CURRENT STATUS OF LATTICE DESIGN AND ACCELERATOR PHYSICS ISSUES OF THE 3 GeV TAIWAN SYNCHROTRON LIGHT SOURCE

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Abstract

Over the past several years, we have been conducting a design work for a synchrotron light facility with low emittance storage ring in the intermediate energy range at NSRRC. A number of design options with different lattice structure types, circumferences, etc., are explored. We present two design cases, i.e., a 24-cell DBA and a 12-cell QBA structures with 486 m circumference. The associated accelerator physics issues are discussed.

INTRODUCTION

Since 1993, a 1.3~1.5 GeV synchrotron light source at NSRRC has been operated successfully. It is getting saturated in the research capacity in this small and low energy ring. Therefore, we are proposing another synchrotron light source with energy around 3 GeV.[1] We have explored a number of design options, and in this report we present a Double-Bend Achromat (DBA) lattice and a Quadruple-Bend Achromat (QBA) lattice.

The natural emittance of the DBA is 1.7 nm-rad in the nonachromatic mode and 5.2 nm-rad in the achromatic mode. The nonlinear beam dynamics of this DBA lattice is acceptable. However, with strong field insertion devices, the nonachromatic mode operation intends to increase the natural emittance and effective emittance. Alternatively, a QBA lattice with 12 non-dispersive and 12 dispersive straights is designed for the installation of the high field IDs in the non-dispersive sections. The natural emittance of the QBA is 3.0 nm-rad. The natural emittance is about half of the DBA achromatic mode. In this paper, we will describe linear and nonlinear beam dynamics of both lattices and ID effects.

DBA LATTICE

The linear lattice functions of the DBA super-period (one-sixth of the ring) are shown in Fig.1. There are 24 straights in total. The long straight sections longer than 10 meters are used for the injection, RF cavity modules, and long IDs. The horizontal beta at the long straights is around 10 m for the injection purpose. In the short straights, both horizontal and vertical betas are small. The working tunes are chosen at some points with small natural emittance and natural chromaticity. There are 8 families of quadrupoles for the DBA and 8-family sextupoles for the chromaticity correction and nonlinear optimization. Figure 2 shows the dynamic aperture for on and off momentum 1000-turn 4D tracked particles of the DBA nonachromatic mode.

The DBA lattice can have emittance between 5.2 nm-rad and 1.7 nm-rad, depending on the values of the dispersion in the straights. If we operate in the low emittance mode in which some finite dispersion in the straights, the strong field IDs will increase the natural emittance.[2] On the other hand, operating in the achromatic mode will decrease the natural emittance. But it needs same amount of ID radiation power as that from the dipole radiation (0.85 MeV per turn) to damp the natural emittance down to half. Recently S.Y. Lee, *et al.*, proposed another lattice structure, i.e., QBA lattice.[3]

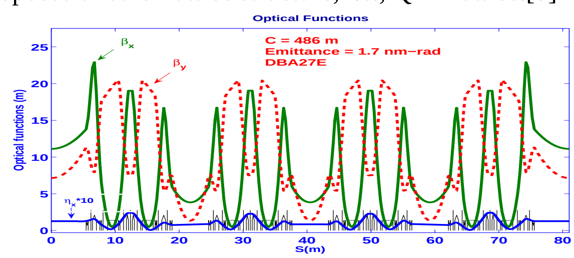

Figure 1: Lattice optical functions of the TPS DBA design.

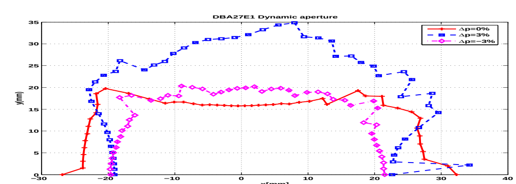

Figure 2: Dynamic aperture tracking of 1000 turns at the long straight centre for the TPS DBA lattice. β_x, β_y, η_x, are: (11.1, 7.1, 0.127), (11.2, 10.5, 0.127) and (10.9, 6.4, 0.127) in meters for 0, 3%, -3%, energy deviations.

QBA LATTICE

One cell of the QBA consists of two cells of the DBA. There are 12 cells of QBA in the TPS design with some dispersion-free straights and some finite dispersion straights so that it can have natural emittance in between the extreme modes of the DBA and this also allows to equip with the strong magnetic field IDs in the dispersion-free sections that helps to damp the natural emittance.

Theoretical minimum natural emittance of the QBA is 0.549 of the DBA if the inner dipole length is $3^{1/3}$ of the outer dipole for the same field strength dipoles. For simplicity, we take the dipole length to be 1.5 m and 1.0 m for the inner and outer dipoles, respectively. The QBA structure in our design is similar to the DBA case, i.e., it is a ring of 6-fold symmetry, 24-straight, 486 m in circumference. Figure 3 depicts the lattice functions in a super-cell. The nonlinear scheme is also similar to the DBA case. The dynamic aperture of the on and off momentum particle is given in Fig. 4. Table 1 is a list of the lattice parameters of the DBA and QBA design.

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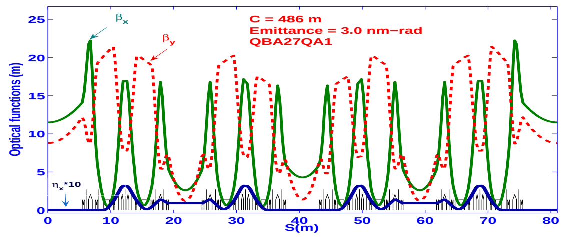

Figure 3: Lattice optical functions of the TPS QBA design.

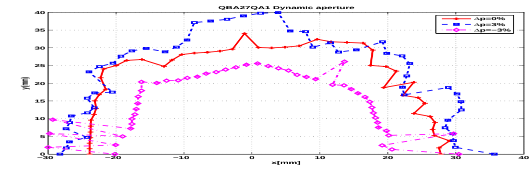

Figure 4: Dynamic aperture tracking of 1000 turns at the long straight centre for the TPS QBA lattice. β_x, β_y, η_x, are: (11.5, 8.8, 0), (12.7, 11.8, 0) and (10.9, 7.6,0) in meters for 0, 3%, -3%, energy deviations.

Table 1: Major machine parameters of the TPS DBA and QBA lattice design.

	DBA	QBA
Energy (GeV)	3.0	3.0
Beam current (mA)	400	400
Circumference (m)	486	486
Natural emittance (nm-rad)	1.7	3.0
Cell / symmetry / structure	24 / 6 / DBA	12 / 6 / QBA
β_x / β_y / η_x (m) long straight centre	11.11 / 7.14 / 0.127	11.49 / 8.78 / 0.0
β_x / β_y / η_x (m) short straight centre	3.84 / 1.34 / 0.082	2.59 / 1.19 / 0.091 4.28 / 1.37 / 0.00
RF frequency	499.654	499.654
Harmonic number	810	810
SR loss/turn, dipole (MeV)	0.853	0.750
Straights	10.9m*6+5.7m*18	10.9m*6+5.3m*18
Betatron tune ν_x / ν_y	26.22 / 12.30	26.28 / 12.25
Momentum compaction (α_1, α_2)	2.4×10^{-4}, 2.4×10^{-3}	3.1×10^{-4}, 2.0×10^{-3}
Dipole strength / length (Tesla) / (m)	1.19 / 1.1	1.04 / 1.0, 1.5
Critical energy (keV)	7.12	6.27
Natural energy spread σ_E	8.86×10^{-4}	8.31×10^{-4}
Damping time (τ_x/τ_y/τ_s) (ms)	11.4 / 11.4 / 5.7	13.0 / 13.0 / 6.5
Damping partition ($J_{x,y,s}$)	0.998 / 1.0 / 2.002	0.998 / 1.0 / 2.002
Nat. chromaticity ξ_x / ξ_y	-69 / -30	-64 /-30

6D TRACING AND TOUSCHEK LIFETIME

Due to a small first order momentum compaction factor and a large second order one, the longitudinal phase space is highly distorted as shown in Fig. 5 for the QBA case at 3.5 MV RF voltage. The 6D tracked dynamic aperture is given in Fig 6. The estimation of 6D tracked Touschek half lifetime using BETA code including small ID vertical chambers of 10 mm size, 1% emittance coupling and bunch current of 0.8 mA is listed in Table 2. If nitrogen equivalent gas pressure is 1 nTorr, total lifetime for the three lattice options is estimated to be more than 10 hours.[4]

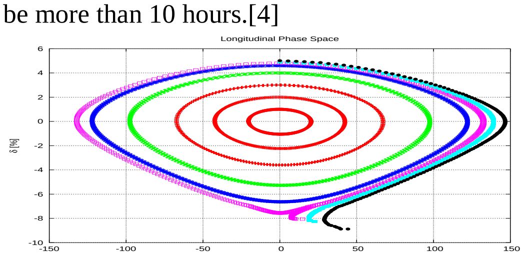

Figure 5: Longitudinal phase space tracked with Tracy 2. RF voltage is 3.5 MV. Energy acceptance is in a range around -6% to 4%.

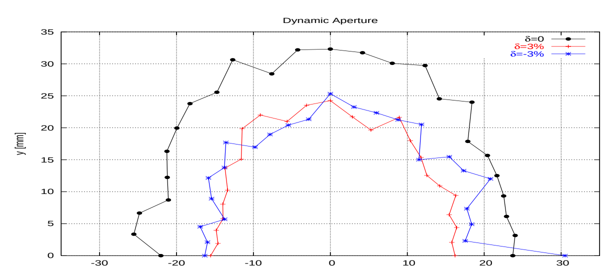

Figure 6: Dynamic aperture tracking including synchrotron oscillations.

Table2: Touschek half lifetime using BETA 6D tracked code including small ID vertical chambers of 10 mm size, 1% emittance coupling, bunch current of 0.8 mA and Vrf=3.5 MV

Lattice	Natural horizontal Emittance (nm-rad)	Touschek half lifetime (hr)
DBA nonachromat	1.7	25.8
DBA achromat	5.2	55.7
QBA	3.0	29.1

ID EFFECTS

The effects on beam dynamics in the presence of the insertion devices are investigated. The tune change, the beta beating, and the closed orbit excursion could be adjusted. The reduction of the dynamic aperture can be minimised too. However, the changes of the emittance, and energy spread are unable to be compensated for. The brightness of the synchrotron light can be expressed as:

$$\text{Brightness } B = \frac{dN/dt}{4\pi^2 \sigma_x \sigma_{x'} \sigma_y \sigma_{y'} \frac{\Delta\omega}{\omega}} \propto \frac{I}{\kappa \varepsilon_{x,eff}^2}$$

Effective emittance is defined as

$$\varepsilon_{x,eff} = \sqrt{\varepsilon_x \varepsilon_{x,1D}} = \sqrt{\varepsilon_x^2 + H\sigma_E^2 \varepsilon_x}\ ,$$

$$H = \gamma_x \eta_x^2 + 2\alpha_x \eta_x \eta_x' + \beta_x \eta_x'^2 \text{ at ID straight.}$$

The effective emittance is equivalent to the natural emittance at the dispersion-free sections. It is shown that operating in the nonachromatic mode can have lower effective emittance or higher brightness than that in the achromatic mode. However, high field IDs can increase the natural and effective emittance substantially. Define a parameter as the ratio between average H function in the dipole to the H function in the ID straight:

$$f_h \equiv \frac{< H_{dipole} >}{H_{ID}}.$$

The changes of the emittance and energy spread for the planar wigglers or undulators, neglecting the ID generated dispersions, are as follows:

$$\frac{\varepsilon_x}{\varepsilon_{x0}} \approx \left(1 + \sum_w \frac{8B_w}{3\pi f_h B_0} \frac{U_w}{U_0}\right) / \left(1 + \sum_w \frac{U_w}{U_0}\right)$$

$$\left(\frac{\sigma_E}{E}\right)^2 = \left(\frac{\sigma_E}{E}\right)_0^2 \times \left(1 + \sum_w \frac{8B_w}{3\pi B_0} \frac{U_w}{U_0}\right) / \left(1 + \sum_w \frac{U_w}{U_0}\right)$$

where B_0, B_w are the magnetic field of the dipole and undulators, and U_0, U_w are the radiation loss from dipole and undulators, respectively.

If the wiggler field B_w is higher than $(3\pi f_h/8)B_0$, the natural emittance will increase, and if higher than $(3\pi/8)B_0$, the energy spread will increase too. The installation of some high field IDs at the dispersion-free straight sections, especially for the QBA, can damp the natural emittance to a smaller value and then QBA becomes an attractive lattice option. Figure 7 plots the natural emittance and effective emittance as a number of high field superconducting wigglers, called SW6.

NOLINEAR FIELD ERRORS, COD, COUPLING, INSTABILITIES, INJECTOR

The nonlinear field error tolerances are evaluated with a set of realistic values. The dynamic aperture tracking with such errors have been performed and results in an acceptable dynamic aperture. The 6D tracking with vertical ID chambers gives acceptable aperture and lifetime too.

The estimation and correction schemes for COD and coupling are similar to the results in [5,6]. It is shown there are same evaluations of instabilities as given in [7]. A transverse feedback damping device is necessary to suppress the vertical instabilities.

Some booster lattice options, either concentric or separated, are designed. We are evaluating which type of booster is the most suitable choice. The transfer lines for linac to booster and booster to storage ring are also designed. We use 4 kickers in a long straight section for the injection bump and a thick septum scheme is adopted.

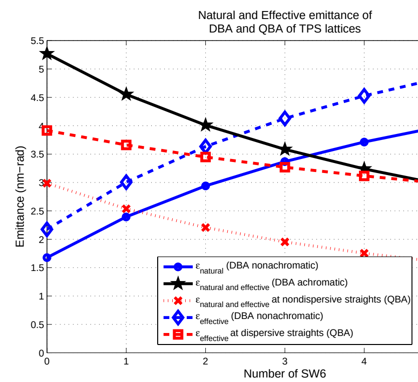

Figure 7: Natural and effective emittance vs. the number of wigglers SW6. Each SW6 is 2 m long, 3.5 T peak field and 60 mm period length. Synchrotron radiation loss per turn is 135 keV from SW6.

ACKNOWLEDGEMENT

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