SOFT X-RAY FREE-ELECTRON LASER AT SINAP*

D. Wang[†], for SXFEL team, SINAP, Shanghai, China

Abstract

Shanghai X-ray Free-Electron Laser (SXFEL) test facility is now under construction in the Shanghai Synchrotron Radiation Facility (SSRF) campus of Shanghai Institute of Applied Physics, Chinese Academy of Sciences. The test facility is designed to be a multi-staged seeded FEL with the baseline goals of generating fully coherent FEL radiation at the wavelength of ~8.8 nm. The civil construction has completed in April, 2016. The subsystems of SXFEL are nearly ready for installation and the commissioning is scheduled at this winter. The project to upgrade the test facility to a user facility that covers the water-window to magnetic-window regime has been officially approved. Two FELs running with seeded and SASE schemes respectively will feed 4 to 5 end stations with doubled beam energy.

INTRODUCTION

X-ray free-electron laser is known as the next generation light source, especially with the advent and great successful of world's first hard x-ray free-electron laser (XFEL), Linac Coherent Light Source (LCLS) at SLAC [1], and Asia's first XFEL, SPring-8 Angstrom Compact free-electron Laser (SACLA) at Spring-8 [2]. Lots of great discoveries and breakthroughs have been achieved on these XFEL facilities, which interest more and more scientists to get involved. For now, there are 6 laboratories worldwide equipped with both synchrotron light source and XFEL facility, i.e. DESY (Germany) [3], SLAC (USA), Spring-8 (JAPAN), ELETTRA (Italy) [4], PSI (Switzerland) [5], and PAL (Korea) [6]. The SINAP is well on the way to becoming the next such photon science laboratory (see Fig. 1).

PROJECT PROGRESS OF SXFEL

SXFEL Test Facility

The test facility is a soft x-ray FEL with laser seeded schemes. Table 1summaries the main design parameters of the SXFEL. The ground breaking of SXFEL test facility was held on Dec. 30, 2014. The construction of accelerator tunnel and klystron gallery was completed in about 16 months. The 293 m long and 6 m wide tunnel is designed to host two linear accelerators in parallel in the future. In test facility the 840 linac occupies the first half of the tunnel and the rest part is for undulator section and diagnostic beamline (see Figs. 2 and 3).

Figure 1: A bird view of SINAP Zhangjiang Campus.

Table 1: Design Parameters of SXFEL

Parameter	Value	Unit
Beam Energy	840	MeV
Peak Current	>500	A
Rep-rate	1-10	Hz
Nor. Emittance	<2.0	mm·mrad
Energy Spread	<0.15%	
Bunch Length	<1.0	ps (FWHM)
Bunch Charge	0.5	nC
FEL wavelength	8.8	nm
FEL power	>100	MW

The baseline design of the SXFEL test facility is to achieve 8.8 nm wavelength fully coherent radiations with a frequency up-conversion factor of 30. The two-staged cascaded scheme could be either HGHG-HGHG [7] or EEHG-HGHG [8], with the multiplication factor 6 and 5 for each stage respectively. The FEL physics simulations demonstrated that the multiplication factor could be 14 by 6 for cascaded HGHG.

Other FEL schemes, i.e. SASE, HGHG, EEHG, mixed HGHG EEHG, etc. will be the key principles to be tested, as well as XFEL related technologies. Eventually the SXFEL could serve as the part of future hard x-ray FEL.

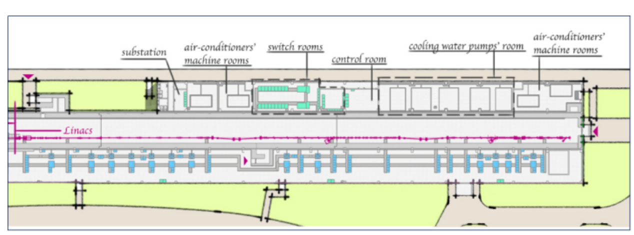

Figure 2: SXFEL LINAC section tunnel design.

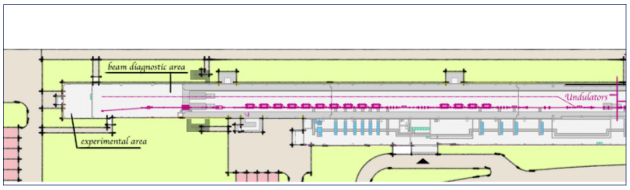

Figure 3: SXFEL undulator and diagnostics section tunnel design.

Figure 4 is the schematic layout of EEHG and HGHG cascaded operation mode. As the electron longitudinal phase space with the micro-bunching at the 6 harmonic of seed laser in the first EEHG stage, the second HGHG could further narrow 5 times in HGHG scheme, which takes advantage of EEHG, to finally generate the intense radiation at the wavelength of 8.8 nm, Fig. 5 shows the numerical simulations by GENESIS 1.3 [9].

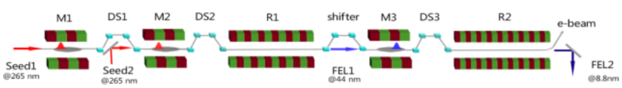

Figure 4: Layout of EEHG + HGHG cascaded mode of SXFEL.

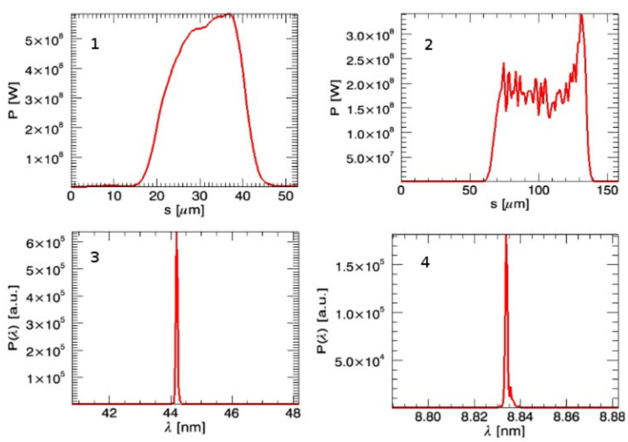

Figure 5: FEL radiation output from EEHG + HGHG cascaded mode of SXFEL, 1 and 3 is from the first EEHG stage, and 2 and 4 are from the second HGHG stage.

On this test facility, single stage high-harmonic EEHG scheme to achieve short wavelength will be explored with 30 harmonic up-conversion factor to get 8.8 nm radiations, simulations also indicate this could be a backup option.

The diagnostics for SXFEL need investigating new approaches and incorporate new technologies to tackle the challenges. Figure 6 shows the design of x-ray online spectrometer and regarding specs.

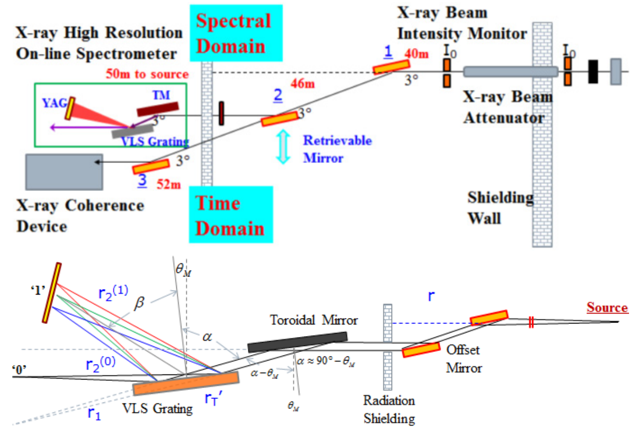

Figure 6: X-ray diagnostic design.

Since the groundbreaking at the end of 2014, the civil construction of SXFEL is finished, and ready for installation now.

Progress of Subsystems

Injector The e-gun is already finished and ready for installation. The photo and testing parameters could be found from Fig. 7 and Table 2.

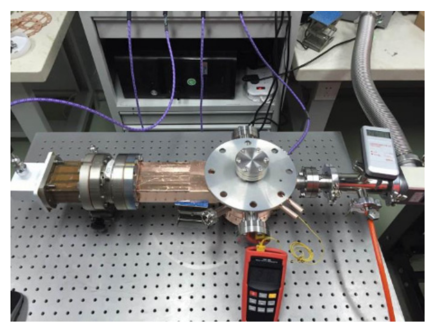

Figure 7: SXFEL photo-injector.

Table 2: Injector Specification

Parameter	Value	Unit
PI mode frequency	2856	MHz
Quality factor Q_0	14000	
Coupling factor β	1.3	
Electric field on cathode	120	MV/m
RF pulse width	1.7	µs
Repetition rate	10	Hz
Peak power of wall heat loss	9.4	MW
Input RF peak power	11.3	MW
Cathode material	Copper	
QE	4×10^{-5}	
Dark current at 120 MV/m	<250	pC/pulse

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C-band structure C-band technology is applied in the LINAC section. There are 6 C-band klystrons and 6 C-band SLEDs and 12 C-band accelerating structure. Beam test shows that acceleration gradient up to 50 MeV/m could be achieved in the home made C-band structure (see Figs 8 and 9).

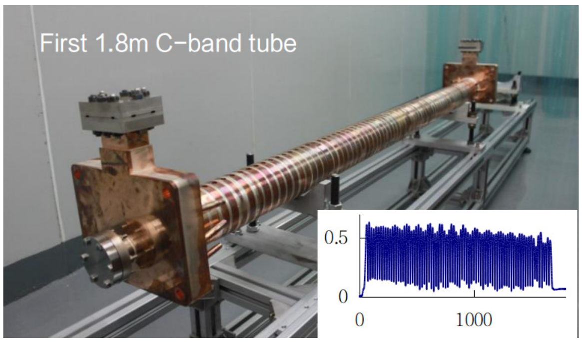

Figure 8: First 1.8 m C-band acceleration tube.

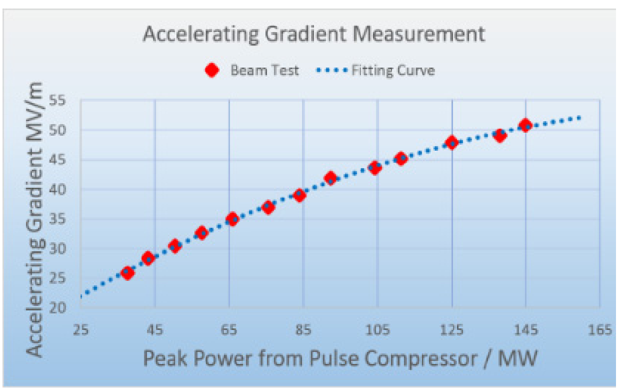

Figure 9: C-band unit beam test.

Movable Chicane The movable chicane of LINAC is finished as Fig. 10 shows. The bending angle could be tuned between 0-7 degrees.

Figure 10: Movable chicane.

Undulator Unit There are 13 undulators of SXFEL test facility. The undulator unit is comprised of one segment of undulator, vacuum chamber and BBA unit. The prototype and massive production can be seen in Figs. 11. and 12.

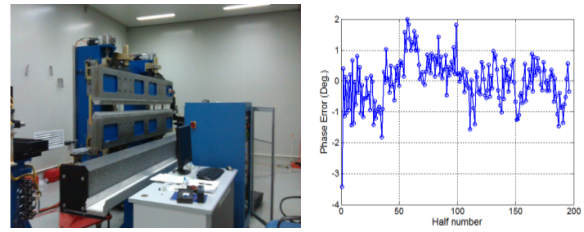

Figure 11: Undulator prototype and test results.

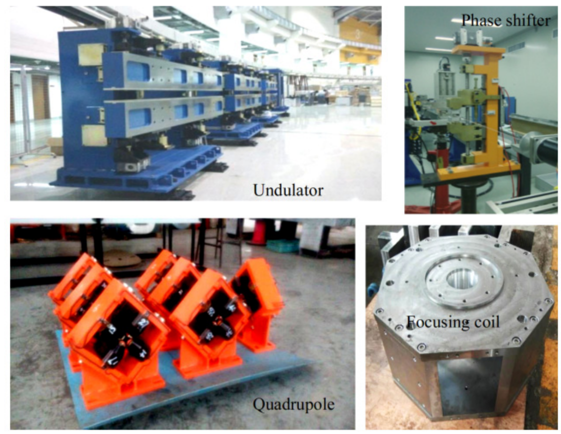

Figure 12: Production of undulator units.

C-BPM Cavity BPMs are important devices for precise measurement of beam positions and arrival times (see Fig 13).

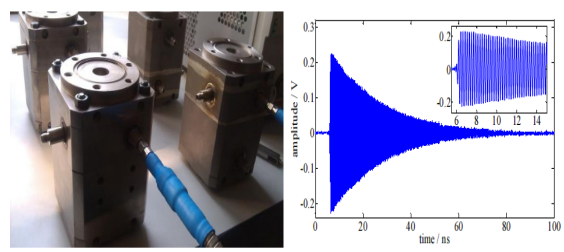

Figure 13: C-BPM product and testing results.

Future Upgrade of SXFEL

Over next couple of years SINAP and Shanghai Tech University (STU) will work together in the SXFEL user facility upgrade with the funding of $110M to build another undulator line and user experiment stations, respectively. Figure 14 shows the building design of the user facility (experimental hall and utility building).

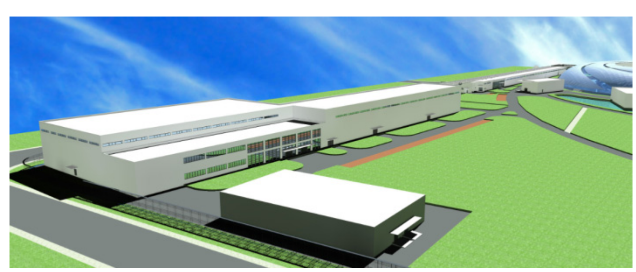

Figure 14: SXFEL user facility.

SXFEL user facility will be able to serve the users with FEL radiation at the wavelength ranging from 1.2 to 10 nm, which covers magnetic and water windows. The repetition rate would be increased up to 50 Hz. To further improve the brightness, the beam energy should be increased to 1.5 GeV and higher, see Table 3.

Table 3: Possible SXFEL User Facility Parameters

Parameter	FEL1	FEL2	Unit
FEL wavelength	2-10	1.2-3	MHz
Principle	HGHG-EEHG	SASE Self-seeding	
Bunch charge	~0.5	~0.2	nC
Beam energy	1.0-1.6	1.0-1.6	GeV
Norm. Emittance	<1.0	<0.5	mm·mrad
Repetition rate	10-50	10.-50	Hz
Peak current	0.7	0.6	kA
Pulse length	0.03-1	0.03-1	ps

To test the harmonic up-conversion limit at seeded FEL facility by EEHG, simulations shows that EEHG at 150 harmonic up-conversion is explored at SXFEL user facility (see Fig.15).

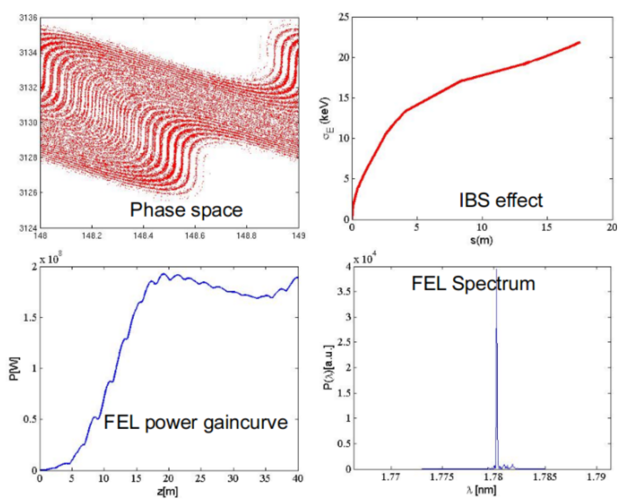

Figure 15: EEHG at 150 harmonic of 265 nm seed laser.

Self-seeding is a popular approach to get short wavelength FELs with better temporal coherence than SASE.

CONCLUSION

As China's first x-ray free-electron laser, SXFEL project completed the building and are ready for hardware unit installation; this paper reports the recent progress of SXFEL, as well as the upgrade options of SXFEL. The user facility transformation has just been approved, it is envisioned that by the end of 2017, first lasing at the wavelength of 8.8 nm will be shining at the northwest site of SSRF campus of SINAP.

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