FIRST COMMISSIONING OF SPring-8

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Abstract

SPring-8 is the third generation synchrotron radiation source in soft and hard X-ray region and consists of an injector linac of 1GeV, a booster synchrotron of 8GeV and a storage ring with a natural emittance of 5.5nmrad. The storage ring can accommodate 61 beamlines in total and 26 of them are under construction. Construction started in 1991 and inauguration is scheduled in October, 1997. We started commissioning of the injector linac on August 1, 1996, and succeeded to get 1GeV electron beam a week later. The synchrotron was commissioned in December and 8GeV electron beam was successfully extracted on January 27, 1997. By the end of February 1997, installation and precise alignment of the storage ring was completed and four insertion devices (in-vacuum undulators) were installed in the storage ring. On March 14 we started commissioning of the storage ring and immediately after we observed the first turn in the ring. After fine adjustment of the parameters we succeeded to store a 0.05mA beam in the storage ring on March 25. Next day the first synchrotron radiations from a bending magnet was clearly observed at the front end of the beamline. On April 17 we succeeded to increase the stored current to 20mA, which is a target value of the stored current in the first phase of commissioning. The first radiations from an undulator was observed on April 23.

1 INTRODUCTION

The SPring-8 (**S**uper **P**hoton **ring-8**GeV, sometimes abbreviated as SP8) facility[1] is one of the world's most brilliant synchrotron radiation sources in an energy range from 0.3 keV to several hundreds keV. It is composed of a 1 GeV electron/positron linac, an 8 GeV booster synchrotron and a low-emittance storage ring with a circumference of 1,436m. The storage ring has a Chasman-Green lattice structure and consists of 44 normal cells and 4 straight cells. In future each straight cell will be converted into a long straight section to accommodate a long insertion device. The storage ring can accommodate 38 beamlines from insertion devices (ID), including 4 long IDs. In addition to these ID beamlines, 23 beamlines from the bending magnet (BM) can be installed in the storage ring.

The estimated natural emittance of the storage ring is 5.5×10^{-9} mrad, allowing SPring-8 to realize a brilliance of 4×10^{19} (photons/s/mm^2/mrad^2/0.1%b.w.) with a 4.5m undulator and a stored current of 100 mA. SPring-8's 8GeV energy will allow us to obtain high-brilliance X-rays in the energy range from 5keV (fundamental) to 75keV (fifth harmonics) from a newly developed in-vacuum undulator with a period length of 32 mm simply by changing its gap.

Figuire 1: Aerial view of the SPring-8 facility. The storage ring is built surrounding a small mountain. The injectors are below the storage ring in the figure.

The storage ring is installed in the machine tunnel together with the front end parts of the beamlines. Optical system for synchrotron radiations (SR) and experimental devices are installed in hutches built in the experimental hall. The maximum length of beamlines in the experimental hall is 80 m from the exit of ID or BM. However we can extend 9 beamlines to 300m and 3 to 1,000m. The RI experimental hall is built neighboring the experimental hall to accommodate 3 beamlines for radioactive samples.

The facility is being constructed jointly by Japan Atomic Energy Research Institute (JAERI) and the Institute of Physical and Chemical Research (RIKEN) at the Harima Science Garden City in Hyogo Prefecture, which is 100 km west of Osaka. Construction was started in 1991 and is going one year ahead of the initial schedule. By now the linac, the synchrotron, and the storage ring was successfully commissioned.

Due to the geographical features of the SPring-8 campus, the storage ring is built surrounding a small mountain. The injector linac and the booster synchrotron are built separately from the storage ring. Figure 1 shows an aerial view of the SPring-8 facility. The injector linac will be used to inject electron beam to another accelerator, that is, a 1.5GeV SR source being constructed by Hyogo Prefecture for Himeji Institute of Technology.

The facility has a legal status of a national user facility and will be open to researchers not only from Japan but also from abroad. The Japan Synchrotron Radiation Research Institute (JASRI) will have responsibility for SPring-8's operation, maintenance, and improvement, after the inauguration in October, 1997.

2 SPRING-8 ACCELERATORS

Table 1 lists the main performance specifications of SPring-8 accelerators. All the figures are design values.

2.1 The Injector Linac

The linac consists of a 250MeV high current linac and an electron/positron converter, and a 900MeV main linac with frequency of 2856 MHz [2]. Electron beam can be accelerated up to 1.15GeV by removing a tungsten target of the electron/positron converter. The linac has 26 accelerator columns which are of $2\pi/3$ traveling-wave and constant-gradient type. Average accelerating field is designed to be higher than 16 MV/m. One high-power klystron of 80MW (Toshiba E3712) supplies microwaves to two accelerator columns.

Modulators for the klystrons provide a maximum output power of 190MW with a pulse width of 4μsec and at the repetition rate of 60Hz.

The beam commissioning was started on August 1. We accelerated the electron beam up till the 7th accelerator column and analyzed the energy by bending magnets on August 7. Next day, August 8, we succeeded to accelerate the beam to the final energy of 1GeV. The final energy of the beam was measured when the beam was sent to the synchrotron in December.

2.2 The Booster Synchrotron

The synchrotron[3] has 64 bending magnets, 80 quadrupole and 60 sextupole magnets and 80 steerers. Integrated field strength was measured for all bending magnets and rms distribution is 8×10^{-4}. All the magnets were aligned within an accuracy of 0.2 mm. Power supplies for these magnets are operated in a ramping pattern of 1Hz and required to have high tracking accuracy and high reliability. The tracking accuracy of the bending magnet and the quadrupole magnet power supplies is less than 1×10^{-4}. Typical time structure of the output current of the magnet power supply is as follows; 0.15sec flat-bottom (for beam injection), 0.40sec ramping, 0.15sec flat-top (for beam extraction), and 0.30sec falling. Delay time of the output current was measured to be 0.33msec.

The RF system of the synchrotron consists of eight five-cells cavities, waveguides, two 508.58MHz klystron (Toshiba E3786) and their power supplies. The required maximum RF power is 1.69MW at 8GeV. The effective RF voltage changes from 8MV to 18.7MV during the electron acceleration from 1GeV to 8GeV. The five-cells cavity is made of OFHC copper and has an effective shunt impedance of 21MΩ.

Table 1: Major Parameters of the SPring-8 Accelerators

Injector Linac		
Energy	Electron	1.15 GeV
	Positron	0.9 GeV
Repetition Rate		60 Hz
RF		2856 MHz
Total Length		140 m
Electron Gun	Cathode	Y796
	Voltage	200 kV
Accelerator Columns	Number	26
Klystrons	Number	13
	Max. power	80 MW
Booster Synchrotron		
Injection Energy		1 GeV
Maximum Energy		8 GeV
Circumference		396.12 m
Repetition Rate		1 Hz
Number of Cells	FODO lattice	40
Super Period		2
RF		508.58MHz
No.of Klystrons	1MW output	2
No. of Cavities	5-cell type	8
Harmonic Number		672
Storage Ring		
Energy		8 GeV
Lattice Type	Chasman-Green	
No. of Cells	Normal Cell	44
	Straight Cell	4
Super Period		4
Circumference		1435.95 m
Stored Beam Current	Single Bunch	5 mA
	Multi-bunch	100 mA
Harmonic Number		2436
RF		508.58MHz
No.of Cavities		8×4
Revolution Period		4.79 μ sec
Natural Emittance		5.9×10^{-9} mrad
Coupling Constant		10%
Source Point Data		
No. of Straight Sections	High β Sections	19
	Low β Sections	15
	Long Sections	4
No.of BM Sources		23
Electron Beam Size	High β Sections	0.35×0.078
($\sigma_x \times \sigma y$, mm)	Low β Sections	0.069×0.052
Beam Divergence	High β Sections	0.015×0.007
($\sigma'_x \times \sigma' y$, mrad)	Low β Sections	0.073×0.01

The beam position monitors (BPM) are located at up-stream positions of 80 quadrupole magnets. Four signal processing systems are used for 80 BPMs and it takes less than 30 msec to obtain all position data.

Installation of the synchrotron was completed in October and commissioning was started on December 10,

1996. We succeeded to accelerate the beam up to 8GeV on December 16. After the winter vacation the operation was restarted and the 8GeV beam was extraceted to the beam dump on January 27, 1997.

2.3 The Storage Ring

The storage ring is a four-fold symmetric ring with a circumference of 1,436 m. The magnet lattice is composed of two types of unit cells, that is, the normal cell and the straight cell. The former consists of 2 bending magnets, 10 quadrupole magnets, and 7 sextupole magnets and has a magnet-free space of 4.5m long with no dispersion. On the other hand, the latter has no bending magnet but has the same focusing magnet arrangement as that of the normal cell, thereby ensuring that both have approximately the same beam-dynamical property. In the first phase of operation, the storage ring will have a lattice structure of 4 × (11 normal cells + 1 straight cell) and be approximately 48-fold symmetric. In the second phase we will operate the storage ring under the condition that all the quadrupole and sextupole magnets in the straight cell are switched off. Then we will change the magnet arrangement of the straight cell to create a long straight section.

Figure 2: Picture of the storage ring. On the left side is a front end part of the ID beamline and on the right side is a dummy chamber for future ID.

2.3.1 Magnets

The storage ring has 88 bending magnets, 480 quadrupole magnets, and 336 sextupole magnets. In addition, four bump magnets and one pulsed and three DC septum magnets and 569 steering magnets with very low remnant field are installed in the storage ring. Performance of the low emittance ring depends strongly on the quality of these magnets and their precise alignment. Measured rms distributions of integrated field strength and gradient for all bending, quadrupole, and sextupole magnets are less than 5×10^{-4}. The bump magnets and the septum magnets are used for injection.

There are three groups of focusing magnets in one cell and each group is installed on one common girder. Magnetic centers of quadrupole and sextupole magnets on the common girder are aligned within an accuracy of 0.025 mm. On the other hand bending magnets and common girders are aligned within 0.1 mm along the whole ring. Final alignment was done in January 1997 and standard deviation of the alignment errors was 0.04 mm. This accuracy was confirmed at the commissioning of the storage ring. We observed the first turn of the electron beam without any correction by steering magnets.

Effective emittance of the beam increases if magnetic centers of quadrupole magnets vibrate. To reduce seismic vibrations as low as possible, the storage ring building is built on the firm bedrock. In addition, cooling system was carefully designed to reduce induced vibration on the storage ring. We observed the maximum vibration amplitude in horizontal and vertical planes was an order of 0.01μm when the cooling water system is in operation.

Control system of magnets power supplies consists of UNIX workstations, an optical fibre network and VME modules. Softwares of the control system has been developed by the magnet group in collaboration with the control group.

2.3.2 RF System

Although there are four straight sections reserved for RF stations in the storage ring, three RF stations were already installed. Each station is composed of eight single cell cavities of bell-shape type, one 1MW cw klystron, its high voltage power supply, and wave guide system. Shunt impedance of a cavity is 5.5MΩ. Frequency of higher order mode (HOM) for each cavity can be controlled by using two movable tuners and a plunger, keeping the fundamental frequency of 508.58MHz constant. Then dangerous HOM frequencies to cause coupled-bunch instability can be well separated from cavity to cavity, so that the threshold current for coupled-bunch instability becomes higher than 200mA. After high power test at the test stand all the cavities were installed in the storage ring.

As the injectors are built about 500m apart from the storage ring, timing system for them was made carefully. For example, temperature dependence of transit time of the reference signal and time jitter should be made as low as possible. We could realize precise timing by using optical fibre with low temperature dependence and newly developed E/O (electrical to optical) and O/E modules and achieved time jitter less than 10 psec.

2.3.3 Vacuum System

Main parts of the vacuum system of one unit cell consists of two bending magnet chamber (BMC), three straight section chamber (SSC) for the focusing magnets on one girder, two crotch chamber, one dummy chamber for an insertion device to be built in future, and other components. The pumping system is based on non-evaporable getter (NEG) strips which are used in SSC and BMC, lumped NEG pumps for SR-induced gas load at crotches and absorbers, and sputter ion pumps. A distributed ion pump (DIP) is also used in the BMC.

The BMC and SSC are extrusions, made of aluminum alloy, A6063-T5. The BMC has a beam chamber with a slot-isolated antechambers for NEG strips and a rectangular pump chamber for DIP. On the other hand, SSC has a beam chamber and an antechamber for NEG strips. The injection section chamber consists of two parts, a stainless steel chamber and an aluminum alloy chamber. The former is equipped with a beryllium window for the injection of the electron beam from the synchrotron.

Each of 48 unit cells has six beam position monitors (BPM), giving a total of 288 BPMs. Because the BPM electrodes are welded directly to the SSC, SSCs should be supported on the common girder to make displacement and deformation of the chamber less than 50μm and 30μm, respectively, at BPM positions. Their sensitivity and difference between mechanical center and electrical center were calibrated for all BPMs. After final alignment of magnets, BPM centers were calibrated to fiducial points of neighboring sextupoles.

Baking and evacuation finished in September 1996 and vacuum pressure reaches below 10nPa.

2.3.4 Beam Diagnostics

Besides BPMs beam current monitors and a tune monitor are installed in a straight section together with absorbers to avoid unnecessary irradiation of SR. Two types of current monitors are developed; one is a DCCT of parametric current transformer type and used to measure the DC component of the stored current with a resolution of 5μA. The other is a pulse transformer with a signal processor to measure the charge of one bunch.

The tune monitor consists of a beam shaker, signal source for it, an amplifier, pick-up electrodes, signal processing circuits, and a spectrum analyzer. All these monitors were verified to work very well on the storage ring commissioning.

3 SPRING-8 BEAMLINES

3.1 Beamlines

SPring-8 can accommodate 61 beamlines(BL). They are divided into four groups according by the source types and source points. They may also classified by users. Table 2 lists the beamlines at SPring-8.

Now 26 beamlines are being constructed. They are 10 public BLs, 6 JAERI/RIKEN BLs, 3 for R&D, 2 for machine study, and five contract BLs. The public BLs are constructed by SPring-8 and will be open to general users. On the other hand, contract BLs are constructed by the specific organizations at their own expenses. In this case about 70% of beam time can be used by them. JAERI / RIKEN BLs are constructed by JAERI / RIKEN for their own use.

Table 2. SPring-8 Beamlines

Total Number of Beamlines	61
Classification by Source Type	
Standard Insertion Device Beamlines(BL)	38
BL from normal Straight Section (highβ)	(19)
BL from normal Straight Section (lowβ)	(15)
BL from long Straight Section (30m long)	4
Bending Magnet Beamlines	23
Classification by Users	
Public Beamlines	30
Contract Beamlines	10~20
JAERI / RIKEN Beamlines	6~10
R&D and Machine Study Beamlines	5

Seven of the public beamlines are ID BLs, four from in-vacuum undulators(U), one from twin-helical U, one from figure-8 U, and one from elliptical multipole wiggler (EMPW). The remaining three are beamlines from BM. On the other hand, JAERI and RIKEN are building three beamlines each, two of them are BLs from IDs. One of IDs being developed by JAERI is a variably-polarizing undulator which can produce circularly-polarized or linearly-polarized X-rays by changing relative phase of horizontal and vertical fields. One ID beamline and another BM beamline will be used for machine study.

3.2 Insertion Devices

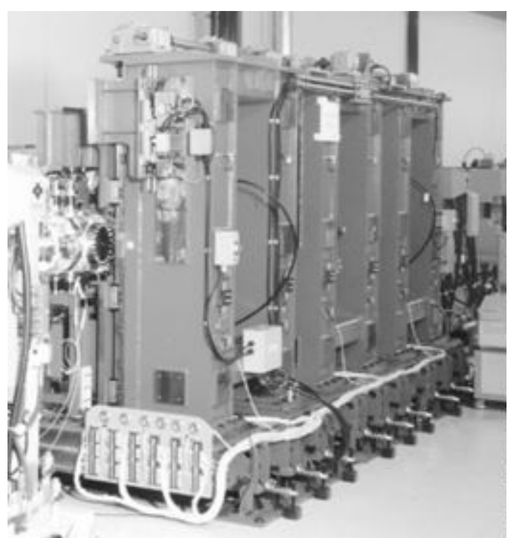

Figure 3: An in-vacuum undulator installed in the storage ring

Insertion device is a key technology for the third generation SR sources, especially for SPring-8. Most of excellent features of synchrotron radiations such as high brilliance, tunability over a wide range of wave length, circular or linear polarization, coherency, microbeam, and time structure of the beam are realized by insertion devices, especially by an undulator. New types of insertion devices have been developed at SPring-8 as listed in Table 3 [4]. Development of in-vacuum undulators allow us to standardize the undulator for SPring-8. For example, an in-vacuum undulator (Figure 3) with a period length λ_u =32mm, one of the standard undulator, can provide X-rays in an energy range from 5.2 to 18.5keV (1st), 15.5 to 51keV (3rd) and 26 to 75 keV (5th) with the brilliance higher than 10^{19} (photons/sec/mm^2 /mrad^2 in 0.1% b.w.). Photon flux in a cone of 50 x 50μrad^2 is 10^{15} (photons/sec in 0.1% b.w.).

An in-vacuum vertical undulator has a horizontal field and provides X-rays linearly-polarized in vertical plane. A figure-8 undulator is composed of horizontal and vertical undulators with a period length of λ_u and $2\lambda_u$, respectively.

Table 3 Insertion devices under construction

Device	λ_u (mm)	N_0.	E(1st,keV)	No.
In-Vac. U	32	140	5.1~18	5
In-Vac Hybrid U	24	188	8.3~24	1
In-Vac. vertical U	37	37x2	4.5~16	1
Twin-Helical U	120	12x2	0.3~ 3	1
Figure-8 U	100	44	0.5~5	1
Variable-Pol. U	120	16	0.5~1.5 0.3~1.5	1
EMPW	120	37	Ec = 42.6	1

Energy range for the variably-polarizing undulator in Table 3 has two values, they are in the cases of circular polarization and linear polarization, respectively.

4 FIRST RESULTS OF COMMISSIONING

Commissioning of the storage ring was started on March 14, 1997. Test operation of the whole accelerator system had been carried on for a week before the commissioning. The strategy of the first phase commissioning is following; we will operate the storage ring and two beamlines, one from an in-vacuum undulator and the other from a bending magnet. A target current of the stored beam is 20mA. After we will succeed to store a current of 20 mA, we will extract SR to the beamlines. On March 14 we injected the beam from the synchrotron to the storage ring. Soon after we could observe the first turn of the beam in the ring. Then we spent five days for fine adjustment of the beam transport line from the synchrotron and the injection section of the ring. On March 21, we started again on-axis injection and after beam energy correction and tune survey, the sextupole magnets were excited. We observed 24 turns of the beam. On March 25, we started operation of RF system. After fine adjustment of phase and frequency we succeeded to store the beam of 0.05mA. The life time of the beam was 7 hours. Next day, March 26, we succeeded to observe the first synchrotron radiations at the front end of the bending magnet beamline (Figure 4). Then we made efforts to correct the COD and to increase the stored current. The target current of 20mA was cleared on April 17. The life time at 20mA was 3 hours but increased to 14 hours at 3.6mA .

Test operation of the in-vacuum undulator was started

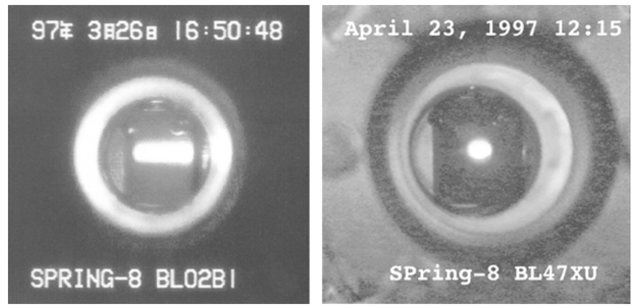

Figure 4: Pictures of the SR spots on the screen monitors in the BM (left) and ID (right) beamlines.

on April 23 and succeeded to observe the first radiations at the front end of the undulator beamline. The spot size of the photon beam on a screen monitor was around 1mm and the position of the spot did not move when the gap was changed from 50 mm to 20mm (Figure4).

4 CONCLUSION

So far the commissioning of SPring-8 has been carried out very smoothly and we found that the performance of the accelerators and the insertion devices is excellent. We will continue to extract photon beams from the bending magnet and the in-vacuum undulator to the mirrors and monochromaters in the optical hutches.

Inauguration of the SPring-8 facility is scheduled in October. The public beamlines will be open for domestic users from October.

REFERENCES

[1] SPring-8 Project Team: 'SPring-8 Project Part 1, Facility Design 1991 [Reviced]' , August 1991. H.Kamitsubo: 'SPring-8 Project' Rev. Sci. Instrum. **63**, 1586 (1992).

[2] H.Yokomizo et al: 'Linac and Synchrotron for SPring-8 Injector' Proc. EPAC'96, 688 (1996).

[3] H.Yonehara et al: 'Synchrotron of SPring-8' Proc. PAC'93, 2093 (1993).

[4] Beamline Handbook; to be published in June 1997 JASRI.