

Compact synchrotron light source of the HSRC

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A 700 MeV synchrotron radiation source optimized in order to be incorporated in the university laboratory is under commissioning at Hiroshima University. The storage ring is of a racetrack type with two long straight sections for installing undulators. The bending field is as strong as 2.7 T, produced by normal-conducting magnet technology, and delivers synchrotron radiation with a critical wavelength of 1.42 nm. The strong magnetic field also enables a low-energy injection scheme to be employed owing to the fast radiation damping. A 150 MeV microtron has been adopted as the injector.

Keywords: compact racetrack-type rings; normal-conducting high-field magnets; radiation-shielding magnets; low-energy injection.

1. Introduction

Hiroshima Synchrotron Radiation Centre (HSRC) at Hiroshima University operates a 700 MeV storage ring with undulators. The injector for the ring is a 150 MeV microtron, which is supposed to be used for other purposes than as the injector. The facility is optimized to be incorporated in a university (Taniguchi & Ghijssen, 1997). The manufacturer of the accelerator system is Sumitomo Heavy Industries Ltd. The light source is now under commissioning. In the following sections the major specifications of the accelerator system and the present status of the commissioning are outlined.

2. Storage ring

2.1. General features

The storage ring is a racetrack type with two 180° bending magnets and two long straight sections for installing undulators, as shown in Fig. 1. The length in the straight section actually available for an insertion device is 2.4 m, while the total length between the quadrupole magnets is 3.4 m. A linear and a helical undulator is installed in each straight section (Hiraya *et al.*, 1998). A distinctive feature of this ring is the strong magnetic field of the bending magnet, 2.7 T, produced by normal-conducting magnet technology (Hori & Takayama, 1995). With an electron energy of 700 MeV, the critical wavelength of the synchrotron radiation from the bending section is 1.42 nm. For conventional magnets, probably of ~1.2 T, an electron energy of 1.1 GeV would be needed to achieve the same critical wavelength, and 1.6 GeV for

Table 1

Specifications 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 min
Beam lifetime (at 200 mA)	>8 h
Beam emittance	0.47 mm mrad
Critical wavelength	1.42 nm
Photon intensity (5 keV)	$1.2 \times 10^{11} \text{ s}^{-1} \text{ mrad}^{-2}$ (0.1% bandwidth) ⁻¹ (300 mA) ⁻¹
Photon beam ports:	
at bending section	7 × 2 with 18° interval
at straight section	2
Angular width of beam port	20 mrad
Ring dimensions:	
width	3.1 m
length	12 m
height	1.8 m
Beam level	1.2 m
Total weight	130 ton

obtaining the same radiation power. Another merit of the high-field magnet is a fast radiation dumping of the injected beam, which is 0.51 s for an injection energy of 150 MeV. Thus we can operate the 150 MeV microtron with a repetition of 2 Hz for injection.

A total of 14 photon beam ports from the bending sections and the two from the straight sections are available. The expected photon energy spectra from the bending section together with those from the undulators are shown in Fig. 2. The main parameters of the storage ring are listed in Table 1.

2.2. Bending magnets

Although the magnetic flux in an iron core saturates at ~2 T, the present bending magnet is specially designed to generate 2.7 T by controlling the oversaturation of the iron core. A cross-

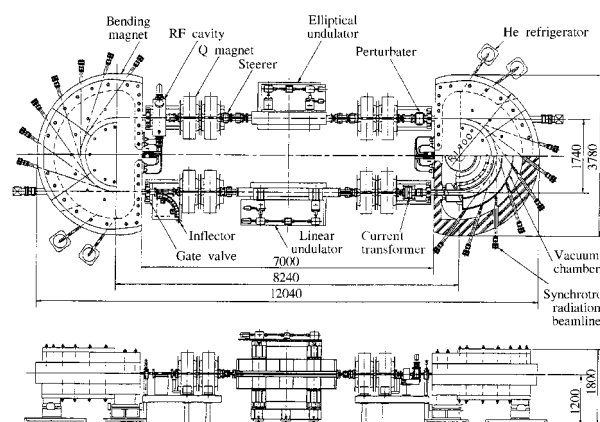


Figure 1
HSRC storage ring. All dimensions are millimetres.

sectional view of the magnet is shown in Fig. 3. The magnet pole is thick at the base and thin at the top, resulting in oversaturation of the magnetic field at the top of the pole. The magnet gap is as narrow as 42 mm to suppress the necessary magnetomotive force, which is 80000 AT generated by an electric power consumption of 50 kW for each magnet. We believe that the running cost may still be less than for superconducting rings. The measured excitation curve is in good agreement with calculation, as shown in Fig. 4. Synchrotron radiation is delivered through holes drilled in the thick magnet yoke. This configuration enables us to ease the radiation shielding since the high-energy gamma rays are absorbed by the yoke, except at the photon beam ports.

2.3. Beam optics

The beta and dispersion functions are shown in Fig. 5. To suppress the vertical beta function in the bending magnet, whose effective gap is 30 mm, we have employed an edge-focus scheme: the magnet edges have a slant of 30.7° with respect to the normal, producing a vertical focusing force. The vertical beta function should be small also at the straight sections where the undulators are installed and the effective gap is only 24 mm. The quadrupole doublets at both ends of the straight section work to control the beta function at the straight section. The natural beam-emittance is reasonably small, about 0.5π mm mrad, in spite of a relatively small number of magnet elements.

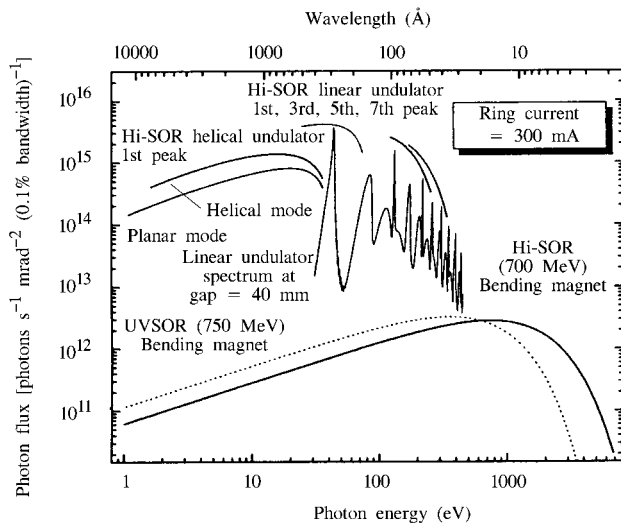


Figure 2 Energy spectra of the photons from bending sections and undulators.

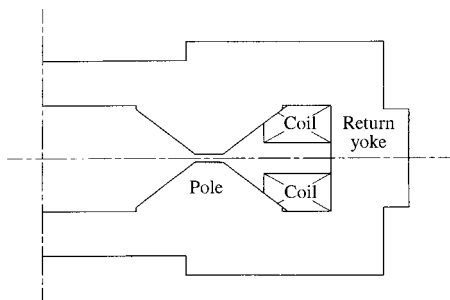


Figure 3 Cross-sectional view of the bending magnet producing 2.7 T at the poles.

2.4. Vacuum system

The main pump of the storage ring is a cryosorption pump at the bending section. A combination of a cryopanel, a photon absorber and baffles, installed between the upper and lower magnet coils, is shown in Fig. 6. Although this part of the vacuum chamber is not bakeable, the strong pumping ability of the cryosorption pump, 40000 l s⁻¹ in total, can deal with the outgas from the chamber surface. The straight sections are pumped by usual ion pumps and NEG pumps.

2.5. Control system

As the control system, we have adopted personal computers supported by a LAN, instead of a large console driven by a mini-computer (Aoki *et al.*, 1997). This scheme will enable us to catch up with the current high technology by replacing part of the hardware with the newest version.

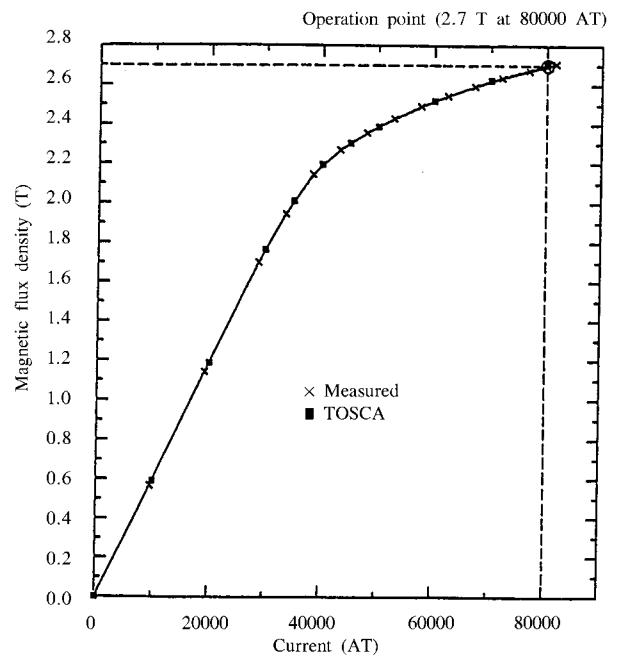


Figure 4 Excitation curve of the 2.7 T bending magnet in comparison with the calculation by a computer code (TOSCA).

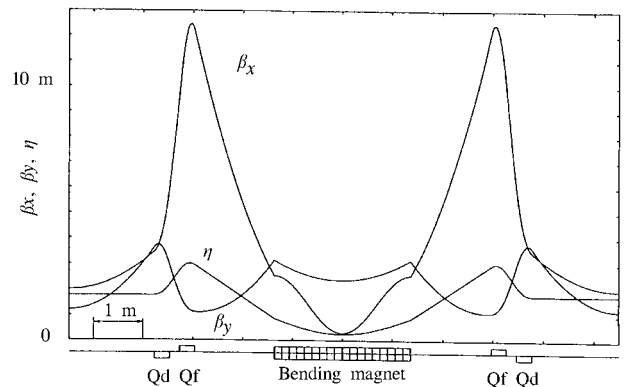


Figure 5 Beta and dispersion functions of the HSRC storage ring.

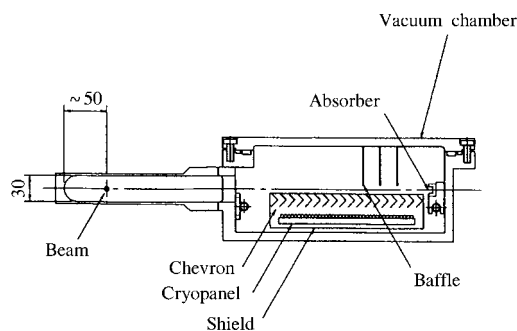
Table 2

Parameters of the racetrack microtron.

Output beam energy	150 MeV
Input beam energy	80 keV
Peak beam current	2–10 mA
Beam pulse width	0.2–2 μ s
Repetition	0.2–100 Hz
Beam emittance	0.5 π mm mrad (1σ)
Energy dispersion	0.1% (1σ)
Magnetic field of bending magnet	1.23 T
Magnetic field gradient	0.14 T m ⁻¹
Pole gap of bending magnet	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 ⁻¹
RF wall loss	1.5 MW (maximum)
Beam loading	2.0 MW (maximum)

2.6. Undulators

The linear undulator has 41 magnetic field periods, with a period length of 57 mm. By varying the gap down to 30 mm, it can be tuned to emit radiation with energies ranging from 30 to 300 eV and with an intensity enhancement of three orders of magnitude compared with bending magnets. The helical undulator, on the other hand, has 18 periods with a period length of 110 mm and produces radiation with circular, elliptical or linear polarization in the range 1–30 eV according to the selected magnet array arrangement.

**Figure 6**

Cryosorption pump system installed at the bending sections. All dimensions are millimetres.

3. Injector microtron

We have adopted a 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 the University of Wisconsin (Hori *et al.*, 1991). After some improvement, the performance and the stability of the SHI microtron are now well established. In Table 2, general parameters of the microtron are listed.

Due to the multi-turn injection, the beam accumulation speed of the ring is expected to be higher than 10 mA s⁻¹ 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.

4. Status of commissioning

The commissioning of the injector microtron was started in February 1997, followed by beam injection into the ring at the beginning of April. The stored current just after injection at 150 MeV and after acceleration up to 700 MeV reached 485 and 276 mA, respectively, until the end of May. The beam lifetime, however, was only about 20 min at that time. The reason for the short lifetime was regarded as due to insufficient vacuum degree, which was supposed to be the result of a rather low baking temperature, 323 K, for the RF cavity and the eight pairs of ion clearers to avoid cracking, while the temperature for other parts of the vacuum chamber was 393 K. After remodelling the relevant parts, we were able to bake the whole vacuum system at 393 K in July. Our tentative aim is to store the beam of 100 mA with a lifetime of 3 h.

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