STORAGE RING DESIGN FOR STA SR PROJECT

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Abstract

This paper outlines the design study for 8 GeV highly brilliant synchrotron radiation X-ray source ring in Japan. The facility consists of a main storage ring, a full-energy injector booster synchrotron and a 1.5 GeV pre-injector electron (positron) linac. The storage ring is optimized for insertion devices. The designed energy of the ring is raised up from 6 to 8 GeV. The ring has 48 unit cells, a circumference of 1428.9 m and 6.5-m long straight sections for insertion devices. The low emittance and sufficiently large dynamic aperture are achieved in Chasman-Green type lattice structure. R&D work on the vacuum system, magnet system, and RF system are also in progress. Three years of Preconstruction R&D ('87 to '89) and five years of construction ('90 to '94) are expected.

Introduction

The request for a highly brilliant synchrotron radiation light source that covers the hard X ray region has been envisaged among the scientific community. In order to promote basic researches and developments of advanced technologies, Science and Technology Agency(STA) of Japanese Government convened an ad hoc committee to discuss the necessity for a new-generation synchrotron light source, and recommended to construct a high energy synchrotron radiation facility. The Institute of Physical and Chemical Research(RIKEN) and Japan Atomic Energy Research Institute(JAERI), which are supervised by STA began to carry out the plan to construct the synchrotron radiation facility. RIKEN started the design study in 1986, and a year later, JAERI joined in the design work. In order to design the facility efficiently and consistently, both design groups were united in the fall of 1988. In this opportunity, systematic re-examination of the design was started. In this process, an energy of the stored positron energy was raised from 6 to 8 GeV. This work is just under way.

General description

Harima Science City was selected to be the only one site candidate among fours judging from land conditions. This city is located in the western part of Hyogo prefecture, and now the ground is under creation from a mountain. The area larger than 140 ha will be provided for this site.

The facility, as is shown in Fig.1, consists of a main storage ring, a full-energy injector booster synchrotron and a pre-injector linac. The linac provides both electron and positrons. The energy of the linac is 1.5 GeV, which is determined for future use of the linac electron beams other than as an injector to the synchrotron. The injector synchrotron accumulates positron beams from 1.5 GeV linac, and then accelerates to 8 GeV. It has a circumference of about 470 m and will be build outside of the storage ring because electron beam from the synchrotron will be used as an injector not only to the light source ring but also to another storage ring for electron scattering in the future. The details of the injectors are presented in this conference[1].

The purpose of this facility is to provide stable photon beams with high brilliance in the X-ray region. In the design of a dedicated synchrotron light source, the following conditions are required:

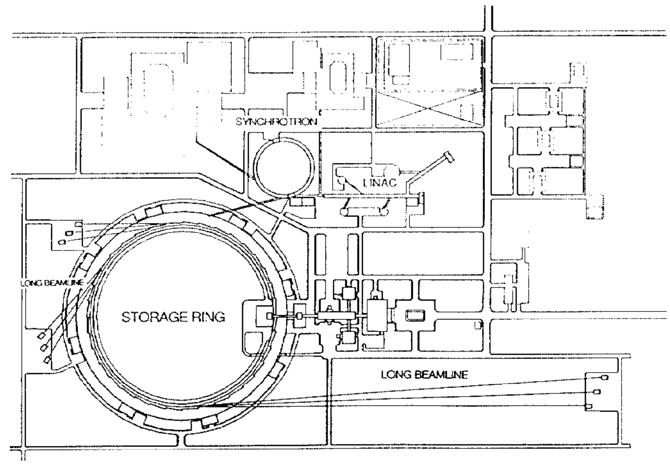

Fig. 1. An example of the arrangement

1) Low emittance operation with ε_x < 10 n m·rad.
2) Optimization for insertion devices.
3) 10-20 keV photon beams with the brilliance of 10^{19} phtons/s/mm^2/mrad^2/.1%b.w. in the fundamental of an undulator.
4) ~100 keV photons from a multipole wiggler with the brilliance of 10^{17} photons/s/mm^2/mrad^2/.1%b.w..
5) Positrons can be stored.
6) A full energy injection system.
7) Long beam life time(>10 hrs).

The energy of the stored electron(positron) is raised from 6 to 8 GeV. This makes the undulator tuning range wide, and provides the potential to get higher energy photons with the same undulator gap. The main parameters of the designed ring are listed in Table 1.

Table 1 Major Parameters of the Storage Ring

Energy	E(GeV)	8
Current(multi-bunch)	I(mA)	100
Current(single-bunch)	I(mA)	5
Circumference	C(m)	1428.87
Dipole magnetic field	B(T)	0.61
Bending radius	ρ(m)	43.72
Number of cells	Nc	48
Length of straight section	L(m)	6.5
Tune	ν_x	51.22
	ν_z	19.16
Synchrotron tune	ν_s	0.00952
Momentum compaction	α	1.373 10^{-4}
Natural chromaticity	ζ_x	-119.35
	ζ_z	-40.34
Energy loss in the arcs	U_0(MeV/rev)	8.3
Energy spread	σ_e/E	0.00103
Damping time	τ_x(msec)	9.203
	τ_z(msec)	9.206
	τ_e(msec)	4.604
Natural emittance	ε (πm·rad)	5.265 10^{-9}
Harmonic number	h	2424
R.F.voltage	V_{rf}(MV)	16
R.F.frequency	f_{rf}(MHz)	508.58

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Lattice

First we investigated dynamic characteristics for three types of lattice: Chasman-Green (CG), Triple Bend Achromat (TBA), and Quadruple Bend Achromat (QBA)[2]. Since absolute superiority could not be found, CG lattice was selected due to the simplest magnet arrangement. In the process of optimization on a cell number, we found that between 40 and 48, there exist many good low-emittance optics with a unit cell length of about 30 m. Larger the number of cells, lower the emittance but slightly smaller dynamic aperture are obtained. From a given site condition, the cell number of 48 with a circumference of 1429 m was employed because of its good symmetry and beam quality.

The basic magnetic arrangement is the same as our previous work on the 6 GeV CG lattice[3]. The length of free straight section for the insertion devices is taken to be 6.5 m. Some of the magnets are designed to be thicker. Spacing among magnets are carefully investigated in order to accommodate the bump magnets for the injection, crotches, correctors, and monitors. The resultant cell length amounts to 29.77 m. In the present study, "hybrid beta" mode was examined, which is also employed by the ESRF[4]. In this mode, the ring has the superperiodicity of 24 at the maximum. The optical functions are shown in Fig. 2. Working point is chosen so that tunes per superperiodic cell should be away from the first and the third order resonances of the sextupoles, and total tunes should avoid non-structural low-order resonances. The chromaticity is corrected by 3 sextupoles in the dispersive sections. Harmonic sextupoles are placed in dispersion-free sections to enlarge the dynamic aperture. Harmonic sextupoles were optimized using the computer code CATS[5]. The obtained dynamic aperture for the ideal machine is shown in Fig. 3. Tracking with various errors in the ring and a correction of closed orbit distortion is done by RACETRACK[6]. A COD correction is quite important for a low emittance ring. A COD is induced by quadrupole misalignment. The COD induces a tuneshift at every sextupole around the ring, which makes dynamic aperture small. The COD correction is done with 8 monitors and 6 horizontal and vertical correctors in a cell. These monitors are installed near sextupoles, and COD is basically corrected near sextupoles. In our calculation, dynamic aperture cannot be fully restored in the limit of zero residual rms COD bacause a local phase advance among sextupoles remains even if rms COD is corrected. An optimization of the correction system is currently carried out. The influence of the insertion devices was also investigated and reported in this conference[7].

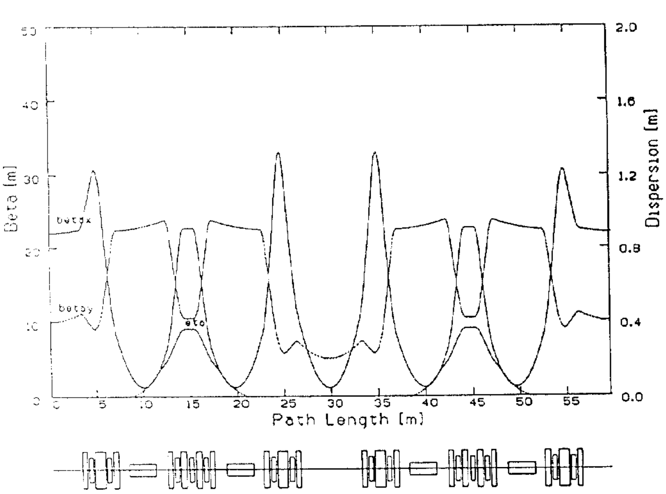

Fig. 2. Betatron and dispersion functions over a superperiodic cell for hybrid mode.

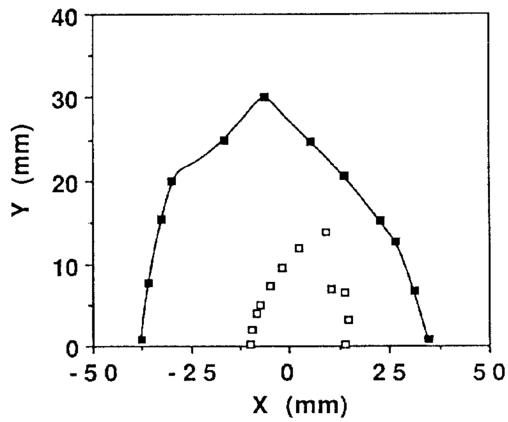

Fig. 3. Dynamic aperture of the ideal lattice. Empty squares indicate the dynamic aperture without harmonic correction, and dark squares represent the dynamic aperture with harmonic correction.

Table 2 Designed parameters of the protptype magnets

	Dipole	Quadrupole	Sextupole
Core length(mm)	2782	473	450
Gap distance(mm)	65	90	110
Pole width(mm)	240	135(max)	90(max)
Magnet height(mm)	652	630	730
Magnet width(mm)	570	660	840
Maximum strength	0.61 T	16 t/m	360 T/m2
Ampere turns(A.T.)	3.25 104	5.32 104	4.8 104
Max current(A)	1200	830	445
Aux. coil currents(A)	30 Max		42 Max
Power (kW)	23	9.2	4.4

Magnet system

The magnet lattice consists of 48 unit cells, each composed of 2 dipole and 10 quadrupole magnets, and 7 sextupole magnets; thus in total, 98 dipole magnets, 480 quadrupole magnets, and 336 sextupole magnets. The required field quality of the dipole and quadrupole magnets is as follows:

Field uniformity: Bending magnet $\Delta B\ell/B\ell = 5\times10^{-4}$

Quadrupole magnet $\Delta G\ell/G\ell = 1\times10^{-3}$

Sextupole Magnet $\Delta G\ell/G\ell = 5\times10^{-3}$

Uniform field region : H = ±35 mm, V = ±15 mm.

In order to design these magnets, we carried out numerical calculation on magnetic fields using the program code LINDA and TRIM. The designed parameters for these magnets are given in Table 2. The bending magnet is C-shaped rectangular type. Quadrupole and sextupole magnets were designed to be inserted vacuum vessel having an extraction space for synchrotron radiation. Moreover sextupole magnet is required to provide a horizontal or vertical dipole field for the closed orbit correction in our lattice. The detailed design of prototype magnets have already been finished and the fabrication of them is now in progress.

RF system

The RF system consists of four 1-MW klystrons and 508.58 MHz cavities which are located in four 6.5-m straight sections with low betatron functions. Two types of cavity structures have been studied; one is a single cell cavity, the other is a 3-cell cavity. Thirty two single-cell cavities or fourteen 3-cell cavities are used. The RF characteristics of these cavities were calculated and measured using the model cavities[8]. High power tests using a 1-MW klystron and prototype cavity, are planned in order to determine the final specifications of the RF system. The control system will be also developed through these tests.

Vacuum system

Our philosophy of the vacuum system for the storage ring is that most of synchrotron radiation is intercepted by crotches and absorbers placed just downstream and upstream by a bending magnet, and not intercepted by the vacuum chamber all around the ring. The crotch is designed so as 1) to trap reflected photons and their associated photo-electrons, and released gas molecules, and 2) to reduce RF impedance, introduced owing to the crotch, by means of smoothing the electron beam chamber side.

At present, prototype bending magnet- and straight section- chambers have been manufactured by extrusion methods. Prototype crotch and Lumped NEG pump will be completed by the end of April. Tests on these prototypes would give some elucidating results by the end of this year.

The vacuum chamber components such as the bellows with RF contact, all metal gate valve, and so on will be designed and manufactured within this year. The details are given in this conference[9].

Beamlines

Main light sources are from the Insertion Devices. Radiations from some bending magnets are also used. The ring has 48 straight sections, and"hybrid" mode operation is basically expected. Four low-β straight sections are used for cavities, and one high-β straight section for injection. Maximum 43 straight sections are available for Insertion Devices. Undulators will be inastalled in the high-β straight sections, and wigglers in the low-βs. At present, it is not fixed how many bending-magnet beamlines should be provided. The radiation spectra from typical undulators, wiggler, and bending magnet are shown in Fig. 4. A design on shielding wall was performed considering the users' request that the first mirror or monochromater be installed as near to the source as possible. With the choice of double shielding-wall structure, we can make the first wall thin, and therefore, the distance between source and the wall short. The second shielding-wall will be helpful in reduction of radiation background caused by mirrors.

References

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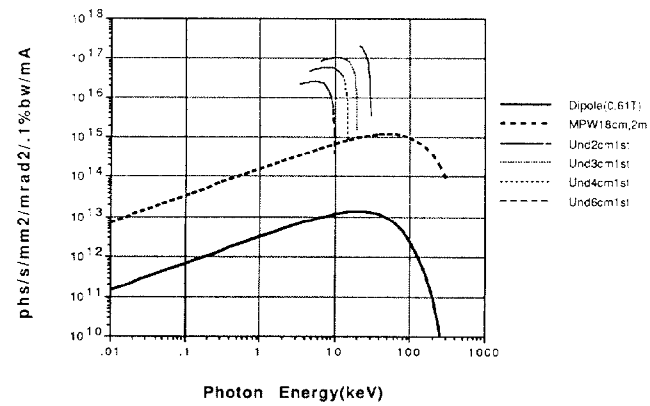

Fig. 4 Spectral brilliance of the 8 GeV synchrotron radiation source. Brilliance for 0.61 T dipole magnet, 1.5 T 22 pole wiggler with magnetic period length of 18 cm, and 2-m undulator fundamental mode with various magnetic periods are shown.

Table 3 Electron beam size and divergence

		undulator	wiggler	bending magnet (15cm from edge)
β_x	(m)	22.0097	1.13394	1.9088
γ_x	(m-1)	0.04543	0.8819	0.81323
β_z	(m)	9.99488	4.9642	23.2348
γ_z	(m-1)	0.10005	0.20144	0.044732
η	(m)	0	0	0.08406
η'		0	0	0.06204
σ_x	(mm)	0.3246	0.0737	0.1293
σ_x'	(mrad)	0.0147	0.0650	0.0896
σ_z	(mm)	0.0692	0.0487	0.1055
σ_z'	(mrad)	0.0069	0.0098	0.0046

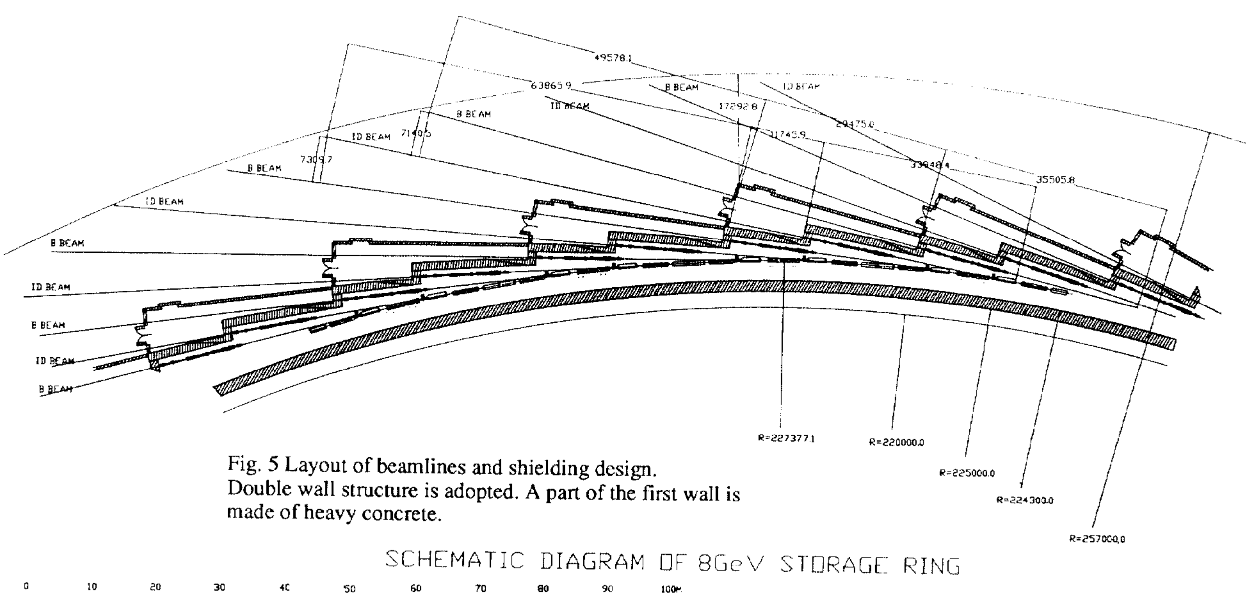

Fig. 5 Layout of beamlines and shielding design. Double wall structure is adopted. A part of the first wall is made of heavy concrete.