THE SSRF ACCELERATOR COMPLEX

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Abstract

The Shanghai Synchrotron Radiation Facility (SSRF) is an intermediate energy light source under design and R&D at Shanghai National Synchrotron Radiation Center (SSRC). Its accelerator complex consists of a 3.5GeV electron storage ring, a full energy booster and a 300MeV linac. Since the SSRF R&D program began in 1999, the design of the SSRF accelerator complex has been evolved smoothly towards a cost-effective machine. The key component prototypes of the SSRF accelerators have been manufactured and tested up to their design specifications. This paper reviews the design and R&D progress of the SSRF accelerator complex and reports its present status.

1 INTRODUCTION

The SSRF as a future third generation light source aims at providing powerful X-rays to the Chinese SR users in a variety of research fields. The recent developments in the applications of the protein crystallography to structure biology lead a new trend of SR researches, and will be the most important applications of the SSRF too. Because of the growing demands of the SR users in life science field, the SSRF design has been evolved to produce high brightness and high flux X-rays in the photon energy range of 0.1~40keV, with the emphasis on 5~20keV. In the latest design version sketched in Fig. 1, the SSRF complex consists of three main parts: a full energy injector including a 300MeV linac and a 3.5GeV booster, a 3.5GeV storage ring and the synchrotron radiation experimental facilities. The SSRF storage ring energy of 3.5GeV has been determined following the concept of using intermediate energy beam and advanced insertion devices to produce X-rays for majority of the SR users. The current design of the SSRF storage ring is not dominated by pursuing extreme low beam emittance but cost-effectiveness to the users.

The SSRF project was proposed by the Chinese Academy of Sciences (CAS) and the Shanghai Municipal Government (SMG) in 1995, its R&D program was approved with a budget of 80M Chinese Yuan in 1998 and was conducted at SSRC from January 1999 to March 2001. During this period, 41 prototypes of the main components of the SSRF accelerators and beam lines have been developed and tested up to their design specifications. In the mean time, the SSRF technical design has been carried out and timely reviewed by the international review committees and the SSRF Committee of Science and Technology.

The site selection for the SSRF was done by the joint efforts of the CAS and the SMG in 1999. Through a bid process among 5 candidates, the Zhang-Jiang High-Tech Park in Pudong, Shanghai has been chosen to site the SSRF complex. The SSRF site is a 600m×300m green land and is readily accessible now.

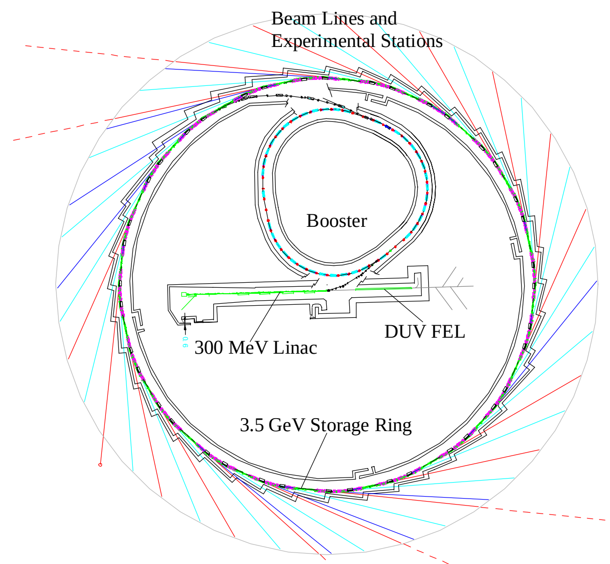

Fig. 1: Layout of the SSRF

2 STORAGE RING

The storage ring is the core part of the SR light source. Its characteristics determine the source performance. The designs of the SSRF storage ring have been evolved to a cost effective machine over the last 5 years [1] [2], its current specifications are featured with robust and flexible lattice configuration and advanced mature technology. Apart from brightness and flux, other essential issues of the storage ring are focused on the beam stability, such as ground conditions, girder vibrations, chamber mechanical stability and temperature control in the storage ring tunnel. Further more the top-up injection is also incorporated into the design considerations.

2.1 Magnetic Lattice and Performances [3] [4] [5]

The latest SSRF storage ring lattice is composed of 20 double-bend achromat (DBA) cells with 396 meters in circumference. It provides ten 7.24m straight sections and ten 5.0m straight sections for accommodating injection components, RF cavities and insertion devices. Each asymmetrical DBA cell contains 2 bending magnets, 10 quadrupoles and 7 sextupoles. Among them there are a quadrupole triplet and two harmonic sextupoles located at each end of the cell. This lattice has high flexibility to

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operate in normal beta and hybrid beta configurations, the beta functions in the middle of the straight section can be adjusted in a wide range. The high β_x is 12m and the low β_x is about 1m, the tunes (Q_x/Q_y) are 18.81/8.77 and 22.19/8.23 for high β_x and hybrid β_x modes respectively. The non-zero dispersion in straight section is also employed in the low emittance lattice configurations, which gives a reduction factor of about 2.4 to the natural emittance.

The main parameters of the SSRF ring are shown in Table 1. The corresponding photon brightness is depicted in Fig. 2.

Table 1: Main Parameters of the SSRF Storage Ring

Energy (GeV)	3.5
Circumference (m)	396
Harmonic Number	660
Nature Emittance (nm·rad)	4.8~12.1
Beam Current, Multi-Bunch (mA) Single-Bunch (mA)	200~300 >5
Straight Lengths (m)	10×7.24, 10×5
Betatron tunes, Q_x/Q_y	18.81/8.77, 22.19/8.23
Momentum Compaction	6.9×10^{-4}
RF Frequency (MHz)	499.654
RF Voltage (MV)	4
Dipole Radiation per Turn (MeV)	1.256
Bunch Length (mm)	4.59
Beam Lifetime (hrs)	>20

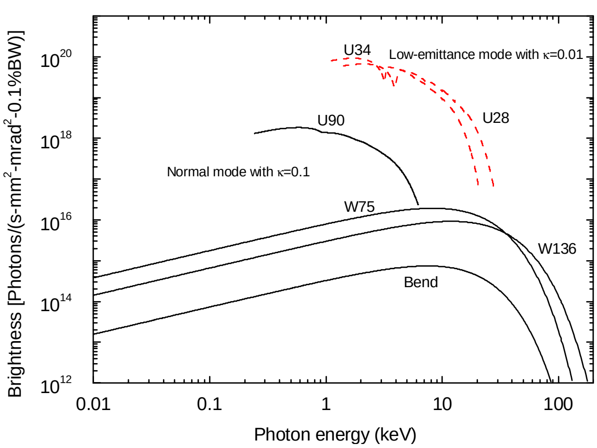

Fig. 2: Spectral Brightness of SSRF

The new developments in insertion devices, such as high harmonic operation, in-vacuum IDs and etc., will enhance the SSRF performance. The photon brightness of the SSRF sketched above can be further improved by employing advanced insertion devices.

The dynamic aperture of each SSRF storage ring lattice configuration has been examined extensively with RACETRACK and MAD, both of the high beta and hybrid beta lattices have reasonably larger dynamic apertures and momentum acceptance with the effects of systematic and random multipole errors of magnets. The influence of insertion devices upon dynamic aperture has been also verified with and without magnet errors, which shows that the magnet errors dominate the ring dynamic aperture.

Analysis of the orbit stability issues and study of the orbit correction methods have been carried out for the SSRF storage ring. Besides a dynamic orbit feedback for correcting the slow variation of the vertical beam orbit within 5μm, a fast global feedback system is planned to stabilise the vertical orbit motion in the frequency up to 100Hz. This global feedback contains 40 broadband air-coil correctors and 38 high stable BPMs.

The collective effects in SSRF have been examined, including the broadband impedance, coupled bunch instabilities and ion trapping issues. The conclusion is that only a transverse beam feedback system is needed for damping the resistive wall induced instability. The beam lifetime of the SSRF storage ring was calculated with ZAP, the estimated lifetime is more than 20 hours.

2.2 Magnet System [6]

The SSRF storage ring has 40 C-shape straight dipoles, 200 Collins-type quadrupoles, 140 C-shape sextupoles and 78 horizontal and vertical combined dipole correctors. All the main magnet protypes have been designed at SSRC, and manufactured in IHEP Beijing, Kelin Co. Shanghai and CUSTC Hefei respectively. The 1.66m dipole has a good field region of ±40.3mm in horizontal plane for accommodating the 32.6mm beam sagitta. The 56mm dipole gap, 72mm quadrupole diameter and 88mm sextupole diameter are determined to meet the minimum beam chamber aperture requirement. The dipole field is 1.105T, the maximum quadrupole gradient is 18.5T/m and the maximum sextupole gradient is $500T/m^2$. There are additional trim coils in the dipoles, quadrupoles and sextupoles, which can provide 3%, 1.8T/m and 0.45T/m skew component adjust range to the corresponding magnets. The prototypes of a dipole, a quadrupole and a sextupole have been built and magnetically measured up to the specifications. Their corresponding harmonic contents of the integral fields in good field regions, normalised to the main magnetic field components, are less than 4×10^{-4}, 5×10^{-4} and 3×10^{-3} respectively.

One SSRF ring arc contains 3 six-strut type girders. Each girder supports a group of magnets with a section of vacuum chamber of equivalent length. A 5.8m long girder was designed and built in Shanghai with adjusting precision of 0.01mm in three directions. This girder's lowest frequencies were measured with 5.88Hz, 6.88Hz and 27Hz to longitudinal, horizontal and vertical vibration modes.

2.3 Vacuum System [7]

The SSRF ring vacuum system is designed to reach the average dynamic pressure less than 1ntorr at beam current of 300mA. Each storage ring arc has 3 machined antechamber sections made of aluminium A5083-H321, 3 horizontal and 5 vertical photon absorbers as well as 2 RF shielded bellows. It forms a separate vacuum section with the gate valves at the ends of the neighboring straight sections. The beam chamber cross section is a 40mm high by 70mm wide octagon with a slot of 12mm gap. The absorbers were designed to intercept 0.2~4 kW SR power each. The combined titanium sublimation pumps (TSP) and sputter ion pumps (SIP) were chosen to provide a total effective pumping speed of more than 1×10^5 l/s for handling the storage ring gas load about 1×10^{-4} torr·l/s. A 150^0C in-situ bake out system is planned to shorten the vacuum conditioning time.

The prototypes of the 6m long antechamber, the RF shielded bellows, the copper absorbers and the TSP and NEG pumps were designed and constructed during the last two years. A 6m antechamber vacuum system was assembled at SSRC with vacuum pumped down to 0.05ntorr by TSP. The PSD test of the horizontal photon absorber was carried out on a KEK PF beam line, and the bellow was tested with high RF power at KEK too.

2.4 Injection System [8][9]

The storage ring injection system has 4 kickers, 1 eddy current septum and 1 DC septum. Two kickers at both ends of the injection chain are located in the neigboring achromatic arcs across the dipoles. The DC septum, the eddy current septum and two central kickers are placed in a 7.24m straight section. In the SSRF R&D phase a kicker system including kicker magnet and its pulser was prototyped, the window frame type kicker magnet with a Ni-Zn ferrite core in air produces 0.12T peak field in amplitude and 4μs bottom width in half-sine-wave pulse. The pulse jitter is less than ±6.5ns and the field amplitude stability is better than ±0.14%. The eddy-current septum and its 60μs half-sine-wave pulser have been developed. Its main field peak is 0.62T with the stability better than ±0.1%. The peak strength of stray field on the bump orbit is less than 0.02% of the main field.

2.5 Magnet Power Supplies [10]

There are about 480 power supplies for the SSRF storage ring magnets. The prototypes for the main power supplies have been developed and tested up to their specifications at SSRC over last two years.

The power supply for the 40 bending dipoles will be a SCR type converter rated for 850A/900V. Its scaled prototype rated for 500A/100V was built and tested with the stability of $\pm1\times10^{-5}$/ 24hrs and the output current ripple less than 6×10^{-6} at the SSRC.

10 chopper type power supplies were designed to excite the main windings of the 200 quadrupoles in 10 families, and the trim coils of each quadrupole will be powered by an individual bipolar power supply. A prototype of the chopper type power supply with ratings of 360A/385V has been built and tested up to the output current stability of $\pm1\times10^{-4}$ / 24hrs.

The full PWM bridge converters with ZVS mode will be employed as the power supplies for the main windings of the 140 sextupoles in 14 families. A prototype rated for 140A/210V was designed and built. Its output current stability reaches $\pm6\times10^{-4}$/24hrs, and the output voltage ripple $<\pm1\times10^{-3}$.

2.6 RF System

In the current RF system design, 8 normal conducting RF cavities are used to provide 4MV RF voltage to the beam, and each cavity is powered by a 180kW klystron power amplifier. In the R&D phase a cold test copper cavity was designed and fabricated with spin forming and electron beam welding techniques. And a high power RF system has been established, which contains a klystron and its power supply from THALES and THOMCAST, a circulator from AFT, a copper cavity borrowed from PF/KEK and low level RF control loops [11] developed at SSRC. The high power RF system and the low level control loops have been integrated together, and the high power tests of the whole system with PF cavity have been conducted. Recently the superconducting RF system for the SSRF storage ring is being considered in cooperation with the BEPC-II project of IHEP in Beijing.

2.7 Beam Instrumentation and Control [12][13][14]

The beam instrumentation system of the SSRF storage ring includes 150 BPMs, a DCCT and a wall current monitor, 2 striplines, a SR light monitor, 7 profile monitors and 86 beam loss monitors. They will be used for measuring the beam current, the electron orbit and the betatron tunes, performing the close orbit correction and the beam based alignment. During last two years, a BPM prototype including four button-electrodes and their corresponding electronics was developed at SSRC. And the calibration of this BPM was conducted on a mapping device. As a result the BPM resolution reaches about 2μm. The BPM's mechanical structure is simple, two BPM buttons are mounted on a flange and two flanges are directly screwed on the up and down side of the vacuum chamber.

The designed SSRF control system is an EPICS-based control system, which contains about 20000 process variables. About 40 distributed VME-based input-output controllers (IOCs) and 650 device controllers will be used in the system. Three kinds of device controllers are planned to be used for various types of equipment. They are the device controller with DeviceNet interface, the PC/104 based device controller and the one with RS485-DC interface. During last two years, the DeviceNet interfaced controller and PC/104 based controller were developed to evaluate their performance. The former controller was integrated into the power supply prototype of the SSRF ring bending magnets for current setting and readout. This power supply with the DeviceNet controller was tested up to a current precision of 3×10^{-5} and stability of $\pm 6\times10^{-6}$ /12hrs during the experiments. The PC/104 controller was examined on a pseudo load with the stability of $\pm 3\times10^{-6}$ /12hrs. In addition, the SSRF timing system has been developed, the measured jitter of timing electronics is less than 50ps.

3 INJECTOR

The SSRF injector [15] comprises a 300MeV electron linac followed by a 1Hz booster, which accelerates the electrons to 3.5GeV. As pre-injector, the linac has two operation modes: single bunch mode with pulse length of 1ns and pulse current of 1.2A, or alternatively multi-bunch mode with pulse length of 300ns and macro pulse current of 180mA. In addition, the linac is also designed as an injector for the proposed DUV FEL facility, and the energy of this linac is therefore chosen for this purpose.

The full energy booster with circumference of 158.4m has 24 FODO cells in 3 super periods. This kind of configuration makes the injection, RF acceleration and extraction separate from each other in space, therefore easier for mechanical installation. The main parameters of the SSRF booster are listed in Table 2.

Table 2: Main Parameters of the Booster

Injection Energy (MeV)		300
Output Energy (GeV)		3.5
Circumference (m)		158.40
Natural Emitance (nm·rad)		203 (@3.5 GeV)
Beam Current (mA)	Single Bunch	0.5
	Multi Bunch	20
Repetition Rate (Hz)		1
RF Frequency (MHz)		499.654
RF Voltage (MV)		2.0
Energy Loss per Turn (MeV)		1.159
Super period Number		3
FODO Cell Number		24
Cell Length (m)		6.600
Betatron Tunes		7.253/4.214
Synchrotron Tune		0.0219
Momentum Compaction		0.02443
Bunch Length (cm)		2.46

During the last two years, a 100kV DC electron gun [16], a pre-buncher and a buncher [17] were developed and tested up to their specifications. The prototypes of the booster dipoles, quadrapoles and sextupoles and their power supplies were constructed within their specification requirements. The 3m stainless steel booster vacuum chamber was prototyped with satisfying performance both in vacuum and in mechanical deformation.

4 CONCLUSION

The SSRF specifications have been detailed with the completion of the technical design, and the prototypes made under the SSRF R&D program are qualified for formal construction by minor modifications. While waiting for the final project approval of the central government, we will start to integrate the existing components into an electron linac from this autumn.

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REFERENCES

[1] S.Y. Chen and H.J. Xu, “Current Status of the Proposed Shanghai Synchrotron Radiation Facility”, APAC’98, Tsukuba, March 23 – 27, 1998.
[2] S.Y. Chen, H.J. Xu and Z.T. Zhao, “Shanghai Synchrotron Radiation Facility”, PAC’99, New York, March 27 - April 2, 1999.
[3] Z.M. Dai, G.M. Liu and N. Huang, “The SSRF Storage Ring Magnetic Lattice Design”, these proceedings.
[4] Z.M. Dai and N. Huang, “Study of Orbit Stability in the SSRF Storage Ring”, these proceedings.
[5] G.M. Liu, N. Yang and N. Huang, “Collective Effects in SSRF”, these proceedings.
[6] Q.G. Zhou, et al, “Design and Measurement of the SSRF Magnet Prototypes”, these proceedings.
[7] D.K. Jiang et al, “Ultrahigh vacuum system of the SSRF”, these proceedings.
[8] Q. Han, W.F. Cao, J. Cui and X.F. Fan, “A Kicker Pulser for SSRF”, these proceedings.
[9] W. Kang, L. X. Fu, and J.B. Pang, “Development of an Eddy-Current Septum Magnet for the SSRF Storage Ring”, these proceedings.
[10]Z.X. Xu, S.L. Lu, Y.J. Qiang and C. L. Guo, “ SSRF Magnet Power Supply System”, these Proceedings.
[11]F. Wang, G.W. Wang and J.F. Lu, “Low Level RF Control Loops for SSRF”, these proceedings.
[12]K.R. Ye, et al, “The Beam Instrumentation of SSRF”, these proceedings.
[13]Y.B. Leng, L.F. Zheng, G.B. Shen and S.Q. Liu, “Device-Level Control in SSRF”, these proceedings.
[14]D.K. Liu, Y.B. Leng, and W.X. Cheng, “SSRF Timing System”, these Proceedings.
[15]D.M. Li, et al, “The Scheme and Construction Progress of the SSRF Injector”, these Proceedings.
[16]S.G. Sheng, G.Q. Lin, Q. Gu and D.M. Li, “Electron Gun For SSRF”, these Proceedings.
[17]J.P. Dai, Y.X. Luo, D.M. Li and J.B. Zhang, “Development of the Bunching System of the SSRF Linac”, These proceedings.