COMMISSIONING STATUS OF THE SHANGHAI SYNCHROTRON RADIATION FACILITY

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Abstract

The Shanghai Synchrotron Radiation Facility (SSRF), an intermediate energy storage ring based third generation light source, is under commissioning at a site in Shanghai Zhang-Jiang Hi-Tech Park. The ground breaking of this project was made on December 25, 2004, and on December 24, 2007 an electron beam at 3GeV was stored and accumulated in the SSRF storage ring. Since then the accelerator commissioning and beamline installation have been being continued toward the scheduled user operation from April 2009. This paper presents an overview of the SSRF status and its machine commissioning progress.

INTRODUCTION

The SSRF complex was designed and constructed as one of the advanced third generation light source facilities worldwide. The SSRF project was approved in 2004, and its groundbreaking was made on December 25, 2004. Since then the construction and commissioning has been progressing towards the target schedule of starting user operation from April 2009 [1].

Constructions of SSRF buildings, including the main building housing accelerator tunnels and the experimental hall, two utility buildings, a technical building, an office building, a cafeteria and a guesthouse, were completed in May 2007. Figure 1 is a photo showing the SSRF main building in July 2007.

Figure 1: The SSRF site July 2007

The construction and the primary commissioning of the SSRF utilities, including electric power stations, water cooling systems, air cooling systems and compressed air system, have been completed ahead of schedule. These systems have been being in normal operation to meet the requirements of the equipment testing and commissioning of accelerator systems and beamlines, their fine operation optimizations are under going along with the facility commissioning and operation. The required performances of the air temperature stability within ±0.2 ^{0}C in the storage ring tunnel and within ±1.0 ^{0}C in the experimental hall have been achieved.

Except the liquid helium cryogenic plant, all the other SSRF accelerator systems were constructed and tested on schedule. The SSRF linac commissioning was performed from May to July, 2007, and the booster commissioning was mainly carried out in October and November, 2007. Then the commissioning of the SSRF storage ring at 3GeV started on December 21 evening, 2007, thanks to KEK for lending SSRF the retired PF copper cavities.

INJECTOR COMMISSIONING

The SSRF injector is consisted of a 150MeV linac and a 3.5GeV booster [2, 3]. Its commissioning is performed in a rapid speed. The linac commissioning started on May 15, 2007, and the first beam with energy higher than 100MeV was obtained at the end of the SSRF linac on the first day. By end of July 2007, the design specifications of this linac were reached both for single bunch and multi bunch operation modes.

The SSRF booster commissioning started on September 30 evening, 2007, and the beam passed the transfer line from linac to the booster and arrived at the entrance of the booster injection septum magnet within 3 hours. The first turns of beam in booster was obtained in the following afternoon, the stored beam and the 3.5GeV ramped beam were achieved on the May 2 and 5 mornings respectively. The extracted beam was obtained on October 29, 2007. Since December 21, 2007, the booster has been operated reliably as a fully energy injector to the SSRF storage ring. Up to now, the main booster specifications were fully achieved in the commissioning and operation over the past 8 months [4].

STORAGE RING COMMISSIONING

The installations and system tests of the SSRF storage ring was mostly completed in the middle of December 2007 [5], and the commissioning is scheduled into three phases according to the practical installation situation and the commissioning plan for the five initial insertion devices, helium cryogenics system and superconducting cavities. In Phase I, three retired copper cavities lent from KEK-PF are used for the storage ring commissioning at 3GeV and 100mA [6]. Its main objectives are to complete the basic storage ring beam commissioning and two bending magnet beamlines commissioning before July 2008. In Phase II, the commissioning will be performed at 3.5GeV with two SRF cavities, the beam current target is over 200mA, more collective beam effects will be studied and transverse multi bunch beam feedback will be in a reliable routine operation. In Phase III, the storage ring commissioning with five insertion devices and their corresponding beamline commissioning will be carried out from October 2008 to April 2009.

The Phase I storage ring commissioning started on a Friday (December 21, 2007) evening, the first turns were achieved two hours after the first attempt injection to the storage ring and 60 hours later the beam storage in the ring was achieved on December 24 morning. On January 3, 2007, a 100mA stored current at 3 GeV was achieved for the first time. Since then the machine characterisations have been carried out effectively and the Phase I storage ring commissioning were completed on June 19, 2008.

Closed Orbit Correction and Optics Calibration

Since the available total RF voltage of the three PF cavities is around 1.5MV, the Phase I commissioning is therefore carried out at 3GeV. Table 1 lists the main SSRF storage ring parameters at 3GeV.

Table 1: Main Parameters of the 3GeV Storage Ring

Energy (GeV)	3.0
Circumference (m)	432
Harmonic Number	720
Number of cells/Super-periods	20/4
Natural Emittance (nm·rad)	2.86
Beam Current (mA)	100
Straight Lengths (m)	4×12.0, 16×6.5
Betatron tunes, Q_x/Q_y	22.22/11.29,
$\beta_x/\beta_y/D_x$ @12m straight (m)	10.0/6.0/0.15
$\beta_x/\beta_y/D_x$ @6.5m straight (m)	3.5/2.5/0.10
Momentum Compaction	4.27×10^{-4}
Natural Chromaticities, (ξx/ξy)	-55.7/-17.9
Relative Energy Spread	8.44×10^{-4}
RF Frequency (MHz)	499.65
Dipole Radiation per Turn (MeV)	0.775
Damping Times $\tau_x/\tau_y/\tau_s$(ms)	11.19/11.15/5.56

After the beam was quickly stored in the ring for the first time, the initial orbit correction was made using MICADO method, and then the SVD based orbit corrections were implemented exclusively. The response matrix (RM) measurements and beam based alignments (BBA) for determining precisely the offset between the center of each BPM and the magnetic center of the adjacent quadrupole were repeatedly performed. With the BPM offsets and the measured response matrix, the storage ring residual closed orbit was quickly corrected to less than 100um (rms). Regarding the current dependence of BPM, the later BBA, response matrix measurements and orbit correction were carried out at 100mA. By using 137 BPMs and 80 correctors in each plane, the residual closed orbit less than 50um could be easily achieved in both horizontal and vertical directions. The maximum corrector strengths used are 0.17mrad horizontally and 0.18mrad vertically. When switch off all of the correctors, the residual closed orbit agrees well with the magnet alignments, the horizontal and vertical bare orbit errors are 4.8mm and 1.8mm (rms) respectively.

The SSRF storage ring optics calibration was carried out based on LOCO [7], the beta function and dispersion were restored in a reasonable precision, the beta function and dispersion beatings were reduced to ±1% based on the magnet by magnet (quadrupole) B-I corrections. After the designed working point (horizontal/vertical tune) of 22.22 and 11.29 was realized in the operation, a group of lattice configurations including dispersion free mode, low tune and high tune modes (see table 2) were established and calibrated according LOCO model. MIA method was also used to check the results from LOCO, and they agree very well at the beta function and dispersion modelling.

Table 2: Main Parameters of Low and High Tune Modes

Mode	Low Tune	High Tune
Energy (GeV)	3.0	3.0
Betatron tunes, Q_x/Q_y	19.22/7.32,	23.32/11.23
Nat. Emit. (nm·rad)	3.98	2.47
Beam Current (mA)	100	100
$\beta_x/\beta_y/D_x$ @12mS (m)	15/8.0/0.15	12/6.0/0.17
$\beta_x/\beta_y/D_x$ @6.5mS (m)	13.5/4.6/0.14	2.5/2.0/0.102
Nat. Chromat. (ξx/ξy)	-45.77/-21.81	-64.39/-19.93
Momen. Compaction	5.89×10-4	3.61×10-4

Orbit Stability

An obvious horizontal orbit drift along with the change of outdoor temperature was verified, it indicates a 1.5mm daily circumference change of the storage ring in March. A RF frequency feedback is implemented to compensate this temperature effect. At such circumstance, the daily orbit drafts at most of the SR source points are less than 50um in both planes. For stablizing the orbit stability at the SR source points, a slow orbit feedback operated at 0.01-0.1Hz was extensively tested at the SSRF storage ring, a maximum orbit deviation within ±1um at the ID BPMs was achieved in the beginning of June 2008. Meanwhile, the injection disturbance to the orbit during top up was figured out and studied, the injection kikers (strength balance and alignment) were optimized, by adjusting the strength balance between the kicker 1 and 4, the horizontal and vertical orbit disturbances were reduced to less than 100nm and 30 nm respectively. It was believed that there is still a room to optimize.

The ground motion is a challenging issue at SSRF site, which is located in urban area and with a soft soil earth condition. The on site ground motion, tunnel floor vibration, quadrupole magnet vibration and beam position vibration in the SSRF storage ring were measured and studied interrelated at various conditions including cases at quiet and noisy time, deliberately arranged truck and crane movements. The results show that the integrated PSD orbit deviations (rms) at quite time are in the sub-micron level. However, there exists a 30-40 Hz noisy signal in the beam spectrum, which has big contribution to the integrated PSD orbit deviations and needs to be identified the sources. The measurements also show that the maglev train running close to the SSRF campus has no influence to the beam vibration spectrum.

Current, Top up Injection, Lifetime and Vacuum

After 100mA at 3GeV was achieved on Jan.3, 2008, the SSRF storage ring then was operating at a top-up like injection mode for beam conditioning of the ring vacuum chamber. The beam current was kept at 99 – 100mA, and the beam life time was soon raised up to 13-15 hours. The initial beam conditioning of the vacuum chamber was very effective, the dynamic vacuum pressure was reduced by two orders of magnitude during the accumulation of the first 10Ahrs integrated current. When the integrated current was over 20Ahrs, the dynamic pressure was down to 9×10^{-12} torr/mA.

The low charge single bunch top up injection was tested and the beam current ripple could be controlled at a level of 99.75 to 100mA. Furthermore it was found that the injection disturbance to the circulating beam orbit was smaller at this low charge injection condition.

Higher current commissioning of the SSRF storage ring was able to be carried out at lower energy due to the RF system settings, a 200mA at 2.0GeV and a 300mA at 1.5GeV were obtained in middle of June 2008, just before completing the commissioning with copper cavities. The limiting factor for reaching high stored current in the ring at this stage is the beam instabilities associated with the cavity higher order modes, and strong longitudinal dipole and quadrupole oscillations were observed at higher beam current, this problem will be solved once the SRF cavities are operated in the SSRF storage ring.

Parameter measurements and Machine Studies

Along with the progress of the machine commissioning, the SSRF beam diagnostics were commissioned and calibrated precisely to meet the parameter measurements and machine studies. For characterising the SSRF storage ring performances, a series of machine parameters have been primarily measured, calibrated and corrected, including transverse (horizontal, vertical) and longitudinal tunes, chromaticities, coupling, emittance, beta function, dispersion, momentum compaction factors, circumference change, broadband impedance, single bunch current threshold, Touschek beam life time. Further systematic and precise measurements will be carried out in Phase II commissioning.

Meanwhile, a number of machine studies on beam instabilities have been made during the commissioning, resistive wall and ion related instabilities were observed, transverse multi bunch beam feedback, RF feedback and zero mode feedback were tested.

BEAMLINE COMMSSIONING

There are 7 initial beamlines included in the current project construction, among them a macromolecular crystallography and a hard X-ray micro-focus beamlines are based on in-vacuum undulators, a XAFS and a medical X-ray image are based on wigglers and a soft X-ray microscopy beamline is based on an EPU. The rest two bending magnet based beamlines are small angel X-ray scattering and high-resolution X-ray diffraction beamlines, which have been commissioned from the beginning of May and June 2008 respectively. These two beamline commissioning are proceed smoothly, the performance of mirrors and monochromators in these two beamlines were characterized and optimized, the rocking curves at 5keV and 10keV were measured. In addition, the absorption spectrum for a copper foil around 8.9keV was measured and a phase contrast image of a small goldfish was obtained as verifications.

CONCLUSIONS

The construction and the first phase commissioning of the SSRF accelerator complex has been very successful. The basic machine characterisations and calibrations have been completed. The storage ring commissioning with two SRF modules will start at end of July 2008, and the machine commissioning with insertion devices and the related beamline commissioning will be carried out from October 2008 to April 2009. The SSRF user operation is scheduled to begin at the end of April 2009.

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