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 that of the SPring-8 storage ring so as to be able to replace the existing storage ring, but has not long straight section (LSS) [1]. Accordingly, the storage ring beam line is slightly different from that of SPring-8 and the positions of photon beam lines are also different from the existing one. To avoid this, a 6 GeV storage ring with four LSSs has been designed. The storage ring consists of twenty ten-bend achromat cells, four five-bend achromat cells and four LSS cells. The dynamic aperture has been studied and the aperture of about ±3 mm at the center of straight section is obtained. The natural emittance is 108 pm-rad. It becomes 50 pm-rad with damping wigglers and about 70 pm-rad with undulators. The brightness of 2.5×10^{22} photons/s/mm^2/mrad^2 in 0.1% BW around 10 keV is obtained with 200 mA beam current when all 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 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 the ultra-low emittance electron storage ring are the short lifetime and the small dynamic aperture.

The ultimate storage ring (USR) alternative to the ERL was proposed [1]-[6]. To construct a new USR economically, we proposed to replace the SPring-8 storage ring to the new storage ring [1]. The proposed storage ring has the same circumference as the SPtring-8 storage ring, but has not LSS that the SPring-8 storage ring has. The position of the photon beam lines are deviated from the existing one and the electron beam line at the LSS is found to locate the outside of the tunnel. To avoid this, we studied the storage ring that has four LSSs.

LATTICE

The original SPring-8 storage ring consists of 44 double-bend achromat (DBA) cells and 4 LSS cells. Each cell length is 30 m. The previously proposed storage ring has 24 ten-bend achromat cells. The cell length is 60m, twice of the original DBA cells. This time we have been studied the storage ring that has 20 ten-bend achromat cells, 4 five-bend achromat cells, and 4 LSS cells. The length of the short straight section (SSS) and the 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 of an ideal lattice. The symmetry of the new storage ring reduces to four and the reduction of the dynamic aperture is anticipated. To avoid this, we designed the ring that has high symmetry for sextupole distribution. If the sum of the phase advance of five-bend achromat and LSS cell is 2nπ and the sextupole magnets are enough weak in the five-bend cell, the ring becomes to have high symmetry for sextupole magnets and the large dynamic aperture is expected [7].

The quadrupole magnets in the LSS cells are placed at every 5.58 m to adjust the partial tune of LSS $\Delta\nu_{lssx}$. Since the partial tune of five-bend achromat cell $\Delta\nu_{5bx}$ must have the value larger than 2 to obtain low emittance, we adjusted $\Delta\nu_{lssx}$ by the quadrupole magnets in the LSS to become $\Delta\nu_{5bx}+\Delta\nu_{lssx}=3$. The betatron and dispersion functions are shown in Fig. 1. The horizontal betatron function at SSS is set to be large by taking the injection into account, though we may be able to choose 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
With undulator	ε_{xu}	~70 pm·rad
Number of cells	N_c	
Ten-bend/Five-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 as following procedure. First the dynamic aperture for a ring that consists of only ten-bend achromat cells is obtained.

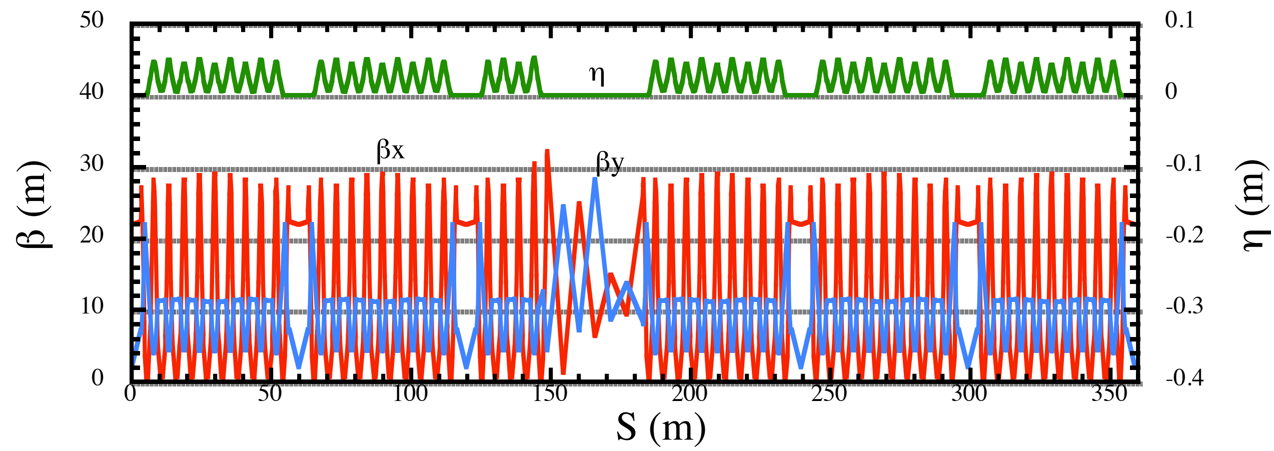

Figure 1: Optics functions in one-quarter of storage ring.

For this lattice, the dynamic aperture is improved by reducing the strength of focusing sextupoles that locate at both ends of a cell [4]. Second the dynamic aperture is calculated for the ring that includes the five-bend achromat cells and LSS. Initially sextupole strength in five-bend achromat cells is set to zero. At this stage, the dynamic aperture is large for on-momentum particle and small for off-momentum particle. As the strength of sextupole magnets in five-bend achromat cells increases, the dynamic aperture decreases for on-momentum particle and increases for off-momentum particle. The acceptable dynamic aperture size for on-momentum particle is determined by injection and for off-momentum particle it 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 of 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].

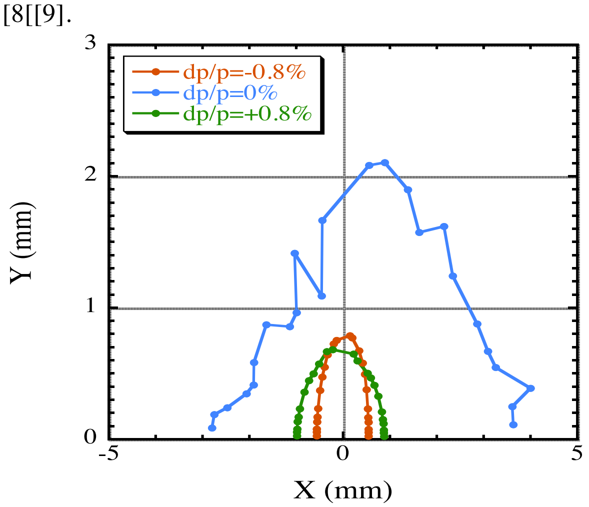

Figure 2: Dynamic aperture at the center of short straight section.

BRIGHTNESS

We studied to reduce the emittance by placing damping wigglers in four LSS cells. Total wiggler length of 120 m is assumed. The emittance reduction and momentum change were calculated as a function of maximum wiggler fields assuming wiggler period from 0.03 m to 0.2 m (Fig. 3, Fig. 4). As shown in Fig. 3 the shorter period length and stronger magnetic fields give the smaller emittance. If a cryogenic wiggler is used, a wiggler with 0.03 m period and 2 T maximum fields is possible under some limited conditions [10]. But we chose 0.05 m period and 1.5 T maximum field strength for the brightness calculation assuming room temperature wigglers. We also calculated the brightness when all undulators are operated in the ring using SPECTRA [11] with undulator period λp=1.8 cm [12], undulator parameter K=1.34, undulator length L=4.5 m, 200 mA beam current, and 0.2% coupling. The undulator lengths in the LSS and the SSS are 108 m (4.5 m × 6 undulators×4 sections) and 72 m (4.5 m×16 sections) respectively: The total length is 180 m.

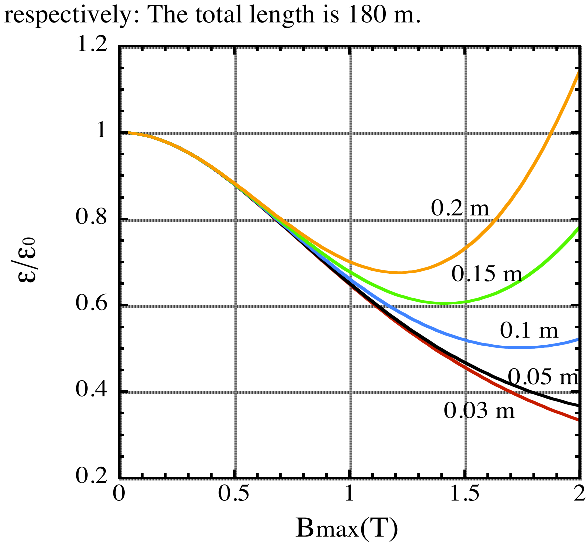

Figure 3: Emittance reduction by damping wigglers: 0.2m, 0.15 m, 0.1 m, 0.05 m, and 0.03 m period wigglers.

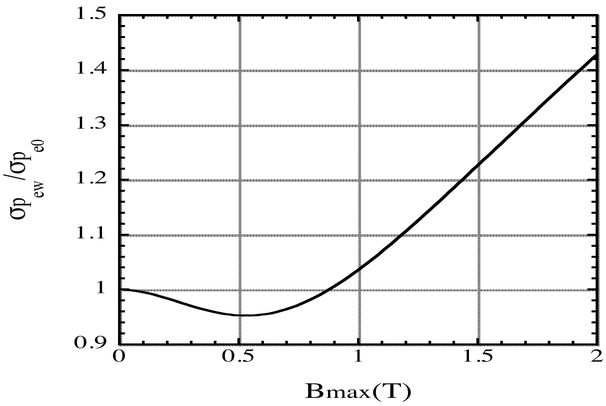

Figure 4: Relative momentum deviation as a function of maximum wiggler fields. Total wiggler length is 120 m.

The beam emittance and relative momentum spread are 50 pm and 1.32×10^{-3} with damping wigglers. When all undulators are working, the emittance and relative momentum spread become 71 pm and 1.05×10^{-3}. Figure 5 shows the brightness for a 4.5 m undulator with no damping wiggler, damping by undulators, and damping by wigglers. Maximum brightness is about 2.5×10^{22} photons/s/mm^2/mrad^2 in 0.1% BW around 10 keV and 1.4×10^{21} photons/s/mm^2/mrad^2 in 0.1% BW at 100 keV. There is only small difference between with wigglers and with undulators. This shows the damping wiggler has not large advantage for this ultra low emittance ring. In this calculation, emittance growth is not taken into account. The bunch must be lengthened to avoid emittance growth and resultant brightness deterioration.

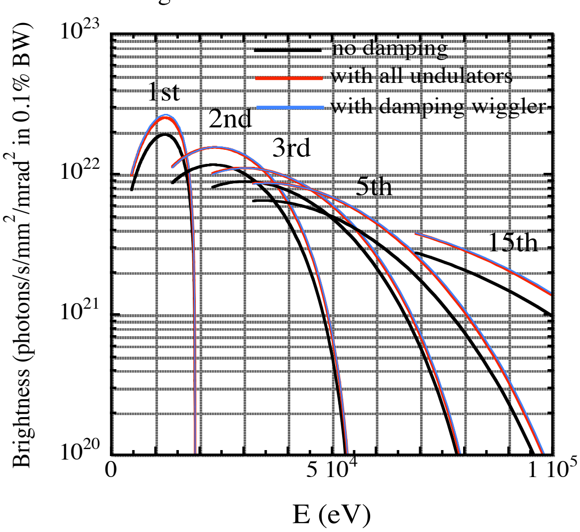

Figure 5: Brightness for a 4.5 m undulator with no damping, damping by undulators, and damping by wigglers.

INJECTION

Lifetime becomes short as the emittance and momentum acceptance decrease. Top-up operation is one of the solutions for the short lifetime problem. If one bunch is injected at one injection, constant beam current cannot maintain for very short lifetime beam even by top-up operation. But a number of bunches are injected at one injection, 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 pattern from the linac to the synchrotron [13]. After measuring the each bunch current of the storage ring, the bunches with small current are chosen and a bunch pattern for these bunches is determined. Then the electron bunches are injected into the synchrotron according to this bunch pattern. After accelerating in the synchrotron, these bunches are injected into the storage ring at one injection. Maximum injection frequency is determined by the repetition rate of synchrotron.

SUMMARY

The storage ring with four long straight sections has been designed. It consists of 20 ten-bend, 4 five-bend achromat cells, and four long straight sections. To obtain the large dynamic aperture, the phase advance in the five-bend achromat cell and the straight section cell is set to 6π and the sextupole strength in the five-bend achromat cells is weakened to about 30% of normal sextupole strength. The dynamic aperture is about ±3 mm for on-momentum particle.

Emittance reduction by damping wigglers and normal undulators has been studied. Natural emittance of 108 pm reduces to 50 pm by damping wigglers. When all undulators in the ring are installed, the emittance becomes 71 pm. The brightness was calculated and the almost same brightness was obtained for both cases. The brightness is about 2.5×10^{22} photons/s/mm^2/mrad^2 in 0.1% BW around 10 keV and1.4×10^{21} at 100 keV.

Top-up operation of multi-bunch injection with various bunch patterns is effective to keep the constant bunch current for short lifetime storage ring.

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