Design of a 1.8 GeV Synchrotron Light Source

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Abstract

A 1.8 GeV electron storage ring was designed for the synchrotron radiation facility proposed at Tohoku University. It consists of sixteen DBA cells with fourteen 5m straight sections and two 15 m straight sections. The circumference is 245 m. The emittance is 4.9 nm-rad for normal operating mode and 8.9 nm-rad in commissioning mode. Optimisation of the dynamic aperture is in progress.

1 Introduction

At Tohoku University, Sendai, Japan, they are proposing construction of a synchrotron radiation facility [1]. It will be constructed at the site of the Laboratory of Nuclear Science, where a 300 MeV linac and a 1.2 GeV stretcher-booster ring are in operation [2]. This accelerator complex will provide 1.2 GeV electron beams to the light source.

In the early stage of the design study, the beam energy was 1.5 GeV and the emittance was several tens of nm-rad. To meet the increasing demands for highly brilliant VUV and soft X-rays, the design has been changed several times [3]. In the latest version, the emittance is 4.9 nm-rad, which is sufficiently small to make this light source one of the brightest in the world. The nominal beam energy was increased to 1.8 GeV to be capable of producing X-rays. Number of straight sections was increased to 16 to provide synchrotron radiation from insertion devices to nation-wide users. The circumference is 245 m, which is almost the maximum size for the space available at the site.

In this paper, we present the latest results from the design study.

2 Linear Lattice

The storage ring consists of 16 DBA cells. The magnetic lattice in the arches was designed to be compact to make available spaces for insertion devices as large as possible, under the constraint on the circumference. Fourteen of sixteen straight sections are 5 m long and the remainders two are 15 m long. The circumference is 245 m.

The beam optics in "normal mode" is shown in Figure 1(a). The main machine parameters are summarised in Table 1 and 2. Six of fourteen short straight sections are "low-β". The betatron functions are about 1m both in horizontal and vertical. The remainder eight are "high-β". The betatron functions are 17 m in horizontal and 5m in vertical respectively.

The high-β sections will be used for undulators and injection, the low-β ones for RF cavities, superconducting wigglers and short period undulators. Small betatron functions are effective to suppress the emittance growth and other perturbations caused by high field wigglers [4].

Since we had expected that the low symmetry of the lattice would reduce the dynamic aperture, we prepared a lattice with much higher symmetry for the commissioning stage. The beam optics is shown in Figure 1(b). The emittance is moderately small, 8.9 nm-rad. In the long straight sections, "missing-bend" cells are inserted to keep the lattice symmetry as high as possible. These cells will be removed after establishing the normal mode operation. The betatron functions are same for all the straight sections. As the result, the lattice has approximately 18-fold symmetry.

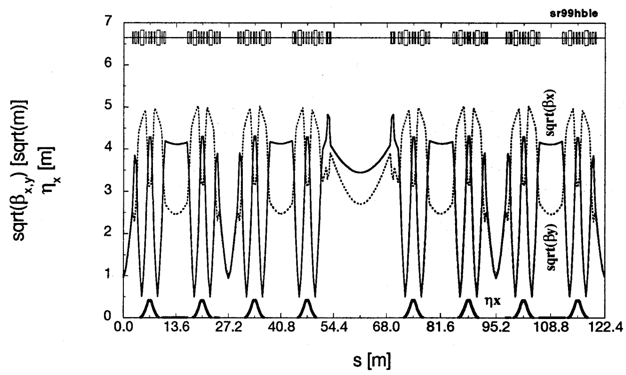

Figure 1(a) Optical functions in "normal mode". A half of the ring is shown.

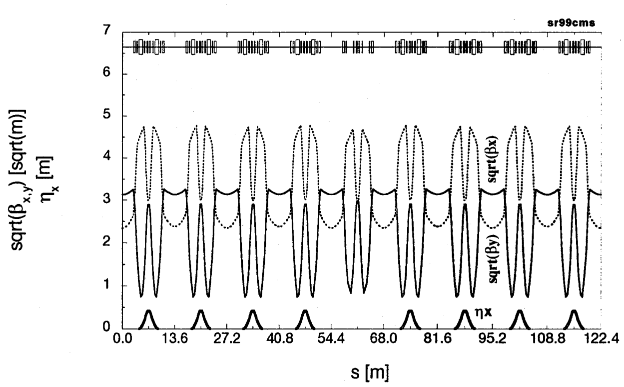

Figure 1(b) Optical functions in "commissioning mode". A half of the ring is shown. A "missing-bend" cell is inserted at the long straight section.

Table 1. Main Beam Parameters

	Normal	Commissioning
Energy	1.8 GeV (1.0 – 2.0 GeV)	
Circumference	244.8 m	
Lattice	DBA x 16	
Straight Sections	5 m x 14, 15 m x 2	
Emittance	4.9 nm-rad	8.9 nm-rad
Betatron Tunes	(17.75, 5.60)	(16.30, 4.40)
Natural Chromaticity	(-59.6, -25.2)	(-29.9, -22.1)
Radiation Loss / Turn	206 keV/turn	
Momentum Compaction	0.00074	
Momentum Spread	7.3×10^{-4}	
Harmonic Number	408	
RF Frequency	500 MHz	
RF Voltage	1.0 MV	
Synchrotron Tune	0.0051	
Natural Bunch Length	0.41 cm	
Beam Current	~400 mA	
Beam Lifetime	~12 hr	

Table 2. Magnet Parameters

Bending Magnets	
Number	32
Field Strength	1.33 T
Bending Radius	4.5 m
Pole Gap	50 mm (full)
Core Length	0.884 m
Quadrupole Magnets	
Number	168
Field Gradient	20 T/m
Bore Diameter	70 mm
Core Lengths	0.20, 0.25, 0.45 m
Sextupole Magnets	
Number	126
Field Gradient	500 T/m^2
Bore Diameter	80 mm
Core Lengths	0.10, 0.15 m

Note: Field gradients are for 1.8 GeV. The magnets in the missing bend cells are included in the numbers.

3. Dynamic Aperture

Optimisation of the dynamic aperture is in progress. Our present approach is simple and practical. We have selected an operating point as far from the structural resonance's of third order as possible. We use relatively small number of sextupole families and search an optimum.

In the commissioning mode, four sextupole families are used. Two of them are in the dispersive sections and are used to compensate the linear chromaticities. The remainder two are in the dispersion-free sections. Their strengths are determined so as to minimize the amplitude dependent betatron tune shifts, by using a computer code, HARMON [5]. The dynamic aperture was calculated by using a computer code, SAD [6]. The result is shown in Figure 2(a, b, c). The size of the dynamic aperture is large enough for the momentum deviation between $\pm 3\%$.

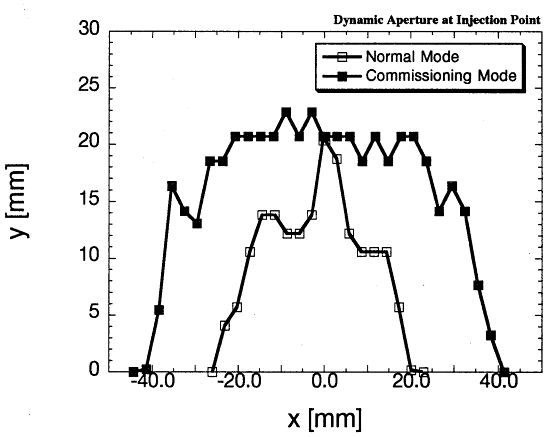

Figure 2(a) Dynamic aperture for on-momentum particle at injection point. White squares are for normal mode and black ones are for commissioning mode. Machine errors are not included in the simulation.

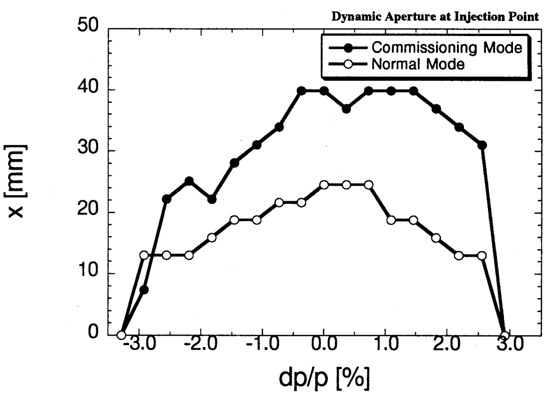

Figure 2(b) Horizontal dynamic aperture for off-momentum particles. White circles are for normal mode and black ones are for commissioning mode. The sharp cut-off near $\pm 3\%$ arises from RF bucket. Same in Figure 2(c).

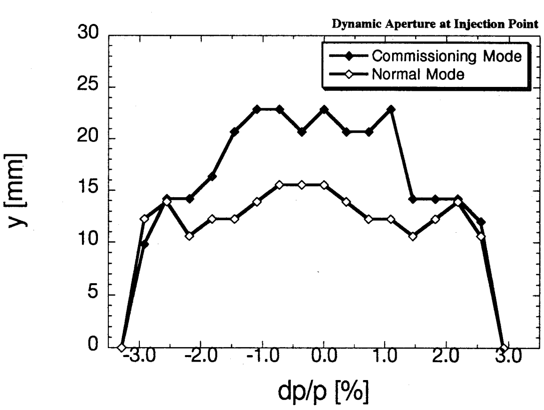

Figure 2(c) Vertical dynamic aperture for off-momentum particles. White diamonds are for normal mode and black ones are for commissioning mode.

In the normal mode, six sextupole families are used. Two families at dispersive sections are used to compensate the linear chromaticities. The sextupoles at dispersion-free sections are divided into two families in the first step. Their strengths are determined in a same manner as the commissioning mode. Then these sextupoles are divided into four families. Two are in the high-β section and others in the low-β ones. Using the values obtained above as an initial guess, an optimum was searched by tracking studies. This work has not been completed yet. The latest results are shown in Figure 2(a, b, c). Although the dynamic aperture is fairly large for the momentum deviation between ±3%, it is necessary to allow some margin for machine errors.

4 Beam Lifetime

Beam lifetime of this ring is strongly limited by Touschek effects as in the cases of other 3rd generation light sources in this energy range. Touschek lifetime was estimated as a function of momentum acceptance. The result is shown in Figure 3(a). To achieve a lifetime longer than 12 hours for 300 mA, a momentum acceptance of about 3% is required.

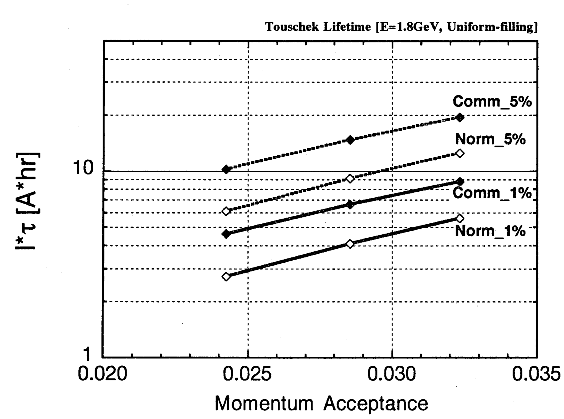

Figure 3(a) Touschek Lifetime as a function of momentum acceptance, calculated for two optics (normal and commissioning) and two cases of the emittance coupling (1% and 5%).

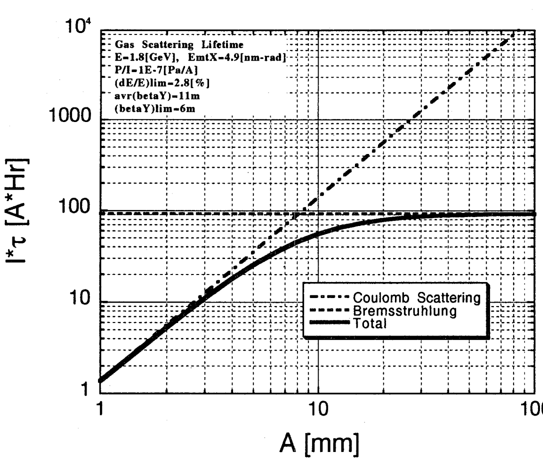

Figure 3(b) Gas scattering lifetime as a function of the vertical aperture (half) at a straight section.

Gas scattering lifetime was estimated as shown in Figure 3(b), as a function of the vertical aperture at a straight section. Even with 8 mm half aperture, the gas scattering lifetime is much longer than Touschek lifetime.

5 Summary and Discussions

We have designed a 1.8 GeV electron storage ring for synchrotron radiation facility proposed at Tohoku University. The emittance is 4.9 nm-rad, which is the smallest in this class (1 to 3 GeV) except for ALS at LBL [7]. The number of straight section available for insertion devices is fourteen. This is same as BESSY-II and the largest in this class [7]. Two straight sections are 15 m long and are reserved for long undulators. This is a unique feature of this machine.

The existence of the long straight sections reduces the dynamic aperture substantially. Some approaches to this kind of problem can be found in literature. One example is to make the transfer matrices of the straight sections unit ones [8]. It requires additional quadrupoles, which would reduce available spaces for long undulators substantially. Another is to use many families of sextupoles [9]. However, a large number of sextupole families may not be practical in real operation.

At present, we are optimising the dynamic aperture for given linear lattice with small number of sextupoles families. We will search the optimum sextupoles strengths and the optimum betatron tunes more systematically. We will investigate the effects of machine errors including insertion devices in the next step.

We have prepared the optics for commissioning, which has sufficiently large dynamic aperture. We will start the operation with this optics. The normal mode optics will be carefully tested in machine studies using real beams. A similar approach was applied to Spring-8 [10].

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