SHORT X-RAY PULSE GENERATION IN TAIWAN PHOTON SOURCE USING DEFLECTING CAVITY*

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

Abstract

We have purposed to use deflecting cavity for short X-ray pulses production in 3 GeV Taiwan Photon Source (TPS). The electrons in a bunch receive vertical kick after passing deflecting cavity. Head and tail of bunch rotate around the center in opposite direction vertically. The photons emitted from insertion devices are vertically separated thus by applying optical elements such as slit and asymmetric crystal in TPS photon beam line, the radiated X-rays will be compressed. For a 60 m photon beam line of TPS, operating of deflecting cavity up to 6MV voltage and eighth harmonic yields an FWHM pulse duration of radiated X-rays of about 0.48 ps for users.

INTRODUCTION

The typical electron bunch length in storage rings is several tens of picoseconds. Several ways are available for producing short X-ray pulses in synchrotron light sources and some of them are currently being implemented [1-2]. Transverse RF deflecting cavity, crab cavity, has been proposed to compress radiation pulses in the storage rings [3-4]. It generates a correlation between longitudinal position and vertical momentum of particles in a bunch. For this purpose, a crab cavity must be operated in a TM_{110} mode. In order to compensate the first vertical kick, a second deflecting structure must be located with mπ (where m is an integer) vertical phase advance downstream of the first cavity. Moreover It is beneficial to locate the insertion devices (ID) in places with nπ (where n is an integer) vertical phase advance from the first cavity ($n<m$) to avoiding problems of life time and RF acceptance. It is because the electron bunch has smallest vertical size and largest vertical slope in this region. Thus the photons emitted from ID will be vertically separated and using some optical elements such as a slit and an asymmetric crystal [5] in the TPS photon beam line, short X- ray pulses can be produced. The pulse duration of emitted X-ray is given by

$$\sigma_{X-ray} \approx \frac{E_b}{eV_0\omega_c}\sqrt{\frac{\beta_{y.ID}}{\beta_{y.C.C}}\left(\sigma_{y'e}^2+\sigma_{r'}^2\right)} \qquad (1)$$

where $\beta_{y.ID}$, $\beta_{y.C.C}$ are vertical beta function in location of ID and cavities and $\sigma_{y'e}$, $\sigma_{r'}$ are the divergence of electrons and photons, respectively. The use of crab cavities for Double Bend-Achromat (DBA) lattice was first addressed by M.Borland [6] in the Advanced Photon Source (APS). He proposed the locations of the cavities in relatively free dispersion straight sections and found the optimum parameters of deflecting cavity. In the present paper we find locations of cavities for Quadruple-Bend Achromat (QBA) low emittance lattice of TPS incorporating dispersive regions to generate subpicosecond pulses. Energy deviation of particles, status of nonlinear and coupling elements, synchrotron radiation effects must be investigated for consideration of deflecting cavities in TPS. These effects degrade transverse emittance of electrons in TPS.

QBA LATTICE

The low emittance QBA lattice [7] has been studied in few low emittance storage rings. It consists of two DBA cells of unequal bending lengths associated with the outer and inner dipoles, defined as a QBA cell for TPS. TPS comprises six super-periods and 12 QBA cells. Ten families of quadrupoles with mirror symmetry are in a super-period and eight families of sextupoles are present to compensate the aberrations. Table I presents the major QBA lattice parameters of TPS.

Table 1: Main parameters of TPS

Parameter	Value
Energy[GeV]	3
Circumference[m]	486
Nat. emittance[nm-rad]	3
Tune[Q_x /Q_y /Q_s]	26.27/12.25/3.058e-3
Nat. chromaticity[ξ_x/ξ_y]	-64/-30
Momentum compaction	2.712e-4
Energy spread	8.319e-4
Energy loss per turn[MeV]	0.75
RF gap voltage[MV]	1.1
RF frequency[GHz]	0.4996540967
Harmonic number	810
Bunch length[mm]	5.699
Dipole filed[T]	1.0479
Dipole length[m]	1 and 1.5

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

Optical function, transverse beam size and divergence in a super-period of TPS are shown in Fig. 1, Fig. 2 and Fig. 3, respectively. TPS contains six long straight (LS) sections and 18 short straight (SS) regions that their lengths are 10.91m and 5.31m, respectively. Accordingly, one third (33%) of the ring is straight line that accommodates insertion devices or special devices such as crab cavities.

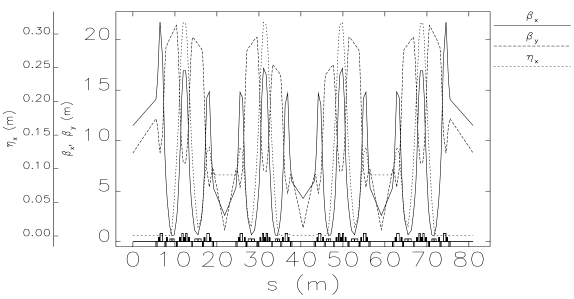

Figure 1: Optical functions in a super-period of TPS.

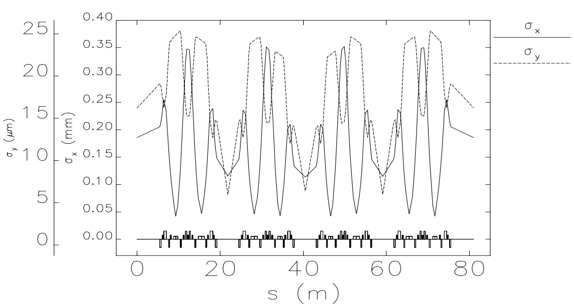

Figure 2: Transverse electron beam size in a super period of TPS.

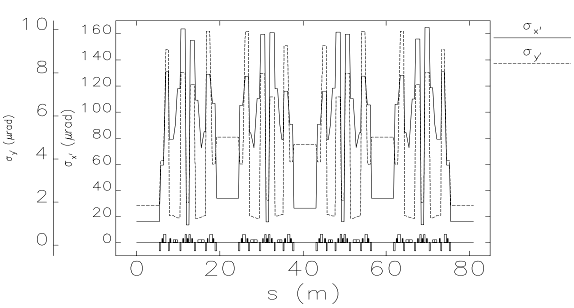

Figure 3: Transverse electron beam divergence in a super period of TPS.

CHOICE OF CRAB CAVITY LOCATIONS

Fortunately, the vertical phase advance in a QBA lattice is about 2π which favors for crab cavities. Three alternative locations are available for installing crab cavities in TPS. Ten thousands electrons per bunch with 5 rms σ Gaussian distribution are tracked for investigation of the options. The effects of energy spread, synchrotron radiation and nonlinear elements between the cavities are considered in all cases. In order to elucidate the cancellation of vertical kick by the second cavity, watch points are established in coordinate mode before of the first and after second cavity for monitoring the bunch.

In the first option, crab cavities are located in the beginning and at the end of a QBA cell. Two dispersion free sections are used for the first and second cavity. Accordingly, a long straight section and one short straight region are occupied for this configuration. Adjusting position of the cavities yields vertical and horizontal phase advances between them of almost 6.2836 and 13.71, respectively. The simulation results reveal that the cancellation of the first kick in the second cavity is not as good as the other choices even for low deflecting voltages and harmonics. As shown in the previous figures, this fact is clearly related to the difference of electron beam parameters such as beta function, beam size and beam divergence at the cavities. They cause that particles in the bunch receive unequal vertical kick at the second structure compare with the first then lead to imperfect cancellation of vertical kick.

In the second scenario, cavities are located in the beginning and at the end of a super-period. The vertical and horizontal phase advances between the cavities are around 12.5653 and 27.318, respectively. The dispersion function at the cavities and the middle ID is zero and they have the same lattice functions at location of cavities. The deflecting structures have been operated in 3MV deflecting voltage and 8th harmonic in this configuration regarding lifetime issues. Despite the cancellation is almost acceptable after the second cavity but the huge distance between the cavities, 78.668m, raises other problems. Energy deviation of particles and nonlinear elements between the cavities strongly degrade emittance at this distance. Moreover parts of two long straight sections of TPS are occupied.

For the remaining case (third choice), the cavities are located in the middle of two QBA cells in a super-period, indicating that two dispersive short straight sections are used for cavities and ID will be placed at the free dispersive straight section in the middle of the super-period. The distance between the cavities is 36.202 m and positions of them are adjusted to yield vertical and horizontal phase advances between the cavities of about 6.2833 and 13.46, respectively. Regarding to life time issues the cavities have been operated in 6MV deflecting voltage and 8th harmonic. Fig. 4 displays vertical kick cancellation after the second structure in the TPS ring.

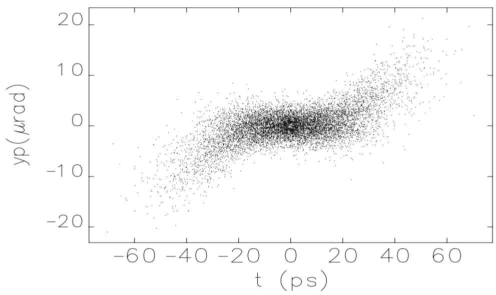

Figure 4: Monitoring of vertical slope of electrons v s time after the second crab cavity in the third option.

We have tracked 1000 electrons per bunch for many turns to find the transverse equilibrium emittance. The effects of energy deviation, synchrotron radiation and nonlinear elements are considered. Since the vertical equilibrium emittance in third case is about 10 pm-rad smaller than second option, third configuration is chosen for cavities. Furthermore, two long straight sections are saved by operating cavities in this configuration. Although we expect that the photon pulse duration in the second case is in the same range as third option but regarding the issues third case has been selected.

BEAM LINE SIMULATION FOR PHOTON COMPRESSION

TPS photon beam line contains 60 m drift space and canonical optical elements. Moreover, a slit and asymmetric crystal are employed for short X-ray pulses production. Parameters of the optical elements such as slit size and R_{53} parameter of crystal are optimized in order to minimize 70 % of X-ray pulse duration. The 100000 photons with Sinc function distribution are applied for tracking the TPS photon beam line. Fig. 5 demonstrates the pulse duration of photons from the slit for various amounts of cavities parameters. It is seen that the minimum duration of X-ray pulse is achieved when the deflecting structures operate at highest possible voltage and harmonics as expected.

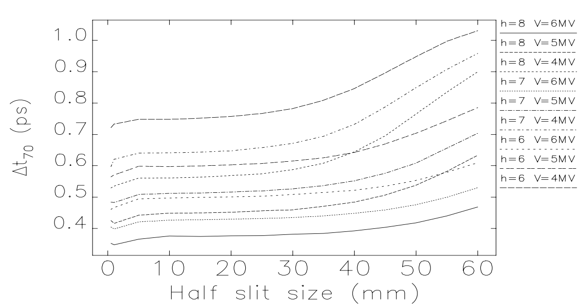

Figure 5: Duration of 70 % of central X-ray pulse as a function of slit size for various deflecting structure parameters.

Though operation of cavities on 6MV deflecting voltage seems impractical but the above figure displays that sub picosecond pulses are achievable even applying lower voltage and harmonic of deflecting structures. Clearly, the slit reduce the intensity of the photons but Fig. 6 indicates that radiation pulse of about 0.48ps with 6MV and the eighth harmonic can yield 60% transmission of photons.

Equilibrium vertical emittance of electrons after many turns tracking of electrons for operation deflecting structures on 8th harmonic, 6MV and 4MV deflecting voltage are around 118 and 57 pm-rad while the difference on 70% photon pulse duration between these two operation modes is 19 ps for 60 % transmission from the slit as shown in Fig. 6. Therefore with regarding to degradation of vertical emittance of electrons, pulse duration of radiated photons and optimum parameters of deflecting cavities could be chosen.

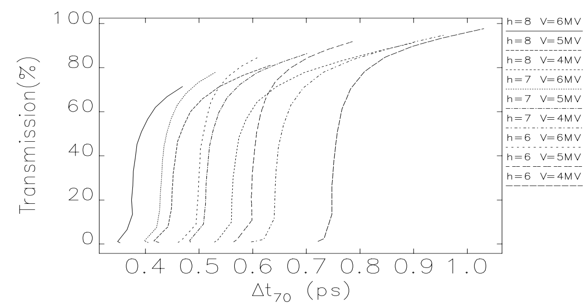

Figure 6: Transmission of photons through the silt vs of duration of radiation for various crab cavity parameters.

CONCLUSION

A pair of deflecting cavity in Quadruple bend achromat low emittance lattice of TPS is proposed to produce short radiation pulses for users. Three configurations for location of cavities have been compared and dispersive straight sections are chosen to place them in QBA lattice of TPS. Regardless of errors, degradation of vertical emittance is mainly due to the vertical kick of cavities, nonlinear elements between the cavities, energy deviation of particles. Considering the effects, vertical equilibrium emittance is found by tracking electrons in many turns during the ring and the duration of radiated pulses can be determined with regard to this issue. The results show that X-ray pulse duration of around 0.5 ps with acceptable intensity is available for users. An investigation at a lower deflecting voltage was conducted as well.

REFERENCES

[1] A. Zholents et al.: Phys. Rev. Lett. 76 (1999) No.6, 912.

[2] M. Borland et al.: Phys. Rev. ST Accel. Beams 10 (2007) 020701.

[3] A. Zholents et al.: NIM-A 425 (1999) 385.

[4] M.Katoh: Jpn. J. Appl. Phys. 38 (1999) 547.

[5] N. Watanable et al.: J. Synchrotron Rad. 6 (1999) 64.

[6] M.Borland: Phys. Rev. ST Accel. Beams 8 (2005) 074001.

[7] S.Y. Lee et al.: Review of Science Instrument 78 (2007) 05510.