CONSTRUCTION OF SHANGHAI SYNCHROTRON RADIATION FACILITY

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Abstract

The Shanghai Synchrotron Radiation Facility (SSRF), a third generation light source based on a 3.5GeV storage ring, is under construction at Zhang-Jiang Hi-Tech Park in Shanghai. The SSRF groundbreaking was made in December 2004 and the construction of the SSRF main and auxiliary buildings was basically completed in November 2006. The construction and installation of the SSRF accelerator components are under going with the target schedule of starting storage ring commissioning in April 2008 and the user operation in April 2009. This paper reports the construction progress of the Shanghai Synchrotron Radiation Facility.

INTRODUCTION

The SSRF complex in phase one consists of a 150MeV electron linac, a full energy booster, a 3.5GeV storage ring with a circumference of 432m and seven beamlines and experimental stations [1].

The SSRF project was fully approved by the central government in December 2004, and its groundbreaking was made a few days later on December 25. Since then the SSRF construction has been in progressing towards the target schedule of starting user operation from April 2009 [1, 2]. 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, have been basically completed, and they have been fully opened for utilization, such as utility installation and commissioning, machine pre-assembly and installation. Figure 1 shows the SSRF main building in January 2007.

Figure 1: The SSRF main building, January 2007.

The SSRF utilities, including electric power stations water cooling systems, air cooling systems, compressed air system and etc., have been installed and partly commissioned. The main power station has been in operation since October 2006. The piping and cabling from the main stations to the substations of the utility systems have been finished, and the engineering work in the main building is still going on. The commissioning of the SSRF utility systems is progressed on schedule, which is able to meet the requirements of various accelerator equipment testing and commissioning.

At this writing, most of SSRF accelerator components are under manufactures in domestic and foreign industries. At the same time, the machine installations, including linac, the booster RF power transmitter, a storage ring mechanical and electrical sector C10 and etc. are under way. The engineering design of the seven beamlines and experimental stations is in the final stage, and beamline components procurements are under going. The contracts of seven front-ends, four mono-chromators and etc. have been awarded.

STORAGE RING

The SSRF storage ring has 20 double bend lattice cells with four-fold symmetry, which incorporate four 12m long and sixteen 6.5m straight sections to accommodate injection magnets, SRF cavity modules and various insertion devices. With the finite dispersions leaking into the straight section, the storage ring natural emittance can be optimized to less than 4 nm·rad. Table 1 shows the main parameters of the SSRF storage ring.

Table 1: Main Parameters of the SSRF Storage Ring.

Energy (GeV)	3.5
Circumference (m)	432
Harmonic Number	720
Number of cells/Super-periods	20/4
Nature Emittance (nm·rad)	3.9
Beam Current, Multi-Bunch (mA) Single-Bunch (mA)	200~300 >5
Straight Lengths (m)	4×12.0, 16×6.5
Betatron tunes, Q_x/Q_y	22.22/11.32,
$\beta_x/\beta_y/D_x$ @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	4.2×10^{-4}
Relative Energy Spread	9.7×10^{-4}
RF Frequency (MHz)	499.65
Dipole Radiation per Turn (MeV)	1.448
Damping Times $\tau_x/\tau_y/\tau_s$(ms)	6.97/6.97/3.49
Bunch Length (mm)	4.0

Magnets and girders [3]

A total of 40 dipole magnets, 200 quadrupoles and 140 sextupoles, are being built for the SSRF storage ring. The dipole and quadrupole magnets are under fabrication at IHEP workshop, Beijing, and the magnetic measurements of the magnets for the first cell are completed. The first 10 dipoles achieved 3×10^{-4} variation in the integrated field across ±27mm, and their magnet to magnet integrated field reproducibility is 1×10^{-3}. The first 20 quadruploes achieve 5×10^{-4} variation in the integrated field across the aperture radius 26mm. These dipoles and quadrupoles are qualified within the specifications. The sextupoles with skew quadrupole windings are being manufactured and measured at SINR Workshop, Shanghai. The first 20 magnets achieved 1×10^{-3} variation in the integrated field across the aperture radius 26mm, and the magnet to magnet integrated field reproducibility is 2×10^{-3}, these are within the required tolerance. The first static corrector magnet has been also manufactured and measured with qualified field parameters, and the rest 80 correctors are under fabrication at SINR workshop.

Figure 2: The storage ring cell C10 in the tunnel.

There are three steel girders and two concrete pedestals in each of the 20 storage ring arc cells, for supporting 10 quadrupoles, 7 sextupoles and 2 dipoles. The steel girders are 3.3 to 4.5m long each, and each one consists of a steel plate and a welded steel structure with rectangular section, supported by 3 ball bearing and wedge jack combined adjusters and 3 accessorial fixed sticks.

The 60 girders and 40 concrete pedestals are under manufacturing on schedule in Baoyie Engineering Technology Co. Ltd, Shanghai. The girders and pedestals for the first cell have been built and installed in the storage ring tunnel, and based on them the first cell of storage ring magnet and vacuum chamber assembly unit has been installed and aligned. Figure 2 shows the first mechanical storage ring sector in the ring tunnel.

Vacuum system [4]

The SSRF storage ring vacuum chamber is made of stainless steel 316LN, and it includes 20 arc cells and 20 straight sections. Each 14m long arc vacuum chamber cell consists of 6 sections of antechamber type vessels with lengths of about 1.42m to 2.97m each. In each arc cell, two DN150 RF shielded bellows are used to connect the two end chambers and the one middle straight chamber, each end chamber comprises two or three short stainless steel chambers with hard connection of rectangular flanges. The vacuum chambers are under manufacturing at Sanjing Vacuum Equipment Co. Ltd, Shanghai, the fabrication of the curved chambers for dipole magnets is completed while the fabrication of the straight chambers is still going on. Before being assembled, all these chambers will be annealed at above 900°C in vacuum furnace for lowering the magnetic permeability of their wielding line. The vacuum chamber sections will be pre-baked and pumped before installation since there is no in-situ baking employed.

There are totally 80 RF shielded bellows, 177 photon absorbers, 188 TSP pumps and 316 SIP pumps required for the SSRF storage ring in phase one. The RF shied bellows are manufactured at AnZ Co. Ltd, Korea, the first one passed the acceptance test in beginning of January, 2007, and now the batch production is under way. The fabrication of the photon absorbers for the arc vacuum chamber cell C10 is completed in December, 2006, and the rest ones are being fabricated at Hangzhou Dahe Thermo-magnetics Co. Ltd.

RF system

The storage ring RF system has five main components, three 499.65MHz SRF cavity modules, three 310kW klystron amplifiers, a 650W liquid helium refrigerator, low level RF control and cryogenic control systems. The SRF cavity modules are located in a 12m long straight section, it will provide 2~6 MV accelerating voltage and about 600kW RF power to the 300mA electron beam which circulates in the storage ring. The SRF cavity modules are under construction at ACCEL Instruments GmbH Germany. After vertical test, two niobium cavities are under chemical processing and baking now. And their cryostats are ready for final assembly. The first SRF module will be shipped to the SSRF site in April 2007 and the last one in August 2007. The first RF amplifier including the klystron and its power supply has been shipped into the SSRF RF building from THALES, France, the installation will start in the beginning of February, 2007 and its site acceptance is scheduled in April 2007. The RF waveguides, circulators and RF loads are all shipped to SSRF and to be installed from February, 2007. The digital low level RF control prototype achieved the required performance when tested on the high power RF system built in the SSRF R&D phase last October, then the first digital LLRF control system will be tested on the SSRF SRF cavity in the coming May.

The cryogenic plant with cooling power of 650W at 4.2K is under construction in collaboration with Institute of Physical and Chemical Technology, CAS, Beijing. The helium refrigerator manufactured at Air-Liquide, France, has been shipped into the SSRF cryogenics building, and its compressors have been installed into the SSRF utility building. The SSRF helium gas tanks and liquid nitrogen tank have been installed in the place close to the utility building, the transfer lines from compressors to the SSRF cryogenics hall have been constructed last December. The commissioning of the SSRF cryogenics plant is expected to be performed from February to April, 2007, and then it will be tested together with the first SSRF SRF module in May 2007.

Power supplies and injection system[5]

The SSRF storage ring requires a total of 520 power supplies in various types and ratings. These power supplies are all switched mode and digitally regulated. The 200 individual quadrupole power supplies rated at 280A/20-40V are being manufactured at Boxing Keyuan Electronic Tech. Co. Ltd., Beijing. A prototype with 5 choppers sharing a common DC link voltage source, which is for 5 quadrupoles, has been made and tested up to the current stability of 50ppm in 24 hours. The dipole magnet power supply rated at 850A/800V and sextupole magnet power supplies rated at 200-280A/100-290V are under fabrication at Xi'an Action Electronics Co. Ltd., Xian. A half scale dipole power supply and a full scale sextupole power supply have been constructed and tested up to the current stability of 20ppm and 100ppm in 24 hrs. Manufactures of all the power supplies will be completed in September 2007.

All the SSRF storage ring injection magnets, including two septum magnets and four kicker magnets, are located in one of the four 12m long straight sections. The kickers and the pulsed power supply are being manufactured at ACCEL Instruments GmbH and Puls-Plasmatechnik GmbH, Germany. The whole system is expected to be delivered to the SSRF site in August, 2007. The prototype of septum magnets and its pulser, manufactured at SKY Technology Development Co. Ltd, and COWEMV Wuhu, are under acceptance test at the SSRF lab. The whole septum system will be installed and tested at the SSRF site in July 2007.

Beam diagnostics

The SSRF storage ring beam instrumentation system includes 140 four button BPMs equipped with the digitalized electronic processor (Libera, Instrumentation Technologies in Slovenia), one synchrotron radiation diagnostics beamline, two beam scrapers, two stripline kickers, two DCCTs and two profile monitors. In addition, there are 12 BPMs for tune measurement, transverse feedback and backups. The BPMs are being manufactured in Kyocera Co. Ltd, Japan, the first 10 pieces will be received at SSRF in beginning of February 2007 and the rest will be delivered to SSRF in April. The Libera processors are scheduled to arrive at SSRF in the coming July. Two NPCTs are being fabricated at Bergoz, France, and will be delivered to SSRF in April 2007.

Installation and alignment [3]

A test installation of a storage ring sector, consisting of magnets, girders, vacuum chambers, photon absorbers, vacuum pumps, a front-end model and utility installations, was performed with the first components received from manufactures in summer 2006, the main purpose is to validate the engineering design and evaluate the cabling and piping techniques as well as installation procedures.

Based on this installation experience, the installation of the first storage ring sector C10 is being carried out in the SSRF storage ring tunnel and the inner technical gallery. The mechanical installation started last December has been completed this January, the utility and electrical installations of this ring sector are being performed and will be completed in February 2007. Along with the pre-assembly and pre-alignment of the ring mechanical sectors, the mechanical batch installation in the tunnel will start in May 2007, which will be followed by the utility and electrical installations as well as systematic equipment testing sector by sector. The SSRF storage ring installation is expected to be completed in a year, and its beam commissioning is scheduled to start in April 2008.

The horizontal and vertical alignment control network has been established in the storage ring tunnel and the linac and booster tunnels as well. For monitoring the deformation of the ring tunnel slab, the vertical control network has been measured twice in two months. And a re-checking of the global control network is in progress.

INJECTOR

Linac[6]

The 150MeV linac is consisted mainly of a 100kV electron gun, a 499.65MHz sub-harmonic buncher, a fundamental buncher, four 3m long/2.998GHz travelling wave accelerating sections, two 45MW klystrons and two 110MW modulators. Its designed performance parameters are reported in elsewhere [6].

All the main linac components have been delivered to the SSRF site for testing and acceptance, and the linac installation, started in November 2006, is being carried out in both the linac tunnel and the klystron gallery. Figure 3 shows the linac under installation in the linac tunnel. At time of this writing, the accelerating sections, focusing coils, magnets, girders and Farady beam dumps have been installed, and the waveguides and the sub-harmonic buncher are being installed. Two klystrons and two modulators have been installed and tested, and their high power acceptance is being performed on site. In addition, the beam diagnostics elements, including three Stripline BPMs, five profile monitors, four wall current monitors and one ICT will be installed in February 2007.

Figure 3: The SSRF linac under installation, January 2007.

The SSRF linac installation is planned to be completed before April, and the linac commissioning is scheduled to start in April 2007.

Booster[6]

The SSRF booster, ramping electrons from 150MeV to 3.5GeV, is a 2Hz synchrotron with a circumference of 180m. Its 48 dipole magnets, 56 quadrupole magnets and 46 sextupole magnets are being fabricated and measured at Kelin Shanghai and USTC Chuangxin Co. Ltd., Hefei, and they will be delivered to the SSRF site for unit cell pre-assembly and pre-aligned in February 2007. In the meantime, the manufactures of the booster stainless steel vacuum chambers including BPM sections will be finished in February, 2007.

The 180kW klystron power amplifier equipped at SSRF in 2001 is relocated and being re-commissioned at the SSRF site, and in the meantime, two 5-cell copper cavities and their associated LLRF system are under factory acceptance tests at ACCEL, Germany. These above equipment will be integrated for the RF system commissioning in April, 2007.

The main power supplies for dipole, quadrupoles and sextupoles, the injection and extraction kickers, septa and extraction bumpers as well as their pulsers are still under manufacturing and will be delivered to the SSRF site for acceptance testing in May 2007. Then they will be tested with the machine central control system from June 2007.

The main booster installation will be carried out from March to July 2007. It will be followed by equipment tests from July to September 2007. The booster beam commissioning is scheduled to start in October 2007.

INSERSION DEVICES

There are seven beamlines and one branch beamline funded as first beamlines in the SSRF project, and among them six are based on insertion devices [7].

Table 2: Main Parameters of first SSRF IDs.

	Type	Period mm	N	Min.Gap mm	Peak Field T
EPU100	PPM	100	42	32	0.6 (By) 0.33(Bx)
IVU25-1	Hybrid	25	80	6	0.94
IVU25-2	Hybrid	25	80	6	0.94
W79	Hybrid	79	19	14	1.2
W140	Hybrid	140	8	14	1.94

Based on the input from beamline specifications, the design of the five insertion devices has been finalized in 2006, table 2 shows their main parameters. The contract of the two in-vacuum undulators has been awarded to Advanced Design Consulting Inc., USA, and these two undulators are under construction and expected to be shipped to SSRF in March 2008. Two wigglers are under manufacturing at Lanzhou Kejin Taiji Technology Co. Ltd, China, they are expected to be delivered to the SSRF site in February 2008. The EPU undulator is being developed in house with the joint efforts of SSRF and Chinese industries [8], and its installation in the SSRF storage ring is scheduled to start in October 2008.

MACHINE CONTROL SYSTEM

The EPICS based machine control system is under development at SSRF [9]. The hardware and software environments have been established, and high level physical application environment has been set up and the online tests of device control using Matlab 2006 R2 with Accelerator Toolbox (AT) and middle layer have been carried out.

A prototype of the power supply control system has been developed, and with it the digital power supplies have achieved the required performance [10]. In the meantime, the timing system, the machine and personnel safety interlock systems are under construction to meet the schedule requirements of machine commissioning.

OUTLOOK

The SSRF project is in the beginning stage of the SSRF accelerator installation, the fast progress of the machine installation is expected in the following year, which creates many challenges in the construction quality and schedule of accelerator components. In the meantime, the linac commissioning and booster commissioning will be carried out and expected to be completed in 2007.

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