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CONSIDERATION ON THE FUTURE MAJOR UPGRADES OF THE SSRF STORAGE RING

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Abstract

The SSRF storage ring began its user operation in 2009, currently it is operating at the energy of 3.5GeV, the natural emittance of 3.9 nm-rad and the beam current of 240 mA, serving for 13 beamlines with 9 IDs. Around 2020, there will be close to 40 operational beamlines at SSRF, which demand to further improve the performance of the existing storage ring, such as implementing the new lattice with superbends and installing 18 more new IDs. Looking for the future beyond Phase-II beamline project, a major upgrade towards a diffraction limited storage ring is under consideration. This paper presents the initial proposal on the ultimate storage ring upgrade for SSRF.

INTRODUCTION

The Shanghai Synchrotron Radiation Facility (SSRF) is a third generation light source, consisting of a 150 MeV electron linac, a full energy booster, a 3.5 GeV storage ring with circumference of 432m, and now 13 operational beamlines and 16 experimental stations. It started users' operation in May 2009 and already served more than 10000 users from all over China.

SSRF switched to top up operation [1] for routine user experiments in December 2012, its ring current had been gradually increased from 200mA to 240mA during the last 3 years. The major efforts for increasing the beam current is made on conditioning the superconducting RF cavity and suppressing beam instabilities. At present, the bunch filling pattern is shown in Fig. 1, four 125-bunch-trains separated by 55-empty-bucket gaps. While previous one is a uniform 550-bunch train, followed by a 170-empty-bucket gap. The main reason for such a filling pattern is to reduce the fast ion instability that is caused by high current and the newly installed undulators where the vacuum pressure is higher than the rest part of the ring.

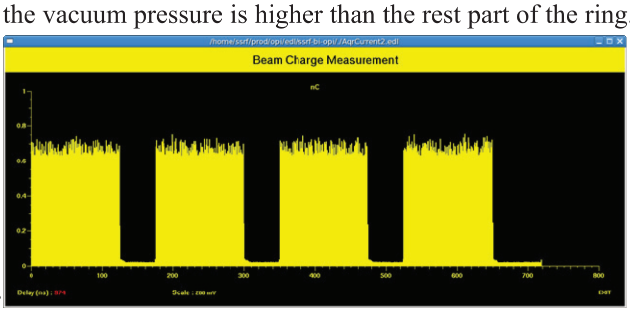

Figure 1: Bunch filling pattern of the SSRF storage ring.

Hybrid filling pattern has also been provided for users. A single bunch of 5 mA which is followed by a bunch train with current of 225 mA has been successfully run for the time resolution experiments. The time gap between single bunch and the bunch train is 110-empty-bucket gap as shown in Fig. 2.

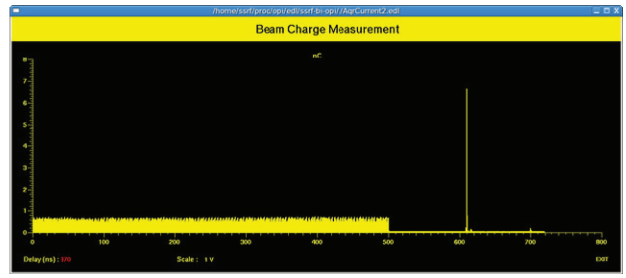

Figure 2: Hybrid bunch filling pattern in the storage ring.

The storage ring fast orbit feedback was successfully commissioned in 2013, and it has been implemented in users' operation since then. The system contains 60 fast correctors and 40 BPMs in each plane working at 10 kHz, controlling the orbit at the both end of straight sections [2]. The effective bandwidth is better than 100 Hz. The fast orbit feedback system works together with the slow orbit feedback system controlling the long term orbit stability to 0.26 μm and 0.25 μm (RMS) in horizontal and vertical planes respectively.

Over the past 3 years, five new insertion devices have been installed in the ring. Three of them are in vacuum undulators and two of which are dual canted with a canted angle 6 mrad. Another one is a double elliptical polarized undulator (DEPU) as shown in Fig. 3. The DEPU holds two undulators with period 58 mm and 148 mm respectively which can be shifted mechanically in horizontal plane to the electron beam orbit. The purpose of such a design is to provide soft X-rays with the photon energy from 20 eV to 2000 eV to one beamline. The additional one is a prototype of cryogenic permanent magnet undulator (CPMU) for performance evaluation. At present the phase error of this CPMU is under calibration and measurement through photon spectrum.

Figure 3: Twin EPU in the storage ring tunnel.

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UPGRADE FOR PHASE-II BEAMLINES

The SSRF Phase-II beamline project was initiated with its proposal approved by central government in March 2015, the main project task is to build 16 more beam lines to fulfil pressing demands of the Chinese users. Besides installation of 13 new IDs, including 4 CPMUs and a superconducting wiggler (4.2 Tesla), the storage ring will be upgraded with two superbend cells to extend the photon energy of the X-ray radiation from bending magnet and add more source points. The field of bending magnet will be increased to 2.3 Tesla from 1.27 Tesla and the length will be shortened to 0.8 m from original 1.4 m. Two 2 m short straight sections in the storage ring arcs will be created for capable of accommodating short IDs [3]. In the meantime, two 12 m long straight sections will be modified to be of double-mini-beta optics, and a 6.5 m standard straight section will be made dispersion free for superconducting wiggler installation. The optics after this upgrade is shown in Fig. 4. The major beam parameters after the ring upgrade is listed in Table 1.

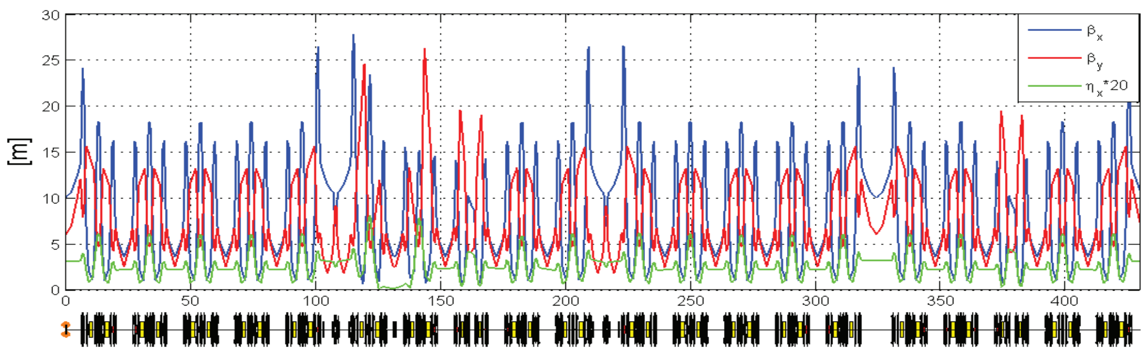

Figure 4: Storage ring optics for the SSRF Phase-II beamline project.

Table 1: Major Storage Ring Parameters after Upgrade

Parameters	Current	Upgraded
Energy/GeV	3.5	3.5
Natural emittance / nm·rad	3.89	4.22 With SW
Tune (H， V)	22.22, 11.29	22.222, 12.153
Natural chromaticity (H， V)	-55.7， -18.0	-55.3， -20.4
Momentum compaction	4.27×10^{-4}	4.2×10^{-4}
Energy spread	9.8×10^{-4}	11.1×10^{-4}
Radiation loss / MeV	1.44	1.70 With SW
Damping time/ms (H， V， S)	7.05, 7.02, 3.51	5.98, 5.94, 2.96

A 3rd harmonic passive cavity system will also be installed at the ring to lengthen the bunch in the Phase-II beamline project. The 3rd harmonic cavity will operate in 2.0K aiming at quality factor is higher than $\sim10^{10}$. A two-cell niobium superconducting cavity module is designed to provide a harmonic voltage higher than 1.4MV. The bunch length is expected to be increased by a factor of 2.3 and the Touschek lifetime can be doubled for high charge single bunch case [4]. Also the 3rd harmonic cavity could provide a strong Landau damping which will help to increase the current threshold of transverse mode coupling instability (TMCI) [5]. TMCI is the most serious single bunch instability at present situation and will getting worse when more and more IDs are added without adding a 3rd harmonic cavity.

SSRF-U CONSIDERATION

The MBA lattice based upgrade of the SSRF machine, termed as SSRF-U, is under consideration. This upgrade aims at reducing the nature emittance of the existing storage ring by a factor of 10, and therefore increasing the brightness by about two orders of magnitude. This upgrade can be conducted after the completion of the SSRF phase-II beamline project.

The storage ring of the SSRF-U will be located in the same tunnel as SSRF, and maintain the same beamlines as much as possible. Its lattice has four super periods and 20 7BA cells [6]. After initial lattice design, the ESRF-type structure with beta and dispersion bump is adopted due to its very effective chromaticity correction [7]. There are only focusing quadrupoles in the arc cells, and all the defocusing gradients are provided by the combined dipoles. The maximum gradients of the quadrupole and sextupole are 80 T/m and 4000 T/m^2, respectively.

Figure 5 plots the liner optics of the SSRF-U storage ring, and Table 2 summarizes the main ring parameters [6]. The working point is optimized to be 43.22 in the horizontal plane and 17.32 in the vertical plane, and the natural emittance reaches down to 202.5 pm.rad at the beam energy of 3 GeV. Due to the IBS effect, the horizontal emittance will increase by about 37.7%, with the coupling of 10%, the RF frequency of 500MHz and the bunch current 0.4mA/bunch. A third harmonic cavity will reduce the horizontal emittance growth to 13.4%. As high gradient magnets will be used, the air bone of the magnets will be 1/3 of current value. Thus the transverse

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resistive wall impedance will be an order higher than present, which is the dominant source of the beam instability. Both for resistive wall instability and TMCI, a powerful and effective transverse feedback system is required.

There are four harmonic sextupoles in each 7BA cell to correct the high order geometric aberrations. The dynamic aperture of on-momentum particle at the injection point is carefully optimized to be 8 mm in the horizontal plane, shown as in Fig. 6. The beam injection can be fulfilled by the traditional injection system. However, the dynamic aperture will be reduced by the magnetic field and the alignment errors. So, it is necessary to apply a new injection system.

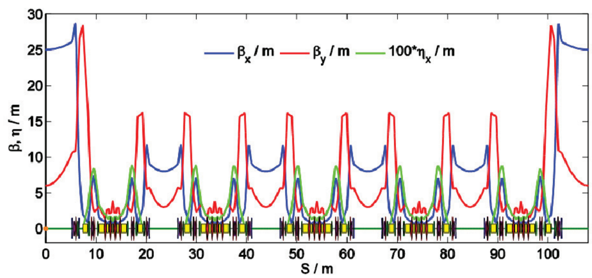

Figure. 5: The Linear Optics of the SSRF-U Storage Ring

Table 2: SSRF-U main parameters.

Beam energy / GeV	3.0
Circumference / m	432
Working point (H, V)	43.22, 17.32
Natural emittance / pm.rad	202.50
Natural energy spread (RMS)	9.2564×10^{-4}
Momentum compaction factor	0.00020
RF voltage / MV	2.0
RF frequency / MHz	499.654
Bunch length / ps	10.9550
Length of the straight / m	16×5.60+4×10.35

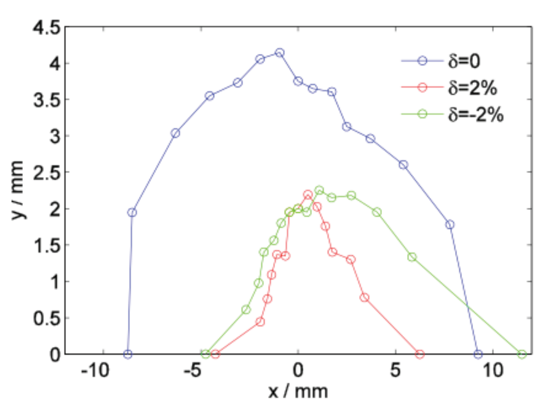

Figure 6: Dynamic aperture of the SSRF-U storage ring.

Injection system based on the pulsed multipole magnet seems a good solution, because of its small residual orbit distortion of the stored beam and required small dynamic aperture of the injected beam. Figure 7 shows a considered injection scheme that can be used at the SSRF-U storage ring [8]. A pair of pulsed quadrupoles locates in the injection straight section, rather than the dipole kickers. The septum moves closer to the central orbit and further to the next sector to release the strength of PQM. The centre of injection beam is at 18mm, and the PQM kicks the beam to 4 mm. The total strength of the PQM is around 4 mrad. At present, the structure of pulsed quadrupole is under design.

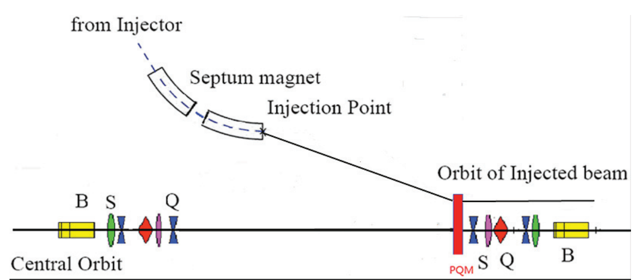

Figure.7: a new injection scheme for the SSRF-U.

CONCLUSION

SSRF has been operated stably and efficiently for user experiments since May 2009. The performance has been gradually enhanced with including top up injection, fast orbit feedback, novel IDs installation, beam current increasing and various filling patterns. The demands of X-ray science in China is extremely pressing, which makes SSRF phase-II beamline project the first priority for the SSRF team in the following years. The journey of MBA lattice based storage ring light source is taking off, which would lead SSRF to a bright future.

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