UTILIZATION OF CRAB CAVITIES IN THE DESIGNED QBA LATTICE OF TAIWAN PHOTON SOURCE†

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Abstract

A pair of superconducting transverse deflecting RF cavities has been studied in the QBA low emittance lattice of 3 GeV TPS for generating ultra short X-ray pulses. During numerous turns of the electron tracking, the nonlinear effects between the cavities, the energy spread, the momentum compaction factor, and the synchrotron radiation effects are taken into account. The configuration with positioning the RF deflectors between the QBA cells in each super-period as an optimum arrangement gives rise to better quality electron bunches and radiated photon pulses. The FWHM of the radiated photon pulses of about 540 fs with an acceptable intensity (70% transmission) is attained by optimizing the compression optical elements of the TPS photon beamline.

INTRODUCTION

In a storage ring, a transverse deflecting RF cavity (crab cavity) can be employed to produce a correlation between vertical momentum and longitudinal position of the electrons in a bunch [1-4]. If an insertion device (ID) like an undulator or a wiggler, as a radiator, is placed between the deflecting cavities, the radiated photons would have some correlations among their time, vertical position and vertical slope. To acquire a shortened X-ray pulse, the radiated X-ray is cut by a slit and to enhance this effect an asymmetrically cut crystal can be used.

As a third generation light source, for the designed Quadruple-Bend Achromat (QBA) lattice, 3 GeV Taiwan Photon Source (TPS) would produce about 19 ps-long (rms) X-ray pulses by operating the accelerating radio frequency (RF) cavity at 1.1 MV. The TPS proposed design is made of six super-periods, each consisting of two QBA cells [5]. The QBA cell consists of two double-bend achromat (DBA) cells of unequal bending lengths associated with the outer and inner dipoles. The optical functions of the QBA lattice are shown in Fig. 1. This type of lattice has some advantages over the double-bend achromat or the double-bend nonachromat by providing a small natural beam emittance and some zero dispersive straight sections. Exploiting these advantages helped us employ crab cavities in our simulation to produce sub-picosecond photon pulses with TPS [6].

† The work is supported by NSRRC

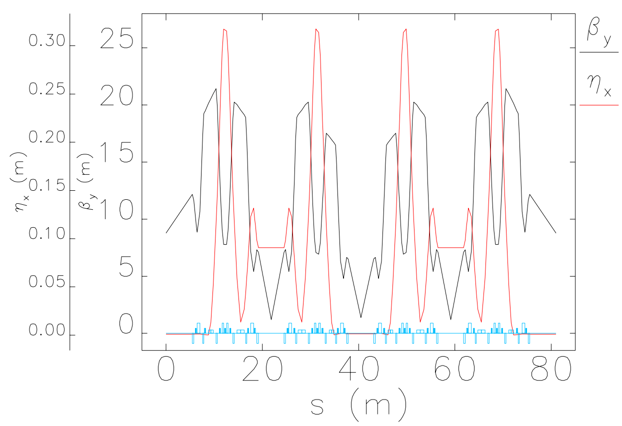

Figure 1: The optical functions in a super-period of TPS.

CONFIGURATION OF CRAB CAVITIES IN TPS

The crab cavities (deflectors) are located in the middle of the two QBA cells in the super-period where two dispersive short straight sections are devoted to the deflectors and the ID is placed at a dispersion-free straight section between the deflectors as shown in Fig. 2.

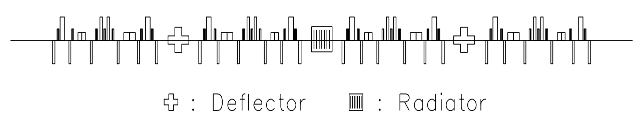

Figure 2: The magnets layout for a super-period of TPS. Approximate location of the deflectors and the radiator in the optimum arrangement at TPS are specified.

The vertical magnetic fields generated by the deflectors are very weak and thus generate small vertical dispersions which cause small impacts on the vertical emitance. Since, the direction of the deflecting kick is vertical and primarily irrelevant to the horizontal dispersion, the effect of dispersion function can be ignored at the crab cavities. The positions of the cavities are fine adjusted to yield a difference in horizontal and vertical phase advances of 13.46 and 6.28 (≈2π), respectively. The distance between the deflectors is 36.2 m and the vertical beta function at the cavities and the ID are 1.45 m and 1.37 m, respectively.

In order to minimize the duration of radiated X-ray pulses or to maximize the vertical kick, it is beneficial to place the crab cavities and the ID at locations where the vertical beta function is high and low, respectively. Likewise, increasing the deflecting voltage and the harmonic of the crab cavities or both would provide a stronger vertical kick to the electrons (as presented in Fig. 3 for this configuration of crab cavities in TPS) and significantly compresses the duration of the photon pulses. Moreover, the length of the ID, the radiation wavelength and the divergence of the untilted electron bunch would not have a drastic effect on the pulse duration.

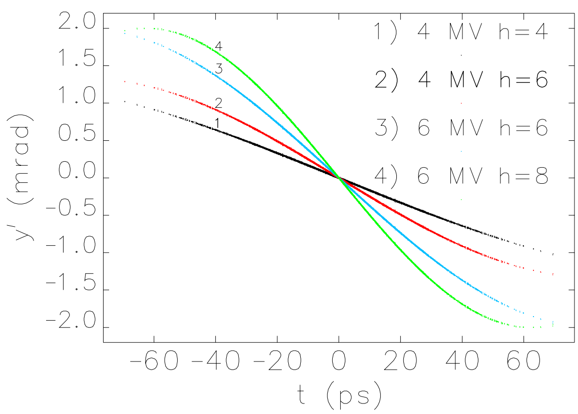

Figure 3: The vertical slope of the electrons for various deflecting parameters after passing through the deflecting structure. 10000 electrons per bunch have been employed for tracking. The electron tracking for various h and V illustrates the impact of increasing deflecting parameters.

Since the distance from the first crab cavity to the narrowest aperture with no elements is 2.1 m, then the upper limit of the kick voltage is calculated to be around 6.42 MV. To produce a large vertical kick and to expect no issues with beam lifetime, the cab cavities are set at 6.0 MV before the electron tracking. The tracking results indicated that the kick cancellation is as sufficient as required. Although the first kick is almost reversed by the second deflector, for this configuration the emittance growth is inevitable. As the QBA lattice functions at the crab cavities are the same, the main sources of emittance degradation and imperfect vertical kick cancellation process are associated with the electrons energy spread and nonlinear elements between the deflectors. In addition to these effects, the synchrotron radiation effects (damping of particle oscillation and excitation of such oscillations) must also be considered during tracking of the electrons. The balance of the two synchrotron radiation effects determines the equilibrium transverse emittance of the electrons in the storage ring. The damping of particle oscillation due to radiation improves the transverse emittance which in turn mitigates the nonlinearity and coupling effects of the interior sextupoles. Since the synchrotron radiation is emitted in quanta of energy, this granular emission effectively provides excitations to the oscillations and thus the effect of quantum excitation degrades the transverse emittance which in turn exacerbates the unwanted interior sextupoles effects. These phenomena can be understood better by tracking the electrons through the system for many turns while considering all the effects during tracking.

BEAM EMITTANCE

Since the transverse damping time is almost 13 ms in TPS, the equilibrium transverse emittance can be observed after 8000 turns. Thus, one thousand electrons are tracked for 8500 turns and the ELEGANT simulation results for h=8 for all three configurations are presented in Fig. 4.

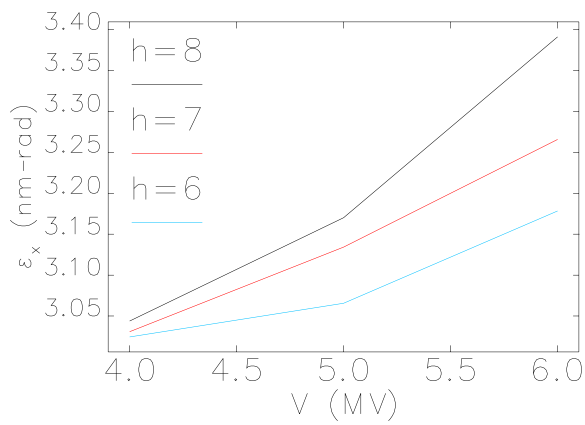

Figure 4(a): The eventual horizontal emittance in the 3rd configuration versus the deflecting voltages for various harmonics. The interior sextupoles were switched on.

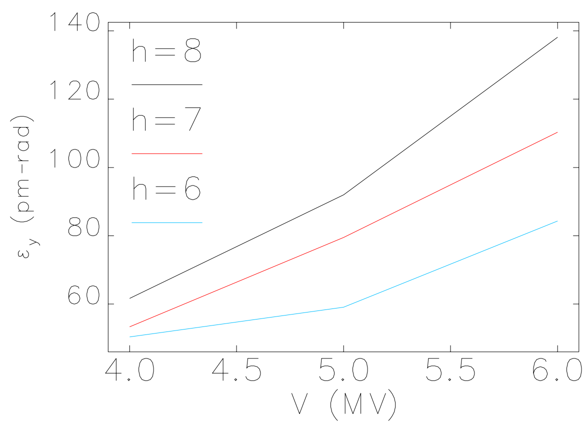

Figure 4(b): The eventual vertical emittances in the 3rd configuration versus the deflecting voltages for various harmonics. The interior sextupoles were switched on.

For the deflecting voltages of 6.0 MV, the eventual vertical emittance in this configuration blows up 4.6 times of its nominal value when the interior sextupoles were switched on as presented in Fig. 4(b). Meanwhile, operating the deflecting voltages at 4.0 MV, the eventual vertical emittance considerably reduces down to around

61 pm-rad. In addition, the eventual horizontal emittance does not change significantly from the nominal value of 3 nm-rad for the lower voltage.

X-RAY

After generating the sinc-function distribution, the radiated photons are tracked in the TPS photon beamline which is composed of a 60 m long drift space, a slit and an asymmetrically cut crystal. When the photons are drifted a long distance, the pulses can be shortened by slicing the photons using a slit. In addition, an asymmetrically cut crystal based on different angles of incidence and diffraction is employed to induce a variation in time-of-flight of the photons for acquiring a shorter pulse duration in a special plane.

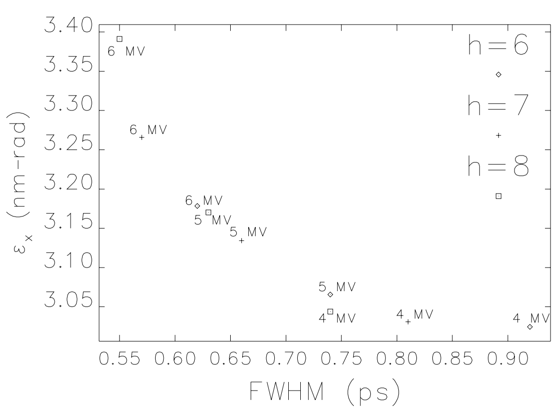

Figure 5(a): Eventual horizontal emittance as a function of achievable pulse duration for around 70% transmission through the slit.

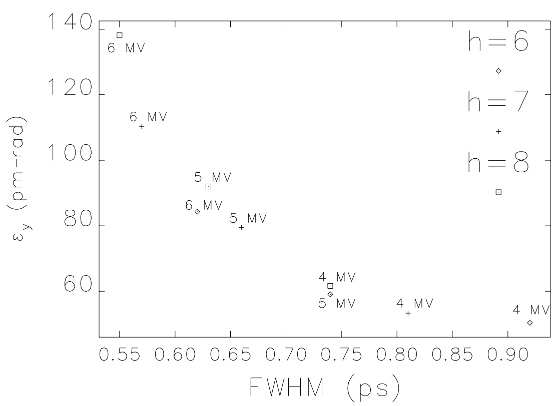

Figure 5(b): Eventual vertical emittance as a function of achievable pulse duration for around 70% transmission through the slit.

However, the final operating point of crab cavities not only depends on the achievable pulse duration, but also on the impact on the rest of the TPS users, which means the impact on the vertical emittance. Fig. 5 shows that the transverse emittance as a function of FWHM when 70% of the photons are allowed through the slits. the minimum pulse duration (for h=8 and V=6.0 MV) is around 0.54 ps−0.55 ps. This is associated with the electron bunch horizontal and vertical emittances of 3.4 nm-rad and 138 pm-rad, respectively. One can see that there is little to be gained from the case with 6 MV and h=8, compared to 4 MV and h=8. For V=4.0 MV, associating with the electron bunch horizontal and vertical emittances of 3.05 nm-rad and 61 pm-rad, a pulse duration of around 0.72 ps is generated. As a result of sacrificing of around 0.18 ps difference in pulse duration, the vertical emittance is improved more than 50%.

CONCLUSION

For the 8th harmonic, employing 4 MV and 6 MV for the crab cavities blows up the vertical emittance up to around 61 pm-rad to 138 pm-rad. Moreover, by optimizing the compression optical elements in the 60 m TPS photon beamline, the FWHM and transmission of the radiated photons for various deflecting parameters are achieved. The results show that for around 70% transmission of photons through the slit, and for these two operation modes of crab cavities (4 MV and 6 MV) the FWHM of about 0.54 ps and 0.72 ps would be obtained.

REFERENCES

[1] A. A. Zholents, P. Heimann, M. S. Zolotorev and J. Byrd, *Generation of subpicosecond X-ray pulses* using RF orbit deflection, *Nucl. Instrum. Meth. A* 425 (1999) 385.

[2] M. Katoh, *Ultra-short pulses of synchrotron radiation on storage rings*, *Jpn. J. Appl. Phys.* 38 (1999) 547.

[3] S. Sakanaka, *Production of short-pulse synchrotron radiation using a head-tail bunch oscillation in* the electron storage ring, *Jpn. J. Appl. Phys.* 43 (2004) 6457.

[4] M. Borland, *Simulation and analysis of using deflecting cavities to produce short X-ray pulses with the Advanced Photon Source*, *Phys. Rev. ST Accel. Beams* 8 (2005) 074001.

[5] M. H. Wang et al., *Quadruple-bend achromatic low emittance lattice studies*, *Rev. Sci. Instrum.* 78 (2007) 055109.

[6] H. Ghasem, G. H. Luo and A. Mohammadzadeh, *Utilization of transverse deflecting RF cavities in the designed QBA lattice of 3 GeV Taiwan Photon Source*. *JINST*, 5, (2010) T01001.