COMMISSIONING OF A COMPACT SYNCHROTRON RADIATION SOURCE AT HIROSHIMA UNIVERSITY

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Abstract

A 700-MeV synchrotron radiation source is under commissioning at Hiroshima University. The ring is of a racetrack type with two undulators, linear and helical ones, at the long straight sections. The bending field, produced by normal conducting magnet, is as strong as 2.7 Tesla, which generates as high radiation power as compatible with the one from usual 1.6-GeV ring. 14 beam-ports from the bending sections together with two from the undulators are prepared. The injector is a 150-MeV racetrack microtron, which is used also for other purposes than the beam injection into the storage ring. As of March 1998, the stored current is typically 100 mA at start and the beam lifetime is three hours. We expect the beam lifetime will be extended to be eight hours after degassing operation for another few months.

1 INTRODUCTION

The project to build a synchrotron radiation (SR) source along with an electron accelerator at Hiroshima University was originally proposed around 1982, 16 years ago, with a nickname HiSOR Project. It was intended that the accelerator facility should benefit the researchers inside the university and outside it as well, especially those from west part of Japan. This policy was affected by the fact that the site for Spring-8 project to build a big third-generation SR source was determined in 1989 to be Nishi-Harima, not so far from Hiroshima. The HiSOR project was thus revised to have a compact SR source which was optimized for research and education in a university. Moreover the injector and the storage ring system was planned to be constructed by industry without creating an accelerator builders group in the university. Current progress of accelerator technology at industries seemed to facilitate this scheme, at least for preparing compact conventional SR source.

In 1996, the revised HiSOR project was approved by the government. The working group in Hiroshima University determined the framework of the SR source to be composed of a 700-MeV storage ring with insertion devices and a 150-MeV microtron as an injector. The working group also specified the characteristics of the SR to be delivered from the storage ring. Through an open tender, the manufacturer of the accelerator system was decided to be Sumitomo Heavy Industries Ltd. (SHI). The electron beam from the microtron was assumed to be used for other research purposes than the injection into the storage ring. The accelerator system was completed until the end of FY1996. Now the storage ring is nicknamed as HiSOR (called as AURORA-2D by SHI) and is operated by Hiroshima Synchrotron Radiation Center (HSRC), Hiroshima University, established in May, 1997[1]. The facilities at HSRC is open also for the researchers from regional universities and institutes. In the following sections, the outline of the SR source system and the results of the commissioning are described.

2 HISOR STORAGE RING

A plan of HiSOR is shown in Fig. 1. It is a 700-MeV synchrotron/storage-ring[2]. A 150-MeV electron beam from the microtron is injected and stored in the ring,

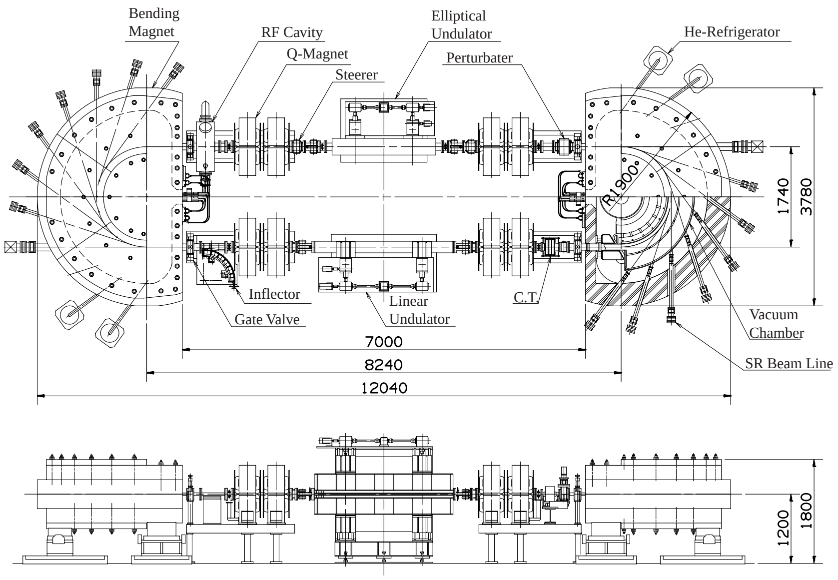

Figure 1: HiSOR storage ring.

accelerated up to 700-MeV and stored to generate synchrotron radiation. The ring is of a racetrack type with two 180° bending magnets and two long straight sections for installing undulators. The distance of the straight sections available for the undulators is about 2.4 m each, in which a linear and a helical undulators are installed. One of the distinctive features of HiSOR is a magnetic field of the bending magnet as strong as 2.7 Tesla, produced by normal conducting magnet technology[3]. In terms of total radiation power, HiSOR ring can be compared with 1.6-GeV ring with usual bending magnet field assumed to be 1.2 Tesla. The critical wave length is equal to the one from 1.1-GeV ring with 1.2 Tesla bending field. The photon energy

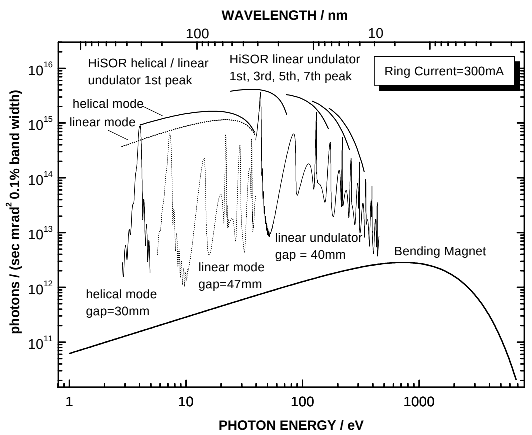

Figure 2 : Photon energy spectra of the synchrotron radiation from HiSOR.

spectra of the SR from HiSOR are shown in Fig. 2. The critical wave length is 1.42 nm. Another merit of the high field magnet is a fast radiation dumping of the injected beam, which is 0.51 sec for an injection energy of 150-MeV. Thus we are able to employ a low-energy injection scheme, and to inject 150-MeV beam with a repetition rate of 2 Hz.

The beam optics of HiSOR ring is shown in Fig. 3. The pole gap of the bending magnet is as narrow as 42 mm in order to keep the necessary magnetomotive force

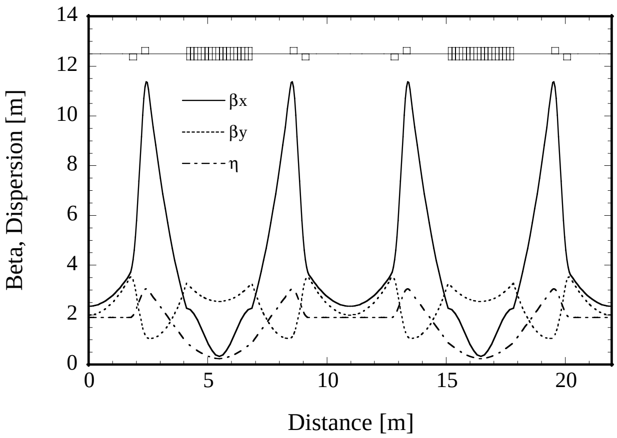

Figure 3: Beam optics of HiSOR ring.

for generating as high magnetic field as 2.7 Tesla below the reasonable level. The inner aperture of the vacuum chamber is only 30 mm. So an edge focusing scheme is employed in the bending magnet to suppress the vertical beta function in the magnet. The vertical beta function should be small also at the straight sections since the vertical aperture of the vacuum chamber is as narrow as 24 mm to allow for the undulator gap to be 30 mm at minimum. The beta function of this part is controlled by the quadrupole doublets at both ends of the straight sections.

The main parameters of HiSOR ring are listed in Table 1.

Table 1 : Parameters of the HSRC Storage Ring.

Type	Racetrack Synchrotron
Injector	Racetrack Microtron
Beam Energy at Injection	150 MeV
at Storage	700 MeV
Magnetic Field at Injection	0.6 T
at Storage	2.7 T
Magnet Pole Gap	42 mm
Bending Radius	0.87 m
Circumference	21.95 m
Betatron Tune, Horizontal	1.72
Vertical	1.84
RF Frequency	191.244 MHz
Harmonic Number	14
RF Voltage	220 kV
Stored Current(Normal)	300 mA
Beam Filling Time	5 Minutes
Beam Lifetime(at 200 mA)	>8 Hours
Beam Emittance	0.4πmm·mr
Critical Wave Length	1.42 nm
Photon Intensity(5 keV)	1.2×10^{11}/sec/mr^2 /0.1%B.W./300 mA
Beam Ports at Bend. Sec.	7×2 with 18°Interval
at Straight Sec.	2
Angular Width of Beam Port	20 mr
Ring Dimensions, Width	3.1 m
Length	12 m
Height	1.8 m
Beam Level	1.2 m
Total Weight	130 Ton.

The specifications of the main components of HiSOR are briefly described below. As for the undulators, the description is given in section 3.

2.1 Bending Magnets

Although the magnetic flux in an iron core saturates at ~2 Tesla, the present bending magnet is specially designed to generate 2.7 Tesla by controlling the oversaturation of the iron core. A cross-sectional view of the magnet is shown in Fig. 4. Th magnet poles are thick at the bases and thin at the tops, resulting in oversaturation of the magnetic field at the tops of the poles. The measured excitation curve is shown in Fig. 5 together with the calculation by TOSCA. The measurements are in excellent agreement with the calculation. The necessary magnetomotive force is rather high, 80000 Ampare Turns, which is generated by electric power consumption of 50 kW for each magnet.

We believe that the running cost may be still less than

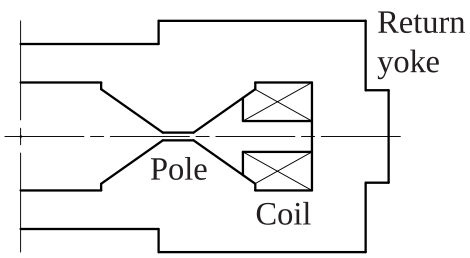

Figure 4 : Cross-sectional view of the bending magnet producing 2.7 Tesla at the poles.

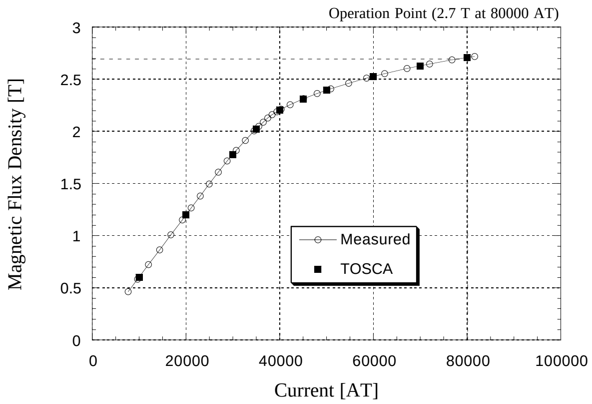

Figure 5: Excitation curve of the 2.7 Tesla bending magnet in comparison with the calculation by TOSCA.

for superconducting rings. The synchrotron radiation is delivered through holes drilled in the thick magnet yoke, as seen in the right part of Fig.1. This configuration enables us to ease the radiation protection since the high-energy gamma rays are absorbed by the yoke, except at the photon beam ports. This situation thus allows the synchrotron radiation users to approach close to the radiation source to have intense photon flux.

2.2 Vacuum System

The cryosorption pump with a pumping speed of 20000 litters/s has been employed for the evacuation of each bending section. The composition of the cryosorption pump is shown in Fig. 6. It is operated with a 80 K

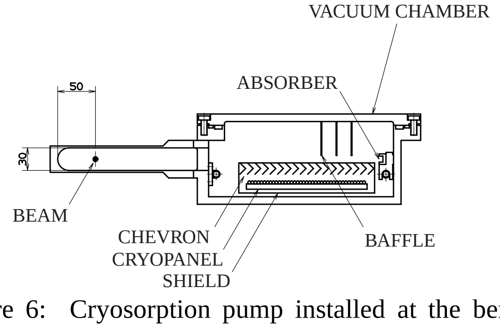

Figure 6: Cryosorption pump installed at the bending sections. All dimensions are millimeters.

and a 5 K refrigerators. Adoption of the cryosorption pump with a large pumping speed is almost inevitable because the photon flux density is very high due to the strong magnetic field, and also because the bending section is composed of a single 180° bending magnet with no space for installing large pumps. The straight sections are pumped by usual ion pumps and NEG pumps.

2.3 Control System

As the control system, we have adopted personal computers supported by LAN, instead of a large console driven by mini-computer[4]. This scheme will enable us to catch up with the current high technology by replacing part of the hardware with the newest version.

3 UNDULATORS

Parameters of the linear and the helical undulators[5] are tabulated in Table 2 . The former generates linearly

Table 2: Parameters of the undulators at HiSOR

Linear undulator	
Period length	57 mm
Number of periods	41
Total length	2354.2 mm
Gap distance	30-200 mm
Max. Magnetic field	0.41 Tesla
Magnet material	Nd-Fe-B(NEOMAX- 44H)
Helical/linear undulator	
Period length	100 mm
Number of periods	18
Total length	1828.6 mm
Gap distance	30-200 mm
Max. magnetic field in helical mode	0.347 Tesla
Max. magnetic field in linear mode	0.597 Tesla
Magnet material	Nd-Fe-B(NEOMAX-44H)

polarized photons in a energy range between 25 and 300 eV with an intensity three orders of magnitude higher than that from the bending magnets. The latter, on the other hand, produces photons with controlled elipticity, from linear to circular, in the energy range from 4 to 40 eV, according to selected magnet array arrangement. The energy spectra of photons from the undulators are shown in Fig. 2.

4 INJECTOR MICROTRON

We have adopted a racetrack microtron as the injector on account of its cost, better beam quality and smaller machine size compared with other conventional accelerators such as the linac and the synchrotron. SHI had developed the racetrack microtron of the present type in 1990 based on the concept designed at University of Wisconsin[6]. After some improvements, the performance and the stability of the SHI microtron are well established. In Table 3, general parameters of the microtron are listed.

Table 3: Parameters of the Racetrack Microtron

Output Beam Energy	150 MeV
Input Beam Energy	80 keV
Peak Beam Current	2-10 mA
Beam Pulse Width	0.2-2μsec
Repetition	0.2-100 Hz
Beam Emittance	0.5πmm-mr(1σ)
Energy Dispersion	±0.1%(1σ)
Mag. Field of Bending Mag.	1.23 T
Magnetic Field Gradient	0.14 T/m
Pole Gap of Bending Mag.	10 mm
Number of Turns	25
Energy Gain per Turn	6 MeV
Accelerator Structure	8 Cell Side-Coupled Cavity
Accelerator Bore	10 mm
RF Frequency	2856 MHz
RF Field Gradient	15 MV/m
RF Wall Loss	1.5 MW(Max.)
Beam Loading	2.0 MW(Max.)

Due to the multi-turn injection, the beam accumulation speed of the ring is expected to be higher than 10 mA/s for a peak injection beam current of 2 mA with a repetition of 2 Hz. A stronger peak current of 10 mA and higher repetition of 100 Hz are prepared for other purposes than injection to the storage ring.

5 COMMISSIONING

The layout of the completed SR facility at Hiroshima University is shown in Fig. 7. The storage ring is surrounded by a 30 cm thick concrete wall as a radiation shield. The injector microtron, on the other hand, is installed in another room whose concrete wall is 150 or 200 cm thick. The reason of this configuration is that the microtron may be used for other purposes than the beam injection to the storage ring, with a beam power 25 times higher than for the beam injection to the storage ring at maximum.

The operation of the microtron was started by SHI in February 1997, followed by beam injection into the storage ring at the beginning of April. The stored current just after injection at 150 MeV and after acceleration up to 700 MeV reached 485 mA and 276 mA, respectively, until the end of May. The beam lifetime, however, was only about 20 min at that time,

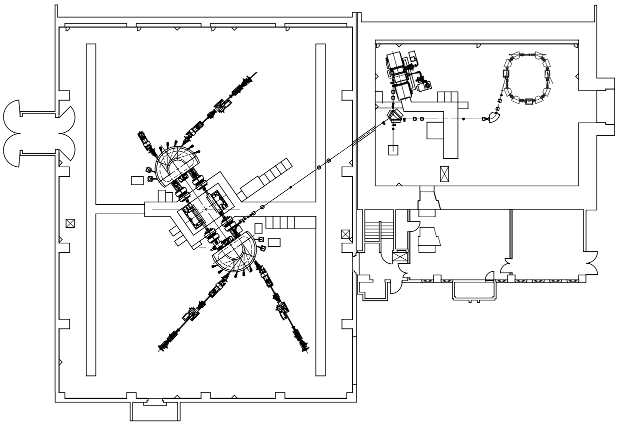

Figure: 7 Layout of the synchrotron radiation facility at Hiroshima Synchrotron Radiation Center.

which was regarded as due to insufficient vacuum degree. After some improvements of the vacuum system, the operation of the accelerators was put into the hands of university staff.

Fig. 8 shows an example of the record of beam storage.

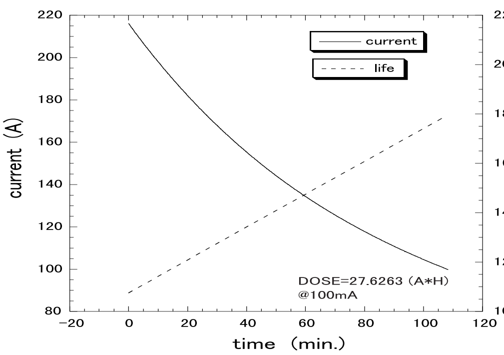

Figure 8: An example of the record of beam storage, showing the decay of the stored current and the change of the instantaneous beam lifetime.

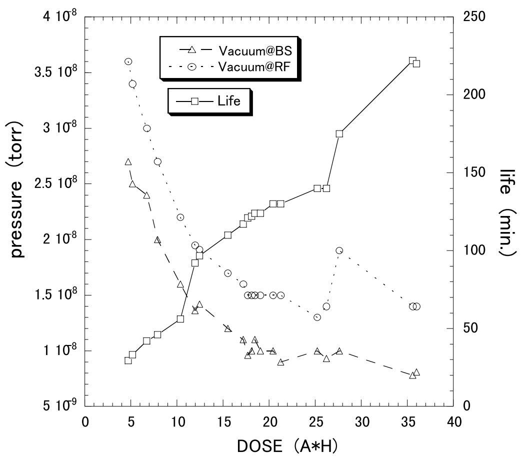

Figure 9: Improvements of the vacuum degree as observed at two points of the storage ring and the beam lifetime at stored current of 100 mA, as a function of integrated dose of stored current times storage hour.

The initial stored current of 220 mA decays down to 100 mA in about 110 minutes. The instantaneous beam life is about 100 minutes when the beam current is 220 mA and is extended to be about 180 minutes for 100 mA, according to the change of the vacuum degree. Thus the beam lifetime is strongly dependent on the vacuum degree, which is expected to improve by degassing operation. Fig. 9 shows the improvements of the vacuum degree and the beam lifetime at 100 mA depending on the integral dose of the stored current(A) times stored time(hour). At the Dose of 36 Ampere times Hour, which corresponds to the operation during about three months, the beam lifetime at 100 mA came up to about 4 hours. The improvement of the vacuum degree, however, seems to approach the saturation. We have a plan of upgrading the vacuum system.

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