DESIGN OF THE SUPER-SOR LIGHT SOURCE

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Abstract

The Super-SOR light source is a Japanese VUV and soft X-ray third-generation synchrotron radiation source and it consists of a storage ring, booster synchrotron and pre-injector linac. The 1.8-GeV storage ring has a circumference of about 280 m and 14 DBA cells with two 17-m and twelve 6.2-m long straight sections used for twelve insertion devices and RF and injection systems. The design goals of the beam lifetime and current are 10 hrs and 400 mA, respectively. The booster synchrotron is one third of the ring in circumference and can achieve a low emittance of about 50 nm rad at 1.8 GeV. The 200-MeV linac is made up of S-band accelerating structures powered by two klystrons and a SLED cavity. These accelerators are designed so as to fully meet requirements for top-up injection.

INTRODUCTION AND OVERVIEW

The Super-SOR light source is a VUV and soft X-ray third-generation synchrotron radiation source and to be operated for nationwide and worldwide users. The University of Tokyo has proposed to construct the facility in Kashiwa campus and we have designed the light source intensively for more than two years [1]. It is composed of a 1.8-GeV storage ring, booster synchrotron and pre-injector linac and top-up injection is planned to overcome a relatively short beam lifetime. The layout of the Super-SOR light source is shown in Fig.1. The storage ring with the experimental floor and the injector will be constructed on and under the ground in separate buildings. The brilliance of the light source is shown in Fig. 2. The design of the Super-SOR accelerators is presented in this paper.

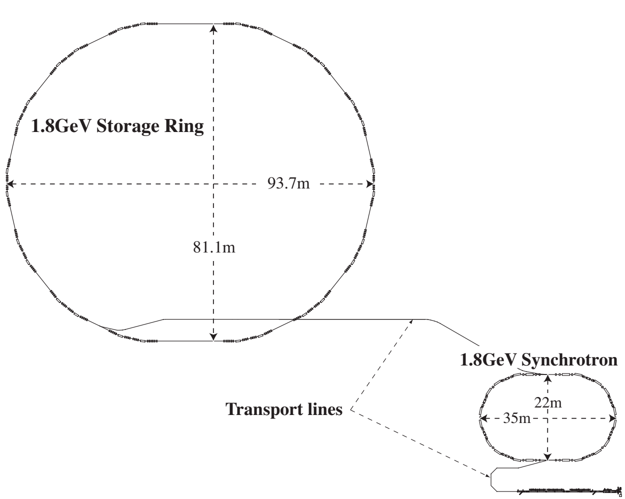

Figure 1: Layout of the Super-SOR accelerators.

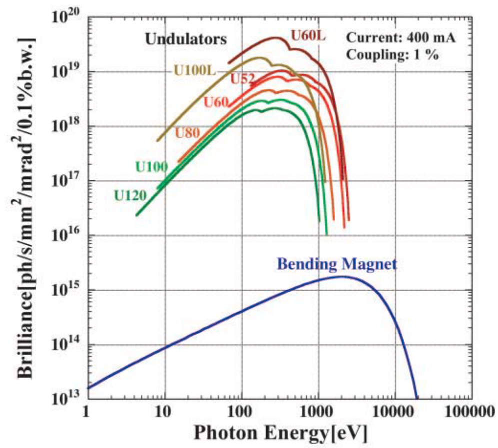

Figure 2: Brilliance of the Super-SOR light source

STORAGE RING

Lattice

The Super-SOR storage ring has a circumference of 280 m and consists of fourteen DBA cells with two 17-m and twelve 6.2-m long straight sections. Two 6.2-m long straight sections are used for injection magnets and RF cavities and the other twelve long straight sections for insertion devices. Two kinds of optics, High-beta and Hybrid optics, have been studied. The basic parameters and the betatron and dispersion functions of the ring optics are shown in Table 1 and in Fig. 3. High-beta optics has identical horizontal and vertical betatron functions for all the 6.2-m long straight sections (β_x = 17.3 m and β_y = 4.3 m at the center). Hybrid optics has very low betatron functions at the centers of four 6.2-m long straight sections (β_x = 1.1 m and β_y = 2.6 m). The four low-beta straight sections of this optics are suitable for installation of the RF system and small-gap undulators and the others for the injection system. By the harmonic sextupole correction, the momentum acceptance can reach ±3 % and the horizontal acceptance at the injection section 20 mm [2].

Table 1: Basic parameters of the storage ring

	High-beta	Hybrid
Energy	1.8 GeV (2.0 GeV max.)	
Circumference	280.55 m	
Emittance	7.26 nm	7.80 nm
Energy Spread	6.68E-4	
Momentum Compaction	1.00E-3	
Betatron Tune (x/y)	14.12/5.18	15.20/5.86
Damping Time (x/y/z)	19.3/19.4/9.72 ms	
RF Frequency	500.1 MHz	
Harmonic Number	468	
Bunch Length	3.94 mm	

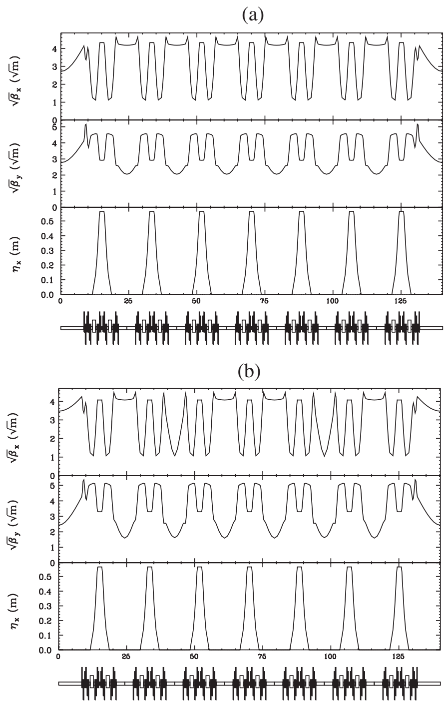

Figure 3: Betatron and dispersion functions of (a) High-beta and (b) Hybrid optics for a half of the storage ring.

Beam lifetime and instabilities

Beam lifetime is important even for the operation in top-up injection, because longer beam lifetime allows lower injection rate for achievement of the high current stability and hence lighter injector load and smaller radiation loss. The Touschek lifetime was calculated for the beam current of 400 mA (0.855 mA per bunch) and found to increase with the horizontal physical aperture and to saturate at the physical half-apertures above 30 mm for the coupling constant of 1 % because the dynamic aperture become dominant. The horizontal physical half-aperture for the present design is 32.5 mm, which is almost optimum in terms of Touschek lifetime. The gas-scattering lifetime was also calculated as a function of the gas pressure (CO equivalent) and the insertion-device (ID) duct aperture. The total beam lifetime is obtained from the calculated Touschek and gas-scattering lifetimes and shown in Fig. 4. The design goal of the vacuum system is to achieve the gas pressure of 0.5 nTorr or less so that the beam lifetime is longer than 10 hours.

The growth rates of vertical coupled-bunch instabilities due to the resistive-wall impedance, a candidate for the current limitation, were calculated for the design beam current of 400 mA. In this calculation, the normal-cell vacuum ducts are approximated by a circular Al pipe with a length of 200 m and a diameter of 40 mm and the insertion-device (ID) vacuum ducts by a circular SUS or Cu pipe of with a length of 80 m and a diameter of 16 mm. Figure 5 shows the maximum vertical growth rate for Hybrid optics as a function of the vertical betatron tune. While the maximum growth rate reaches 3000 – 10000 sec^{-1} in the case of the SUS ID duct, it is reduced to 700 – 2200 sec^{-1} in the case of the Cu ID duct, because the Cu duct has the lower resistive-wall impedance by a factor of seven than the SUS duct. Almost the same effect can be obtained by the copper coating with thickness of 100 - 200 μm on the inner surface of SUS ID ducts [3]. Eddy currents in the copper coating caused by the magnetic gap or phase change of the insertion device are sufficiently small to have little effect on the beam. The R&D on the ID copper-coated vacuum ducts is in progress [4] and a bunch-by-bunch transverse feedback system is under design to suppress the coupled-bunch instabilities.

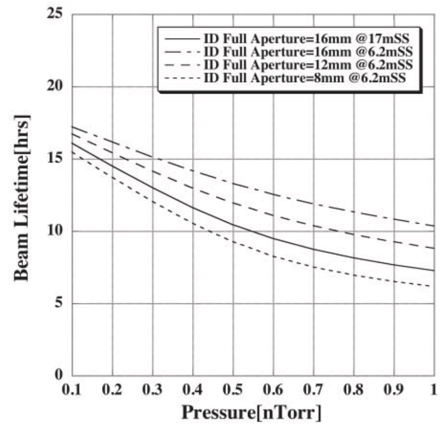

Figure 4: Total beam lifetime as a function of the gas pressure (CO equivalent) and ID-duct aperture for the coupling constant of 1 % and the horizontal physical half-aperture of 32.5 mm.

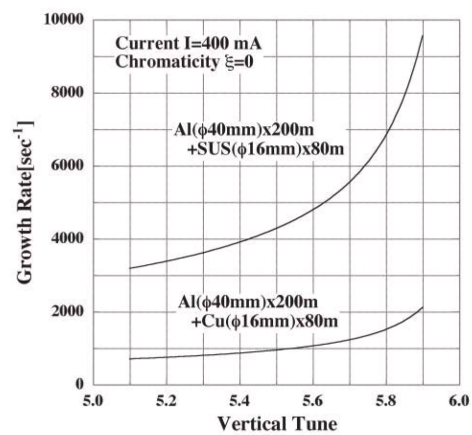

Figure 5: Maximum growth rate of the vertical coupled-bunch instabilities due to the resistive-wall impedance as a function of the betatron tune.

INJECTOR

Pre-injector Linac

The basic parameters and the layout of the pre-injector linac are shown in Table 2 and in Fig. 6. The linac consists of a thermal electron gun, sub-harmonic buncher, pre-buncher, buncher and six 2-m accelerating structures. The bunching section except the sub-harmonic buncher and the accelerating structures are driven by two 50-MW klystrons and a SLED cavity. Two operation modes, short and semi-long pulse modes, are provided for injection to the storage ring in single- and multi-bunch operations of the ring. In the short pulse mode, the electron beam with 1-ns bunch length is ejected from the gun and compressed down to 10 ps at the bunching section. In the semi-long mode, multi-bunch electron beam with 10 – 100 ns pulse duration is bunched and accelerated. The energy spread due to the beam-loading effect is reduced to less than 0.5 % in full width by tuning the timing of phase reverse of the SLED cavity [5]. For both modes, the beam current can be changed by a factor of 25 by use of a collimator located in front of the gun to match both normal and top-up injections. A linac design with the RF frequency of 3 GHz is also being studied to improve the capture efficiency of the synchrotron in the semi-long mode.

Table 2. Basic parameters of the linac

Beam energy	200 MeV	
RF frequency	2856 MHz	
Normalized emittance	< 50 mm mrad	
Repetition rate	50 Hz (max.)	
Operation mode	Short	Semi-long
Pulse duration	10 ps	10 – 100 ns
Peak current (max.)	80 A	400 mA
Energy spread	0.5 %	0.5 %

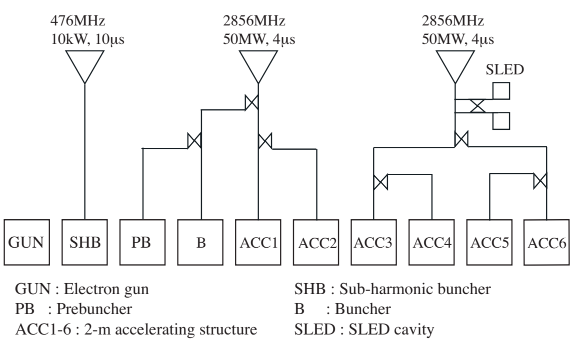

Figure 6: Layout of the linac

Booster Synchrotron

The basic parameters of the booster synchrotron are listed in Table 3 and the betatron and dispersion functions are shown in Fig. 7. The synchrotron is about 93m in circumference, one-third of the storage ring and it has six families of quadrupoles (QF, QD, QFX in the arc sections, QX, QY, QFM in the straight sections) and two families of sextupoles. The beam emittance of 52 nm rad at 1.8 GeV is much smaller than that of an usual FODO lattice with the same circumference. In addition, the lattice can vary the momentum compaction factor from 0.01 to 0.003 to match the injection to the storage ring, increasing the emittance from 52 to 100 nm rad. The repetition rate of the synchrotron is 1Hz at highest. The dynamic aperture is larger than the physical aperture and the energy acceptance is larger than ±1 %, which is sufficient for the electron beam injected from the linac.

Table 3. Basic parameters of the booster synchrotron

	Extraction	Injection
Beam energy	1.8 GeV	0.2 GeV
Circumference	93.5 m	
Harmonic number	156	
Emittance	52 nm rad	-
Energy spread	7.06×10^{-4}	-
Betatron tune (x/y)	7.35/3.30	
Momentum compaction	0.0108	
Repetition rate	1 Hz (max.)	
RF frequency	500.1 MHz	

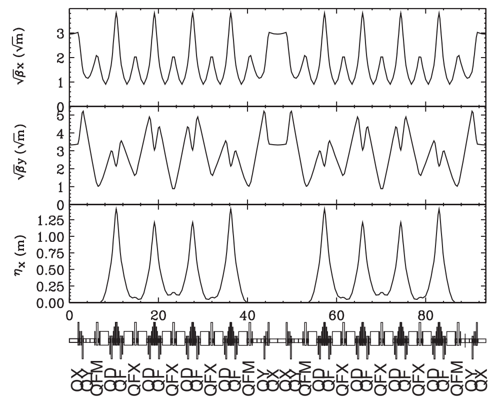

Figure 7: Optics of the synchrotron

SUMMARY

In the lattice design of the storage ring, two kinds of optics with a large dynamic aperture are prepared. The beam lifetime of 10 hours and the beam current of 400 mA will be guaranteed by the careful design of the vacuum and feedback systems. The injector can be tuned to be suitable for top-up injection as well as normal injection in the single- and multi-bunch operations of the storage ring. The designs of magnet and vacuum systems are almost completed [4,6] and the other ring components are also being designed and developed[7].

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