SSRF: A 3.5 GEV SYNCHROTRON LIGHT SOURCE FOR CHINA

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Abstract

The Shanghai Synchrotron Radiation Facility (SSRF) is an intermediate energy light source that will be built at Zhang-Jiang Hi-Tech Park in Shanghai. The SSRF consists of a 432 m circumference storage ring with an operating energy of 3.5 GeV and a minimum emittance of 3.0 nm-rad, a full energy booster, a 100 MeV electron Linac as well as dozens of beamlines and experimental stations. The design of the SSRF accelerator complex evolves timely along the technological progress such as top-up injection, mini-gap undulator, superconducting RF system and etc. This paper reports the design progress and status of the SSRF project.

INTRODUCTION

The SSRF project was proposed and designed to meet the growing demand for Synchrotron radiation in China. From 1995 to 2001, this project went through a concept design study phase and an R&D program phase [1] [2], and finally its proposal was approved by the central government in January 2004. There still exist two more crucial project steps, a feasibility study phase and an engineering design phase, before the groundbreaking of the SSRF main building. This project will be jointly founded by the central government, the Shanghai local government and the Chinese Academy of Sciences, its total budget, including the R&D fee, is about 150 MUSD. The facility is expected to start construction from the end of 2004 and to provide photon beam for user experiments before the end of 2009.

As an intermediate energy light source, the SSRF is intended to produce high brightness and high flux X-rays in the photon energy range of 0.1 ~ 40 keV, particular for the structure biology in the 5 ~ 20 keV energy range. It foresees the use of mini-gap undulators and the use of the synchrotron radiation from high harmonics of undulators, and this implies the in-vacuum IDs are more preferable. On the other hand, the small gaps in IDs make a critical challenge to the storage ring beam lifetime, and this in turn make top-up injection scheme more demanding in this intermediate energy light source [3].

The SSRF complex, as sketched in figure 1, consists of a full energy injector including a 100 MeV linac and a 3.5 GeV booster, a 3.5 GeV storage ring and its associated synchrotron radiation experimental facilities. The SSRF design optimizations have been being performed towards a high performance and cost-effective light source since its initial concept issued in 1996 [1-2] [4-5]. The latest optimized design has been carried out based on the following considerations: 1) to enhance the light source capabilities, including to accommodate more insertion device based beam lines, 2) to operate the machine in top up injection mode, 3) to achieve high beam orbit stability.

Zhang-Jiang Hi-Tech Park of Shanghai was chosen for locating the SSRF in 1999, it provides the SSRF a green land of 600×300 m. Following the official approval of the SSRF project proposal this January, the building architectural designer, Shanghai Institute of Architectural Design and Research, was appointed in April 2004. For the time being, the detailed design of the SSRF main building, utility building and guest house is in progress. The construction contractor will then be selected in a few months, and the building construction is expected to start at the end of this year.

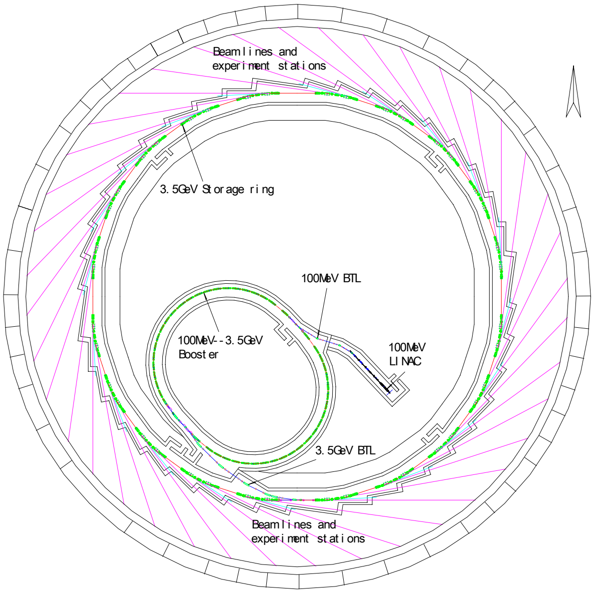

Figure 1: Layout of the SSRF

STORAGE RING DESIGN UPDATE

The SSRF storage ring has been designed to be a cost effective machine over the past 8 years, [1-5], its existing specifications are featured with robust and flexible lattice configuration and advanced mature technology. The latest SSRF storage ring design focuses on optimizing straight section parameters, including straight lengths and their corresponding beta functions, reducing beam emittance and particularly providing high stable beam to meet user demands by controlling beam orbit disturbances and employing orbit feedbacks as well as operating top up injection mode.

The new SSRF storage ring lattice is a 20-cell double bend structure with 5 super-periods and a circumference of 432 m. Each super-period contains 5 cells, including one 12.0 m long straight section and four 6.7 m standard straight sections. Each double bend cell is equipped with 2 gradient bending magnets (1.22T and 2.92T/m), 10 quadruple magnets (maximum gradient of 20T/m), 3 chromatic and 4 harmonic sextuple magnets (maximum gradient of 480 T/m2). In addition, all the 200 SSRF storage ring quadruple magnets will be individually powered for getting more flexible lattice configurations to match various insertion device requirements, and the 140 sextuple magnets are designed to be powered in 8 families.

The straight section parameters are defined to meet various requirements from insertion devices and accelerator itself. Among the four 12.0 m long straight sections, one is used for installing injection elements including 4 kickers and 2 septum magnets, another one is used for accommodating 3 superconducting RF cavities, and the rest two are reserved for installing long undulators or twin undulators. These 6.7 m standard straight sections are designed for accommodating 4.5 ~ 4.8 m standard undulators, 2 m mini-gap undulators, chicaned mini-gap undulators and wigglers.

The SSRF storage ring is designed to operate with both non-achromat and achromat lattices. When the storage ring operates with the distributed dispersion of 0.15 m in the 12.0 m long straight sections and 0.12 m in the 6.7 m standard straight sections, its optimized beam emittance can reach down to 3 nm·rad. When it works with the achromat lattice, its operating beam emittance is about 8nm·rad. Table 1 lists the main parameters of the newly optimized storage ring.

Table 1: Main Parameters of the SSRF Storage Ring

Energy (GeV)	3.5
Circumference (m)	432
Harmonic Number	720
Number of cells/Super-periods	20/4
Nature Emittance (nm·rad)	3.0
Beam Current, Multi-Bunch (mA) Single-Bunch (mA)	200~300 >5
Straight Lengths (m)	4×12.0 16×6.7
Betatron tunes, Q_x/Q_y	22.22/11.32
$\beta_x/\beta_y/D_x$ @12m straight (m)	10.0/6.0/0.15
$\beta_x/\beta_y/D_x$ @6.7m straight (m)	3.5/2.5/0.12
Momentum Compaction	4.7×10^{-4}
RF Frequency (MHz)	499.654
RF Voltage (MV)	4
Dipole Radiation per Turn (MeV)	1.39
Damping Partition factor $J_x/J_y/J_s$	1.16/1.00/1.84
Damping Times $\tau_x/\tau_y/\tau_s$(ms)	6.27/7.26/3.94
Bunch Length (mm)	4.32
Beam Lifetime (hrs)	>10

Figure 2 shows the lattice function of a half SSRF storage ring super-period, and figure 3 shows the calculated spectral brightness curves of the SSRF synchrotron radiation from a bending magnet, typical wigglers and undulators at a beam current of 300 mA and coupling of 1%. The nonlinear beam dynamics in the SSRF storage ring has been studied using MAD, TRACY2 and RACETRACK, and the particle tracking studies show that the SSRF storage ring has reasonable energy acceptance and dynamic aperture even with magnetic field errors.

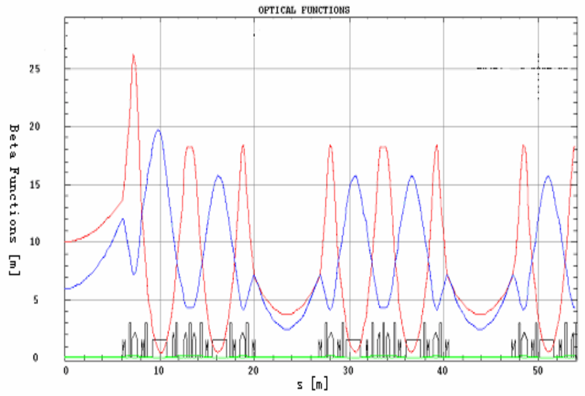

Figure 2: Lattice functions of a half SSRF super-period

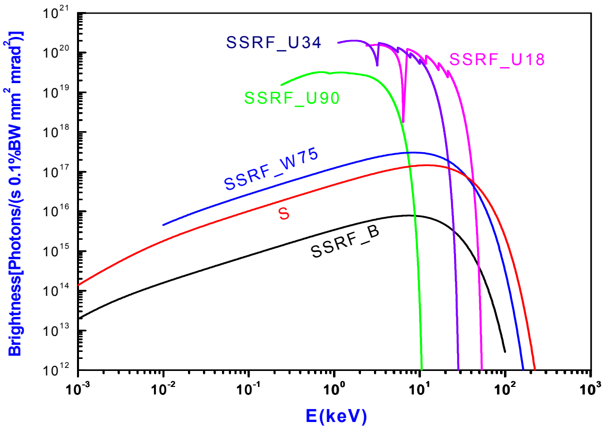

Figure 3: Spectral Brightness of SSRF

TOP-UP AND INJECTOR UPDATE

Top-up operation is a desired performance of the new generation storage ring light source. It keeps a constant thermal load on the storage ring vacuum chamber and beamline optic elements, which are essential to the photon beam position stability, and overcomes the short beam lifetime problem caused by low energy and low emittance beam as well as the extensive use of small gap undulators in storage rings. This merit and the successful routine operation of top-up injection at APS, SLS and Spring-8 [6-8] lead us to optimize the SSRF design based on the requirements of top-up injection.

Top-up operation of a light source implies a non-stop and high-reliable operation of its linac and booster, and this in turn limits the linac to be used for other purpose, such as for driving FEL as that proposed in the previous SSRF design. Therefore, the SSRF linac has been redesigned as a dedicated pre-injector with output energy of 100 MeV. This linac, designed to operate with both single bunch and multi-bunch modes for normal and top-up injections, consists of a 100 kV electron gun, a 499.65 MHz sub-harmonic buncher, a 2997.9 MHz fundamental buncher and four 3 m SLAC type accelerating sections. The linac operates at a repetition rate of 1 ~ 5 Hz, its output energy spread is less than 0.5% and its normalized beam emittance is less than 100 mm·mrad. The linac working frequency (2997.9 MHz) is harmonically related to the SSRF storage ring RF frequency.

Top-up injection is performed while the beam line shutters are keeping opened, and this requires an almost lossless beam injection for ensuring the radiation safety and minimizing the distortion to the experiments. A low emittance booster, which delivers the injected beam with smaller horizontal size and smaller betatron oscillation amplitude to storage ring and results in a clean injection, therefore is more favourable.

The re-design of the SSRF booster aims at reducing its beam emittance down to 110 nm·rad. After examining the characteristics of the lager booster which is housed in storage ring bunker and the normal booster which is put in an independent bunker, the normal booster scheme is re-confirmed due to its reasonable cost and convenience in construction, commissioning and maintenance. The new booster lattice is a two fold 28 FODO cells structure with 8 missing dipoles and a circumference of 180 m [9]. The basic parameters of this new booster are given in table 2.

Table 2: Main Parameters of the Booster

Injection Energy (MeV)		100
Output Energy (GeV)		3.5
Circumference (m)		180.0
Natural Emitance (nm·rad)		110 (@3.5 GeV)
Beam Current (mA)	Single Bunch	1.6
	Multi Bunch	15
Repetition Rate (Hz)		2
RF Frequency (MHz)		499.65
RF Voltage (MV)		1.74
Energy Loss per Turn (MeV)		0.915
Super-period Number		2
FODO Cell Number		28
Cell Length (m)		6.429
Betatron Tunes		8.21/4.18
Synchrotron Tune		0.0219
Momentum Compaction Factor		0.01811
Bunch Length (cm)		2.12

BEAM ORBIT STABILTY

Beam position stability is of overwhelming importance to ensure the SSRF performance. Like most of the third generation light sources, the SSRF sets its orbit stability criteria as 10 percent of beam dimensions and 10 percent of beam divergence. This leads to a horizontal orbit stability level at 10 ~ 20 microns in position and 1~3 micro-radians in divergence and a vertical stability level at sub-micron to micron and a part of a micro-radian respectively.

The building stability and the machine thermal stability are examined for controlling the slow orbit variations in the SSRF storage ring. A complete specification on the building foundation and the conventional facility of the SSRF machine complex has been produced, and as the representative requirements, the differential foundation stability criteria is set as 0.1 mm/10m/year for the storage ring, the LCW temperature stability criteria and the air temperature stability criteria in the ring tunnel are set as ±0.1 ^{0}C and ±0.2 ^{0}C respectively. Mechanical vibrations and magnet power supply's ripples are simultaneously examined to control the fast orbit variations. This results in re-optimizing the SSRF storage ring girder design and re-checking the magnet power supply's specifications.

The SSRF will be equipped with slow and fast orbit feedbacks to stabilize beam orbit. The SSRF slow orbit feedback, consisting of 140 BPMs and 80 horizontal and vertical combined correctors, will correct both beam closed orbit distortion (COD) and slow beam orbit motion in the storage ring every few minutes. The SSRF fast feedback adopts the global feedback scheme, which tries to minimize the orbit variation at all the photon source points around the storage ring. 40 high stable BPMs located at ends of straight sections are included to detect the orbit deviation, and about 80 wideband correctors will be used to correct the vertical orbit variation at frequency up to 100 Hz.

REFERENCES

[1] S.Y. Chen and H.J. Xu, "Current Status of the Proposed Shanghai Synchrotron Radiation Facility", APAC98, Tsukuba, March 23 – 27, 1998.

[2] S.Y. Chen, H.J. Xu and Z. T. Zhao, "The SSRF Accelerator Complex", APAC01, Beijing, Sept. 17-21, 2001.

[3] Z.T. Zhao, "Intermediate Energy Light Source and the SSRF Project", Nuclear Science and Techniques, Vol.14, No.1, 1 - 8, 2003.

[4] S.Y. Chen, H.J. Xu and Z.T. Zhao, "Shanghai Synchrotron Radiation Facility", PAC99, New York, March 27 - April 2, 1999.

[5] Z.T. Zhao and H.J. Xu, "Progress of the Shanghai Synchrotron Radiation Facility", APAC04, Gyeongju, March 22 - 26, 2004.

[6] L. Emery, "Top-Up Experience at APS", Proc. of SSILS, 25th ICFA Advanced Beam Dynamics Workshop, Shanghai, Sept. 24 - 26, 2001.

[7] A. Ludeke and M. Munoz, "Top-up Operation Experience at the Swiss Light Source", EPAC2002, Paris, June 3 - 7, 2002.

[8] H. Tanaka, M. Adachi and et al, "Top-up Operation at Spring-8", this conference.

[9] D.M. Li, Q. Gu and Z.T. Zhao, "New Scheme of the SSRF Injector", APAC04, Gyeongju, March 22 – 26, 2004.