STA SR PROJECT

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Introduction

RIKEN, which is supervised by Science and Technology Agency of Japanese Government (STA), started the design study and R&D work on the low emittance storage ring dedicated to the synchrotron radiation source in the X-ray region in 1986. In the fall of 1987, Japan Atomic Energy Research Institute (JAERI), which is also supervised by STA, joined with RIKEN in the design work. Present design work is done by RIKEN. Synchrotron radiation facility, which is shown in Fig. 1, is composed of a 6 GeV storage ring, a full-energy injector synchrotron and a 1.5 GeV linac. The storage ring has a 1069.2 m circumference and 36 long straight sections. Thirty straight sections are available for insertion devices.

Although construction site has not been decided yet, three years of Preconstruction R&D and five years construction are expected. The facility will be opened equally to research groups of universities, national laboratories, and industries to promote the basic research and development of advanced technology.

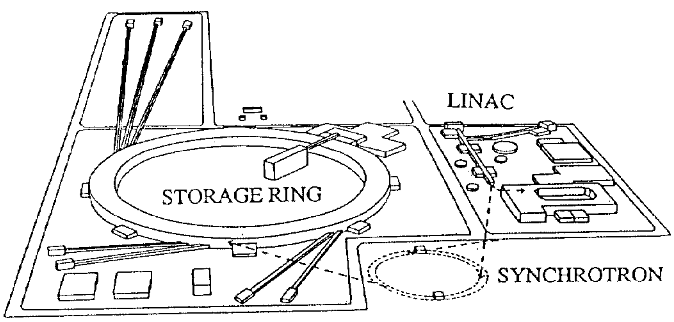

Fig. 1 An example of the arrangements.

Light source

The storage ring is designed to satisfy the following conditions:

high-brilliance photon beams (10^{17} photons/s mA mm^2 mrad^2 0.1% bw)

low emittance operation with ε_x less than 10 n mrad

a great number of long straight sections (7 m) for insertion devices

large dynamic aperture sufficient for injection and high flexibility in the lattice configuration

The energy of the storage ring is tentatively decided to be 6 GeV. Radiation spectra from bending magnets, typical multipole wigglers, and undulators are shown in Fig. 2.

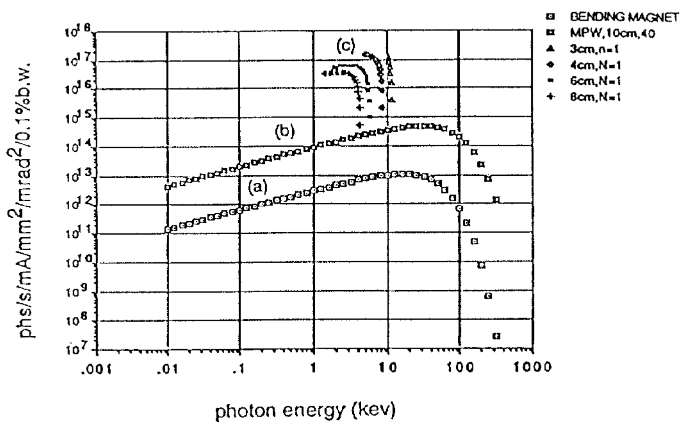

Fig.2 Spectral brilliance of the 6 GeV synchrotron radiation source. (a) B_0=0.8 T, dipole magnet; (b) B_0=1.5 T, λ_u=10 cm, total length 4m multi-pole wiggler; (c) Undurator radiation, total length 4 m, fundamental mode, B_0=1.25 T, minimum gap = 12 mm. Fundamental mode for λ_u = 3cm, 4cm, 6cm,8cm are shown.

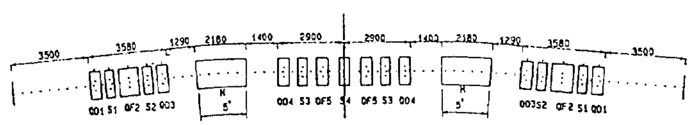

Fig. 3 Layout of one cell of the storage ring.

Lattice

The storage ring has 36 superperiodicity and each cell is a slightly modified Chasman-Green lattice as shown in Fig. 3. Unit cell consists of a dispersive section and straight section where the dispersion is suppressed to be zero for the minimization of the insertion device effects on the stored beam emittance. Three quadrupole magnets are placed beyond the achromatic-bend dipoles on either end to have sufficient flexibility in adjusting the horizontal betatron function in the straight sections. There are, therefore, two bending magnets and ten quadrupole magnets per unit cell. The lattice functions are shown in Fig. 4 and the main parameters of the storage ring are listed in Table 1.

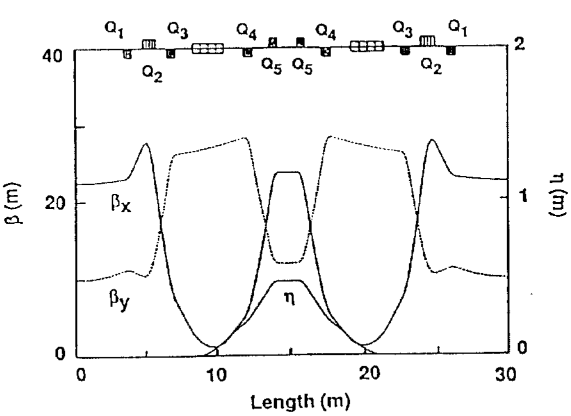

Fig. 4 Betatron and energy dispersion functions in a single cell.

Table 1 Lattice Parameters

Beam Energy	6.0 GeV
Revolution Period	3.57 μsec
Circumference	1069.2 m
Cell No	36
Length of Straight Section	7.0 m
Bending Radius	25.0 m
Dipole Field	0.8 T
Dipole Length	2.18 m
No of Dipole Magnet	72
No of Quadrupole Magnet	360
No of Sextupole Magnet	
- Chrom. Correct.	108
- Harmonic Sext.	144
Momentum Compaction Factor	1.86×10-4
Tune vx, vy	32.22,11.16
Energy Loss / Turn	
Bending Magnets	4.6 MeV/Turn
Insertion Devices	2.4 MeV/Turn
Damping Time	
- Horizontal	9.3 msec
- Energy	4.7 msec
Natural Energy Spread	0.103 %
Chromaticity ξx, ξy	-67.9, -28.8
Natural Emittance	8.2×10-9 m.rad
Beam Current	I > 100mA
RF Parameters	
Radio Frequency	504.7 MHz
Harmonic Number	1800
RF voltage	9.0 MV
Shunt Impedance	22.5 MΩ/m
No. of Cells	20
RF Power	1.3 MW

A low emittance ring with many long dispersion free straight sections has large natural chromaticity. The chromaticity is corrected by sextupole magnets in the dispersion section. The use of sextupole magnets, however, produces amplitude dependent tune shifts, which make the beam unstable by driving the harmful resonances and resultant dynamic aperture is too small to circulate the beam. Additional sextupole magnets (harmonic sextupoles) are introduced to suppress these harmful resonances(1). Particle tracking calculations were done by the program Racetrack(2) to obtain a large dynamic aperture and a fairly large dynamic aperture was found even with the magnet alignment and field errors(3).

Influence of insertion devices on the betatron motion of the circulating beam is studied(4) using the analytical expression of the magnetic field proposed by K. Halbach(5). With the undulator type devices, the extent of linear optics distortion was found to be considerably small primarily due to the largeness of curvature ($\rho \approx 30$ m). Satisfactory restoration of the linear optics was achieved using only those quadrupole magnets adjacent to the insertion devices. It was found that the main nonlinear contribution comes from the octupole-like fields. Tracking calculation showed that the vertical dynamic aperture was reduced to 20 mm with the presence of insertion devices, however, it was larger than the undulator gap height.

Beam stability and lifetime

Beam stability and lifetime are studied by the program Zap(6). Since the broad band impedance Z/n is not yet evaluated precisely, it is treated as a parameter in the calculation of instabilities. As for the cavity impedance, KEK cavity results are adopted(7). As a result, the bunch lengthens three times for the 5 mA single bunch operation. The growth rates of the coupled bunch instabilities for the 100 mA beam current are less than 200 1/s. Corresponding growth time is 5 ms, which is less than the radiation damping time for the longitudinal motion and shorter than that for the transverse motion. A feed back system or a higher order mode damper will be necessary for the storage of 100 mA beam current.

Gas scattering lifetime is 100 hours at the pressure of 10^{-10} Torr for the undulator gap height of 8 mm. In case of 5 mA beam current, Touschek lifetime is 100 hours and 23 hours with and without bunch lengthening, respectively. These lifetimes are quite acceptable.

Magnet

The dipole magnet is the c-shaped sector type as shown in Fig. 5. The dipole is flat over the horizontal range of 104.3 mm and has radial shims of 1.5 mm in thickness at both ends. The good field region within a radial variation $\Delta B/B = 1.0\times10^{-4}$ is expected over an aperture of x= 60 mm and y= 15 mm.

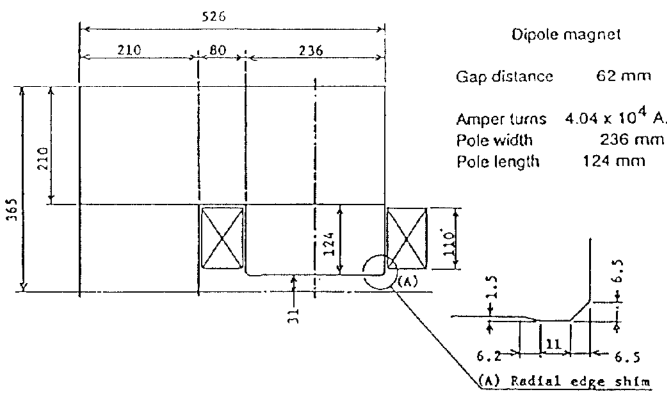

Fig. 5 Cross-sectional view of the dipole magnet.

RF system

The Frequency is determined to be 504.7 MHz because well-proven cavities are used in this frequency range at KEK, BESSEY, DARESBURY, DESY, and so on. The RF design parameters are listed in Table 2. Two dispersion free straight sections are used for the arrangement of the cavities. Two types of cavity structure, a single-cell cavity and a multi-cell cavity, are under consideration.

Vacuum system

The vacuum system consists of two different shaped aluminum alloy chamber extrusions, two types of absorbers and three kinds of pumps. To minimize synchrotron radiation-induced desorption, the vacuum chambers are made of aluminum alloy(A6063T6) and are designed so as not to intercept the photon beam. One of the two chambers is for the bending magnet and the cross section is shown in Fig. 6. A distributed ion pump

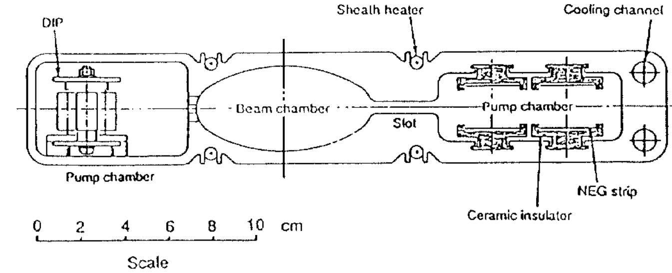

Fig. 6 Cross-sectional view of the bending magnet vacuum chamber.

(DIP) and non-evaporable getter (NEG) strips are installed on opposite sides of the electron beam chamber. Thus these pumps not only evacuate gases desorbed from the bending magnet chamber but also assure efficient removal of gases which emanate from the crotch and absorber, and result in low operating pressure in the electron beam chamber.

The crotch and strip absorber are placed just downstream and upstream to the bending magnet. This crotch is designed to trap reflected photons and associated photo-electrons. SR-induced outgassing from the crotch is also locally pumped with three different pumps; NEG, SIP, and TSP. The main pumping system is based on DIP and NEG strips, installed in the bending magnet, and NEG strips and TSP's, equipped in the straight sections which occupy most of the vacuum chamber.

Synchrotron

The booster synchrotron is designed to accelerate electrons from 1.5 GeV to the full energy of the storage ring of 6 GeV. Positrons are also accelerated to get high quality beams. As the beam current for positron is about 1/10 of the electron beam, high capture efficiency of positron beam is required. For this purpose, adoption of two RF system, which consists of low and high frequency cavities, is considered. The low frequency system with f= 28 MHz or 48 MHz is operated at injection and switched to the high frequency system with f= 500 MHz in its acceleration to 6 GeV.

The lattice is a simple FODO arrangement and consists of 36 FODO cells which is the same cell number as the storage ring. The super periodicity of the ring is four and the lattice of a super period consists of normal cells and a straight section where a dispersion is suppressed by a missing dipole. Lattice functions are shown in Fig. 7 and the main parameters are listed in Table 2.

Chromaticity is corrected by means of two families of sextupoles and the dynamic aperture was calculated by the particle tracking. The dynamic aperture turned out to be large enough for the particle acceleration.

Table 2 Major Parameters of the Booster Synchrotron

Energy	E(GeV)	6
Maximum bending field	B(T)	0.8
Bending radius	ρ(m)	25.0
Quadrupole magnet strength	KF(m^{-1})	0.343
	KD(m^{-1})	0.343
Tune	νx	10.232
	νz	10.419
Momentum compaction	α	0.015
Circumference	C(m)	342.145
Natural chromaticity	ζ_x	-14.2
	ζ_z	-14.3
Energy loss	U0(MeV/rev)	4.59
Energy spread	σ_e/E	0.00103
Damping time	τ_x(msec)	3.0
	τ_z(msec)	3.0
	τ_e(msec)	1.5
Emittance	ε (πmrad)	2.7×10^{-7}
Harmonic number	h	576
R.F.voltage	V_{rf}(MV)	9
R.F.frequency	f_{rf}(MHz)	504.7

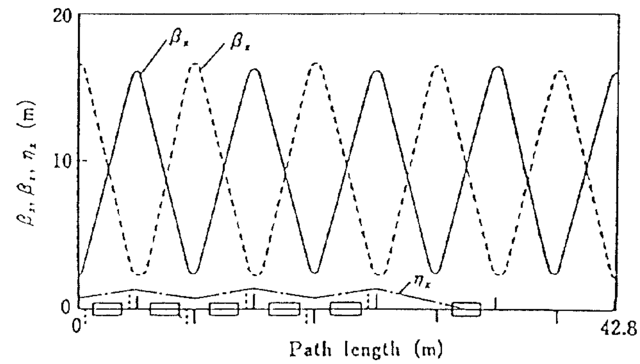

Fig. 7 Betatron and energy dispersion functions in one half period.

Pre-injector linacs

In the e^- mode, the electrons are accelerated to 250 MeV in the e^- linac, and are injected in the common linac. In the e^+ mode, the positrons which are produced by the 200 MeV electron linac, are gathered and accelerated to 250 MeV in the e^+ linac, and are injected to the common linac. Electrons or positrons are accelerated to 1.5 GeV in the common linac. The nominal linac parameters are listed in Table 3.

Table 3 Nominal Linac Parameters

Frequency	2856 MHz
Structure type	Constant Gradient
Accelerating type	Travelling Wave
Accelerating mode	2/3 π
Section length	3 m
Sections/Klystron	2
Klystron power	50 MW
Energy gain	17.2 MV/m
Output energy	1.5 GeV
Output energy spread	± 1 %

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