COMMISSIONING OF THE SSRF STORAGE RING

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Abstract

The Shanghai Synchrotron Radiation Facility (SSRF) is a third generation light source with 3.5GeV beam energy. Its accelerator complex consists of a 150MeV linac, a full energy booster and a 3.5GeV storage ring. Commissioning of the storage ring on 3.0GeV beam energy began on Dec. 21st evening 2007 prior to the schedule. The first turn was observed after three hours with RF off. The beam was stored after twelve hours, and then cumulated up to 5 mA current. On Jan. 3, 2008, a beam with 100mA current is successfully obtained in the machine for the first time. Since then, the storage ring has been brought close to the designed specifications, and frequently operated with 100mA beam current for cleaning the vacuum chamber. In this paper, commissioning results of the storage ring is presented in details.

INTRODUCTION

The SSRF storage ring consisting of 20 Double Bend Achromatic cells with four super-periods is designed with a low emittance of 3.9nm.rad on 3.5GeV beam energy [1]. Each super-period contains three standard cells and two matching cells. All the 40 bending magnets are powered in series with one power supply, 200 quadrupoles with independent power supplies group into ten families and allow large flexibility of linear optics, 140 sextupoles in 8 families are elaborately optimized to provide ample dynamical acceptances, 80 correctors in each transverse plane and 140 Beam Position Monitors (BPMs) are used for closed orbit correction. Table 1 summarizes main parameters of the storage ring. Because the normal conductity cavity can't compensate beam energy loss on the 3.5 GeV beam energy, Phase I of the ring commissioning is on the beam energy of 3.0 GeV, where natural emittance is 2.86nm.rad. The nominal vertical tune has been changed from 11.32 to 11.29 in order to avoid a serious nonlinear resonance [2]. Figure 1 is the optical functions of one fold of the ring. The βx/βy/ηx is matched as 10/6/0.15m and 3.6/2.5/0.106m in the middle of the long and the short straight sections, respectively.

COMMISSIONING OF THE STORAGE RING

First turn and multi-turn

On December 21, 2007, commissioning of the storage ring was started and electron beams were injected on the central orbit of the ring by an on-axis injection. The bending magnets, quadrupoles, as well as sextupoles, were powered on to fields corresponding to 3 GeV. When cycling the sextupoles, the first turn beam signal was accidentally observed in BPMs. And then two horizontal correctors in the last cell were adjusted to obtain several beam revolutions in the ring, shown as Figure 2. More than 20 revolutions were observed by slightly tuning sextupole strengths. When the sextupoles were switched off, and all the correctors were scanned, the first turn and multi-turn signal was reproduced easily.

Table 1: Parameters of SSRF Storage Ring

Energy	3.5	GeV
Circumference	432	m
Straight sections	4×12 16×6.5	m
RF frequency	499.654	MHz
Harmonic number	720	
Multi-bunch current	300	mA
Single bunch current	5	mA
Betatron tune	22.22/11.29	
Natural emittance	3.9	nm.rad
Natural chromaticities	-55.7/-17.9	
Momentum compaction	4.27×10^{-4}	
Radiation loss per turn	1.44	MeV
Relative energy spread	9.84×10^{-4}	

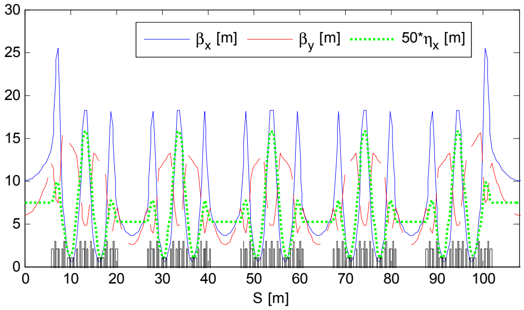
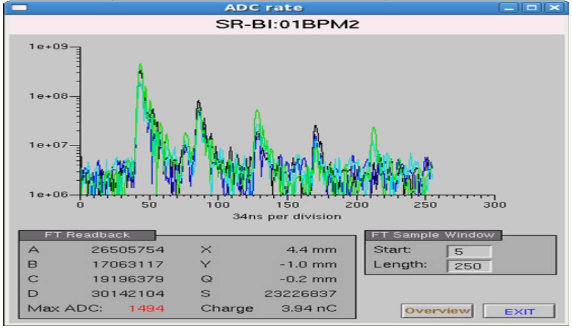


Figure 1: Optical functions of one fold of the ring



A 26505754 X 4.4 mm
B 17063117 Y -1.0 mm
C 19196379 Q -0.2 mm
D 30142104 S 23226837
Max ADC: 1494 Charge 3.94 nC

Start: 5
Length: 250

Figure 2: The multi-turn signal observed in a BPM

Beam storage and accumulation

The sextupoles were switched on again, and to 20% of their theoretical values, the number of turn increased simultaneously. In order to store beam, the RF was turned on. After optimization of the RF frequency and phase, the beam circulated the storage ring for 2500 turns or so. With these encouraging results, the RF frequency and the bending fields were carefully balanced to improve the acceleration condition, and the first stored beam was successfully obtained in Dec. 24th morning, 2007, when only six correctors were used. The first synchrotron radiations were observed at the beam line for synchrotron radiation diagnosis and the front end of Beam line BL16B [3]. Figure 3 is the first stored beam signal on VNC of the storage ring.

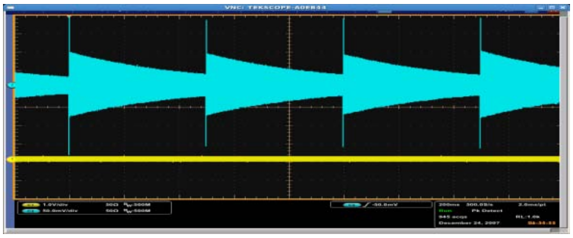


Figure 3: The first stored beam signal on VNC of the storage ring

By means of gradually increasing of the sextupole strengths, appropriate closed orbit correction based on SVD, and injection optimization, the beam lifetime was improved, and thus the beam accumulation was achieved. On Dec. 24 2007, 16:23, the beam was accumulated to a 4 mA current with a lifetime of two hours or so. The subsequent efforts were emphasized on protect systems about closed orbit interlock and temperature interlock for high beam current. With result of the first round BBA, the closed orbit can be corrected to 1.7/0.85 mm (RMS) for horizontal and vertical plane. At 20:19 on Jan. 3 2008, a beam with 100 mA current was obtained successfully. After about one month for cleaning the vacuum chamber, the beam lifetime on 100mA current could increase to 20 hours approximately. Due to the cavity restrictions, the beam current during Phase I commissioning was limited to 100mA.

Machine correction and calibration

With higher beam current, it seemed to give a better resolution in beam positions in BPMs. The offsets between quadrupoles and their closest BPMs were accurately measured after several rounds of BBA [4], shown as Figure 4. After setting all the offsets in BPMs, the closed orbit deviations were corrected sufficiently with highly precise measured orbit response matrix. On March 16 2008, the storage ring achieved RMS closed orbit deviations less than 50 um in both transverse planes. Figure 5 plots the beam positions at BPMs along the ring, where the closed orbit deviations at all BPMs are within ±0.15 mm in both transverse planes. At the start of March 2008, we began to test the slow orbit feedback system. The correction technique was still based on SVD, and included adjusting the RF frequency to compensate the circumference variation due to temperature variation. In May 2008, the slow orbit drifts were restricted within ±5um for the horizontal and the vertical planes, during 10-hour operation [5]. At the start of June 2008, the slow vertical orbit stability in the high stable BPMs reached down to ±1um, shown as in Figure 6.

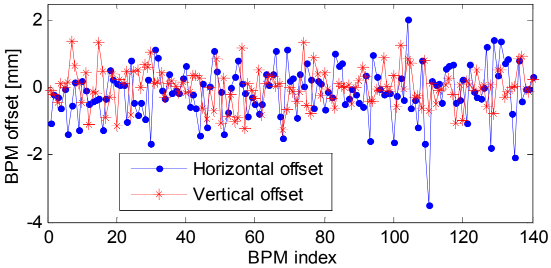


Figure 4: BPM offsets

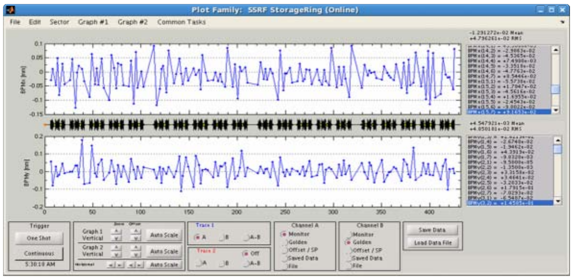


Figure 5: The closed orbit along the ring

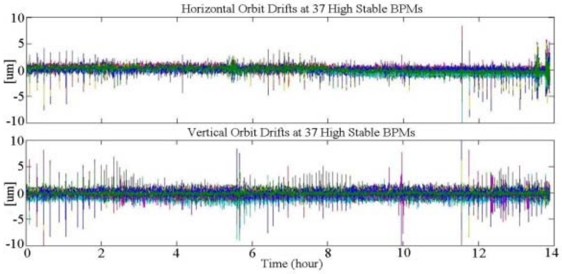


Figure 6: Slow orbit feedback results

Calibration of the linear optics is an indispensable commissioning task. The LOCO technique [6] has become a standard tool to characterize and correct as needed. At the first step, we used LOCO to correct the magnetic coefficients of the quadrupoles by means of fitting family-by-family, and then restore periodicity and symmetry of the linear optics by fitting magnet-by-magnet. Beta-beating between the machine and the designed mode was sufficiently minimized from ±10% to ±1%, shown as Figure 7.

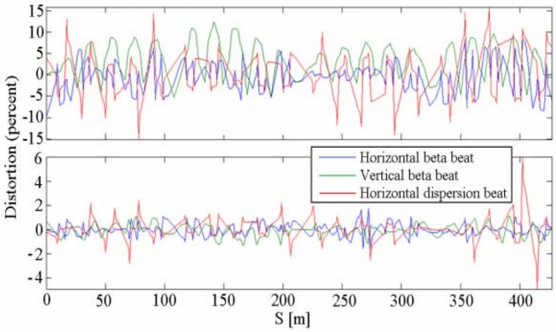


Figure 7: Beta and dispersion beating between the machine and the designed mode before (the top plot) and after (the bottom plot) LOCO calibration

Milestones of the storage ring commissioning

The important milestones in Phase I of the SSRF storage ring commissioning are summarized there, and some results of the machine physics study are presented in the following section.

- Dec. 21 2007, 21:08, first turn
- Dec. 24 2007, 06:55, beam storage
- Dec. 25 2007, accumulation of 5 mA beam current
- Jan. 3 2008, accumulation of 100 mA beam current
- March 16 2008, closed orbit is corrected to less than 50 um (RMS) for both transverse planes
- March 17 2008, periodicity and symmetry of the linear optics is restored
- May 2008, slow orbit drifts were restricted within ±5um for horizontal and vertical plane
- Start of June 2008, slow vertical orbit drifts of high stable BPMs were restricted within ±1um.

MACHINE PHYSICS STUDY RESULTS

As the commissioning went forward, the ring parameters were measured extensively. At present, we can accurately operate the machine with a designed optical mode. The LOCO technique takes an important role, mentioned as above paragraphs. Four different optical modes have been commissioning in the SSRF storage ring so far, including a dispersion mode with a tune of 22.22/11.29 (the nominal mode presented in Table 1), a dispersion-free mode with a tune of 22.22/11.29, a dispersion mode with a lower tune of 19.22/7.32, and a dispersion mode with a higher tune of 23.324/11.232 and a lower emittance as 2.47nm.rad on 3.0GeV beam energy. In this section, parameter measurements of the nominal mode are presented.

Optical functions

Measurements of the optical functions were done with two methods by LOCO and directed measurement. The errors between the real machine and designed have been shown that the real machine is very close to the designed one.

Tunes, chromaticities, emittance and coupling

Integer parts of the tunes are measured by response matrix, and fractional parts are extracted from BPM turn-by-turn signals when exciting the beam with an injection kicker and a stripline. Natural chromaticities are calculated by measuring tune shifts as a function of bending field shift. The natural emittance is calculated from beam sizes of the bending magnet. Linear betatron coupling is determined by the closest tune approach, and seems to be very low (0.52%). These results are summarized in Table 2, and show an excellent agreement with the designed mode.

Table 2: Comparison between Designed and Measured

Parameter	**Designed mode**	**Measured value**
tune	22.22/11.29	22.2213/11.2905
chromaticity	-55.7/-17.9	-50/-17
emittance	2.86 nm.rad	2.83 /nm.rad
RF frequency	499.654 MHz	499.675 MHz

Instabilities

The vertical beam blowup of single bunch was observed, and the threshold is 4.78mA. Vertical multi-bunch instability is evidenced by the appearance of betatron sidebands around the orbit harmonics in the beam spectrum on beam current of 64mA, and the threshold increased exceeding 100mA as chromaticities increased to 0.5 on 1/2 filling pattern. According to tune shifts as a function of single bunch current, the vertical broadband impedance was characterized as 136KΩ/m with an assumption of 7mm beam length, and the longitudinal broadband impedance as 0.30 Ω. The measurements are agreed with theory.

CONCLUSIONS

The Phase I commissioning of the SSRF storage ring is encouraging. The different steps of the commissioning were covered very quickly and prior to the schedule. Some important specifications have been reached. The linear optics was calibrated to very close to the designed mode. The slow orbit feedback has achieved large improvement. Once the superconductive cavity is equipped in the ring, the commissioning on a beam with 3.5GeV energy and 300mA current will start..

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