# DESIGN STUDY FOR THE SIAM PHOTON SOURCE

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*Abstract*

The magnet lattice for the Siam Photon Source, the first storage ring for synchrotron radiation research in Thailand, has been designed. The storage ring has a double bend achromat lattice and fourfold symmetry with four straight sections. An emittance value of 74 π nm rad has been obtained, which is only 1.4 times as large as the theoretical minimum emittance with eight bending magnets. The dynamic aperture is found to be much larger than the physical aperture even with errors. Another operation mode with the non-zero dispersion in the long straight sections is being studied with the same magnet configuration to reduce the emittance further.

## 1 INTRODUCTION

The Siam Photon Project is being conducted by the National Synchrotron Research Center for establishing the first synchrotron radiation facility in Thailand[1]. The accelerator system, including the 40 MeV electron linac, the 1 GeV booster synchrotron and the 1 GeV electron storage ring used in the SORTEC Laboratory in Tsukuba, Japan [2], has been transferred to Thailand and will be re-assembled at Nakhon Ratchasima, 250 km to the northeast of Bangkok. The Siam Photon Source will be used for studies on basic and applied sciences.

The SORTEC storage ring was optimized for basic studies on microlithography with synchrotron radiation. The emittance was 510 π nm rad at 1 GeV, the circumference was 45.7 m, and there were no long straight sections for insertion devices [3]. The SORTEC storage ring consisted of eight bending magnets and two families of sixteen quadrupole magnets. It had eightfold symmetry with doublet structure cells. The storage ring will be remodeled to meet the new requirements as follows: (i) some long straight sections are available for insertion devices; (ii) the emittance of the electron beam should be as low as possible. The design study of the storage ring is in progress and some preliminary results will be published elsewhere [4].

## 2 DESIGN PRINCIPLE

The design goal of the Siam Photon storage ring is to realize low emittance and long straight sections using the components of the SORTEC storage ring. Additional magnets should be as few as possible. As a result, we have employed the double bend achromat (DBA) lattice. The ring has fourfold symmetry with four long straight sections. It consists of eight bending magnets, four families of quadrupole magnets and two families of sextupole magnets.

The minimum emittance attainable with the double bend achromat is given by

$$\varepsilon_{x0}^{\mathrm{min}}\ [\pi\ \mathrm{nm\ rad}]\ \_\ 2.3510^4\ E^2[\mathrm{GeV}]/J_x N_B^{\,3}\ , \qquad (1)$$

where $E$ is the electron energy, $J_x$ is the horizontal damping partition number and $N_B$ is the number of bending magnets [5]. The minimum value is obtained when the minimum of the horizontal betatron function in the bending magnet is 0.097$L$ at a position (3/8)$L$ away from the edge on the dispersion-free straight section side, where $L$ is the bending magnet length. As the emittance is minimized, the horizontal betatron function in the dispersion-free straight section tends to be larger, and, accordingly, quadrupole triplets with strong focusing forces would be necessary to keep both the horizontal and the vertical betatron functions at moderate values. Natural chromaticities become larger and non-linear effects become serious due to strong sextupole strengths for compensating them. It is, therefore, not easy to obtain the theoretical minimum emittance given by Eq. (1). On the other hand, as long as the minimum position of the horizontal betatron function is maintained at the optimum position (3/8)$L$, the emittance does not increase very much in the vicinity of the emittance minimum as the betatron function becomes larger than the optimum value [4]. This means that the minimum value can be made larger at little expense of the emittance increase. Then the betatron functions and quadrupole strengths in the dispersion-free straight sections do not become very large. Therefore, we decided to relax the requirement so that the horizontal betatron function in the straight sections is made moderate with quadrupole doublets, whose focusing strength can be obtained with the existing quadrupole magnets.

In order to install long insertion devices up to 5~6 m and medium ones even in the straight sections where the injection septum magnet and the RF cavity are installed, the length of the dispersion-free straight sections are determined to be 7 m.

It is known that the emittance can be further reduced if non-zero dispersion is allowed in the long straight sections [6]. With the same magnet configuration used in

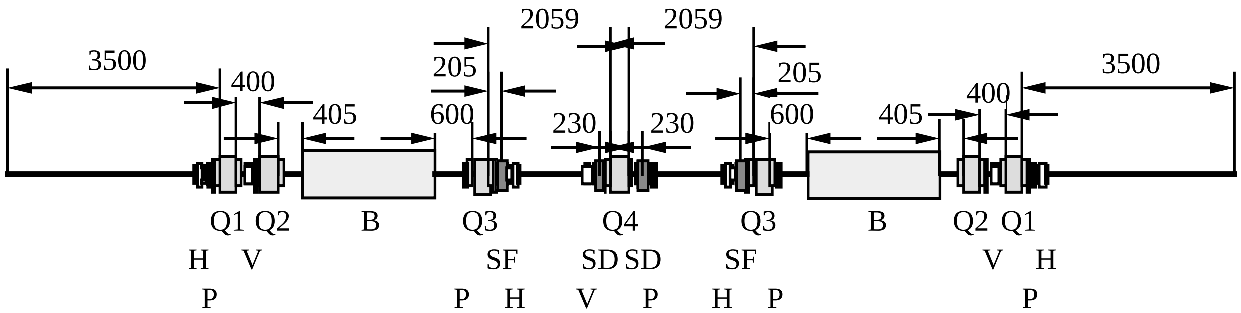


Fig. 1. Magnet arrangement in a quadrant of the storage ring. B: bending magnet, Q1~Q4: quarupole magnet, SF and SD: sextupole magnets, H: horizontal steerer, V: vertical steerer, and P: position monitor. The distances are shown in mm.

the DBA lattice, we are studying another operation mode to reduce the emittance.

## 3 LINEAR LATTICE

The magnet arrangement in a quadrant of the storage ring is shown in Fig. 1 and parameters of the magnets used are listed in Table 1. We use four families of quadrupoles. Positions of some magnets shown in Fig. 1 are changed from the original ones in ref. [4] due to technical requirements from the vacuum system; the distance between a quadrupole magnet Q2 and a bending magnet B is expanded from 350 to 405 mm and the distance between Q3 and Q4 is made shorter to keep the total length constant. Calculation was carried out for the linear lattice using the computer program LATTICE [7].

Table 1. Parameters of magnets.

| | |
|---|---|
| bending magnets B | |
| type of the magnets | sector bend |
| number of magnets | 8 |
| bending angle | 45° |
| radius $\rho$ | 2.78 m |
| magnetic field $B$ | 1.2 T |
| quadrupole magnets Q1~Q4 | |
| number of magnets | 28 |
| pole length | 0.29 m |
| field gradient $\lvert dB_z/dx \rvert$ | < 13 T/m |
| sextupole magnets SF, SD | |
| number of magnets; SF, SD | 8, 8 |
| pole length; SF, SD | 0.15, 0.2 m |
| field gradient $\lvert d^2B_z/dx^2 \rvert$ | < 60 T/m$^2$ |

Table 2. Parameters of the Siam Photon Ring.

| | |
|---|---|
| Electron energy, $E$ | 1.0 GeV |
| Circumference, $C$ | 81.3 m |
| Magnet lattice | DBA |
| Superperiodicity | 4 |
| Long straight sections | 7 m ∞ 4 |
| Betatron wave numbers; $\nu_x$, $\nu_y$ | 4.76, 2.82 |
| Momentum compaction factor | $\alpha$ = 0.0214 |
| Natural chromaticities; $\xi_x$, $\xi_y$ | -7.59, -6.73 |
| Natural emittance, $\varepsilon_{x0}$ | 74 $\pi$ nm rad |
| Damping partition numbers; $J_x$, $J_y$, $J_\varepsilon$ | 0.9, 1.0, 2.1 |
| Damping times; $\tau_x$, $\tau_y$, $\tau_\varepsilon$ | 18.9, 17.0, 8.1 ms |
| RF frequency, $f_{RF}$ | 118 MHz |
| RF voltage, $V_{RF}$ | 100 kV |
| Harmonic number, $h$ | 32 |
| Beam size at the long S. S.; $\sigma_x$, $\sigma_y$ | 0.96, 0.17 mm |
| critical energy of SR, $\varepsilon_c$ | 0.96 keV |

The resulting main parameters of the storage ring are listed in Table 2. The natural emittance is 74 $\pi$ nm rad, which is approximately 1/7 of the emittance of the SORTEC storage ring and only 1.4 times higher than the theoretical minimum emittance attainable with DBA and eight bending magnets. The betatron functions and the dispersion function are shown in Fig. 2. Calculated beam sizes are shown in Fig. 3, where 10 % emittance coupling is assumed.

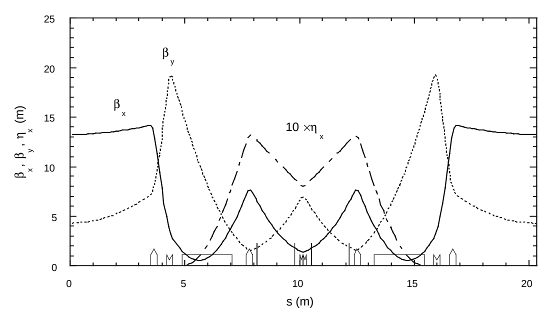


Fig. 2. Betatron functions and the dispersion in a unit cell.

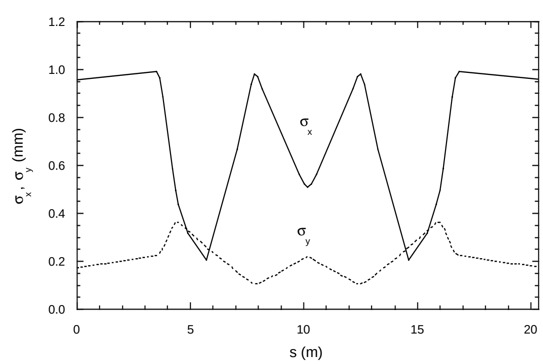


Fig. 3. Beam sizes in a unit cell. 10 % coupling is assumed.

## 4 DYNAMIC APERTURE

The natural chromaticities listed in Table 2 are corrected with two families of sextupole magnets, SF and SD, shown in Fig. 1. The effects of the non-linear fields introduced by the sextupole magnets are studied using the computer program BETA [8]. Fig. 4 shows dynamic apertures for a perfect machine and a realistic machine with errors calculated at the center of the long straight section by tracking a particle for 7500 turns, which is one tenth of the transverse damping times. Errors taken in account are misalignment and gradient errors of the quadrupole magnets and field errors of the bending magnets shown in Fig. 4. They are much larger than the physical aperture of the vacuum chamber shown by the dashed line in Fig. 4. In order to see the effects of the sextupole magnets more clearly, particle trajectories in the phase spaces at the center of a long straight section were calculated for various oscillation amplitudes both in the horizontal and the vertical directions. The phase space trajectories within the physical aperture were not distorted very much. Judging from these studies and the maximum sextupole strength of $|d^2B/dz^2|\infty l/B\rho = 3.6\ m^{-2}$, it seems that the effect of the sextupole magnets is not serious.

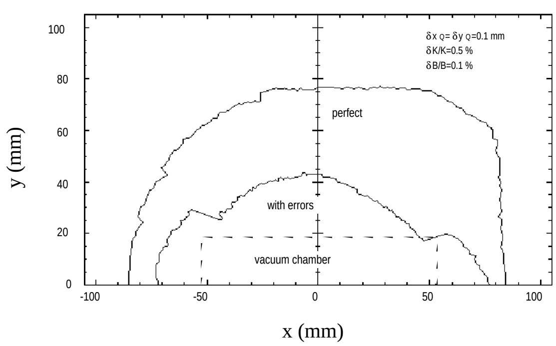


Fig. 4. Dynamic apertures for a perfect machine and a realistic machine with errors.

## 5 SMALL EMITTANCE MODE

In order to reduce the emittance further, another mode of operation is being studied with the same magnet configuration. Figure 6 shows betatron functions and the dispersion function obtained with such a operation mode. The dispersion function in the long straight sections is 0.8 m. The emittance is 28 $\pi$ nm rad, which is 2.6 times smaller than the emittance obtained with the double bend achromatic mode, the momentum compaction factor is 0.0166, and beam sizes at the center of the long straight sections are 0.78 and 0.09 mm for the horizontal and the vertical directions, respectively, for the 10 % coupling beam. The other parameters of the storage ring are practically the same as those listed in Table 2.

Non-linear behaviors in this operation mode such as the tune shift with momentum and the dynamic aperture are as good as those obtained with the double bend achromat mode. A problem with this operation mode is that sextupole strengths necessary for compensating natural chromaticities are higher than those obtained with the sextupole magnets listed in Table 1 due to the smaller dispersion function at the sextupoles. We already have the sextupole magnets with the pole length 0.15 m since they were used in the SORTEC storage ring. We would have to make new sextupole magnets with a higher strength to operate the storage ring in this mode.

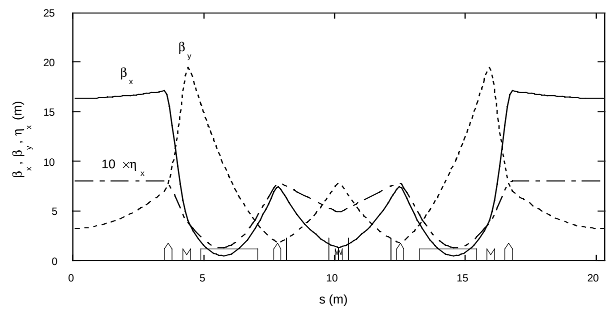


Fig. 5. Betatron functions and the dispersion in the small emittance operation mode.

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