STORAGE RING DESIGN FOR THE SPring-8,THE 8 GEV SYNCHROTRON RADIATION FACILITY IN JAPAN

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Abstract

This paper outlines the status of design study for the 8 GeV highly brilliant synchrotron radiation X-ray source ring, recently named Super Photon Ring (SPring-8). The light source ring which stores electrons or positrons, is optimized for insertion devices. The ring is 1436 m in circumference, based on the extended Chasman-Green type of achromatic cell, and the number of cell is 48. In order to have very long straight sections, bending magnets are extracted from the symmetric four cells, leaving quadrupoles and sextupoles as they are. The low emittance (ε_x = 7.18 n m•rad) and sufficiently large dynamic aperture are achieved even with field errors and misalignments. The currents of 100 mA for multi-bunch and 5 mA for single-bunch mode operations are expected. The RF frequency and harmonic number are 508.58 MHz and 2436, respectively. R&D work on the vacuum system, magnet system, and RF system are also in progress.

INTRODUCTION

The need for highly brilliant photon beams in X-ray region was widely envisaged. To meet the need, construction of the third generation synchrotron light sources of 6-8 GeV region, such as ESRF[1] and APS[2], is in progress. In Japan, RIKEN and JAERI, which are supervised by Science and Technology Agency (STA) of Japanese Government made a joint design team and started the design study of synchrotron radiation X-ray source. In 1988, Harima Science Garden City which is under construction in Hyogo prefecture was selected as the site. Recently the light source was named SUPER PHOTON RING (SPring-8). In this May, project review committee was organized, and the machine parameters are being reviewed. In this committee, request for special long straight section was discussed, and as a result, lattice design was changed. Construction of the facility is expected to start in FY1990, and commissioning will be in 1995.

General description

The facility, as is shown in Fig.1, consists of a main storage ring, a full-energy injector booster synchrotron[3] and a pre-injector 1 GeV linac[4]. 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:

1) Low emittance operation with ε_x < 10 n m·rad.
2) Optimization for insertion devices.
3) Up to 120 keV photon beams within the fifth mode of undulator.
4) ~200 keV photons from a multipole wiggler.
5) Positrons and electrons can be stored.
6) A full energy injection system.
7) Long beam life time(>10 hrs).

The main parameters of the designed ring are listed in Table 1.

Magnet lattice

The magnet lattice of SPring is based on the double bend achromat (extended Chasman-Green) structure. The length of free straight section for the insertion devices is 6.5 m. According to the discussion in the review committee, lattice

Table 1 Comparison of storage ring parameters

	SPring-8	APS	ESRF
Ring Energy(GeV)	8.0	7.0	6.0
Current(Multi-bunch, mA)	100	100	100
Lattice	CG	CG	CG
Number of cells	44+4	40	32
Bending Radius(m)	40.1	39.0	25.0
Bending Field(T)	0.67	0.6	0.8
Ring circumference(m)	1436	1104	844
Natural Emittance(πnmrad)	7.2	8	6.8
Number of bending magnet	88	80	64
Critical Photon Energy(keV)	28.4	19.5	19.2
Number of Straight Section	44	40	32
Betatron tune(ν_x)	50.78	35.22	36.2
(ν_y)	17.84	14.30	11.2
Momentum compaction	1.49×10^{-4}	2.37×10^{-4}	3.10×10^{-4}
Damping time(τ_x,τ_y,msec)	8.48	9.08	7.4
(τ_s, msec)	4.24	4.54	3.7
E. loss in the arcs(MeV/rev)	9.04	5.45	4.6
Harmonic number	2436	1296	992
RF frequency(MHz)	508.6	352	352
RF voltage(MV)	17	12.0	10.64

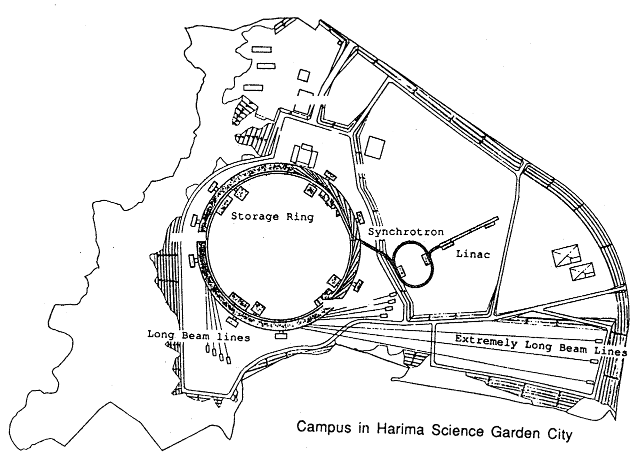

Fig. 1 Accelerator Arrangement of SPring-8.

design was slightly changed. In the previous design[5] the lattice had the 24-fold symmetry with alternatively high and low beta straight sections (hybrid mode). Without changing the basic optics, we extracted bending magnets from four cells, leaving quadrupoles and sextupoles as they were. In this way, we can get 44 normal cells and 4 straight cells. At each straight cell, four spaces are available on a line for insertion devices. Reduced number of dipole magnets makes the emittance of the ring slightly large. Figure 2 shows the lattice functions for hybrid mode in a straight cell. Betatron functions in the straight section are almost the same as those in the normal cell. Natural emittance of 7.18 nm•rad was 36 % larger than the previous lattice. Extraction of bending magnets makes the sextupole correction complicated. The chromaticity is corrected by 3 sextupoles in the dispersive sections in normal cells. Harmonic sextupoles are placed in dispersion-free sections to enlarge the dynamic aperture. To make the problem simple, we set the sextupole field in the straight cell be the same as that in the normal cell. The strengths are optimized

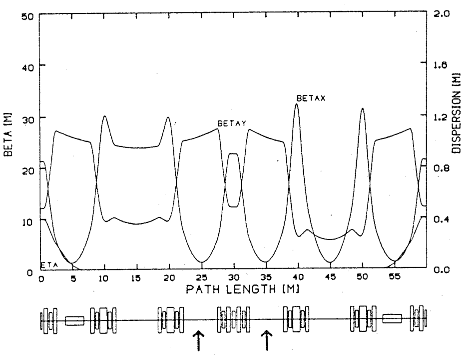

Fig. 2 Lattice functions over a straight cell. Bending magnets are extracted from the position indicated by arrows. Betatron functions are matched and tunes per cell are adjusted.

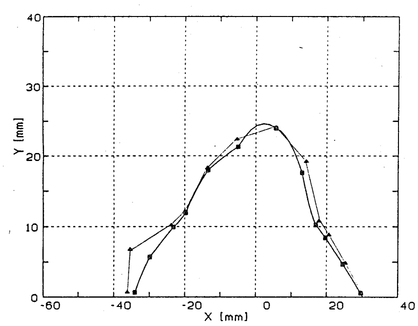

Fig. 3 Dynamic aperture of the ideal lattice. Empty triangles and dark square indicate the apertures for the virtual ring composed of normal cell, and for the actual ring, respectively.

using the computer code CATS[6], and the obtained dynamic aperture for the ideal machine is about the same as previous lattice, as is shown in Fig. 3. In this way, by extracting bending magnets from four cells, we can see that the lattice does not loose the good dynamical property.

We can rearrange quadrupole and sextupole magnets in these four straight cells, and can produce very long straight sections about 30 m in length without moving other magnets. An example of such lattice is shown in Fig. 4. We investigated dynamic properties for this lattice, and obtained dynamic apertures are indicated in Fig. 5. Because the symmetry is reduced to four, position dependence of dynamic aperture is also calculated.

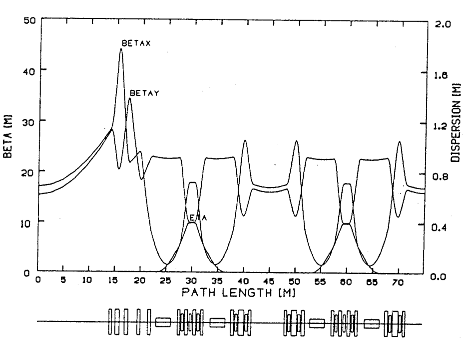

Fig. 4 Lattice functions with four extremely long straight sections. To reduce the betatron function at the end of long straight section, five quadrupoles are used. ε_n=8.49 nm

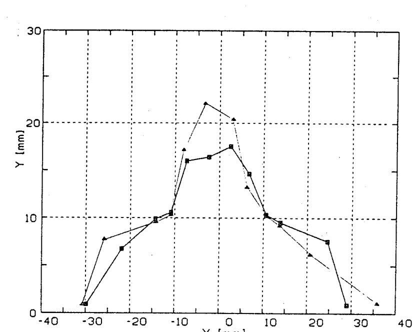

Fig. 5 Dynamic aperture of the ideal lattice. Empty triangles and dark square indicate the apertures at the extremely long straight and the farthest straight section, respectively.

In the first phase of operation, quadrupole and sextupole magnets are installed in these four straight cells as in normal cells. In the mature stage of operation, rearrangement of four straight cells will be performed. In the normal 8 GeV operation, emittance of the stored electron beam is larger than that of photons. The merit of these long straight section is not so large in 8 GeV operation. The storage ring emittance, however, is proportional to the square of the electron energy. When the energy lowered, and using the damping wiggler, electron emittance can be lowered and diffraction limit can be obtained in certain energy region. The effect of damping wiggler is shown in Fig. 6. In low energy operation with damping wiggler, these specially long straights will be of use in FEL experiments of VUV region.

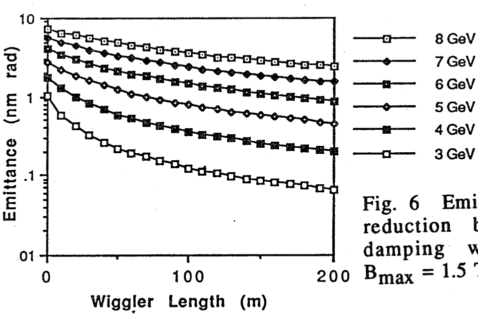

Fig. 6 Emittance reduction by damping wiggler. B_{max} = 1.5 T, λ_w = 18 cm

Magnet system

In total, 98 dipoles, 480 quadrupoles, and 336 sextupoles are used. The required field quality is 5×10^{-4} for dipoles and 1×10^{-3} for quadrupoles, and 5×10^{-3} for sextupoles. The required good field region is ±35 mm in horizontal and ±15 mm in vertical. We carried out numerical calculation on magnetic fields using the program code LINDA and TRIM. The bending magnet is C-shaped rectangular type. Quadrupole and sextupole magnets were designed to install vacuum vessel having extraction space for synchrotron radiation. Moreover sextupole magnet is required to provide a horizontal or vertical dipole field for the closed orbit correction. Prototype magnets have already been fabricated for quadrupole and dipole. Magnetic field measuring instruments have also finished and the field measurement will start within this year. For sextupole magnet, detailed design has been finished and fabrication is now in progress. On the other hand, spaces between magnets are very tight and now the possibility of reducing the apertures of quadrupoles and sextupoles, hence the lengths of them, are investigated.

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. Thirty two single-cell cavities are used. First, we investigated a single-cell cavity with nose cone. In order to reduce the impedance of HOM, single cell cavity without nose cone (Fig. 7) has been designed and cold model cavity has been ordered. Cold test will start within this year. High power teststand with a 1-MW klystron have already been designed and ordered. This teststand will be completed in a year. Prototype cavity, tuner, and power feeder for high power test are being designed now. Power test will be performed next year. The control system will be also developed through these tests.

Vacuum system

Most of synchrotron radiation is intercepted by crotches and absorbers placed just downstream and upstream of a bending magnet, and not intercepted by the vacuum chamber all around the ring. The crotch is designed so as 1)

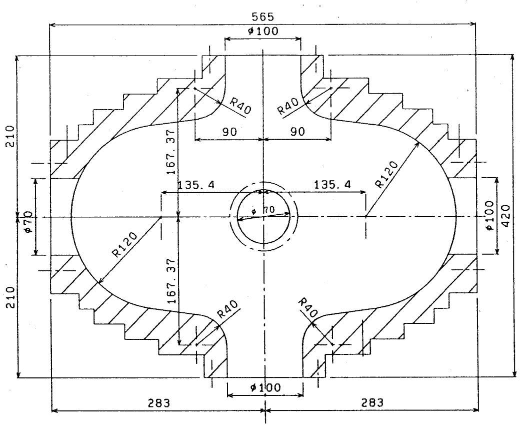

Fig. 7 Cross sectional view of 508.58 MHz single cell cavity without nose cone.

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 have been completed. Tests on these prototypes are in progress. The designed crotch is shown in Fig. 8. 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. Mounts of vacuum chamber, thermal expansion in baking, support of Button position monitor, and position and number of bellows are now in investigation. Space problem between magnets is serious to vacuum components.

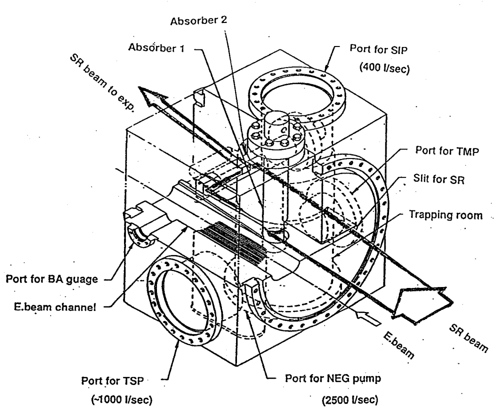

Fig. 8 Isometric view of the designed crotch.

Beamlines

Main light sources are from the Insertion Devices. Radiations from some bending magnets are also used. The hybrid mode operation is basically expected. Four low-beta straight sections are used for cavities, and one high-beta straight section for injection. Two extremely long straight sections are occupied for machine adjustments and tests. Then total 36 insertion device beamlines will be opened to users including from two extremely long straights. Nine bending magnet beamlines are also installed. In the review committee, the increase of bending magnet beamlines is recommended. In the commissioning, six ID and four bending magnet beamlines are to be installed. Undulators will be installed in the high-beta straight sections, and wigglers in the low-betas. The radiation spectra from typical undulators, wiggler, and bending magnet are shown in Fig. 9. An experimental hall is under design so that the length from the end of ID to experimental station is 80 m. In Fig. 10, a part of storage ring building design, shielding wall and experimental area are shown, where the thickness of shielding wall is 175 cm. Some kinds of experiments require long beamlines. The facility can accommodate 8 long beamlines up to 300 m and 3 extremely long beamlines up to 1000 m.

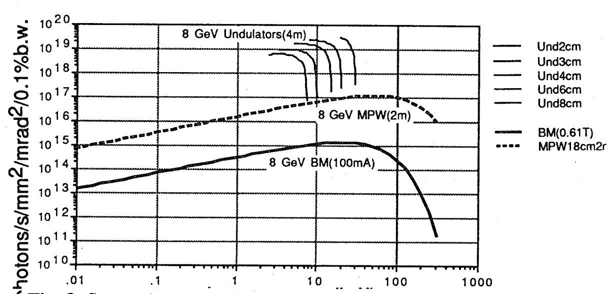

Fig. 9 Spectral brilliance of SPring with currents 100 mA.

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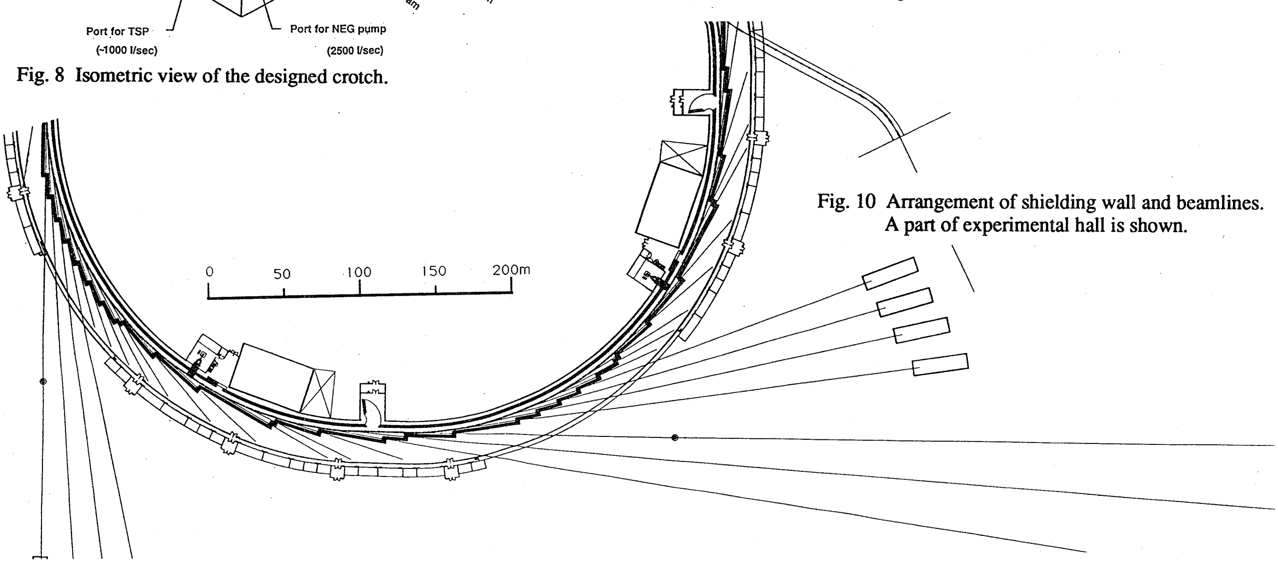

Fig. 10 Arrangement of shielding wall and beamlines. A part of experimental hall is shown.