STUDY OF ERRORS DUE TO UTILIZATION OF THE TRANSVERSE DEFLECTORS IN QBA LATTICE OF TAIWAN PHOTON SOURCE*

H. Ghasem#, School of Particles and Accelerators, IPM, P.O.Box 11395-5531, Tehran, Iran
G.H. Luo, NSRRC, Hsinchu 30076, Taiwan

Abstract

A pair of transverse deflecting RF cavities in the quadruple-bend achromat (QBA) lattice of 3 GeV Taiwan Photon Source (TPS) has been studied for generating ultra short X-ray pulses. Since errors are characteristic of real machine, any errors associated with utilization of deflectors as compression system must be considered and the tolerance of them must be evaluated. In this paper the simulation of main errors due to deflecting structures, the QBA lattice functions and injection system were presented and their tolerance was evaluated.

INTRODUCTION

The attempts were made to cancel the first kick at the second deflector and reduce the leakage of vertical emittance between the deflecting cavities in TPS. Typically, even for an ideal storage ring, perfect cancellation does not happen at the second cavity [1]. The degradation of the equilibrium emittance was mainly related to the nonlinearities of interior sextupoles, non-zero momentum compaction factor that generates various electron time of flights, energy spread, radiation damping and quantum excitation. Since errors are a characteristic of a real machine, any errors associated with the compression system for the selected configuration (third configuration) [2] should be considered and their tolerances must be evaluated. In this configuration the deflectors were located in the middle of two QBA cells in a super-period where two dispersive short straight sections were devoted to the deflectors. The errors due to the deflectors such as deflecting voltage, deflecting RF phase and the rolling of cavities were primarily explained. Then, the errors of the QBA lattice functions such as the vertical beta function at locations of the cavities and the vertical betatron phase advance difference in between the cavities were taken into consideration. Meanwhile, the cavities were assumed to operate in 8th harmonic of main normal RF system.

DEFLECTING VOLTAGE

Any errors in the adjusted deflecting voltage of the cavities directly have an effect on the vertical kick. Voltage deviation from the nominal value causes the second kick to be different from the first. The rms slope error due to this deviation is given by

$$\Delta y' = \frac{\omega_c \sigma_t}{E} e\Delta V \qquad (1)$$

where E is the nominal energy of the electrons, ΔV is the peak deflecting voltage, $\omega_c = h\omega_{RF}$ is the angular frequency of deflecting cavities, h is the harmonic number, ω_{RF} is the main angular RF frequency and e is the electron charge. The error in the vertical slope leads to an imperfect cancellation and degradation of vertical emittance. For simulating this error, we fixed the voltage of the first cavity at 6 MV to generate the minimum duration of the X-ray pulses and the second deflecting voltage was varied around this value. The effect of voltage deviation on the equilibrium vertical emittance is shown in Fig. 1. It indicates that the impact on the emittance for the relative voltage error of a fraction of a percent is modest. Requiring a voltage error of under 0.5% seems prudent. We have also found that the equilibrium horizontal emittance is not very sensitive to this error and it could be neglected.

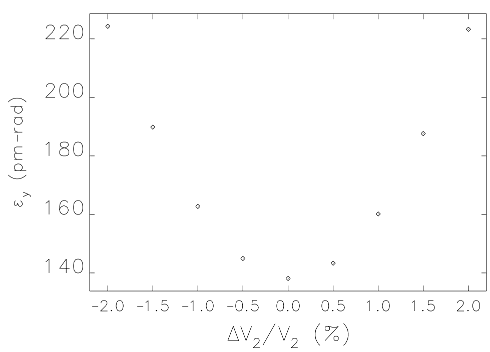

Figure 1: The eventual vertical emittance versus the second cavity relative voltage error.

DEFLECTING RF PHASE

The second aspect of deflecting structure errors is related to the RF phase of the cavities. In order to maximize the vertical kick using RFTM110 routine of ELEGANT [3-5], it is essential that the first and second deflectors operate on 90 and 270 degrees RF phases, respectively. Coupled variation of the RF phases from these values only produces a smaller kick and thereby a smaller equilibrium emittance, but minimum pulse duration is not attainable. An uncoupled variation of the RF phases leads to an imperfect vertical kick cancellation. In order to simulate the uncoupled RF phase error, in a manner similar to the voltage error, the first RF phase was fixed at 90 degrees and the second was set around 270 degrees. The electron tracking results, as shown in Fig. 2b, demonstrated that the eventual vertical emittance is

*The work is supported by NSRRC.
Email address: ghasem@nsrrc.org.tw

sensitive to the RF phase. It indicated that the uncoupled RF phase error should not be far from zero. Additionally, as anticipated and similar to the voltage error, it was observed that the horizontal emittance is not so sensitive to this error, (see Fig. 2a).

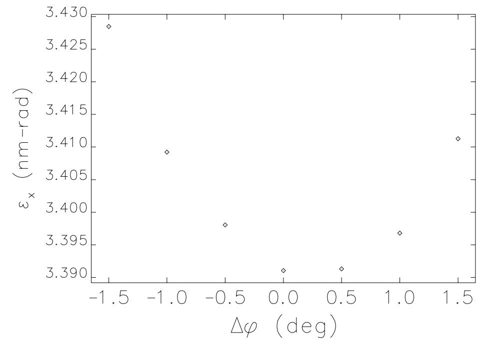

Figure 2(a): The eventual horizontal emittance as a function of uncoupled RF phase error.

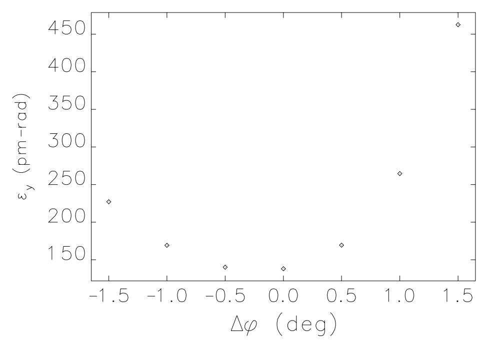

Figure 2(b): The eventual vertical emittance as a function of uncoupled RF phase error.

ROLLING OF DEFLECTING STRUCTURES

In order to generate a vertical kick, the deflecting structure should be operated in TM_{110} mode. The transverse magnetic fields of this operation mode with paraxial approximation in a simple pillbox cavity are given as follow

$$B_x \approx \frac{E_0 \sigma_x \sigma_y}{8c^2} \mathrm{Cos}(\omega_c t), B_y \approx \frac{E_0}{2c} \mathrm{Cos}(\omega_c t) \quad (2)$$

where E_0 is the electric field, c is the speed of light, σ_x and σ_y are the horizontal and vertical beam sizes, respectively. The rms horizontal and vertical beam sizes in TPS are approximately 116.6μm and 6.58μm, respectively. According to the Eq. (2), the vertical component of the magnetic force is much smaller than the horizontal. Therefore, the cavities were rolled 90 degrees using the program code RFTM110 TILT option [3-5] to simulate the desired vertical kick. In this case, the horizontal force stays negligible and any horizontal emittance blow up due to the reinforcement of the horizontal force could mainly be associated with rolling of the deflectors. The errors in the girders or in the installation of deflectors may generate a rotation around the longitudinal axis. Deflectors undergo coupled and uncoupled types of rolling. Both deflectors are rotated in the same direction to simulate a coupled roll. The coupled roll in the opposite direction can be simulated as well. The uncoupled roll is simulated by rolling the second cavity around 90 degrees while the first one is fixed. Degradation of the transverse emittance as a function of turn is shown in Fig. 3. The vertical emittance overlaps as a result of various rolls, Fig. 3(b), reveal that degradation of the vertical emittance is insensitive to the rolls. The horizontal emittance blow-up up to 6 mrad was not huge as seen in Fig. 3(a). Therefore, the roll of deflectors was not as significant as the other associated errors and it was easily maintained under a few milliradians using present-day alignment techniques.

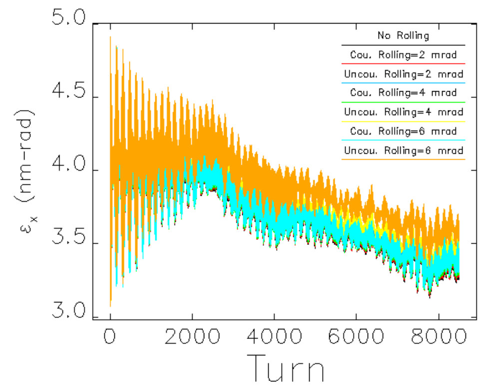

Figure 3(a): The horizontal emittance degradation versus the number of turns for both coupled and uncoupled rolling of the deflectors.

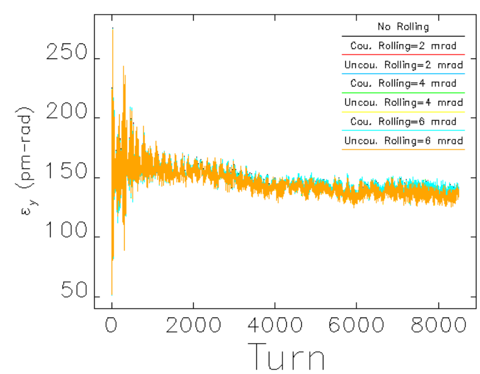

Figure 3(b): The vertical emittance degradation versus the number of turns for both coupled and uncoupled rolling of the deflectors.

VERTICAL BETA FUNCTION ERROR

This error is exclusively associated with the lattice. The slope of the electrons at integer π vertical phase advance downstream from the first cavity (at the radiator) is given by

$$y' = \sqrt{\frac{\beta_{yr}}{\beta_{yc}}} \frac{eV\omega_c}{E} \sigma_t \quad (3)$$

where V is the deflecting voltage, β_{yr} and β_{yc} are the vertical beta functions at the radiator and at the cavities. As it can be seen in the equation, any discrepancy between the vertical beta functions at the deflectors generates different slopes for the particles which in turn leads to an emittance degradation. This accounts as one of the main reasons for an imperfect cancellation for the first configuration which led to an exclusion of this configuration. The beam line steering, power supply drift and misalignment may be sources of this discrepancy. The vertical beta functions at the locations of deflectors in the QBA lattice is 1.45 m. A simple simulation method was employed to change the vertical beta function at the second deflector to assess the error tolerance. Since the vertical betatron phase advance between the deflectors in the third configuration was around 2π, the transfer matrix from the first deflector to the second is given by

$$T = \begin{pmatrix} \sqrt{\dfrac{\beta_2}{\beta_1}} & 0 \\ 0 & \sqrt{\dfrac{\beta_1}{\beta_2}} \end{pmatrix} \tag{3}$$

where β_1 and β_2 are the vertical beta functions at the first and second deflectors, respectively. It motivated us to simulate this error by applying a simple diagonal matrix with a determinant of one, called EMATRIX [3] as a routine of ELEGANT [3-5], prior to the second deflector. The matrix elements R_{33} and R_{44} were set different than one to change the vertical beta function at the second deflector and the inverse of this matrix was employed after the second deflector to undo the perturbation. As shown in Fig. 4 the simulation results indicated that this error must be kept less than 1%.

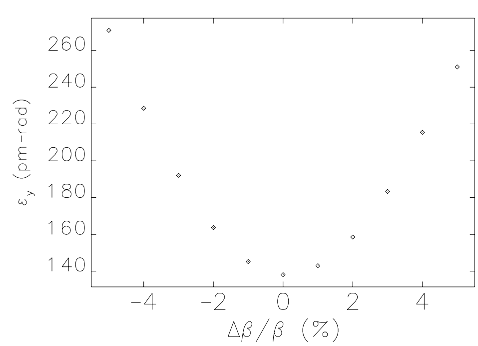

Figure 4: The eventual vertical emittance as a function of beta function error.

VERTICAL BETATRON PHASE ADVANCE ERROR

The second error associated with the lattice arises from not exactly an integer π vertical phase advance difference between the deflectors. It causes the vertical position and slope of the electrons at the second cavity to be different from the first and as a result the first kick is not compensated by the second deflector. For the third configuration, the second cavity is at 6.2833 vertical phase advance downstream from the first cavity. The dependency of the beta functions on the phase advance made the exact evaluation of this error difficult. Therefore, we moved the deflectors closer together or farther apart symmetrically where the beta functions stayed identical at the two deflectors and only the phase advance changed. Fig. 5 shows the equilibrium vertical emittance relative sensitivity to the normalized vertical phase advance error. The minimum point in the figure is slightly offset from phase advance of 2π. This presumably resulted from the use of canonically integrated quarupoles in our simulation which does not give the exact phase advance from the lattice functions. The results indicated that the vertical phase advance error of up to 0.1% can be ignored.

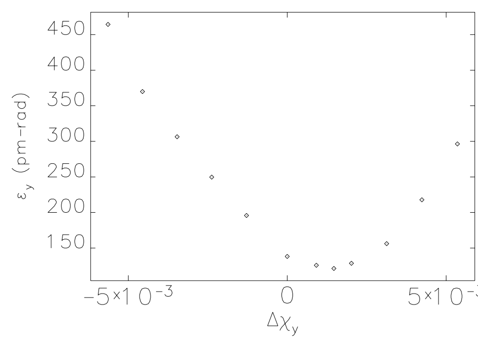

Figure 5: The eventual vertical emittamce as a function of $\Delta\chi_y$ defined as a phase advance difference $\Delta\psi_y$ in the equation of $\Delta\chi_y = \dfrac{\Delta\psi_y}{2\pi} - 1$.

CONCLUSION

We have studied the errors associated with utilization of deflecting structures in the QBA lattice of TPS which were employed for ultra short X-ray pulses production. The results show that the eventual emittance is so sensitive to the voltage and RF phase of deflectors and it was almost insensitive to rolling of them. In addition, the QBA lattice functions such as the vertical beta function and vertical betatron phase advance are very important at cavities. The error in these parameters of lattice must be kept close to zero.

REFERENCES

[1] H. Ghasem and G. H. Luo: This proceeding.
[2] H. Ghasem and G. H. Luo: Proceedings of EPAC, Genoa, Italy, (2008) 2025.
[3] M. Borland, "elegant: A flexible sdds-compliant code for accelerator simulation", Argon National Laboratory Advanced Photon Source Report No.LS-287 (2000).
[4] M. Borland, Proc. of PAC, Knoxville, Tennessee (2005) 4200.
[5] M. Borland: Phys. Rev. ST Accel. Beams 8 (2005) 074001.