ULTRA-LOW EMITTANCE LIGHT SOURCE STORAGE RING WITH FOUR LONG STRAIGHT SECTIONS

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Abstract

An ultra-low emittance storage ring proposed as a next generation synchrotron radiation source at SPring-8 has the same circumference as the SPring-8 storage ring so as to be able to replace the existing one, but it does not have a long straight section (LSS). Accordingly, the storage ring beam line is slightly different from that of SPring-8 and the photon beam line positions are also different from the existing ones. To avoid these problems, we propose another design of a 6 GeV storage ring with four LSSs. This storage ring consists of twenty ten-bend achromat cells, four five-bend achromat cells, and four LSS cells. A study of the dynamic aperture gave an aperture size of about ±3 mm at the center of a straight section. The natural emittance is 108 pm-rad and is reduced to 50 pm-rad with damping wigglers. The maximum brightness of 2.8×10^{22} photons/s/mm^2/mrad^2 in 0.1% BW at around 10 keV is obtained with a 200 mA beam current when all wigglers and undulators are working.

INTRODUCTION

An energy recovery linac (ERL) is widely accepted as a next generation synchrotron radiation source, but there are many technical challenges such as a high current low emittance electron gun and high gradient superconducting linac. The beam stability will not reach the stability of electron storage ring. Contrary an electron storage ring is matured technically. The problems of an ultra-low emittance electron storage ring are short lifetime and small dynamic aperture.

The ultimate storage ring (USR) has been proposed as an alternative to the ERL [1]-[6]. To construct the USR economically, we proposed replacing the SPring-8 storage ring by the new storage ring [1]. It has the same circumference as the SPring-8 storage ring, but does not have LSS, whereas the SPring-8 storage ring does. The photon beam line positions would deviate from those of the existing one. To avoid this problem, we studied a storage ring that has four LSSs.

LATTICE

The original SPring-8 storage ring consists of forty-four double-bend achromat (DBA) cells and four LSS cells. Each cell is 30 m in length. The previous storage ring proposal has the ten-bend achromat cells with a cell length of 60m, which is twice that of the original DBA cells. We have studied a storage ring that has twenty ten-bend achromat cells, four five-bend achromat cells, and four LSS cells. The lengths of the short straight section (SSS) and LSS are 6.6 m and 34.0 m. Since the previous storage ring has 24 symmetry, we took only one cell into consideration for the dynamic aperture calculation for an ideal lattice. The symmetry of the new storage ring is only 4 and a reduction in the dynamic aperture is anticipated. To avoid this, we designed a ring that has high symmetry for sextupole distribution. If the sum of the phase advance of a five-bend achromat and LSS cell is $2n\pi$ and the sextupole magnets are weak enough in the five-bend cell, the ring will have high symmetry for sextupole magnets and a large dynamic aperture is expected [7].

The quadrupole magnets in the LSS cells are placed with a space of 5.58 m to adjust the partial tune of the LSS $\Delta\nu_{lssx}$. Since the partial tune of a five-bend achromat cell $\Delta\nu_{5bx}$ must be larger than 2 to obtain low emittance, we adjusted $\Delta\nu_{lssx}$ by means of the quadrupole magnets in the LSS to obtain $\Delta\nu_{5bx}+\Delta\nu_{lssx}=3$. The betatron and dispersion functions are shown in Fig. 1. The horizontal betatron function at an SSS is set to be large by taking the injection into account, though we may be able to choose a smaller value to increase the photon beam brightness. The main parameters are shown in Table 1.

Table 1: Main parameters of storage ring.

Parameters	Symbol	Value
Energy	E	6 GeV
Circumference	L	1436 m
Natural emittance	ε_{x0}	108 pm·rad
With damping wiggler	ε_{xw}	50 pm·rad
Number of cells	N_c	
10-bend/5-bend/LSS		20/4/4
Horizontal tune	ν_x	104.40
Vertical tune	ν_y	30.92
Horizontal beta at ID	β_x	21.9 m
Vertical beta at ID	β_y	2.1 m
Horizontal chromaticity	ξ_x	-430
Vertical chromaticity	ξ_y	-84
Momentum compaction	α	1.7×10^{-5}
Energy spread	σ_E/E	1.08×10^{-3}
Bunch length	σ_ℓ	1.83 mm
Damping time	τ_x	11.4 ms
RF frequency	f_{rf}	508.6 MHz
RF voltage	V_{rf}	7 MV
Energy loss	U_0	5.0 MeV/turn

DYNAMIC APERTURE

The dynamic aperture is obtained through the following procedure. First, the dynamic aperture for a ring consisting of only ten-bend achromat cells is obtained. For this lattice, the dynamic aperture is improved by reducing the strength of focusing sextupoles located at both ends of a cell [4]. Second, the dynamic aperture is calculated for a ring that includes five-bend achromat

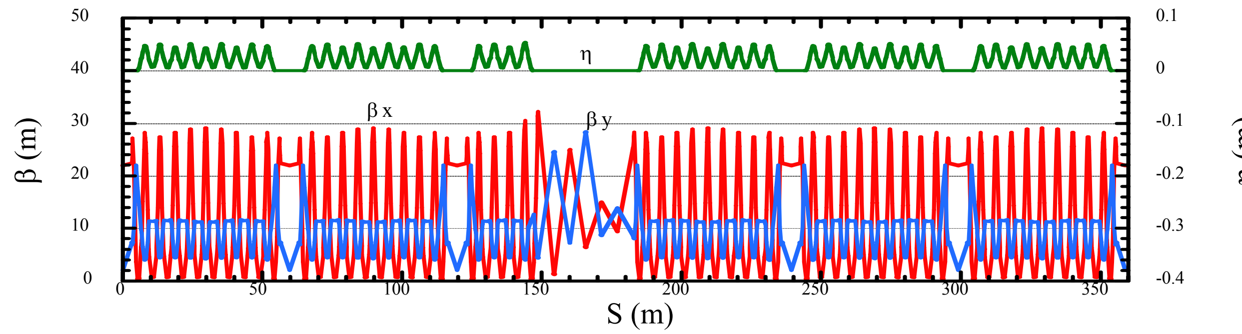

Figure 1: Optics functions in one-quarter of the storage ring.

cells and LSSs. The sextupole strength in the five-bend achromat cells is initially set to zero. At this stage, the dynamic aperture is large for on-momentum particles and small for off-momentum ones. As the strength of the sextupole magnets in the five-bend achromat cells increases, the dynamic aperture decreases for on-momentum particles and increases for off-momentum ones. The acceptable dynamic aperture size for on-momentum particles is determined by injection and that for off-momentum ones is determined by lifetime. The acceptable lifetime depends on how frequently we can supply electrons to each bunch.

The dynamic aperture at the center of the SSS is shown in Fig. 2. The sextupole strength in the five-bend cells is about 30 % that in the ten-bend cells. No stable linear optics could be obtained for particles with a relative momentum deviation larger than 1 %. The dynamic aperture is not so large that we may need the injection method using pulsed quadrupole or sextupole magnets [8[[9].

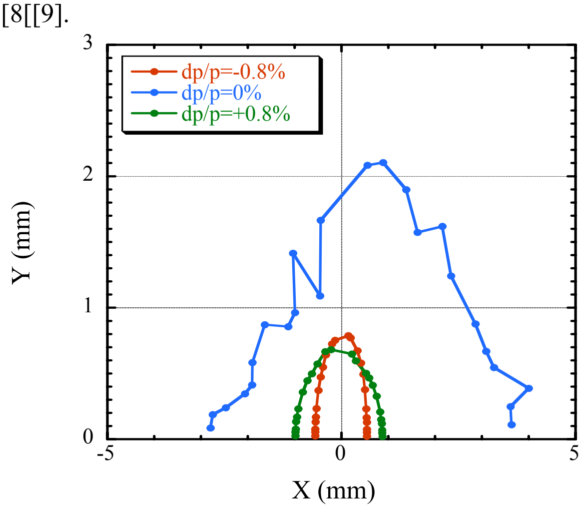

Figure 2: Dynamic aperture at the center of a short straight section.

BRIGHTNESS

We calculated the emittance reduction and momentum change for the following three cases. (i) Damping wigglers are placed in the four LSS cells. (ii) Every straight section is filled with undulators except for one injection, one monitor, and two RF sections. (iii) Damping wigglers are placed in the LSSs and undulators fill the SSSs. In the first case, a total wiggler length of 120 m and wiggler period from 0.03 m to 0.2 m are assumed. In the second case, an undulator length of 4.5 m is assumed. The total undulator lengths in the LSSs and SSSs are 108 m (4.5 m × 6 undulators × 4 sections) and 72 m (4.5 m × 16 sections), respectively. In the third case, the total wiggler length is the same as that for the first case and the total undulator length is 72 m.

The emittance reduction and energy change for the first case are shown in Figs. 3 and 4 as a function of maximum wiggler field. As shown in Fig. 3, the shorter period length and stronger magnetic fields result in lower emittance. If a cryogenic wiggler is used, a wiggler with a 0.03 m period and 2 T maximum field strength is possible under some limited conditions [10]. However, we chose a 0.05 m period and 1.5 T maximum field strength assuming room-temperature wigglers. In this case, the emittance and relative momentum spread are 50 pm and 1.32×10^{-3} respectively. In the second case, we assumed a 0.018 m period undulator with undulator parameter K=1.34 [11]. The emittance and energy spread are reduced to 71 pm and 1.05×10^{-3}. In the last case, we assumed a 0.05 m period and 1.5 T maximum field strength wiggler and 0.018 m period and K=1.34 undulator. Emittance of 46 pm and relative energy spread of 1.29×10^{-3} were obtained.

The brightness was calculated for these three cases using SPECTRA[12] with an undulator period of 0.018m, undulator parameter of 1.34, undulator length of 4.5m, beam current of 200 mA, and beam coupling of 0.2 %.

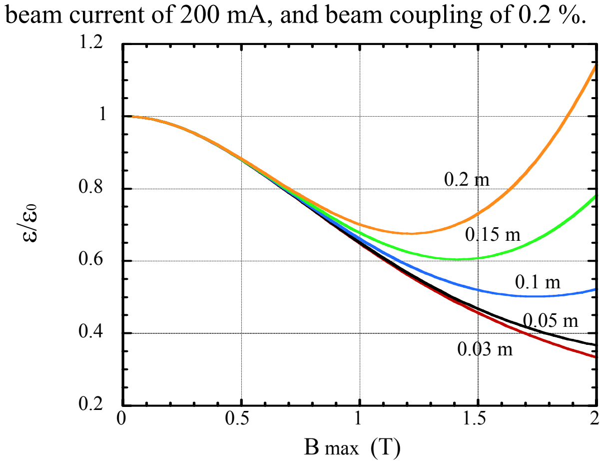

Figure 3: Emittance reduction with damping wigglers: 0.2 m, 0.15 m, 0.1 m, 0.05 m, and 0.03 m period wigglers.

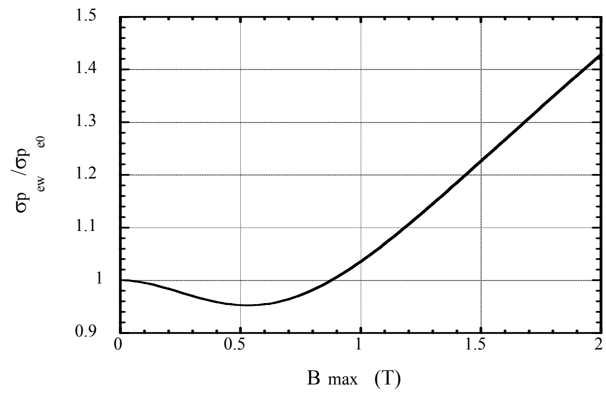

Figure 4: Relative momentum deviation as a function of maximum wiggler field. Total wiggler length: 120 m.

Calculation results are shown in Fig. 5. Maximum brightness is about 2.8×10^{22} photons/s/mm^2/mrad^2 in 0.1 % BW around 10 keV and 1.5×10^{21} photons/s/mm^2/mrad^2 in 0.1 % BW at 100 keV. In this calculation, emittance growth was not taken into account. The bunch must be lengthened to avoid emittance growth and brightness deterioration. Emittance reduction, energy spread, and brightness are summarized in Table 2.

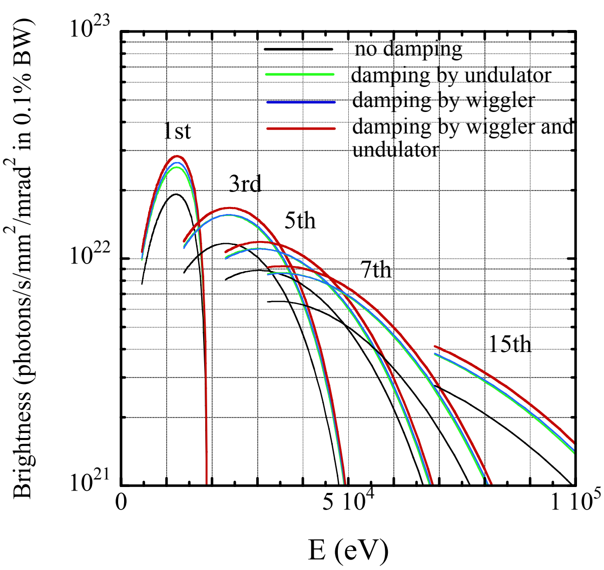

Figure 5: Brightness for a 4.5 m undulator with no damping, damping by undulators, damping by wigglers, and damping by wigglers and undulators.

Table 2: Emittance, energy spread, and brightness.

	ε (pm)	σ_E/E	B(ph/s/mm^2/mrad^2/0.1%BW)
natural	108	1.09×10^{-3}	1.9×10^{22}
undulator	71	1.05×10^{-3}	2.5×10^{22}
wiggler	50	1.32×10^{-3}	2.6×10^{22}
wiggler+undulator	46	1.29×10^{-3}	2.8×10^{22}

INJECTION

Lifetime becomes short as the emittance and momentum acceptance decrease. One solution to this short lifetime problem is a top-up operation. If one bunch is injected at one injection, a constant beam current cannot be maintained for a very short lifetime beam even when a top-up operation is applied. However, if multiple bunches are injected at one injection, the beam current can be kept constant. Assuming a linac and a synchrotron as injectors, it is possible to inject the electron beam with many kinds of bunch patterns from the linac to the synchrotron [13]. After each bunch current in the storage ring has been measured, the bunches with small currents are selected and a bunch pattern for these bunches is determined. The electron bunches are then injected into the synchrotron according to this bunch pattern. After being accelerated in the synchrotron, these bunches are injected into the storage ring at one injection. The maximum injection frequency is determined by the repetition rate of synchrotron.

SUMMARY

A storage ring with four long straight sections has been designed. It consists of twenty ten-bend and four five-bend achromat cells, and four long straight sections. Emittance reduction by damping wigglers and normal undulators has been studied. The natural emittance of 108 pm is reduced to 50 pm by damping wigglers and to 46 pm by both damping wigglers and undulators. The maximum brightness is 2.8×10^{22} photons/s/mm^2/mrad^2 in 0.1% BW around 10 keV and 1.5×10^{21} at 100 keV with a 200 mA beam current.

We studied a ten-bend achromat cell with 60 m cell length, but it is easy to design a five-bend achromat cell with 30 m cell length. With five-bend achromat cells, calculations gave a 104 pm emittance storage ring [14].

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