STORAGE RING DESIGN OF SPring-8, 8 GeV SYNCHROTRON RADIATION FACILITY IN JAPAN

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Introduction

RIKEN and JAERI have made a joint team to construct an 8 GeV synchrotron radiation facility. The light source is an insertion device oriented third generation ring with a large number of straight sections for wigglers and undulators. The purpose of the facility is to provide stable photon beams, with high brilliance from undulator fundamental mode in the X ray region up to 24 keV, with high flux radiation from multipole wigglers around 100 keV. Wide tunability is also requested for undulators. In order to answer these purposes, the light source ring should be an low emittance ring of $\varepsilon_n < 10$ nm•rad, with the energy of 8 GeV. A full energy injection system and positrons are used for stable operation.

Construction was started in this April. The completion of the facility is scheduled in 1998.

The facility, as is shown in Fig. 1, consists of a main storage ring, a full-energy injector booster synchrotron and a pre-injector 1 GeV linac. The injector linac and synchrotron are laid outside of the storage ring because we want to leave a small mountain inside, and want to have a possibility to use linac and synchrotron not only as an injector but also as electron or positron beam sources. Design of injector system is written elsewhere[1].

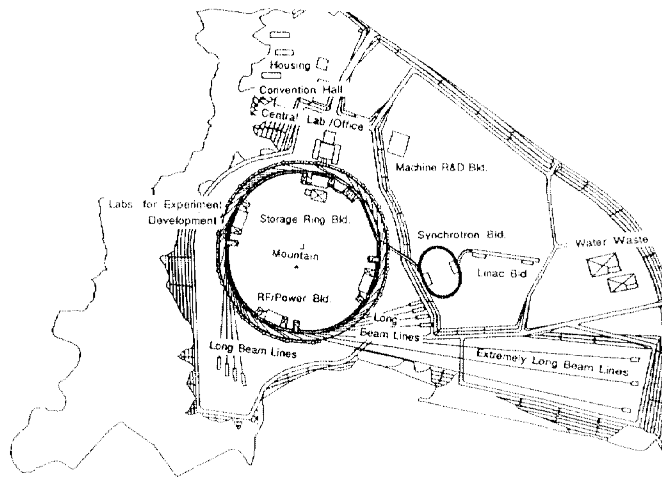

Fig. 1. Site and layout of the SPring-8.
The site is in the north part of the Harima Science Garden City.

The Lattice

Performance of the light source is determined primarily by lattice design. A storage ring must have a low emittance lattice for a photon beam to be highly brilliant. It is well known that an emittance is in proportion to the square of the electron energy and inversely to the cube of the number of bending magnets. Then it is effective to have a large number of bending magnets. An extended Chasman-Green (double bend achromat) structure has been chosen for the SPring-8 storage ring among several achromatic lattices[2]. Number of cells is 48. A unit cell is composed of 2 bending magnets, 10 quadrupole magnets, and seven sextupole magnets. Four very long straight sections are introduced in the ring. This will be done in two steps.

In the first phase of operation, symmetrically arranged four normal cells are changed to straight cells by extracting bending magnets. We could get almost the same betatron functions at the straight cells as at normal cells, which is because the focusing force of the bending magnets is negligible. Lattice functions at straight and normal cells are shown in Fig. 2. At each straight cell, four spaces are available for insertion devices on a line.

Reduced number of dipole magnets results in a slight increase of emittance. The ring has a flexibility in operating modes, and, is operated basically in a mode that alternatively has high and low betatron functions at the straight sections (hybrid mode). The main parameters of the first phase operation lattice are listed in Table 1.

Low emittance ring requires strong quadrupole magnets, hence comes large natural chromaticity. In order to suppress a head-tail instability, chromaticity is corrected by two families of sextupole magnets at a dispersive section in a normal cell. Introduction of strong chromaticity correction sextupole field results in a small dynamic aperture. Harmonic sextupole magnets are used in dispersion free sections for dynamic aperture improvement. The strength of these sextupole field is optimized by computer codes CATS[3], and a calculated dynamic apertures are shown in Fig. 3.

In the second phase, the quadrupole and sextupole magnets in a straight cell are rearranged and very long straight section about 30 m in length can be obtained without changing the orbit. An example of such a ring is calculated, and are shown in Fig. 4.

Misalignment of magnets and position monitor error deteriorate the performance of the linear lattice. The total relative tolerance of 0.1 mm is required including monitor error. The accuracy of magnets alignment and beam position monitor affects the commissioning and linear coupling. There are two possible strategies for commissioning[4]. One is the direct commissioning of the low emittance mode. The other is indirect commissioning via. detuned modes. Good accuracy guarantees the direct commissioning. Detuned modes also have been investigated[5]. Electron beams having vertical COD at sextupoles feel skew quadrupole field, which makes linear coupling between horizontal and vertical emittances. These effects are discussed elsewhere[6].

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)	1435.95
Dipole magnetic field	B (T)	0.665
Bending radius	r (m)	40.098
Type of lattice	Chasman-Green	
Number of cells	Normal cell	44
	Straight cell	4
Length of straight section		
normal	L (m)	6.5
long	L (m)	28.1
Natural emittance	ε_n (πm·rad.)	6.89×10^{-9}
Critical photon energy	ε_c(keV)	28.32
Tune	ν_x	51.22
	ν_y	16.16
Synchrotron tune	ν_s	0.010198
Momentum compaction	α	1.49×10-4
Natural chromaticity	ξ_x	-113.168
	ξ_z	-43.319
Energy loss in the arcs	U_0 (MeV/rev)	9.04
Energy spread	σ_e/E	0.00108
Damping time	τ_x (msec)	8.473
	τ_z (msec)	8.481
	τ_e(msec)	4.242
Harmonic number	h	2436
R.F. voltage	V_{rf} (MV)	17
R.F. frequency	f_{rf} (MHz)	508.58

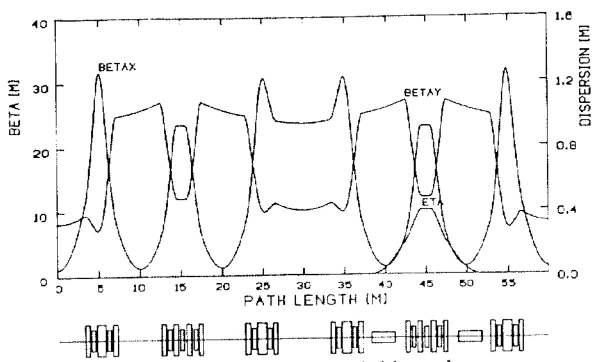

Fig. 2. Lattice functions for hybrid mode. Left and right halves are straight and normal cells.

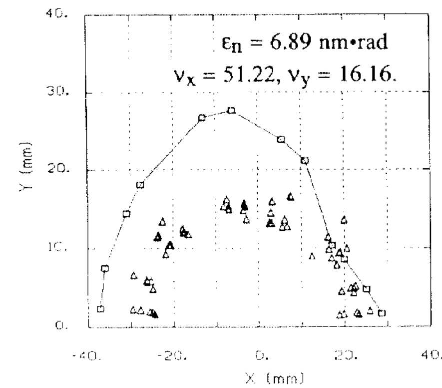

Fig. 3. Dynamic apertures for the lattice with 4 straight cells. Squares:Ideal lattice, Triangles:with errors, Q &S Disp.=0.2 mm, BM Tilt $=5\times10^{-4}$, Q, S Tilt $=5\times10^{-4}$, $\Delta B/B=5\times10^{-4}$, $\Delta Q/Q=5\times10^{-4}$, $\Delta S/S=5\times10^{-4}$.

Magnet System

The design of the storage ring magnets has been completed. There are 88 dipoles, 480 quadrupoles, 336 sextupoles, and 576 steering devices for orbit correction, 364 of which are incorporated into the sextupole magnets using extra windings, other 96 for individual horizontal corrections, and the other 96 for both vertical and horizontal corrections. Three septum magnets and four bump magnets are used for beam injection.

Required field uniformities are 5×10^{-4} for dipoles and quadrupoles, and 1×10^{-3} for sextupoles. Required good field regions are ±35 mm in horizontal and ±15 mm in vertical. These magnets are constructed from 0.5-mm-thick laminations of silicon-steel sheets. The cross sectional views of quadrupole and sextupole magnets are shown in Figs. 5 and 6.

Full scale prototypes of dipole, quadrupole, and sextupole magnets have been build. Field measurement of these magnets and construction of prototype pulse septum and bump magnets are underway.

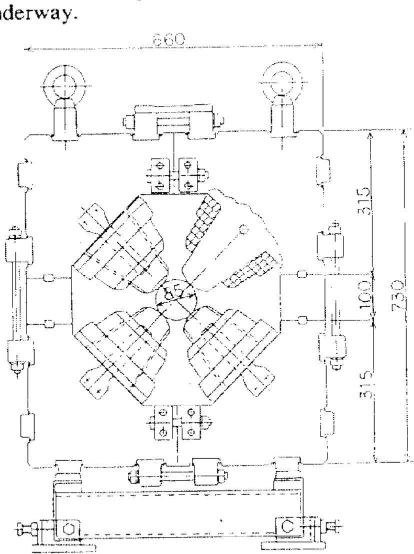

Fig. 5. Cross-sectional view of a quadrupole magnet. Bore diameter is 85 mm. Top and bottom halves are jointed through non magnetic materials to make space for photon beam extraction port.

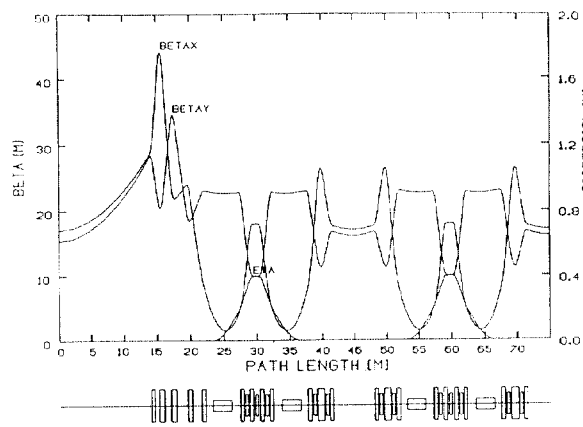

Fig. 4. Lattice functions with 4 long straight sections and high β mode. Rree long straight section (about 30 m) can be obtained.

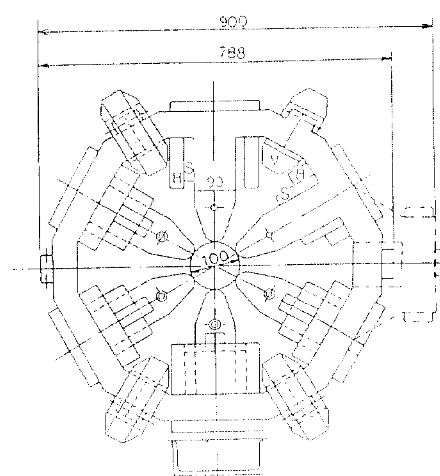

Fig. 6. Cross-sectional view of a sextupole magnet. Two different types have been designed. One is symmetric and the other is asymmetric in the yoke structure. Steering coils for COD correction in vertical and horizontal are indicated by V and H.

RF System

A frequency of 508.58 MHz has been chosen for the RF system. This is the same frequency used at KEK TRISTAN. There are four RF stations symmetrically located around the ring. Each station has 1-MW klystron and 8 single cell cavities which are located in 6.5-m straight sections with low betatron functions. Space for harmonic RF system is reserved. In order to reduce the excitation of higher order modes (HOM), cavity has smooth shape (no nose corn). Schematic drawing of the single cell cavity is shown in Fig. 7. Cold model cavity has been build and the RF characteristics have been investigated.

High power test-stand for 1-MW klystron has been designed and ordered. This test-stand will be installed in this autumn. Prototype cavity, tuner, and coupler have been designed. These prototypes will be completed by the end of October.

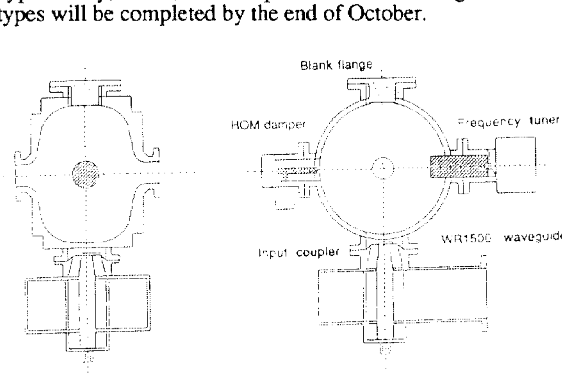

Fig. 7. Schematic drawing of a 508 MHz single cell cavity. Totally 32 cavities are used.

Vacuum System

Vacuum system consists of two types of vacuum chamber, two types of absorber, and various chamber components such as bellows, flanges, and valves. Most of synchrotron radiation is intercepted by crotches (Fig. 8) and absorbers placed just downstream and upstream of a bending magnet, and vacuum chamber wall is basically not hit by the radiation. The crotch is designed to trap reflected photons and photo-electrons, and released gas molecules.

Cross sectional view of the vacuum chamber for the straight section is shown in Figs. 9. The vacuum chamber consists of an electron beam chamber and a slot isolated antechamber in which NEG strip pumps are installed. The bending-magnet chamber has additional ion-pump chamber. At present prototype bending magnet- and straight section- chambers have been manufactured by extrusion methods(Aluminum alloy). Prototype crotch has been completed. Tests on these prototypes are in progress.

Radiation Sources and Beam Lines

There are 44 straight sections. Five low-β straight sections are used for cavities, and one high-β for injection. The other 38 straight sections can be used for insertion devices. There are four very long straight sections. Two of them are used for machine adjustment and tests. Undulators are installed in high-β straight section, and wigglers in low-βs. About seventeen beamlines from bending magnet are expected. Ten beamlines (6 ID and 4 BM) will be prepared in the commissioning. Parameters of typical insertion devices are listed in Tab. 2. In Fig. 10, spectral brilliance from typical undurators, wigglers, and bending magnets are shown. A part of a plan view of the storage ring is shown in Fig. 11. The length of beamline from the end of ID to experimental station is 80 m. Thickness of shielding wall is taken to be 1.2 m. The facility can accommodate 8 long beamlines up to 300 m and 3 extremely long beamlines up to 1000 m.

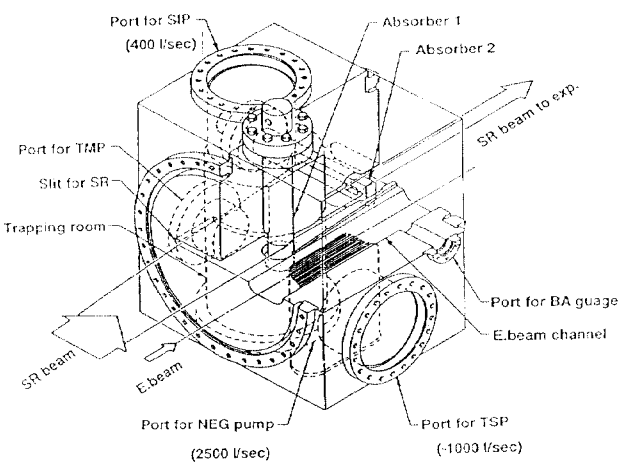

Fig. 8. Isometric view of an crotch.

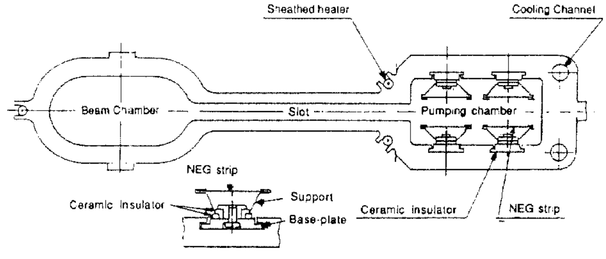

Fig. 9. Cross-sectional view of the vacuum chamber for the straight section.

TABLE 2 Parameters of the typical wiggler and undulator

Device	λ_0 (cm)	B_0 (T)	K	Medium Photon Energy (keV)	Photon Beam Divergence(σ) hor.	ver.(mrad)
Und.1	10	0.22	2.0	2	0.02	0.014
Und.2	4	0.28	1.0	10	0.016	0.009
Wig.1	30	1.0	28.0	42	1.8	0.042
Wig.2	18	1.5	25.0	64	1.6	0.042

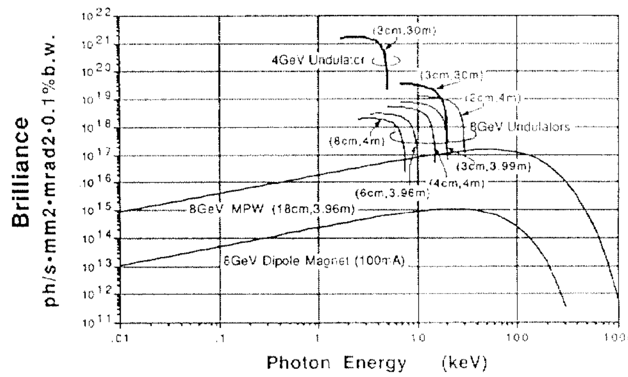

Fig. 10. Spectral brilliance of SPring-8.

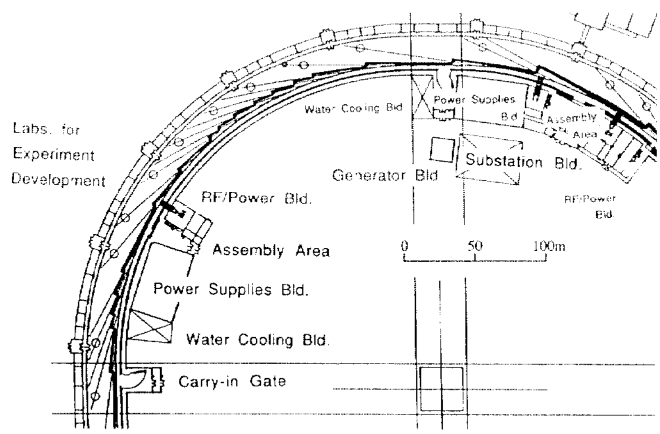

Fig. 11. A part of a plan view of the storage ring. Layout of beamlines and shielding wall are shown. Beamlines indicated by circles are from straight sections(ID).

References

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