OPERATIONAL STATUS AND PERFORMANCE UPGRADES OF THE SHANGHAI SYNCHROTRON RADIATION FACILITY

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Abstract

The Shanghai Synchrotron Radiation Facility (SSRF), a 3.5GeV storage ring based third generation light source, started its user operation with 7 beamlines in May 2009. During the passed year, the facility reliably operated about 4000 hours for user experiments. This paper presents the operational status of the SSRF in the first year and its future performance improvement plans.

INTRODUCTION

The Shanghai Synchrotron Radiation Facility (SSRF) is an intermediate energy storage ring based third generation light source [1]. Its accelerator complex consists of a 150 MeV electron linac, a full energy booster and a 3.5 GeV storage ring. Its first seven beamlines (phase-I) are:

- Macromolecular Crystallography
- High-Resolution X-ray Diffraction
- X-ray Absorption Fine Structure Spectroscopy
- Hard X-ray Micro-focus and Application
- X-ray Imaging and Biomedical Application
- Small Angel X-ray Scattering
- Soft X-ray Microscopy

The SSRF has been fully operational with the 7 phase-I beamlines delivering light to users since May 2009, its main operating parameters are shown in Table 1. As of May 2010, the SSRF has provided about 4000 hours beam time to user experiments and served more than 1250 users from 114 universities and institutes all over China. About 540 experiments have been carried out and by end of this April about 30 research papers have been published in journals.

Table 1: The SSRF Operational Parameters

Storage ring energy (GeV)	3.5
Beam current (mA)	
Multi-bunch	210
Single bunch	6.5
Natural emittance (nm-rad)	~3.8
Natural energy spread	~0.1%
Betatron tunes	22.22/11.29
Coupling	~0.7%
RF voltage (MV)	>4.2
Beam lifetime (hours)	~30
Linac energy (MeV)	158
Booster bunch charge (nC)	~1.0
Booster rep. rate (Hz)	2

The SSRF accelerators operated stably and reliably in the first year from May 2009 to May 2010, the overall accelerator availability and MTBF are 95.6% and 31.8 hours respectively for about 4000 experiment hours. Besides providing beam for beamline commissioning and facility performance measurements to start the user operation and pass the Government acceptance, the SSRF has operated about 2070 hours for user experiments in 2009. In 2010, the SSRF is scheduled to provide 4000 hour's beam time to user experiments, and in addition, it will operate about 2000 hours for beamline developments and machine studies.

OPERATION PERFORMANCE

The SSRF started user operation on May 6, 2009. According to the requirements of the beamlines, the storage ring commenced its operation in beam decay mode with the start current of 120mA. Then the start operating current was increased by three steps through 150mA and 180mA to 200mA within two months. The storage ring has been operating in beam decay mode since the very beginning of the user operation. Currently the typical operating beam current is from 210mA to 140mA, the beam lifetime is around 30 hours, and the beam was injected twice a day, at 9:00 and 21:00 respectively. Figure 1 shows a typical beam current variation in the storage ring over 24 hours. The storage ring is continuously filled with uniform bunches followed by an empty bunch gap, the typical bunch number for user operation is either 500 or 600. Figure 2 shows the beam filling pattern with 600 bunches.

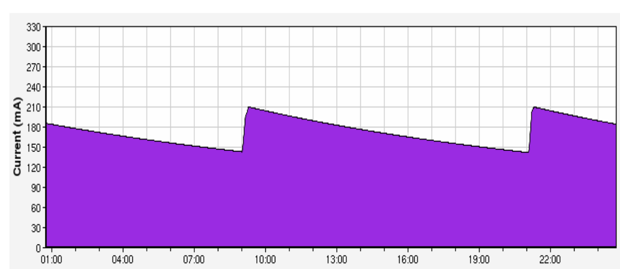

Figure 1: The SSRF Beam Operation Status

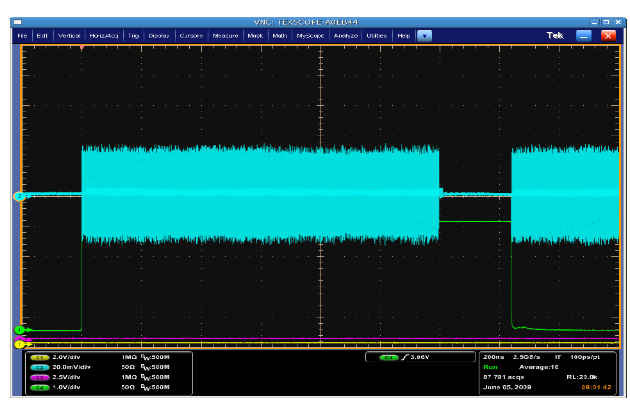

Figure 2: The Storage Ring Bunch Filling Pattern

The SSRF injector has been operated stably, reliably and efficiently since the beginning of the storage ring commissioning, the availability and MTBF of both the linac and the booster are all at 99.8% and 38 days level for the user operation in the passed year. In the mean time, the beam transmission efficiency from the LTB transport line through the booster to the BTS transport line is larger than 85%, and the beam transmission efficiency from the booster DCCT to the ring DCCT is larger than 95%.

The operation of the whole SSRF accelerator complex is very smooth in the first year, the longest uninterrupted beam running time is 137 hours, and the longest MTBF is 79 hours. Figure 3 shows the machine availability and MTBF in the 24 runs from May 2009 to May 2010, and figure 4 shows the statistics of the SSRF system failure time.

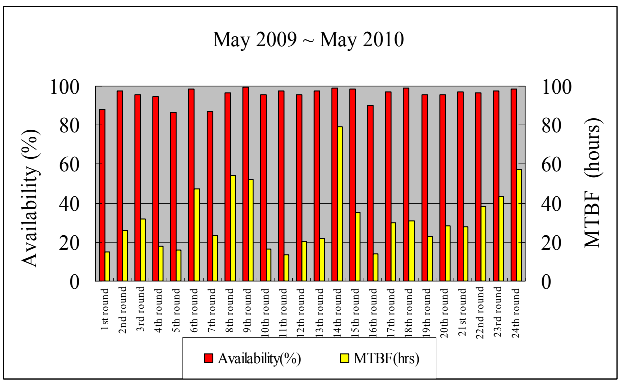

Figure 3: Availability and MTBF for Experiments

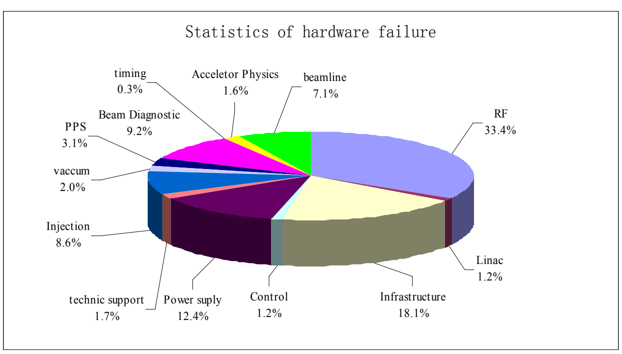

Figure 4: Statistics of the SSRF System Failure Time

The operation of the SSRF RF system is also quite smooth in terms of its initial performance [2], but it is the main system which causes most of the beam trips. The MTBF of the whole RF system in the passed year is about 43 hours, mainly determined by three superconducting cavities. There are two abnormal types of cavity trips in the SSRF RF system, cavity 1 trips are mostly caused by the bad vacuum near the ceramic window. When this kind of cavity trip occurs in high input power, there will be 3-4 cavity trips followed in a 4-5 hours interval. Cavity 3 trips are most likely caused by arc or multipacting inside the waveguide coupler. Conditioning cavities to high input power and high voltage is proved to be an effective method to get rid of superconducting cavity trips at SSRF. Therefore the cavity conditioning with beam has to be done after a long machine shut down. Up to now, the longest operating time without RF trip is about 450 hours.

MACHINE DEVELOPMENTS AND PLANS

The top-up operation was tested during the SSRF machine conditioning and studies [3], the horizontal and vertical orbit disturbances to stored beam from the injection elements has been suppressed to 100um and 30um respectively at the injection efficiency larger than 95%. In the meantime, the beam trace simulations against every possible unsafe condition are being performed, and the top-up operation related interlocks, including the interlocks for the stored beam, the injection efficiency, the beamline hutch dose control, injection and storage ring energy, are being implemented. It is planned to commence the top-up operation for the user experiments before the summer of 2011.

The SSRF storage ring operates routinely with the slow orbit feedback and the RF frequency feedback, the fast orbit feedback was also tested during the machine studies. As shown in figure 5, the horizontal and vertical orbit vibrations at ends of the storage ring straight sections are effectively suppressed. The fast orbit feedback is expected to be implemented at the storage ring right after the top-up operation start.

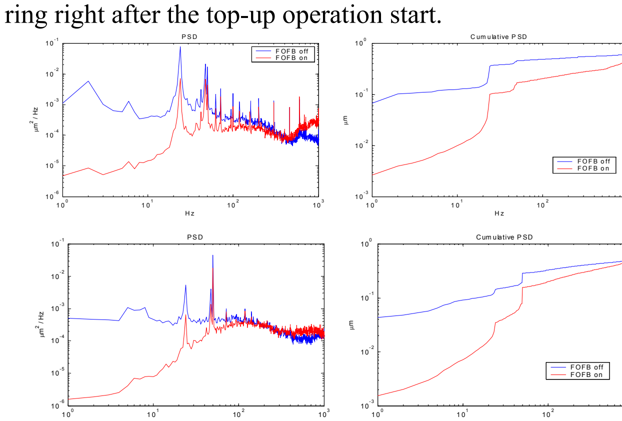

Figure 5: The Orbit Vibration Spectral Density (left) and Integrated Amplitudes (right) With (red)/Without (blue) Fast Orbit Feedback (upper: horizontal, low: vertical)

Besides the studies on non-linear beam dynamics behaviours in the SSRF storage ring and the low alpha optics, a low emittance lattice was commissioned up to 200mA in machine studies. By increasing the horizontal tune from 22.22 to 23.31, the emittance and effective emittance of this lattice are all reduced by ~10%.

Table 2: Low Emittance Lattice Parameters

Beam energy / GeV	3.5
Beam current /mA	~200
Tune (H/V)	23.31/11.23
$\beta_x/\beta_y/\eta$ @ long straight /m and standard straight /m	10/6/0.13 3.0/2.0/0.09
Natural emittance / nm.rad	3.5
Effective emittance / nm.rad	4.6
Momentum compaction	4.03×10^{-4}
Natural energy spread	9.84×10^{-4}

The maximum stored beam current of 300mA was achieved during the machine studies on July 18, 2009, and sometimes was running at top-up operation mode for only conditioning the machine itself, as shown in figure 6. In present user operation at SSRF, the maximum beam current in the storage ring is 210mA, and the beam lifetime is determined by a collimator with the vertical gap of 4.6mm. This collimator is located at downstream of the injection section, it can limit the electrons to hit on the magnet blocks of in-vacuum undulator at its minimum gap. As shown in figure 7, the beam lifetime gets short when this collimator gap is less than 10mm and drops linearly when it is less than 6mm. At vertical collimator gap of 4.6mm, changing the gap of the in-vacuum undulator gas has no any influence to the beam lifetime. Whereas, increasing RF voltage even up to 5.0MV can still improve the beam lifetime, which indicates that the beam lifetime is dominated by Touschek effect.

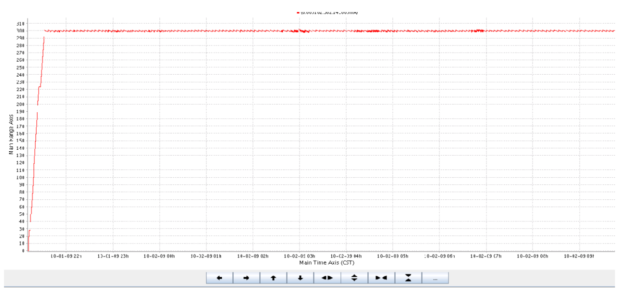

Figure 6: Maximum Stored Current Achieved at SSRF

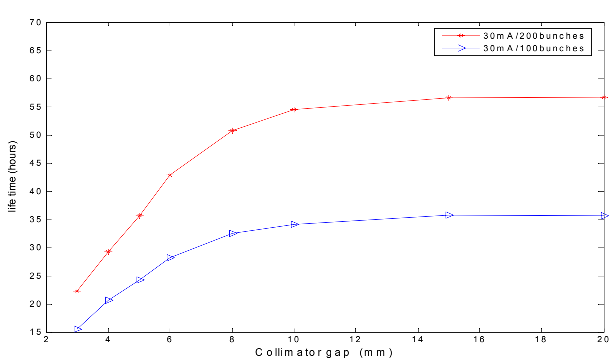

Figure 7: Beam Lifetime and Vertical Collimator Gap

A few of beam instrumentations were put online to use in 2009, including X-ray pinhole camera to measure the transverse beam dimension with an accuracy better than 10% and filling pattern monitor with 0.1% resolution and 0.5% accuracy. A new timing system based on real-time synchronized data bus, which is fully compatible with present event timing system, is developed as a spare at SSRF [4]. Its rms time jitter respect to RF clock is less than 10ps. It can also be used to distribute event trigger and exchange data and integrate orbit feedback, interlock and timing into a uniform system.

For keeping a long term stable operation of the SSRF RF system, a spare SRF cavity module is planed to develop based on in house infrastructure at SINAP. A KEK-B type single cell model niobium cavity has been fabricated and welded and the vertical cooling test to check the cold leakage has been performed after cavity surface polishing and chemical processing. The vertical test to check the cavity microwave performance is planed to carry out next month and an operational SRF cavity module is expected to be successfully developed in the following three years. For controlling the bunch length and damping the longitudinal beam instability in the storage ring, a passive third harmonic superconducting cavity system is considered, and a two cell SRF cavity is investigated. It will be developed and tested in the following five years.

To meet the requirements of the SSRF beamline short term development, a 5T superconducting wiggler is being designed and developed for a medical application beamline. A canted undulator layout is also under design consideration for two protein crystallography beamlines, which is planned to be implemented in three years.

FUTURE BEAMLINES

There are mainly two packages of planned SSRF beamlines under preparations, which will be funded by central government next year. The first ones are the five beanlines for National Protein Science Facility, which include three protein crystallography beamlines, one small angle X-ray scattering beamline and one IR Beamline with two end-stations. The second ones are the SSRF-II beamlines, which include 24 beamlines and will be constructed from 2011 to 2016. In addition, there are few beamlines under construction and discussion, which will be founded by other institutes and universities.

SUMMARY

The first year operation of the Shanghai Synchrotron Radiation Facility is quite smooth and reliable. As the first third generation light source in mainland China, it triggers a rapid development of synchrotron radiation applications national wide and the research interests of the scientists in various Chinese universities and research organizations as well as industries. In the following year, the top-up operation will be implemented to upgrade the SSRF operation performance.

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