# PERFORMANCE OPTIMIZATION AND UPGRADE OF THE SSRF STORAGE RING

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*Abstract*

Performance of SSRF was optimized and improved in the past year, including implementing top-up injection, operation with low emittance optics in a round of users' run, and the machine test of the fast orbit feedback. In order to meet the requirements of accommodating more beamlines and high demanding performance in its Phase-II beamline project, the SSRF storage ring is being upgraded with super-bends and third harmonic RF cavity. This paper summarizes these results.

## INTRODUCTION

SSRF is a third generation light source based on a 3.5GeV electron storage ring. It has been opened to users since 2009 with its first seven beam lines. At present another 8 new beam lines is under construction or commissioning. In December 2012, top-up operation for user experiments started at SSRF. Since then the machine reliability and the orbit stability were further improved. The continuous efforts to reduce the natural emittance of the storage ring have been made. In the test run, about 20% reduction of the emittance and 10%~30% increase of the photon intensity at five beamlines are achieved comparing to the designed operation mode. The injection efficiency is around 60%.

In the Phase-II beamline project, we plan to replace eight nominal dipoles with super-bends, and then form four new short straight sections. In this way, more IDs could be installed, and the brightness of the hard X-ray from super-bend could be enhanced. Together with other funded beamlines, there will be about twenty IDs in the SSRF storage ring. These IDs will make the beam lifetime shorter, so the bunch lengthening system with 3$^{rd}$ harmonic cavity is necessary to prevent from frequently beam injection during top-up operation.

## CURRENT STATUS

Currently SSRF operates to deliver the photon beam about 5500 hrs/year, among them 4500 hrs/year are scheduled for public users. In 2012, the machine availability and MTBF during user operation are 98.4% and 69.8 hrs respectively, and show an improvement year by year. It has served more than 5500 users from all over the country since May 2009, and delivered fruitful and important experimental results.

The efforts to run top-up injection had been made including beam tracking for radiation hazards analysis[1], hardware interlock, injection disturbance optimization[2]. Top-up operation for users' experiments began on Dec. 6, 2012, and now it is a routine operation mode, as shown is Fig.1. The operating beam current is 200 mA, and when the beam loses 1 mA, the injection starts. Currently the injection interval is about 10 minutes. During the first top-up operation run, the best RMS orbit stability within 12 days is about 0.56 um in the horizontal plane and 0.25 um in the vertical plane respectively.

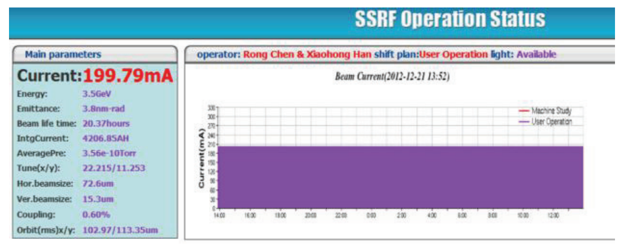


Figure 1: TOP-UP injection of the SSRF storage ring.

## PERFORMANCE IMPROVEMENT

There are continuous efforts to reduce the storage ring emittance and thus increase the photon brightness in the existing light sources. We have designed and tested a new optics with a natural emittance reduced from 3.9 nm.rad to 2.88 nm.rad, and the effective emittance reduced by about 1 nm.rad [3]. With great efforts of commissioning, the linear optics aberration, the coupling, the closed orbit and its stability can be corrected or controlled as the same level of the nominal optics. The designed and measured beam parameters are summarized in Table 1, and these results show a good agreement. This optics has been operated for users' experiments for four days. The photon intensity of five beam lines with an increase of 10%~30% is achieved. The lattice optics operating at 3.0 GeV has also been tried and 210mA current had been stored, the natural emittance at this energy is 2.12 nm.rad. The designed and measured beam parameters of this setting are summarized in Table 1.

The RF frequency feedback and soft orbit feedback are used in routine operation. The fast orbit feedback is still under commissioning. The system now employs 60 BPMs and 40 fast correctors. With drop off 39 small singular values, the PID parameter can be optimized and the beam motion can be suppressed over the frequency beyond 100 Hz, as shown in Fig. 2.

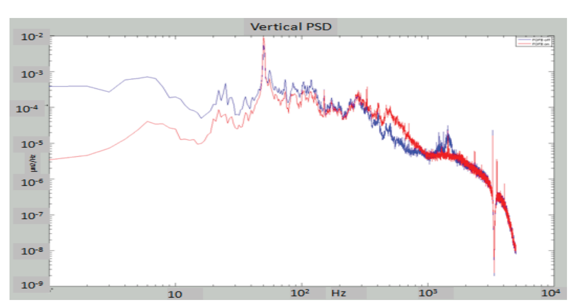


Figure 2: The beam motion with (red line) and without (blue line) fast orbit feedback.

The cross talk between slow orbit feedback (SOFB) and fast orbit feedback (FOFB) systems is done by update reference orbit of FOFB system when SOFB corrects orbit. In this way the strength of power supply of FOFB can be partly released which enable a long time operation without saturation of the power supply[4].

Table 1: Beam Parameters of the SSRF Storage Ring with Low Emittance Optics

| Parameter / unit | Designed value | Measured value | Designed value | Measured value |
|---|---|---|---|---|
| Beam energy / GeV | 3.5 | 2.50±0.02 | 3.0 | 2.99±0.02 |
| Tune (X, Y) | 23.31, 11.23 | 23.309, 11.238 | 23.31, 11.23 | 23.313, 11.233 |
| Synchrotron frequency | 0.0071 | 0.0074±0.0002 | 0.0078 | 0.0078±0.0003 |
| Natural emittance / nm.rad | 2.88 | 2.9±0.2 | 2.12 | 2.0±0.3 |
| Natural chromaticity (X, Y) | -74.5, -26.7 | -67, -23 | -74.5, -26.7 | -67, -24 |
| Corrected chromaticity (X, Y) | ------ | 2.0, 3.0 | ------ | 3.0, 4.0 |
| Momentum compaction factor | 4.13×10-4 | (4.2±0.2)×10-4 | 4.13×10-4 | (3.9±0.3) ×10-4 |
| Beam current / mA | ------ | 210 | ------ | 210 |
| Coupling | ------ | 0.5% | ------ | 0.4% |
| Beam lifetime / hrs | ------ | 15.0 | ------ | 8.5 |
| RMS beta beating (X, Y) | ------ | 0.7%, 0.8% | ------ | 0.6%, 0.8% |
| Injection efficiency | ------ | ~60% | ------ | ~60% |

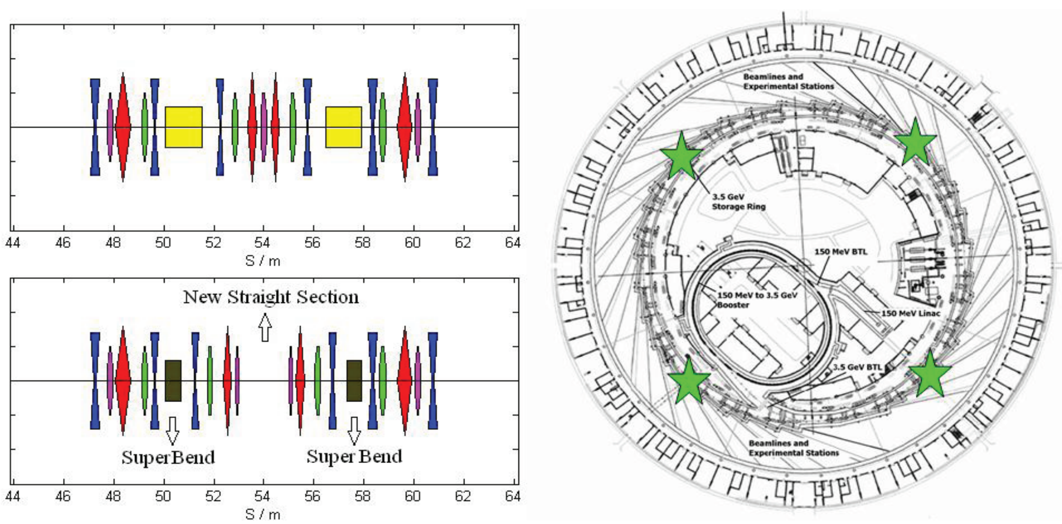


Figure 3: Lattice upgrade of the SSRF storage ring with super-bends (the green stars show the super-bend cells).

## STORAGE RING UPGRADE

Users' demands for high brightness hard X-rays (10-40 keV) have been the main requirements at the SSRF. However, straight sections to install insertion devices are limited in the storage ring. This makes us implement the super-bend scheme, whose brightness or flux of the hard X-rays will be significantly enhanced in the intermediate energy light sources. And in the meantime, short straight sections for IDs can be created. In the SSRF Phase II beamline project, we propose to replace eight normal dipoles with super-bends in four symmetric DBA cells, and divide these cells from center to form four new short straight sections, shown as in Fig.3. These new straight sections can be used for installing new short IDs. The length of the super-bend is 0.8 m, and the magnetic field is about 2.3 T. When the beam energy is 3.5 GeV, the critical photon energy is about 18.7 keV, increased from 10.3 keV of the normal dipoles. The arcs the four DBA cells are adjusted, and the length of new short straight sections is about 2 meters. In order to maintain the low effective emittance, the horizontal working point is increased from 22.22 to 23.23, and its natural emittance is 3.51 nm.rad. Fig.4 plots the linear optics in one fold of the storage ring, and Table 2 summarizes the lattice parameters. A good nonlinear solution is obtained, whose horizontal dynamic aperture is larger than 15 mm, resulted from simulation with a realistic model[5].


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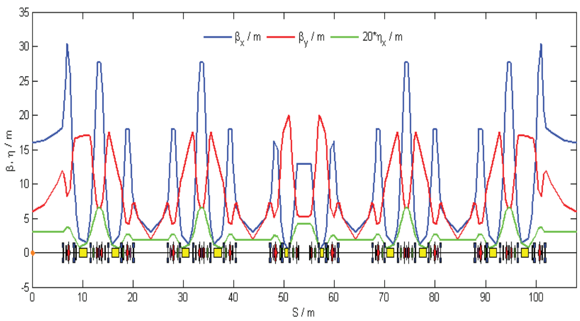


Figure 4: Linear optics in one fold of the SSRF storage ring with super-bend.

Table 2: Beam Parameters of Super-bend Optics

| Parameter / unit | Value |
|---|---|
| Circumference / m | 431.9785 |
| Beam energy / GeV | 3.5 |
| Tune (H, V) | 23.23, 11.31 |
| Natural emittance / nm.rad | 3.51 |
| RMS energy spread | 0.0011 |
| Natural Chrom. (H, V) | -71.50, -22.02 |
| Energy loss per turn / MeV | 1.670 |
| Mom. Compact. Factor | 3.64×10-4 |
| Synchrotron frequency | 0.00678 |
| Natural bunch length / ps | 13.5 |

The high order harmonic cavities have been applied in many low energy rings and some of the medium energy rings. The main purpose of the high order harmonic cavity is to stretch the bunch length and then increase the Touschek lifetime. The longer bunch also induces a less beam power loss of single bunch. The heating effects to the vacuum chamber will be greatly reduced, this makes the several high current bunch operation modes possible. Also the high harmonic cavity can introduce Landau damping effects which can increase both longitudinal and transverse instability thresholds. According to the limited space for the 3$^{rd}$ harmonic cavity at the SSRF storage ring, we plan to install a passive superconducting one which will operate at 2.2 K. The main parameters of the cavity are listed in Table 3.

Table 3. Main Parameters of the 3$^{rd}$ Harmonic Cavity

| | |
|---|---|
| RF Frequency (MHz) | 1500 |
| R/Q (Ohm) (2-cell) | ~180 （2cell） |
| Accelerating voltage Vc (MV) | 1.5~1.8 |
| Accelerating gradient（MV/m） | 7~9 |
| Qo | 1E10 |
| Operating temperature (K) | 2.2 |
| Operating pressure (mbara) | 31 |
| Dynamic load of cavity （W） | <5W |

For asymmetry fill pattern the transient beam loading causes significant variation of the bunch synchronous phase and bunch lengthening factor along the bunch train. This beam dynamics have been studied by the tracking method. For a long bunch train the average lengthening factor is 2.3, rising from less than a factor of 2 at the head and tail of the train to a factor of 2.7 in the middle of the train. For the hybrid fill, the timing bunch is suggested to locate at the middle of the empty gap which gets the maximum lengthening factor as shown in Fig. 5.

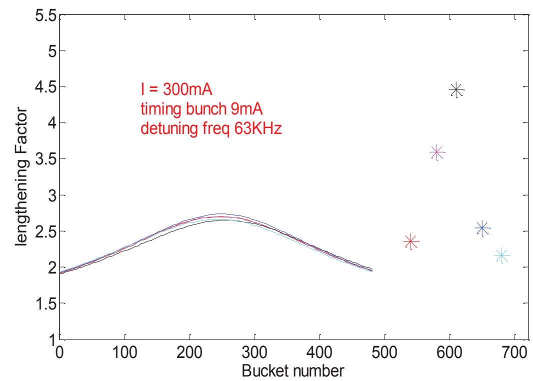


Figure 5: Transient loading tracking result of bunch lengthening factor for hybrid fill.

## CONCLUSIONS

The SSRF accelerators have been in high performance operation since May 2009. It has served more than 5500 users from all over the country delivering fruitful and important experimental results. The operation of the SSRF accelerator complex is very reliable, and many improvements in performance have been made, including obtaining the lower eimttance of 2.88nm-rad at 3.5 GeV and 2.12 nm-rad at 3.0 GeV, top-up operation with sub-micron orbit stability. Performance upgrade of the SSRF storage ring, including super-bend based lattice and 3$^{rd}$ harmonic RF cavity, are being considered to meet the increasing users' demands.

## REFERENCES

[1] B.C. Jiang, et al., High power laser and particle beams, V25(04): 985-988 (2013).

[2] Z. T. Zhao, et al., Proceedings of IPAC11, San Sebastián, Spain, 3008-3010, (2011).

[3] S. Q. Tian, et al., Proceedings of IPAC12, New Orleans, Louisiana, USA, 1647-1649, (2012)

[4] B.C. Jiang, et al., Proceedings of IPAC12, New Orleans, Louisiana, USA, 2855-2857, (2012)

[5] S.Q. Tian, Proceedings of IPAC12, New Orleans, Louisiana, USA, 1644-1646, (2012)