PROGRESS OF THE SHANGHAI SYNCHROTRON RADIATION FACILITY

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Abstract

The Shanghai Synchrotron Radiation Facility (SSRF) is a 3rd generation light source that will be built to produce high brightness and high flux X-rays in the photon energy range of 0.1~40keV. Its design modifications and optimizations have been going on since the completion of the SSRF R&D program in 2001. The light source now is based on a 432m circumference storage ring with an operating energy of 3.5GeV and a minimum emittance of 2.95nm-rad, and the accelerator complex design is top-up injection optimized. The progress and the design update of the SSRF project are presented in this paper.

INTRODUCTION

The SSRF project was proposed in 1995, then in the following 8 years it went through a concept design study phase and an R&D program phase [1] [2], finally its project proposal was officially approved by the central government in January 2004. This will be followed by two 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, and its total budget, including the R&D fee, is about 150M USD. The project construction goal is to provide photon beam for user experiments by end of 2008.

The SSRF will be an intermediate energy light source capable of producing high brightness and high flux X-rays in the photon energy range of 0.1~40keV, particular for the structure biology in the 5 ~ 20keV 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 design optimizations of the SSRF complex 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, 2) to operate the machine in top up injection mode, 3) to achieve high beam orbit stability. As sketched in figure 1, the SSRF complex consists of three principal parts: a full energy injector including a 100MeV linac and a 3.5GeV booster, a 3.5GeV storage ring and its associated synchrotron radiation experimental facilities.

The selection of the building architectural designers for the SSRF project is in progress. The architects will conduct the detailed design of the SSRF main building, utility building, guest house and cafeteria from the coming April. The construction contractor will then be selected in few months, and the building construction is expected to start in this autumn. Since the design and R&D results as well as the selected first beamlines of the SSRF project were reported regularly [1-2] [4-5], here in the following we mainly report the SSRF design progress.

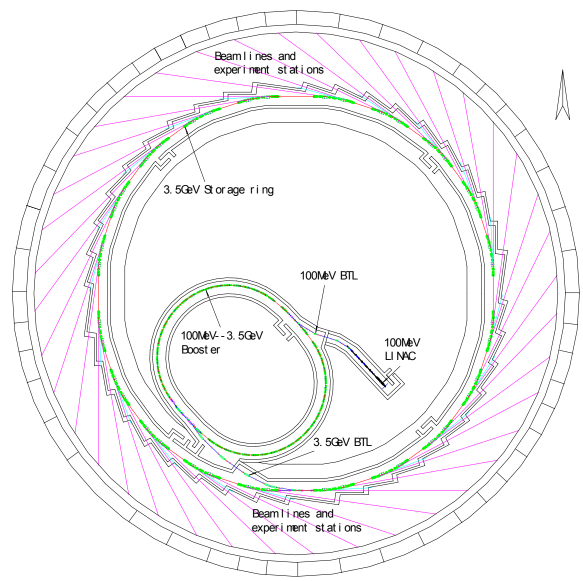

Figure 1: Layout of the SSRF

NEW STORAGE RING LATTICE

The new SSRF storage ring lattice design aims at reducing its beam emittance, optimizing its straight lengths and corresponding beta functions as well as their adjust flexibility [6]. It employs gradient bending magnets (1.1T and 2.333T/m) and distributed dispersion scheme to get storage ring beam emittance down to 2.95nm·rad and in the meantime induces long, medium and short straight sections (4×12.0m and 8×7.0m as well as 8×5.0m) to meet various requirements from insertion devices and the ring itself. The new lattice of the SSRF storage ring is a four-fold double bend structure consisting of 20 cells. Among these, there are four cells containing long straight sections of 12.0m in length, one of those is used for installing four injection kickers and two septum magnets, another one is for accommodating superconducting RF cavities, and the rest two are reserved for installing long undulators or twin undulators. Eight cells contain medium straight sections of 7.0m in length, which are designed for putting 4.5~4.8m long standard undulators. And eight cells have short straight sections of 5.0m in length, which are dedicated for mini-gap undulators and wigglers. The straight section sequence is 12.0m, 5.0m, 7.0m, 7.0m, 5.0m and again 12.0m in a storage ring super-period. By keeping the 20 double bend cells, the storage ring circumference is increased to 432m.

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)	2.95
Beam Current, Multi-Bunch (mA) Single-Bunch (mA)	200~300 >5
Straight Lengths (m)	4×12.0 8×7.0 8×7.0
Betatron tunes, Q_x/Q_y	22.24/11.23,
$\beta_x/\beta_y/D_x$ @12m straight (m)	10.0/5.0/0.15
$\beta_x/\beta_y/D_x$ @7m straight (m)	3.5/2.5/0.118
$\beta_x/\beta_y/D_x$ @5m straight (m)	3.0/2.0/0.114
Momentum Compaction	5.2×10^{-4}
RF Frequency (MHz)	499.654
RF Voltage (MV)	4
Dipole Radiation per Turn (MeV)	1.256
Damping Partition factor $J_x/J_y/J_s$	1.15/1.00/1.85
Damping Times $\tau_x/\tau_y/\tau_s$(ms)	6.96/8.03/4.35
Bunch Length (mm)	4.23
Beam Lifetime (hrs)	>15

Each double bend cell is equipped with ten quadruple magnets for getting high lattice tuning capability, three chromatic and four harmonic sextuple magnets for achieving large dynamic aperture. 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 also planed to be powered individually too for flexibly controlling dynamic aperture. The particle tracking in the SSRF storage has been conducted using MAD and a good dynamic aperture with magnetic errors has been achieved. The momentum dependent tune shift is small, and extensive nonlinear beam dynamics studies are still under way. Table 1 lists the main parameters of the newly optimized storage ring. 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 current of 300mA and coupling of 1%.

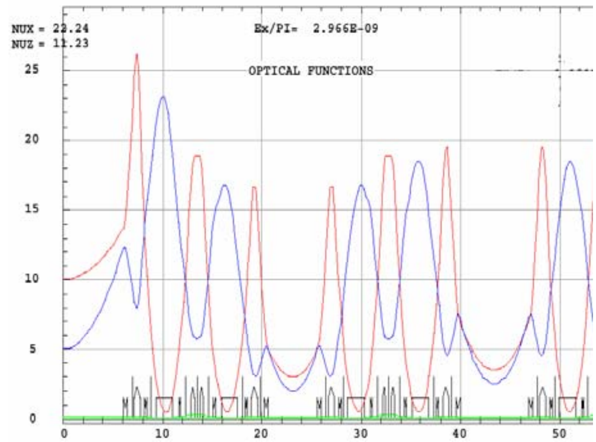

Figure 2: Lattice functions of a half SSRF super-period

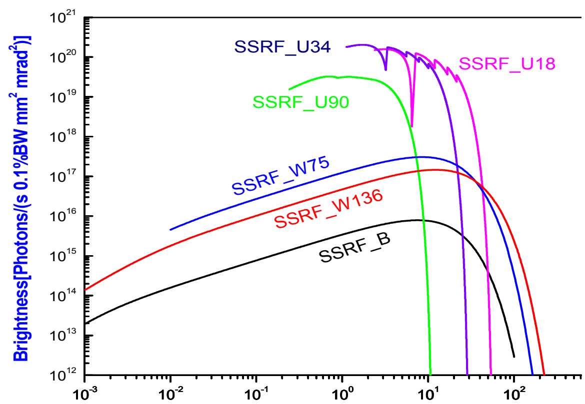

Figure 3: Spectral Brightness of SSRF

TOP-UP AND INJECTOR UPDATE

Top-up operation is a desired performance of the new generation storage ring light source. It has several outstanding advantages: 1) increasing the integrated brightness of the photon beam; 2) keeping a constant thermal load on the storage ring vacuum chamber and beamline optics, which are essential to photon beam position stability; 3) overcoming the short beam lifetime problems 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 and SLS [7-8] stimulate our great interest to look up the details for optimizing the light source complex 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 prevents the linac to be used for other purpose, such as for driving FEL as that proposed in the SSRF previous design. Therefore, the SSRF linac has been re-designed as a dedicated pre-injector with output energy of 100MeV. 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 3m SLAC type accelerating sections. Its beam pulse repetition rate is 1~5 Hz, its output energy spread is less than 0.5% and its normalized beam emittance is less than 100 mm·mrad. The electron linac working frequency is 2997.9MHz, which is harmonically related with 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 with low beam losses during the injection process, therefore is more favourable.

The re-design of the SSRF booster aims at reducing its beam emittance down to 100nm·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 180m [9]. The basic parameters of this new booster are given in table 2. In the top-up operation, the booster is expected to repeat its single injection every two minuets.

Table 2: Main Parameters of the Booster

Injection Energy (MeV)		100
Output Energy (GeV)		3.5
Circumference (m)		180.0
Natural Emitance (nm·rad)		101 (@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)		1.159
Super-period Number		2
FODO Cell Number		28
Cell Length (m)		6.600
Betatron Tunes		8.21/4.18
Synchrotron Tune		0.0219
Momentum Compaction		0.02443
Bunch Length (cm)		2.46

BEAM ORBIT STABILTY

Beam position stability is of overwhelming importance to ensure the lower emittance light source performance. It has to be considered in every related aspect from early design stage and then adopt the passive and active controls for achieving the position stability goals. Like most of third generation light sources, the SSRF sets its orbit stability specification 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-radian in divergence and a vertical stability level at sub-micron to micron and a part of micro-radian respectively.

The building stability and the machine thermal stability are examined for controlling the slow orbit variations. This will soon produce a complete specification to the building foundation and the conventional facility of the machine complex. As the representative requirements, the differential foundation stability is set at 0.1mm/10m/year for the storage ring, and the air temperature stability in the ring tunnel is set at ±0.1 ^{0}C. Mechanical vibrations and magnet power supply's ripples are preliminarily examined for controlling the fast orbit variations. This results in re-optimizing the storage ring girder design and re-checking the magnet power supply's specifications.

Orbit feedbacks are indispensable for achieving high beam orbit stability even with good passive control of slow and fast orbit disturbances. 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 100Hz.

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