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Magnet lattice for the Siam Photon Source

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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. Although the magnet lattice is relaxed, an emittance value of 72 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.

Keywords: electron storage rings; emittance; magnet lattices.

1. Introduction

The Siam Photon Project is being conducted by the National Synchrotron Research Centre to establish the first synchrotron radiation facility in Thailand. 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 (Kodaira *et al.*, 1991), 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.

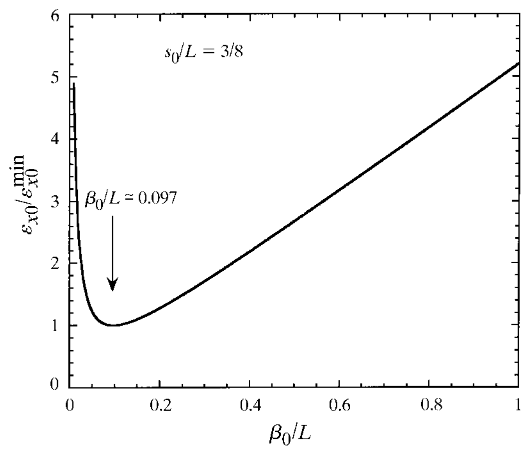

Figure 1
Relative emittance, $\varepsilon_{x0}/\varepsilon_{x0}^{\min}$ as a function of the minimum betatron function, β_0, in the bending magnet for the double-bend achromat lattice. L is the length of the bending magnet and s_0 is the location where β takes the minimum.

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 (Takanaka *et al.*, 1989). 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 remodelled 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.

2. Design principle

The design goal for the Siam Photon Source 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 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

$$\varepsilon_{x0}^{\min}\ [\pi\,\mathrm{nm\,rad}] \simeq 2.35\times10^4 E^2\,[\mathrm{GeV}]/J_x N_B^3, \tag{1}$$

where E is the electron energy, J_x is the horizontal damping partition number and N_B is the number of bending magnets (Sommer, 1983). The minimum value is obtained when the minimum of the horizontal betatron function in the bending magnet is $0.097L$ 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 (1).

Fig. 1 shows the emittance as a function of the minimum horizontal betatron function in the bending magnet, where the position of the minimum is fixed at the optimum one, $(3/8)L$. In the vicinity of the emittance minimum, the emittance does not increase very much as the betatron function becomes larger. As long as the minimum position of the horizontal betatron function is maintained at the optimum position, 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 lengths of the dispersion-free straight sections need to be 7 m.

Table 1
Parameters of magnets.

Bending magnets, B	
Type of magnets	Sector bend
Number of magnets	8
Bending angle	45°
Radius, r	2.73 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^{-1}
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
Main parameters of storage ring.

Electron energy, E	1 GeV
Circumference, C	81.3 m
Magnet lattice	DBA†
Superperiodicity	4
Long straight sections	7 m × 4
Betatron wave numbers; ν_x, ν_z	4.71, 2.78
Momentum compaction, α	0.0214
Natural emittance	72 π nm rad
Natural chromaticities; ξ_x, ξ_z	−7.96, −6.45
RF voltage, V_{RF}	120 kV
RF frequency, f_{RF}	118 MHz
Harmonic number, h	32
Energy spread, σ_E/E	5.02×10^{-4}
Energy loss per turn, U_0	31.8 keV $turn^{-1}$
Synchrotron oscillation frequency, f_s	13.5 kHz
Critical energy of synchrotron radiation, ε_c	958 eV
Bunch length, σ_l	135 ps
Beam sizes;‡ σ_x, σ_z	0.94, 0.15 mm
Damping times; τ_x, τ_z, τ_e	18.9, 17.0, 8.1 ms

† Double-bend achromat. ‡ At the centre of the long straight sections and 10% coupling assumed.

3. Linear lattice

The magnet arrangement in a part of the storage ring is shown in Fig. 2 and parameters of the magnets used are listed in Table 1. We use four families of quadrupoles. Qualitatively speaking, the quadrupoles Q1 and Q2 are used to control the betatron functions in the long straight sections and the minimum value of β_x in the bending magnet, and also to determine the betatron tunes. The quadrupoles Q3 and Q4 are used to make the long straight sections dispersion-free and to control the position of the horizontal betatron minimum in the bending magnet. Calculations were carried out for the linear lattice using the computer program *LATTICE* (Stamples, 1987) running on a personal computer. Several constraints were given to the program including the position of the minimum horizontal betatron function and its magnitude in the bending magnets. In order to relax the magnet lattice, we selected a value of the minimum betatron function 2.5 times larger than the optimum value and accordingly the emittance became 1.4 times larger than the theoretical minimum value, as can be seen in Fig. 1. Although the beam size became 1.2 times larger than that obtained with the theoretical minimum emittance, there are not many additionally required magnets and the magnet lattice is simple.

The resulting main parameters of the storage ring are listed in Table 2. The natural emittance is 72 π nm rad with the horizontal damping partition number $J_x = 0.9$. The betatron functions and the dispersion function are shown in Fig. 3. The minimum value of the horizontal betatron function is 0.5 m. The horizontal betatron function is 13.3 m at the centre of the long straight section and the vertical betatron function is 3.4 m.

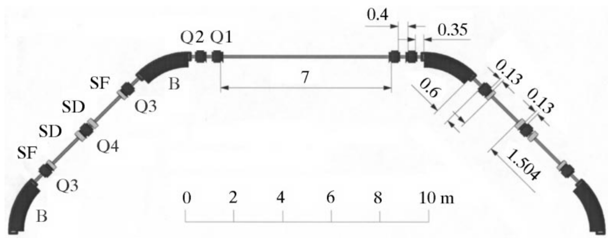

Figure 2
Magnet structure in a part of the storage ring. The symbol B denotes a bending magnet, Q1–Q4 quadrupole magnets, SF and SD are focusing and defocusing sextupole magnets. The magnet arrangement has reflection symmetry with respect to the centre of the long straight section and the centre of the Q4 magnet.

4. Dynamic aperture

The natural chromaticities listed in Table 2 are corrected with two families of sextupole magnets, SF and SD, shown in Fig. 2. The effects of the non-linear fields introduced by the sextupole magnets were studied using the computer program *BETA* (Farvacque *et al.*, 1987). Fig. 4 shows the dynamic aperture calculated at the centre of the long straight section by tracking a particle for 5000 turns. It is 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 centre of a long straight section were calculated for various oscillation amplitudes

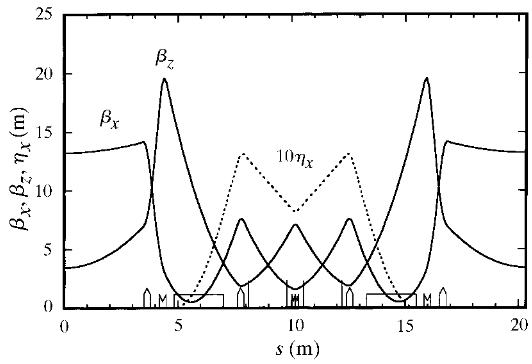

Figure 3
Betatron functions and the dispersion functions in a unit cell.

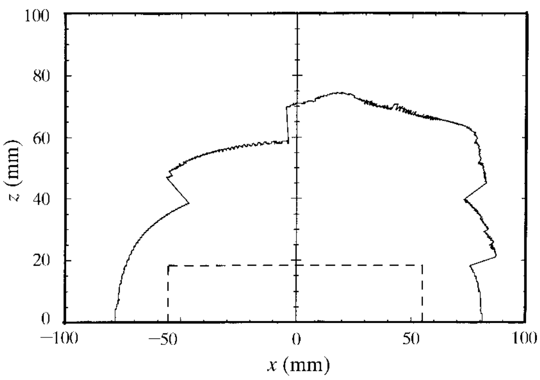

Figure 4
Dynamic aperture at the centre of the long straight section. The dashed line is the physical aperture of the vacuum chamber.

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 $|d^2B/dz^2|(l/B\rho) = 3.6\ \mathrm{m}^{-2}$, it seems that the effect of the sextupole magnets is not serious.

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