ELECTRON BEAM DYNAMICS STUDY AT SIAM PHOTON SOURCE

Su Su Win, Masumi Sugawara, Goro Isoyama, Somchai Tancharakorn,
Chanita Kaewprasert, Lek Boonanan, Takehiko Ishii and Weerapong Pairsuwan
National Synchrotron Research Center (NSRC), Thailand

Abstract

The Siam Photon Source is the first storage ring for synchrotron radiation research in Thailand. The light source accelerator system includes an injector linac at 40 MeV, a booster synchrotron at 1.0 GeV and a storage ring at 1.0 GeV electron energy. The storage ring is composed of four identical cells with a total circumference of 81.3 m. The lattice is modified into DBA from FODO that was previously designed in SORTEC. In this paper, the study of electron beam dynamics in low energy beam transport, booster synchrotron, high energy beam transport, and storage ring has been presented.

1 INTRODUCTION

The accelerator of SIAM photon source is complex of a linac at 40 MeV, a booster synchrotron to increase the electron energy from 40 MeV to 1 GeV, and a storage ring at 1 GeV from which the synchrotron light is extracted to the experimental halls. The critical photon energy with the modified DBA is 798 eV with the emittance of 72π nm.rad. The injector linac and the booster are installed at underground level, and the storage ring is at ground level. The high energy beam transport takes the electron from booster and to storage ring and injects from inside of the ring. In this paper, the electron beam dynamics in low energy beam transport, booster synchrotron, high energy beam transport and storage ring are presented.

2 MAGNET LATTICE

The low energy transport line (LBT) transports the electron beam, having 40 MeV electron energy, from the exit of linac to the injection point of booster synchrotron. The LBT is of 11.998 m long and consists of 2 identical dipoles, 11 quadrupole magnets and one injection septum magnet. Each dipole has bending angle of 50.5° with the edge of 13.87° and bending radius of 0.5 m.

In booster synchrotron (BS), the electron energy is increased from 40 MeV to 1 GeV. The magnet lattice is FODO lattice with six superperiodicity. Among six straight sections, one is adopted for injection, one for extraction and one for acceleration. Each section consists of two identical bending magnets, one focusing quadrupole and one defocusing quadrupole magnet. Each bending magnet has 3.03 m bending radius and 30° bending angle. The main parameters of BS are summarised in Table 1. The accelerated electrons with the energy of 1 GeV are extracted from booster and transported through high energy-beam transport line to inject into the storage ring from its inside.

Table 1: Booster synchrotron parameters

Injection energy	40 MeV
Maximum energy	1 Gev
Circumference	43.19 m
Lattice structure	FODO
Beam current	30 mA
Betatron tune (ν_x/ν_y)	2.25/1.25
Maximum dipole field	1.1 T
Maximum gradient of quadrupole field	4.8 Tm-1
RF frequency	118 MHz
Maximum rf voltage	60 kV

The high energy transport (HBT) is composed of 1 extraction septum magnet, 2 horizontal bending magnets, 2 vertical bending magnets, 8 quadrupole magnets and one injection septum magnet. The extraction septum magnet has the bending radius of 3.333 m with the angle of 15°. Each of the vertical bending magnets has the bending radius of 3.335 m and bending angle of 17.5°. Two horizontal bending magnets have the same bending radius of 7.162 m with different bending angles of 4° and 2° respectively. The total length of HBT is of 46.643 m.

In storage ring the lattice structure is DBA type with 4 superperiodicicity. A unit cell of DBA lattice is presented in fig.1 and the main parameters of storage ring are in table 2. Each cell consists of two identical dipoles and seven quadrupoles. The bending radius and angle of each dipole are 2.78 m and 45° respectively.

Table 2: Storage ring parameters

Energy	1 Gev
Circumference	81.3 m
Lattice type	DBA
Number of cells	4
Betatron tune (ν_x/ν_y)	4.71/2.78
Momentum compaction factor	0.0241
Natural emittance (ε_{x0})	72 π nm.rad
Natural chromaticities (ξ_x, ξ_y)	-7.643/-6.726
RF voltage	120 kV
RF frequency	118 MHz

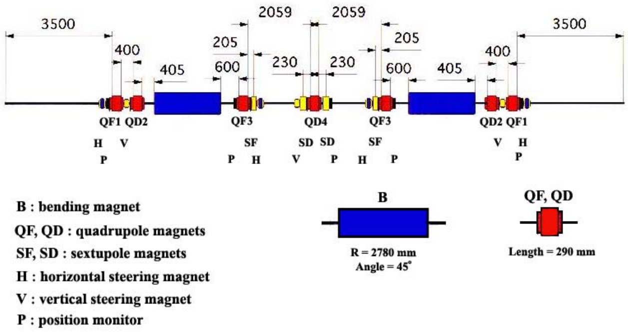

Figure 1. Layout of DBA-lattice (one unit cell) of storage ring

Table 2: Storage ring parameters (contd.)

Energy spread	5.02×10^{-4}
Energy loss/turn	31.8 eV
Synchrotron oscillation frequency	13.5 kHz
Critical photon energy	798 eV
Bunch length, σ_z	135 ps
Beam sizes, σ_x/σ_y	0.94/0.15 mm
Damping times, $\tau_x/\tau_y/\tau_s$	18.9/17.0/8.1 ms

3 ELECTRON BEAM DYNAMICS

In this study we used the computer codes, LATTICE and BETA to study the electron beam dynamics. As there are dynamic aperture limit, orbit oscillation in the transverse plane and the longitudinal acceptance in the whole ring, the beam cannot be injected into the ring smoothly. It needs special matching for lattice parameters and some injection elements to fulfil these requirements.

The electron beam extracted from the linac has 40 MeV electron energy and 60~80 mA beam current. To inject the beam into booster with minimum loss, the strengths of quadrupoles in LBT are calculated so that the designed beam optics at the entrance of booster is achieved. The beam optics functions at the entrance of LBT are $\beta_x=\beta_y=4.38$ m, $D_x=0$, and $D'_x=0$. The maximum field of dipoles and the field gradients of quadrupoles that satisfy the beam optics at the entrance of the booster are shown in table 3. The beam optics along the low energy beam transport is shown in fig. 2.

Table 3 The strengths of quadrupoles in LBT

	Field grad. (T/m)		Field grad. (T/m)		Max. field (T)
Q1	-0.423	Q6	-0.573	BM1	0.27
Q2	0.631	Q7	0.066	BM2	0.27
Q3	-1.060	Q8	0.848		
Q4	1.037	Q9	1.083		
Q5	1.538	Q10	-1.136		

Q = quadrupole magnet, B = dipole magnet

The beam optics in one unit cell of booster synchrotron is illustrated in figure 3. The betatron tunes are used as a set of constraints in the calculation of the quadrupoles strengths. The betatron tune values are 2.25 and 1.25 in horizontal and vertical directions, respectively. At the extreme of the each cell, the beta functions are $\beta_x=6.77$ m and $\beta_y=3.33$ m in horizontal and vertical directions, respectively. The horizontal dispersion function is $D_x=1.86$m and its derivative $D'_x=0$. The transverse beam size at the exit of injection septum magnet is 2.2 mm in horizontal and 1.5 mm in vertical direction. The quadrupole field gradients in this FODO lattice cell are QF= 4.843 and QD= -3.625 Tm^{-1} and the

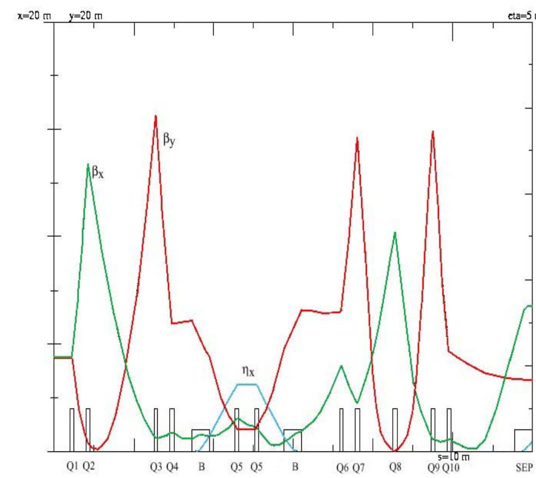

Figure 2. The beam optics of LBT

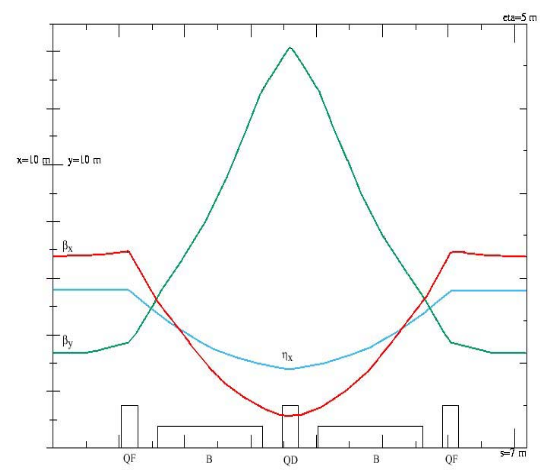

Figure 3. The beam optics of BS in a unit cell

maximum field of each dipole magnet is 1.1T.

The quadrupole fields in HBT are selected to achieve the designed beam optics at the entrance of storage ring. At injection point, the beta functions are $\beta_x=13.5$ m and $\beta_y= 4.28$ m and the transverse beam sizes are 1.8 mm and 1.1 mm in horizontal and vertical directions, respectively. Table 4 presents the maximum dipole fields and the field gradients of quadrupoles that satisfy the beam optics at the entrance of the storage ring. Fig. 4 illustrates the beam optics along HBT with the magnet arrangement.

Table 4. The field gradients of quadrupoles in HBT

	Field grad. (T/m)		Field grad. (T/m)		Max. field (T)
Q1	-5.679	Q5	3.320	BH1	0.47
Q2	6.953	Q6	-4.337	BH2	0.47
Q3	-7.353	Q7	4.783	BV1	1.0
Q4	5.856	Q8	-4.856	BV2	1.0

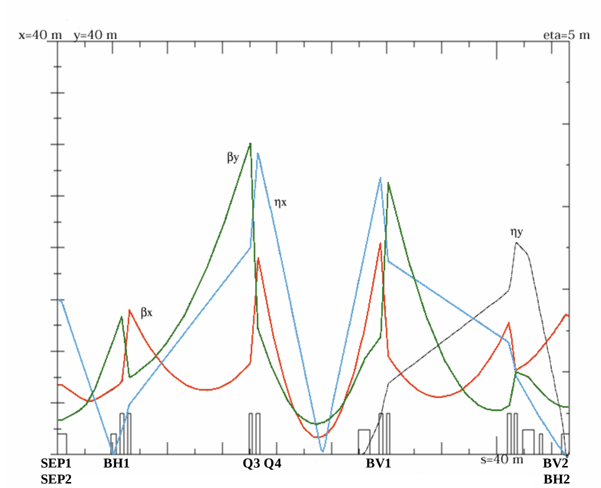

Figure 4. The beam optics of HBT

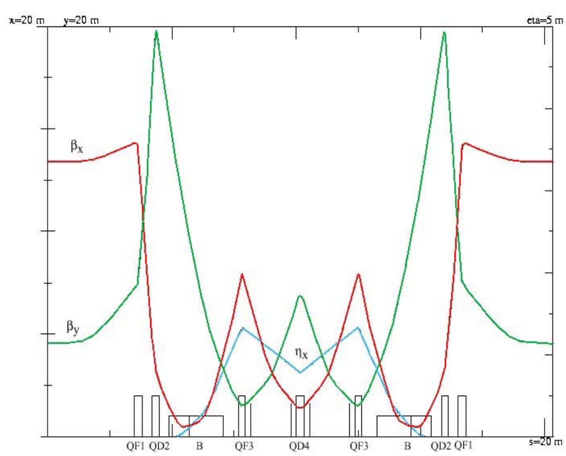

Figure 5. Beam optics of storage ring in a supercell

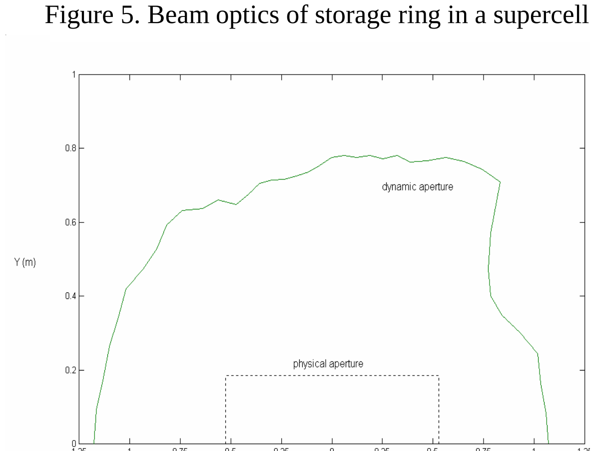

Figure 6. Dynamic aperture of storage in perfect status

As one of the optimization tasks in light source is to minimize the emittance, the DBA lattice in Siam Photon source is primarily designed to provide the critical photon energy of 798 eV with the emittance of 72 π nm.rad. The designed working points are Q_x=4.75 and Q_y=2.82. The maximum dipole field of the bending magnets in the storage is 1.20048 T. The strength of QF and QD are used to select the desired working point for low emittance with large dynamic aperture. The strength of QF3 and QF4 are selected to vanish the horizontal dispersion at the long straight sections. The field gradients of quadrupoles are 9.197869, -9.572795, 8.41036, -6.890131 Tm^{-1} for QF1, QD2, QF3 and QD4 respectively.

Fig.5 shows the beta functions and dispersion function of a unit cell of storage ring. The beam optics functions at the extremes of a unit cell are β_x=13.50 m, β_y=4.28 m, $\alpha_x=\alpha_y$ and $\eta_x=\eta'_x=0$. The value of minimum horizontal betatron function is 0.53 m and is obtained in the bending magnet at a position of 0.8188 m away from the edge on the dispersion free straight section side. The maximum values of horizontal and vertical betatron function are 14.41 m and 19.24 m respectively. The horizontal and vertical beam sizes at the extremes of a unit cell are x=0.95 mm and y = 0.17 mm respectively. The maximum beam sizes for horizontal and vertical directions are x=0.98 mm and y = 0.35 mm, respectively.

The natural chromaticities of storage ring for x and y directions are ξ_x= -8.634 and ξ_y= -7.574 respectively. For natural chromaticities correction, 2 sextupole families are placed between QF3 and QD4 in DBA cell. The dynamic aperture for a perfect machine calculated at the centre of the long straight section by tracking a particle for 4000 turns is illustrated in fig. 6. The sextupole fields of SF and SD are 46.32 and 68.50 T/m^2 respectively. The storage ring with the working point (Q_x=4.75, Q_y=2.82) with chromatic sextupoles has the dynamic aperture that is higher than physical one as can be seen from fig. 6. However, fig. 6 does not include the errors due to the misalignment of magnets, field gradient error of quadrupoles and field error of dipoles. These errors could results reduction in dynamic aperture and energy acceptance and thus, these errors must be taken into account in the practical operation.

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