dimensions will be estimated. The vibrations in quadrupoles need to be well controlled under 0.05(H) / 0.03(V) μm rms and 0.33(H) / 0.21(V) μm rms for slow orbit motion and fast orbit motion, respectively. All of average efficiencies of fast correction scheme are smaller than required at all radiation source points.

CLOSED ORBIT CORRECTION DUE TO MAGNETIC ERRORS

The closed orbit distortion due to imperfections of magnetic field and misalignment of magnets is an important issue in the lattice design. The detailed correction scheme is proposed in report [1]. Here, the results of the orbit correction for TPS updated lattice are given. The typical tolerances for the alignment and field error are:

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

Using simulation code AT [2], the rms value of the whole ring for 200 sampled machines is 3.8 mm and 2.22 mm in the horizontal and vertical plane, respectively. In this design, each super-period comprising four cells contains 28 BPM (7 per cell), corresponding to 168 for the machine. With correctors of suitable number in both horizontal and vertical planes, the acceptable residual COD can be obtained using a limited number of eigenvalues in the SVD algorithm. We choose 72 and 96 correctors in the horizontal and vertical planes, respectively. Table 1 summarizes the results of the COD calculation using the SVD method. The corrector strengths and residual COD obtained with 200 sampled machines are given. The COD is 0.05 mm (rms) in the horizontal plane and 0.025 mm (rms) in the vertical plane after correction. The maximum corrector strength is 0.38 mrad and 0.19 mrad in the horizontal and vertical planes, respectively.

Table 1: Results of COD calculation using the SVD method.

	Before Correction		**After Correction**	
Plane	H	V	H	V
COD (mm)	3.8	2.2	0.05	0.025
Max. COD (mm)	21	9.2	0.15	0.1
Max. COD at Quads. (mm)		10.2		0.1
Max. COD at Sexts. (mm)		9.2		0.1
Max. CORs Strength (mrad)			0.38	0.19
Mean CORs Strength (mrad)			0.08	0.03

TOLERANCES OF ORBIT STABILITY

Orbit stability tolerances are usually specified as 10% of emittance ratio corresponding to 5% of the electron beam transverse dimensions both in position and divergence [3]. The emittance is usually tolerated as:

$$\frac{\Delta\varepsilon}{\varepsilon_0} = (\varepsilon - \varepsilon_0)/\varepsilon_0 = \varepsilon_{cm}/\varepsilon_0 = 0.1 \qquad (1)$$

Where ε_0 is the unperturbed emittance. ε_{cm} is the "centre-of-mass emittance". The corresponding beam size and beam divergence are:

$$\frac{\Delta\sigma_{x,y}}{\sigma_0} = 0.05 \text{ and } \frac{\Delta\sigma'_{x,y}}{\sigma_0} = 0.05 \qquad (2)$$

The displacement of centre-of-mass will be measured by its invariant ε_{cm}. The relationship between different ε_{cm} will be discussed in two cases, depending on the frequency of the motion compared to the observation time.

◆ Fast motion: The delta centre-of–mass Δx_{rms} and $\Delta x'_{rms}$ motion is faster than the user observation time. The definition of emittamce growth corresponds to a quadratic combination of beam sizes and centre-of –mass distribution:

$$\sigma^2_{x,y} = \sigma_0^2 + \Delta x_{rms}^2 \text{ and } \sigma'^2_{x,y} = \sigma'^2_0 + \Delta x'^2_{rms} \qquad (3)$$

Condition (2) becomes:

$$\Delta x_{rms} = 0.32\sigma_0 \text{ and } \Delta x'_{rms} = 0.32\sigma'_0 \qquad (4)$$

◆ Slow motion: The Δx_{rms} and $\Delta x'_{rms}$ motion is slower than the experiment data acquisition time. The effective beam dimensions result from the linear sums:

$$\sigma_{x,y} = \sigma_0 + \Delta x_{rms} \text{ and } \sigma'_{x,y} = \sigma'_0 + \Delta x'_{rms} \qquad (5)$$

Condition (2) becomes:

$$\Delta x_{rms} = 0.05\sigma_0 \text{ and } \Delta x'_{rms} = 0.05\sigma'_0 \qquad (6)$$

The most effects of surrounding noise on centre-of–mass motion depend on the amplification coming from quadrupole motion:

$$\Delta x_{rms} \cong A\Delta x q_{rms} \text{ and } \Delta x'_{rms} \cong A'\Delta x' q_{rms} \qquad (7)$$

Where $\Delta x q_{rms}$ and $\Delta x' q_{rms}$ are motion in quadrupoles, A and A' [rad/m] are the quadrupoles amplification factor. The tolerances of fast and slow quadrupole motion in three radiation source location are shown in the Table 2. The tolerances of quadrupole displacement set by the limit of beam size increase: the minima are 1.13(Fast) / 0.18(Slow) μm rms and 0.21(Fast) / 0.03(Slow) μm rms in the horizontal and vertical planes. Both tolerances are dominated by dipole and short straight section. The tolerances of quadrupole set by the limit of beam divergence are 0.33(Fast) / 0.05(Slow) μm rms and 0.46(Fast) / 0.07(Slow) μm rms in horizontal and vertical planes. Both tolerances are dominated by the short straight section and dipole.

Table 2 : Tolerances of fast and slow quadrupoles motion in three radiation source location.

			Long Straight		**Short Straight**		**Dipole**	
			H	V	H	V	H	V
Beam Size		σ_0(μm)	165	9.80	120	5.00	40.0	16.0
		A (m/m)	35.2	5.80	30.0	7.70	11.3	10.90
	Fast	Δx_{rms}(μm)	52.8	3.14	38.4	1.60	12.8	5.12
		Δxq_{rms}(μm)	1.5	0.54	1.28	0.21	1.13	0.47
	Slow	Δx_{rms}(μm)	8.25	0.49	6.00	0.25	2.00	0.80
		Δxq_{rms}(μm)	0.23	0.08	0.20	0.03	0.18	0.07
Beam Divergence		σ'_0(μrad)	12.5	1.60	5.10	3.10	76.0	1.00
		A' (rad/m)	3.36	1.08	4.90	2.10	16.1	0.70
	Fast	$\Delta x'_{rms}$ (μrad)	4.00	0.51	1.63	0.99	24.3	0.32
		$\Delta x'q_{rms}$(μm)	1.19	0.47	0.33	0.47	1.51	0.46
	Slow	$\Delta x'_{rms}$ (μrad)	0.63	0.08	0.26	0.16	3.80	0.05
		$\Delta x'q_{rms}$(μm)	0.19	0.07	0.05	0.07	0.24	0.07

ORBIT CORRECTION SCHEME

◆ Fast Correction Scheme: orbit motion > 0.1 Hz, is induced from either ground or mechanical vibration sources. The correction of closed orbit distortion caused by the fast motion is performed with dedicated correctors, which need to obtain high bandwidth, low induction, and low eddy current. In the TPS design, the fast correctors will use the some correctors that are combined in sextupoles. We will put bellows inside these sextupoles so that the operation bandwidth can be up to 100 Hz. The layout of the faster corrector magnets, phase advance and BPMs is shown in Figure2.

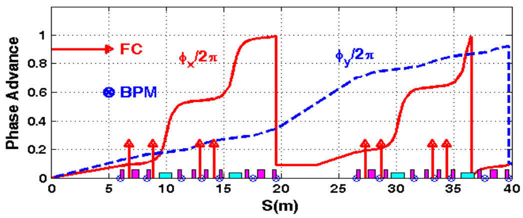

Figure 2: Layout of the fast corrector magnets, phase advance and BPMs

From equation (2), a useful definition of correction efficiency in percentage is given by:

$$\frac{\max[\Delta x_{rms}]}{\sigma_0} \text{x100 and } \frac{\max[\Delta x'_{rms}]}{\sigma'_0} \text{x100} < 32\% \quad (8)$$

Efficiencies smaller than 32% are required to meet the 5% beam size specification at the radiation source points. Correction efficiencies were assessed by applying random quadrupole magnet displacements with the expect ground motion amplititude ~2/1 μm rms in both planes, which are larger than the tolerance of fast motion in Table 2. The histogram of the correction efficiency over 200 random seeds in beam size and beam divergence at LS, SS and dipole sources in both planes are shown in Figures 3-4, where |E| is average efficiency and P is achievable percentage of efficiency. It can be seen that average efficiencies achieve requirement for all radiation sources in both planes over 200 random seeds on a corrected virtual machine. The achievable percentage are more than 90% for all radiation sources in both plane except that vertical source of SS in beam size with 73% achievable percentage. For more correction efficiency in SS, the extra fast vertical corrector will be installed on both side of ID in the SS.

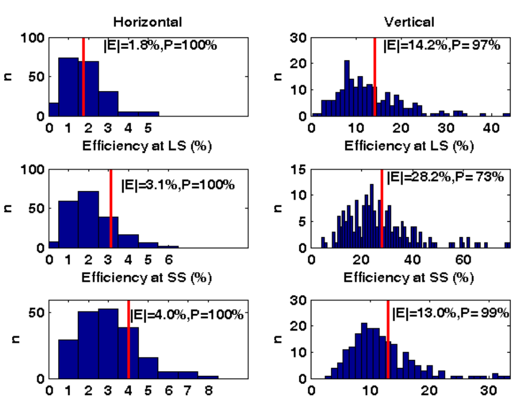

Figure 3: Histogram of the correction efficiency over 200 random seeds in beam size at LS, SS and dipole source in both planes.

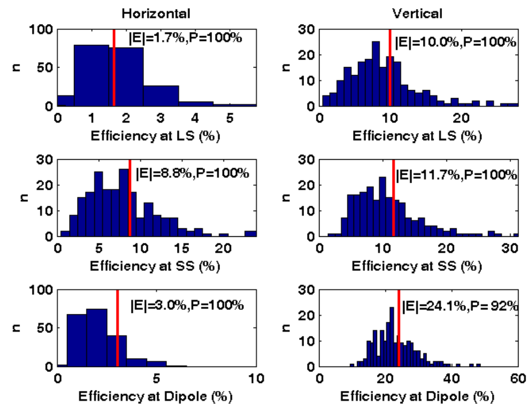

Figure 4: Histogram of the correction efficiency over 200 random seeds in beam divergence at LS, SS and dipole source in both planes.

◆ Slow Correction Scheme: orbit motion < 0.1 Hz. Long-term drift and static element misalignment errors are included in this analysis. The displacement of the element due to long-term drift, settlement of the ground under load, movements from season and environment effects is many orders of magnitude greater than in the fast correction case. Slow orbit, RF frequency and beam-based correction schemes will be used alternately. The slow orbit correction scheme is similar to the closed orbit correction due to imperfections of magnetic field and misalignment of magnets in section 2. The layout of slow orbit correction scheme is shown in Figure 5. The BPMs and some correctors are similar to fast orbit correction scheme.

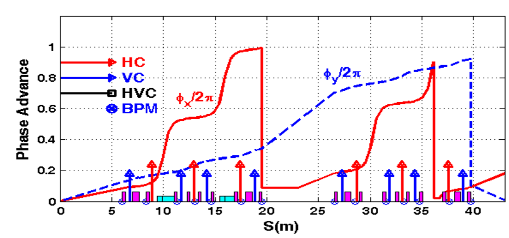

Figure 5: Layout of the slow corrector magnets, phase advance and BPMs.

CONCLUSION

The TPS with small beam sizes requires tight tolerances on the orbit stability. The sources of orbit motion include ground settlement, thermal drift, ground vibration, power supply stability and BPMs stability need to be fully studied. Correction schemes for both fast and slow motion are proposed.

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