CURRENT STATUS OF THE PROPOSED SHANGHAI SYNCHROTRON RADIATION FACILITY

Senyu Chen and Hongjie Xu, SSRF Project Team, Chinese Academy of Sciences, China

Abstract

The Shanghai Synchrotron Radiation Facility (SSRF) was proposed by the Chinese Academy of Sciences and the Shanghai Municipal Government in 1995. The estimated total budget is around US$100 M, and the operation is scheduled to begin in the end of 2003. The whole SSRF project is still awaiting final approval, but its R&D has been approved. The SSRF is a third-generation synchrotron light source designed to produce high brightness VUV and soft X-ray in the energy region of 10 eV~3 keV and high flux X-ray with moderate brightness in the energy region of 3~30 keV. It consists of the injector (including a 100 MeV Linac and a 2.2-2.5 GeV Booster), the 2.2-2.5 GeV storage ring and the synchrotron radiation experimental facilities. In this paper, the main parameters and features of the SSRF are presented.

1 INTRODUCTION

In China, there are two existing synchrotron radiation light sources, the Beijing Synchrotron Radiation Facility (BSRF) and the Heifei National Synchrotron Radiation Laboratory (HNSRL). The BSRF is a “parasitic” first generation light source. It’s mainly running for high energy physics and only 15% of beam time can be dedicated to synchrotron radiation. The HNSRL is just an 800 MeV ultraviolet light source. They cannot meet the needs and requirements of Chinese users.

The construction of a third generation synchrotron radiation light source in China was proposed at the end of 1993 in order to meet the demand of the development of science and technology of the country in the 21st century. This proposal attracted much interest of the science community, and received an immediate response from more than 60 universities and research institutions.

In April, 1995, the Chinese Academy of Sciences (CAS) and the Shanghai Municipal Government (SMG) agreed in principle to make joint efforts for a proposal to construct such an advanced third generation synchrotron radiation light source in Shanghai. The SMG promised to contribute one third or more of the total budget if the proposal is approved by the State, and the CAS is responsible for the scientific and technical guarantee. Then, in June, 1995, this proposed project was named as the "Shanghai Synchrotron Radiation Facility" (SSRF), and a working group was set up by the CAS. The major task of the group is to carry out the feasibility study of the project.

One year later, the draft of the SSRF Conceptual Design Report (CDR) was basically completed, and the international review on the SSRF CDR by the CAS and SMG has been successfully accomplished in September, 1996.

In June of 1997, the R&D of the SSRF project was approved by the National Science and Technology Leading Group. The site of the SSRF will be in Shanghai area, and the Shanghai Institute of Nuclear Research, CAS will be responsible for the construction of the SSRF. Now the 80 million Chinese yuan budget for R&D of the SSRF project has been allocated, and the recruiting of the staff members of the SSRF project has also started. But the whole SSRF project is still awaiting final approval.

2 DESIGN PHILOSOPHY

2.1 Design Goal

The purpose to construct the SSRF is to establish a multi-discipline frontier research center and a high-tech R&D base in order to offer attractive research opportunities for a wide variety of fields in China.

The requirements of the CAS and the SMG on the construction of SSRF are: The performance of the Shanghai Synchrotron Radiation Facility should be better than that of the present existing third generation light sources, and be at the forefront of its kind when it is completed at the beginning of the 21st century; The research lifetime must be longer than 20-30 years after its establishment; And its budget should be around 100M USD. They are quite ambitious. It is unreasonable to construct a light source with obvious inferior characteristics compared with other newly designed light sources, like SLS, SOLEIL, DIAMOND, HBLS, etc..

Based on our investigation, the largest part of user community in China works in the X-ray region of the spectrum from 4-40 keV, and the second largest in the soft X-ray region of 0.1-4 keV. So the SSRF is designed to produce high brightness VUV and soft X-ray in the energy region of 0.1-4 keV, and high flux X-rays with moderate brightness in the energy region of 4-40 keV.

2.2 Design Requirement

2.2.1 The nominal design energy is 2.2 GeV, it can be upgraded to 2.5 GeV.

The SSRF will be a VUV and soft X-ray light source, and cannot fully meet the user’s requirements. This is mainly due to the budget limitation. If the investment could be increased and the designed energy can be raised to 3-3.5 GeV, the SSRF performance will more fully meet the requirements or even better.

According to the suggestion of the experts participating in the review meeting on the SSRF CDR[1], we are seriously considering the possibility to increase the energy to 3-3.5 GeV with some sacrifice in VUV/soft X-ray performance by adding a little investment with the circumference remaining the same.

2.2.2 Several of the normal bending magnets can be replaced with superconducting dipoles (4-5T).

This is based on the fact that China's economic strength can hardly support the construction of a higher energy light source (6-8 GeV) in the next foreseeable 20 years. And the vast majority of the Chinese X-ray users strongly demand that the SSRF provide them with hard X-ray with energy as high as possible from such a machine.

2.2.3 The ring circumference is around 300 m

2.2.4 The natural horizontal emittance (rms) must be in the range of 3-4 nm.rad.

2.2.5 The storage ring should be equipped with two straight sections of approximately 18 m length.

3 MACHINE PARAMETERS

The SSRF consists of three major parts (see Fig.1.). The injection system (including the 100 MeV linac, the 2.2-2.5 GeV booster, and the corresponding low energy linac to booster beam transport line and the high energy beam transport line from the booster to the storage ring), the 2.2-2.5 GeV storage ring and the synchrotron radiation experimental facilities (including the beam lines and the experimental stations).

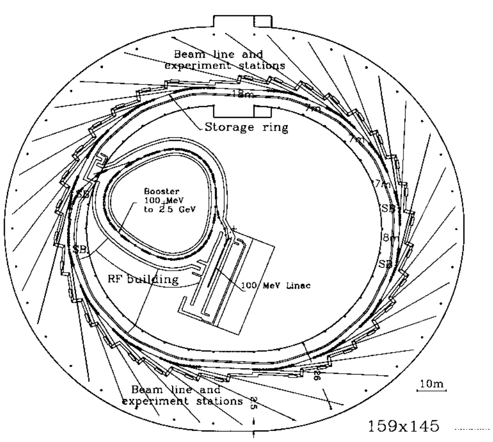

Figure 1 Layout of the SSRF

3.1 Lattice

It is known to all that the performance of the light source is determined primarily by the design of the storage ring "Lattice". The main problems concerning the realization of low emittance lattice are related to the strong focusing required, which implies strong chromatic and geometric aberrations as well as high sensitivity to magnetic and alignment imperfections. In addition, the replacement of normal dipoles with superconducting magnets and insertion of super-long straight sections cause more serious nonlinearity, and this will make the tough lattice design of the SSRF become even more difficult.

To meet the design goal, several possible lattice structures including the DBA[2], and the modified TBA[3], QBA[4], FBA[5] and SBA[6] structures have been studied and are available for the SSRF. The results show that the DBA lattice with the superconducting dipoles seems hard to meet the requirement of the low emittance of the SSRF. Considering that the TBA version lattice has a simpler configuration with more straight sections and many successful experiences which have been accumulated in the world, we chose the TBA version lattice.

The storage ring lattice is a modified TBA structure with 2 superperiods. The circumference is 345.36 m. It consists of 16 normal cells with 12 of 7 m long and 2 of 8 m long dispersion-free straight sections as well as 2 of 18 m long super-long straight sections. Each normal cell contains 3 bending magnets, 12 focusing quadrupoles and 6 chromaticity correction sextupoles. The studies show that, the contribution to the emittance from each side of bending magnets is much greater than that from the center ones. So in order to minimize the emittance we has modified the bending magnet deflection angle of the TBA lattice. The deflection angle of the side dipole is 6°, and the one of the center dipole is 10.5°. The advantages of the lattice is that, it is convenient to replace any center dipole of the cells with the superconducting magnet. In the design, we only replaced four bending magnets with superconducting dipoles.

The linear lattice functions of a quarter of the storage ring are shown in Fig.2.

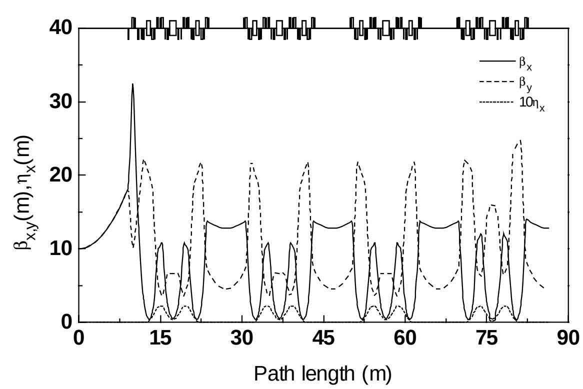

Figure 2 Lattice functions of one quarter of storage ring

There are total 9 families of sextupoles, in which three families located at a proper position in the achromatic arcs are used to correct chromaticities and the other 6 families distributed in the non-dispersive region are used for harmonic correction to improve the dynamic aperture as well as the energy acceptance. Fig.3, Fig.4 and Fig.5 show the dynamic aperture , the momentum-depend tune variation and the dynamic aperture Vs energy deviation using tracking results from RACETRACK[7]. After optimization, the horizontal dynamic aperture at the injection point reaches 28 mm and the energy acceptance of the ring is 4%.

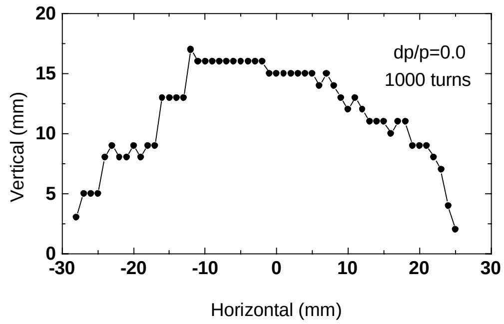

Figure 3 Dynamic aperture at the injection point

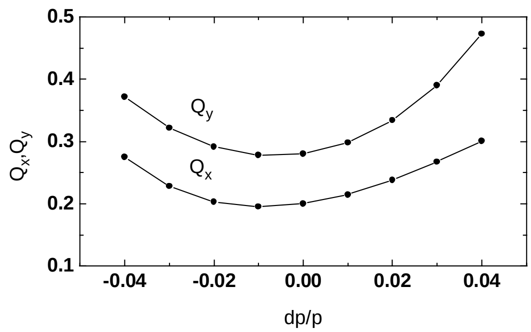

Figure 4 Momentum-dependent tune variation

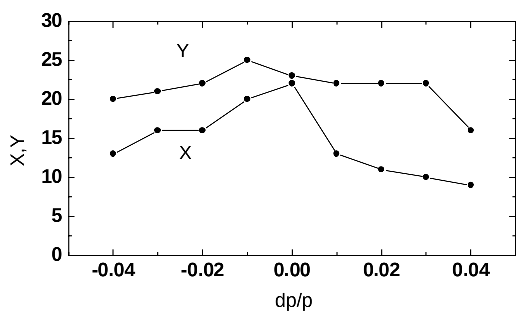

Figure 5 Dynamic apertures vs. energy deviation at the mid-piont of the super-long straight section.

Moreover, the effects of magnetic imperfect, the closed orbit distortion and correction, the effects of insertion devices, the beam instabilities and the lifetime, the injection and etc. have been studied. They also meet the design requirement. The optimization of the lattice is still underway.

3.2 Main Parameters of the storage ring

Energy:	2.2 -2.5 GeV
Circumference:	345.36 m
Natural Horizontal Emittance (rms):	3.78 (2.56*)-4.88 (3.30*) nm.rad
Beam Current:	400-300 mA(multi-bunch)
	>5 mA (single bunch)
Number of superperiods	2
Number of cells:	16
Insertion Straight Sections:	12×7.0 m, 2×8.0 m, 2×l8.0 m
Magnetic field, normal dipole	1.201 - 1.364 T
superconducting dipole	4.203 - 4.776 T
Number of quadrupoles	200
Max. gradient for quads	20 T/m
Number of sextupoles	160
Max. sextupole strength	600 T/m^2
Betatron tunes, Q_x/Q_y	22.20/7.28
Natural chromaticities ξ_x / ξ_y	-51/-29
Momentum compaction	4.1×10^{-4}
Harmonic number	576
Radio Frequency	500 MHz
RF Voltage	2.0 - 2.5 MV
Energy Loss per Turn:	438 - 730 keV
Bunch Length (rms) σ_s :	4.1 mm
σ_t :	14 ps
Beam Lifetime:	> 8hrs

* Without Superconducting dipoles

3.3 Main Parameters of the Booster

Energy:	2.2 -2.5 GeV
Injection Energy	100 MeV
Circumference:	122.22 m
Lattice Structure	FODO
Repetition Frequency	1 Hz
Beam Current:	8 mA (multi-bunch)
	1.5 mA (single bunch)
Number of superperiods	3
Number of cells:	21
Natural Emittance (rms):	194-250 nm.rad
Betatron tunes, Q_x/Q_y	5.73/3.81
Natural chromaticities ξ_x / ξ_y	-6.14/-4.83
Radio Frequency	500 MHz

4 MAIN FEATURES

As the SSRF would be the premier synchrotron radiation facility in China, it is important that the lattice design with 16 families of quadrupoles has a high flexibility to make the SSRF continue to be a world class facility in the 21st century. It can meet the requirements in various operating modes so that the beam brightness will be capable of being improved by retuning the lattice.

The proposed SSRF has several important advantages as compared to the present existing synchrotron radiation light sources. They are summarized as follows:

- Due to the low natural emittance of about 3-4 nm.rad, the SSRF will provide a very high brightness of VUV light and soft X-rays from undulators, whereas the multipole wigglers (MPWS) or superconducting wiggler (SCW) will provide the high flux hard X-rays. Fig.6 and Fig.7 show the brightness and flux curves under the following parameters of generic insertion devices.

Name	period (mm)	B_{MAX} (T)	K_{MAX}	Gap (mm)	N_{PERIOD}	Length (m)
U31	31	0.687	1.99	10.0	145	4.5
U50	50	0.830	3.88	15.4	98	4.9
U90	90	1.150	9.64	20.9	53	4.77
MPW	136	1.600	20.3	20.0	33	4.5
W185	185	4.200	72.6	12.6	3	0.555

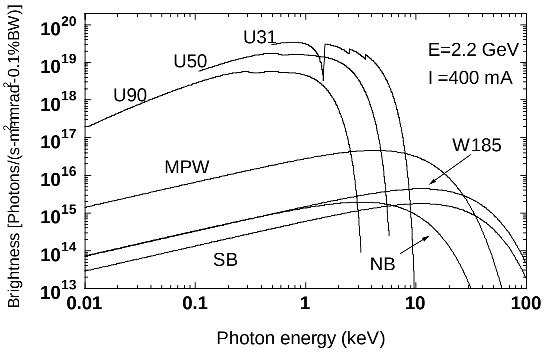

Figure 6 Brightness of radiation generated at SSRF

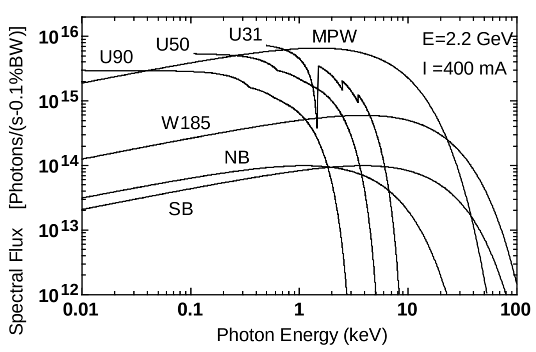

Figure 7 Spectral flux of radiation generated at SSRF

- Even in the initial phase all the bending magnets will be normal conducting, but it leaves the option to replace at least 4 normal bending magnets with superconducting dipoles. Therefore the photon wavelength can be shifted up to hard X-ray region (60 keV) without using the wavelength shifter, thereby avoiding its occupation of straight sections and its effects on the lattice.
- With two 18 m super-long straight sections, the SSRF has the growth potential for future development. For example, the long straight sections can accommodate a 15 m long undulator or several undulators in series. The other future developments being considered are that the super-long straight section can be used for research and development of short wavelength Free Electron Laser.

5 BEAM LINES AND EXPERIMENTAL STATIONS

It is not possible to predict precisely the scientific research which will be undertaken on SSRF. Based on an extensive investigation of the existing users and potential users of the SSRF and 61 proposals regarding the designs of beam lines and experimental stations, we have selected the following beam lines and experimental stations for the first phase construction of the SSRF, as follows:

Protein crystallography
XAFS
General purpose diffraction
Photoelectron spectroscopy
General purpose scattering
Soft X-ray microscopy
LIGA
Circular dichroism
Gas phase reaction
Fluorescence analysis
Infrared
Beam diagnostic
Optical standard
Lithography
Medical

But due to the budget limitation, only 5 to 7 (including 2 insertion devices) among the above 15 beam lines will be constructed during the initial stage. Therefore further appraisal is needed to determine which proposed beamlines are going to be constructed during the initial stage. Final decision will be made at an appropriate time this year.

6 COST ESTIMATE AND SCHEDULE

The structure of the SSRF project management has three levels: Level 1 for major categories, Level 2 for functional systems and Level 3 for components. The major category level includes the injection system (including the 100 MeV linac, the 2.2-2.5 GeV booster, the low energy from linac to the booster and high energy from booster to the storage ring beam transport lines), the storage ring, the synchrotron radiation experimental facilities and conventional facilities. Here, we only give the cost estimation at the major categories level based on the present outline design. And we must note that the estimated cost doesn't include the project management cost and the salary for internal manpower (about 300 persons).

6.1 Cost Estimate

Since the 90's, six third generation synchrotron radiation light sources have been successfully commissioned and operated. Many others are in the process of being tested or in the construction stage. All of the commissioned light sources have reached and even surpassed their design target performances. A lot of ripe experiences have been accumulated in this field. So there is no difficulty in principle, and the requested key techniques to be solved in the R&D of the SSRF are:

- The superconducting wiggler
- The high performance insertion devices
- To search for HOM free RF cavities
- The dynamic ultra high vacuum system with pressure of 1×10^{-9} torr or less
- The excellent beam position stability
- The feedback system to suppress the multi-bunch instabilities
- The optics to sustain the heat load and high performances of the detectors

The construction of the SSRF is a great challenge to the Chinese scientists and engineers. We should be very sober to face this fact and to make great endeavors.

Based on the information available from many sources, the preliminary estimated cost is no less than 800 million Chinese yuan (in the FY 1995 Yuan). Of course, the final estimated cost will be achieved when we make the detail design after the completion of the R&D.

The estimated cost of the SSRF is shown in Table 1.

Table 1 Project Cost Summary

Item	Estimated cost (M yuan)
Injector	80
Storage Ring	250
Synchrotron Radiation Experimental Facilities	150
Conventional Facilities	180
R&D	80
Contingency	60
Total	800

6.2 Schedule

To catch up with the SLS, SOLEIL, DIAMOND, HBLS and other new projects, we shall strive to make the SSRF one of the advanced third generation synchrotron radiation facilities that will be operated at the beginning of the 21st century. The tentative project schedule has been proposed under the important prerequisite that the whole SSRF project should be approved by the Chinese government before the end of 1998.

The proposed overall schedule of the SSRF project is as follows:

- 1998 — 2000
  R&D
- 2000 — 2002
  procurement, fabrication & construction
- 2002 — 2004
  installation, testing and commissioning
- The end 0f 2004
  completion

7 ACKNOWLEDGMENT

This work was supported by the Chinese Academy of Sciences and the Shanghai Municipal Government and performed by the SSRF project team. Particularly, our colleague, L.M.Chen, X.F.Zhao, Z.M.Dai, and G.M. Liu have played an important role in the design of the storage ring lattice. We are also thankful to Dr. H.Winick, M.Ando, A.Chao, C.T.Chen, J.Galayda, H.Hsieh, H.Kamitsubo, S.Krinsky, F.Schlachter, R.Schlueter, L.Teng, E.Weihreter, W.T.Weng and A.Wrulich, etc. for their important consultation, useful comments, helpful suggestions and discussions on the review of the CDR of the SSRF.

8 REFERENCES

[1] H.Winick, et al,“Report of the Review Committee on the Conceptual Design Report (CDR) of the Shanghai Synchrotron Radiation Facility (SSRF)”September 19-20, 1996

[2] R.Chasmann and K.Green, “Preliminary Design of A Dedicated Synchrotron Radiation Facility”,IEEE Trans. Nucl. Sci., NS-22, 1765 (1975)

[3] A.Jackson,“A Comparison of Chasmann-Green and Triple Bend Achromat”, Particle Accelerators, Vol22, 111(1987)

[4] D.Einfeld and M.Plesko,“A Modified QBA Optics for Low Emittance Storage Rings”,Nucl. Inst. Meth. In Phys. Res. A336(1993)402-416

[5] D.Einfeld et al, “The Synchrotron Light Source ROSY”, Proceedings of the ParticleAccelerator Conference PAC 93, Washington, 1993

[6] Conceptual Design of the Swiss Synchrotron Light Source, Paul Scherrer Institut, 7.September 1993

[7] A.Wrulich, “RACETRACK” DESY-84/26, 1984.