Design and R&D's of Accelerator Components for the VSX Light Source

The VSX accelerator group, presented by Tadashi KOSEKI
Synchrotron Radiation Laboratory (SRL), The Institute for Solid State Physics (ISSP),
The University of Tokyo, 3-2-1, Midori-cho, Tanashi-shi, Tokyo 188-0002, Japan

Abstract

Design studies for the VSX light source facility have been going on at the University of Tokyo in close collaboration with Photon Factory (PF) of KEK. The outline of the facility and recent status of the design and R&D work for accelerator components are described in this paper.

1 Introduction

Figure 1 shows a layout of the VSX light source accelerator complex. It consists of a 1.0-GeV S-band linac (underground), a beam transport line and a 1.0-1.6 GeV racetrack ring (on the ground) with a circumference of about 250 m. The ring is composed of two long (29 m) straight sections, two short (2 m) straight sections, eight matching sections and 20 normal cells [1]. The lattice configuration of normal cells is "theoretical minimum emittance" type, which is possible to obtain an emittance smaller than the DBA lattice by a factor of three. For synchrotron radiation (SR) experiments, the following two operating modes are preparing; (1) low-emittance mode optimized at a beam energy of 1.0 GeV and (2) high-emittance mode that can be operated up to an energy of 1.6 GeV. In the low-emittance mode, the ring can reach an emittance of diffraction limit, and 27 m undulator installed in one of the long-straight sections can provide extremely high-brilliance radiation more than 10^{20} [photons/sec/mm^2/mrad^2/0.1%b.w.] in the VUV region. On the other hand, in the high-emittance mode, high-brilliance radiation comparable to that of existing third-generation SR sources is generated over a wide wavelength range from VUV to Soft X-ray.

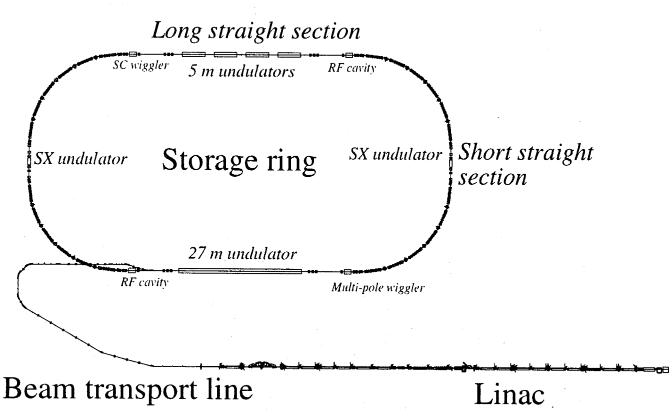

Fig. 1 Layout of the VSX accelerator complex.

Figure 2 shows the lifetimes due to gas scattering of the VSX ring. Lifetimes in this figure are calculated in three cases of minimum transverse acceptance; they are defined by (1) dynamic aperture, (2) the gap at insertion device (ID) of 10 mm and (3) the gap at ID of 16 mm. The vacuum pressure is assumed to be CO-equivalent. The beam lifetimes for the low-emittance mode and high-emittance mode are determined by dynamic aperture and gap at ID, respectively. As shown in this figure, low pressure less than 0.1 nTorr is required to attain a long enough lifetime.

Figure 3 shows the Touschek lifetime of the ring. The RF voltage of 0.7 MV is obtained by one RF cavity. Thus two cavities will be used to provide the sufficient accelerating voltage at 1.6 GeV with high current.

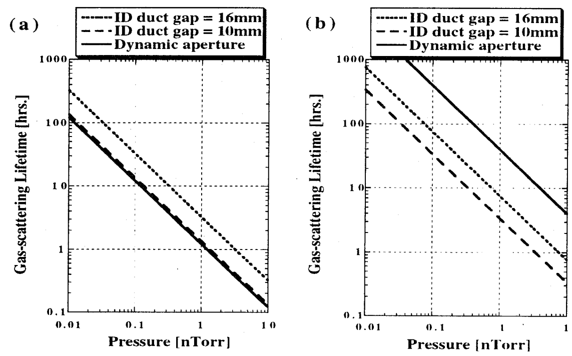

Fig. 2 Beam lifetime due to gas scattering. (a) for the low-emittance mode at 1.0 GeV, coupling of 10 %, and accelerating voltage of 0.7 MV; (b) for the high-emittance mode at 1.6 GeV, coupling of 1 %, and accelerating voltage of 0.7 MV.

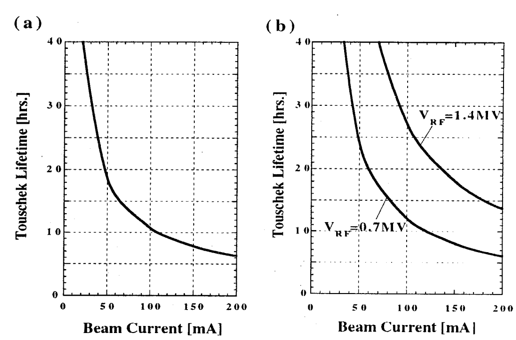

Fig. 3 Touschek lifetime. (a) for the low-emittance mode at 1.0 GeV, coupling of 10 %, and accelerating voltage of 0.7 MV; (b) for the high-emittance mode at 1.6 GeV and coupling of 1 %.

2 Storage Ring

2.1 Magnet system

The VSX ring lattice has 28 dipoles, 148 quadrupoles and 72 sextupoles. The main parameters of the magnets are listed in Table 1. The magnet cores are made of forged low-carbon solid-steel for the dipoles and laminated silicon-steel for the quadrupoles and sextupoles. All magnets are designed to be able to split in the mid-plane in order to install a vacuum chamber easily. The dipoles are electrically connected in series and powered by a large power supply with thyristor rectifiers. On the other hand, the quadrupoles and sextupoles are individually powered for operational flexibility.

Table 1: Main parameters of the magnets.

Magnet	Dipoles		Quadrupoles				Sextupoles	
Family	B	BH	QF	QD	Q's in the matching sections		SF	SD
Number required	20	8	40	48	44	16	48	24
Gap or Bore diameter [mm]	40		70		70	80	70	
Effective length [m]	0.8	0.4	0.4	0.3	0.2/0.3/0.35/0.4	0.4	0.2	0.4
Max. strength [T, T/m, T/m^2]	1.74		20		22	15	500	500
Turn numbers / pole	30		25		25		26	
Conductor size [mm]	16×15-ø9		8×8-ø5		8×8-ø5		8×8-ø5	
Max. current [A]	680		410		470	400	130	130

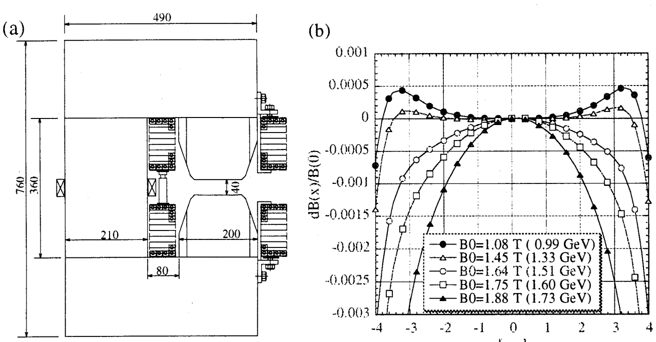

Fig. 4 The VSX dipole magnet. (a) cross section, and (b) field distribution.

The dipole magnets B and BH have an identical cross section as shown in Fig. 4 (a). They have a C-type rectangular configuration and bending radius of 3.056 m. The required magnetic fields for 1.0-GeV and 1.6-GeV operations are 1.09 Tesla and 1.75 Tesla, respectively. In order to obtain good field uniformity for such high field, the corners of the pole edges are largely cut off as shown in this figure. Figure 4 (b) shows the horizontal field uniformity calculated by the 2D code LINDA. The construction of a prototype model of the dipole is now in progress and will be completed by the end of October 1999.

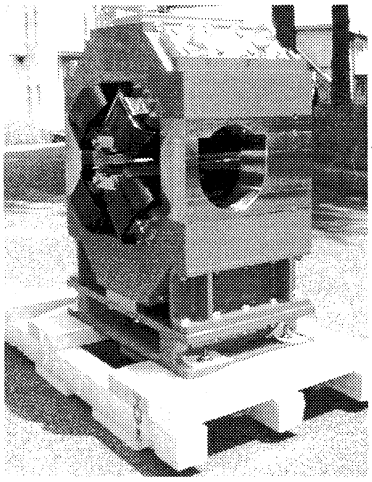

Fig. 5 Prototype model of the C-type quadrupole

For all quadrupoles except for some of those installed in the matching sections, C-type profile is adopted to accommodate SR beamline. The magnet core consists of symmetrical upper and lower parts, which are joined by stainless-steel spacers. Each spacer has a hole of 190 mmϕ, to which a pumping port can be attached in order to obtain a high pumping speed at the downstream of the ring arcs. Figure 5 shows a photograph of the prototype model of the C-type quadrupole. The silicon-steel laminations are assembled by gluing without any supporting plates. Although the magnet has a C-type configuration, the core and support have a fairly symmetrical structure, so that it would be robust for deformation caused by magnetic field or thermal load.

2.2 RF cavity

The RF cavity of the VSX ring is the HOM (Higher-Order Mode) damped cavity developed by the collaboration of SRL-ISSP and KEK [2]. The cavity has a large diameter beam duct, a part of which is made of SiC microwave absorber. In the PF ring, all of four cavities have been already replaced by the damped cavities and no coupled-bunch instabilities due to the cavities have been observed [3].

Though the cavities are operating at the PF ring quite successfully, our R&D effort is continuing to obtain still better performance of HOM damping for the VSX ring. One of the recent progresses is a development of HOM coupler with a rod-shaped coupling antenna to reduce impedance of "trapped modes". The trapped modes are HOM's which can not be absorbed by the SiC beam duct. We fabricated two cold models of HOM coupler and tested them at a low power level. It was found that they could reduce impedances of the six trapped modes without affecting the accelerating modes [4].

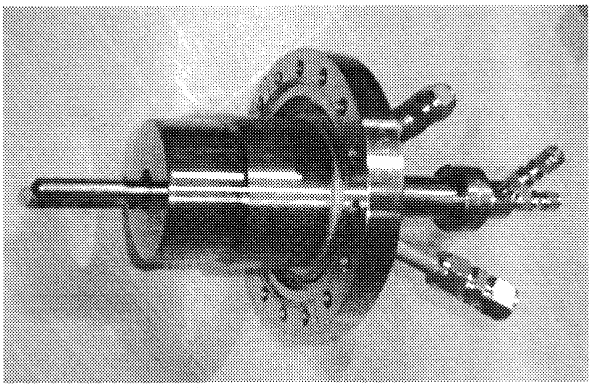

Fig. 6 High-power model of the HOM coupler.

Recently, we have designed and fabricated a high-power model of the HOM coupler [5]. Figure 6 shows a photograph of the high-power model. The rod antenna is followed by a coaxial waveguide structure. To dissipate the extracted HOM power, a taper-shaped SiC piece, which is the same material as the microwave absorber at the beam duct, is mounted on the end of the waveguide. The rod antenna, inner conductor and outer block are made of OFHC copper and cooled by water. The high-power test of the HOM coupler will be carried out at an RF test bench of KEK-PF in the near future.

2.3. Vacuum system

The vacuum system of the VSX ring is required to achieve a vacuum pressure less than 0.1 nTorr with the beam. A large number of the pumping units, each of which consists of standard titanium sublimation pump and sputter ion pump, will be installed in the ring. Figure 7 shows the schematic of the vacuum chamber and magnets for a normal cell. As mentioned the previous subsection, the pumping units will be attached not only to the bending sections but also to every quadrupole section.

All chambers of arc sections would be made of aluminum alloy, except for flanges and bellows. On the other hand, the chambers of ID's are all made of stainless-steel. Because of relatively low conductivity of the stainless-steel and narrow vertical aperture of the ID chamber, the growth rate of the transverse resistive-wall instability becomes large and also heat load due to the parasitic loss is not negligible. In order to suppress the influence of the resistive-wall impedance, the inner surface of all ID chambers will be coated with copper [6]. We have fabricated the stainless-steel test chamber, the inner surface of which is coated with copper of 100~200 μm thick. The baking test and measurement of out-gas from the copper surface are now in progress.

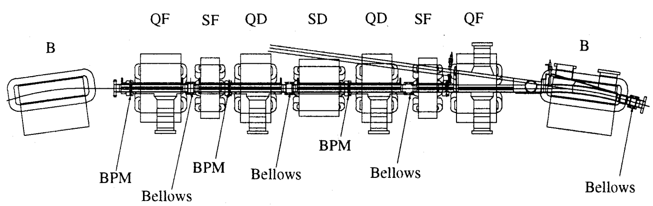

Fig. 7 Schematic view of a normal cell.

2.4. Control system, feedback system, injection system and insertion devices.

The control system of the VSX accelerator facility consists of several computers (workstations and personal computers), VME systems that are installed at various locations near the hardware devices, and high-speed network system using FastEthernet. Each VME system has a branch network, in which the PLC and the NIO (Network I/O) systems are also utilized as device controllers.

The R&D of the fast orbit feedback system is going on now. The feedback control is based on the VME system containing high performance DSP's and shared memory networks [7]. For the orbit correction, more than 100 fast steerings will be installed in the ring. A steering that is made of laminated silicon-steel has a square window-frame yoke and can produce both horizontal and vertical fields. It would be able to operate in a frequency range up to 100 Hz. A prototype model of the fast steering magnet is being fabricated and it will be delivered to SRL-ISSP this October.

The design study of the transport line and the pulse injection magnets is in progress. R&D of a power supply for the kicker magnet is also being carried out. The power supply has a high voltage switch using IGBT modules instead of a thyratron switch. It is designed to operate with 2 kA peak current, less than 780 ns pulse width and 37 kV charged voltage.

For insertion devices, the basic design of the 5 m planer and circular undulators have been finished. Manufacturing procedure of the 27 m undulator is under investigation. The 27 m undulator will be comprised 6 units, each of those being 4~5 m long. It will have one unit in the commissioning phase of the ring, and will be extended one by one up to 27 m long. The brilliance and photon flux to be obtained by some typical devices are shown in the WWW site of the VSX project [8].

3 Injector linac

The injector linac consists of an electron gun, S-band pre-bunchers and buncher, and 12 regular accelerating sections. The accelerating sections, each of which has a constant gradient structure with 2π/3 operating mode, are driven by six 80 MW klystrons, each having a SLED cavity. Table 2 lists the main parameters of the linac. There are three operating modes of the linac. The short and semi-long modes are for beam injection to the storage ring. The long mode is to generate the slow positron beam for material science experiments. The target for positron production will be located at the end of the linac. When the ring is in a storage mode, the linac can be dedicated to the slow positron experiments.

Table 2 Main parameters of the linac

Frequency [MHz]	2856		
Normalized emittance	< 50 πmm·mrad		
Repetition rate [Hz]	50 (max.)		
Beam pulse mode	Short	Semi-long	Long
Energy [GeV]	1	1	0.5
Pulse duration	1 ns	15~30 ns	0.5 ~ 2 μs
Current [mA]	400	400	300

We have designed an accelerating structure with higher shunt impedance than the conventional SLAC-type structure [9]. The prototype model of an accelerating section having this new structure is being fabricated. The RF characteristics and high-power performance of the new structure will be investigated in the near future. For the long pulse mode, large energy spread of the linac beam due to initial beam loading effect is one of the main factors of beam loss. R&D of a new method for compensating the initial beam loading by amplitude modulation of RF input to the klystron is also well under way.

References

[1] H. Takaki *et al.*, "Optics of the VSX Light Source", in these proceedings.
[2] T. Koseki *et al.*, Rev. Sci. Instrum., **66**, 1926, (1995)
[3] M. Izawa *et al.*, J. Synchrotron Rad., **5**, 369, (1998).
[4] T. Koseki *et al.*, Proc. 6th EPAC, Stockholm, 1998, p. 1776.
[5] T. Takahashi *et al.*, Proc. 1999 PAC, New York, 1999, p. 904.
[6] N. Nakamura *et al.*, Proc. 6th EPAC, Stockholm, 1998, p. 984.
[7] M. Satoh *et al.*, "Fast Orbit Feedback Control System for the VSX Ring", in these proceedings.
[8] http://www.issp.u-tokyo.ac.jp/labs/sor/index-e.html
[9] K. Hanakawa *et al.*, Proc. 23rd Linear Accelerator Meeting in Japan, Tsukuba, 1998, p. 384.