PROGRESS AND MECHANICAL ENGINEERING OF FEL PROJECTS AT SINAP

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Abstract

Free electron laser (FEL) technology is the next focus at Shanghai Institute of Applied Physics (SINAP). Shanghai Deep Ultraviolet Free-Electron Laser (SDUV-FEL), a test facility for new FEL principles, was operated for 5 years and got a series of important results. Dalian Coherent Light Source (DCLS), a 50~150nm wavelength FEL user facility based on a 300MeV linac located at Dalian Institute of Chemical Physics, started beam commissioning in August. Shanghai X-ray Free-Electron Laser (SXFEL), a soft X-ray FEL test facility based on an 840MeV linac, will be installed in this month and the commissioning is scheduled at the beginning of 2017. The Progress of the FEL projects and the mechanical engineering in the design and construction are presented.

INTRODUCTION

Shanghai Synchrotron Radiation Facility (SSRF) is a 3.5 GeV light source opened to users from 2009. There are 15 beamlines in operation and the SSRF Phase-II Project, including 16 new beamlines, will be started at the end of 2016. In the meantime, the free-electron laser (FEL) projects are also performed at Shanghai Institute of Applied Physics (SINAP). The Shanghai Deep Ultraviolet Free-Electron Laser (SDUV-FEL) source is a test facility for new FEL principles and techniques. A series of experiments have been successfully carried out in it. It will be closed when SXFEL starts operation in 2017. Dalian Coherent Light Source (DCLS) is developed jointly by Dalian Institute of Chemical Physics (DICP) and SINAP. It is a EUV coherent light source based on ultrafast lasers and electron accelerator techniques. The installation was just completed at DCIP campus and the first light is hoped to be obtained in this autumn. It will be the first user FEL user facility in China. Shanghai X-rays Free-Electron Laser (SXFEL) project, approved by the central government at the beginning of 2015, is under construction. It is located at the north of Zhangjiang campus, just adjacent to the SSRF facility. Fig. 1 shows the view of the SXFEL building. Installation of the facility was started in August and will be completed by the end of 2016. The FEL commissioning is scheduled in early 2017.

Figure 1: The SXFEL building adjacent to SSRF.

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SDUV-FEL

SDUV-FEL is an integrated multi-purpose test platform for FEL principles and techniques. The linac is mainly composed of a low emittance photocathode injector, five 3 m long S-band accelerating structures and one bunch compressor. The undulator line includes six 1.5 m long planar undulators with period length of 25 mm and fixed gap of 10 mm. Fig. 2 shows the undulators of SDUV-FEL. The FEL experiments were began in 2009. Some major milestones are achieved. In the end of 2009, SASE experiments were carried out and the SASE light at the end of the 9 m long undulator were obtained. Seeded FEL experiments were began in May 2010. The HGHG saturation was achieved at the end of 2010. The FEL with an EEHG scheme was obtained at the 10^{th} harmonic of the seed in 2013 (shown in Fig. 3). Besides these, a widely-tuneable HGHG, cascaded HGHG and the polarization control via crossed-planar undulators are demonstrated in the following years [1- 3].

Figure 2: Undulators of the SDUV-FEL.

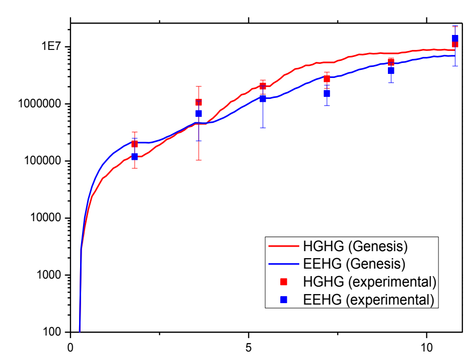

Figure 3: Gain curves of HGHG and EEHG.

DCLS

DCLS is based on the HGHG technique and will provide the highly bright and ultrafast laser light pulses. Electron pulses of 500 pC with normalized emittance below 1 mm·mrad are generated using a photo-injector. The linac consists of 6 S-band accelerating structures and an adjustable chicane. Fig. 4 shows the injector and the linac. The electrons are accelerated to 300MeV before entering the HGHG amplifier. In the amplifier, six undulators are used to generate 50~500 nm FEL with pulse energy of >5.2 uJ @ 130 fs. In the beamline, the FEL radiation will be delivered to four end stations.

Figure 4: DCLS injector and linac.

Six 3 m long planar undulators with period length of 30 mm, minimum gap of 8.75 mm and maximum adjustable taper of 0.5 mm are developed. Fig. 5 shows the undulators installed in DCLS tunnel. The requirement of undulator phase error is less than 5 degrees rms and the beam orbit straightness in the undulator is less than 5 μm rms. Measurements have been performed and the results show that the performance satisfies DCLS's requirements, as shown in Fig. 6.

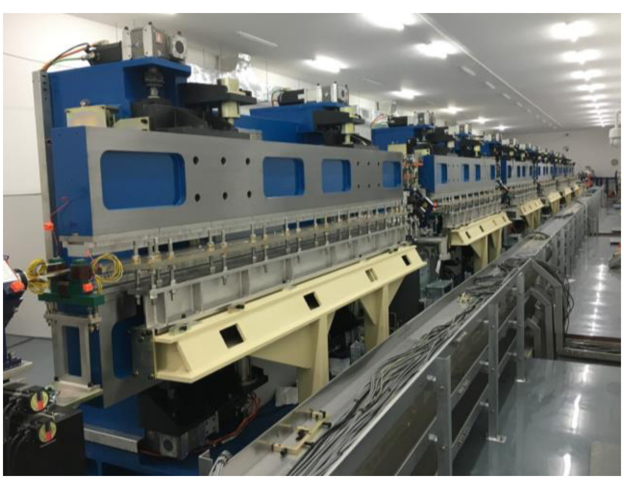

Figure 5: Undulators installed in DCLS tunnel.

In the gap of undulator, an aluminium extrusion vacuum chamber with elliptical beam channel of 15mm(H) × 6mm(V) and minimum wall thickness of 0.75 mm is set with flatness of 0.2 mm. Two Φ4 mm channels are designed at each side of the beam channel for horizontal correction coil and optical fibre of beam loss monitor. Two pairs of grooves on top and bottom side of the chamber are arranged to set the vertical correction coils. Fig. 7 shows the cross section of the chamber. A roughness of about 200 nm in the inner surface of the beam channel was achieved by a precision extrusion. A pressure of less than 10^{-6} Pa is achieved at each end of the chamber after 90 ℃ bakeout for the chamber and pump.

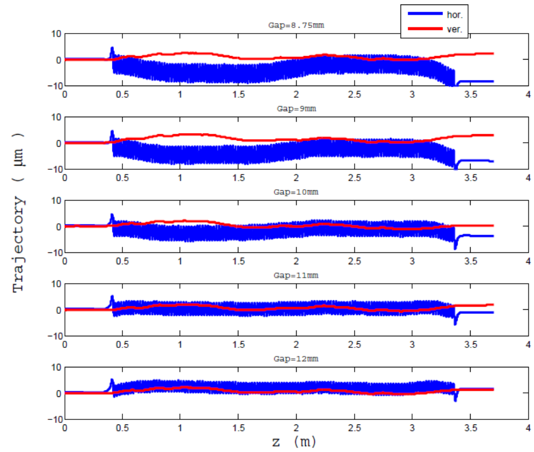

Figure 6: Trajectory of the beam in undulator.

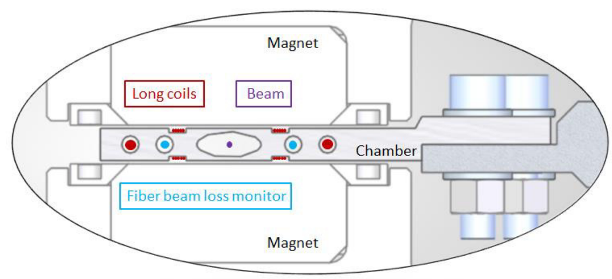

Figure 7: Cross section of the vacuum chamber.

Better than 1μm beam position measurement resolution is necessary for FEL. To achieve this resolution, a cavity type BPM (CBPM) system was developed at SINAP, consisting of a cavity pick-up, a RF frontend and a signal processing unit. The cavity pickup is comprised of a reference cavity working at 4693 MHz and a position cavity at 4680(H) and 4688(V) MHz. Precision machining and vacuum brazing are adopted to fabricate the pick-up from OFHC. Fig. 8 shows the parts fabrication of the pick-up. A beam test at SDUV-FEL for the prototypes shows that the resolution is better than 1μm @ 0.5 nC.

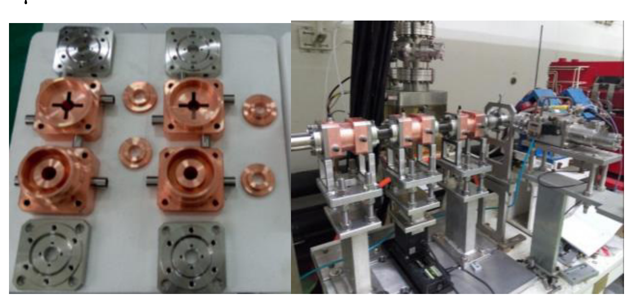

Figure 8: CBPM fabrication and beam test.

SXFEL

The main purpose of the SXFEL test facility is to promote the development of FEL science, which includes exploring the possibility of seeded X-ray FEL by using two-stage cascaded HGHG-HGHG and EEHG-HGHG schemes, and conducting R&D on X-ray FEL related key techniques. The SXFEL test facility consists of a 130 MeV photo-cathode injector, an 840 MeV main linac, an undulator system and a diagnostic beamline. The layout of SXFEL is schematically shown in Fig. 9.

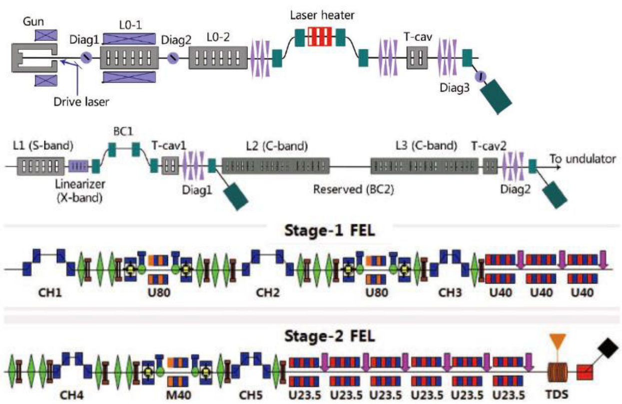

Figure 9: Layout of SXFEL.

The accelerator is based on S-band and C-band linac techniques, and it is designed toward a compact linac with the high performance photo-cathode RF gun and C-band high gradient RF accelerating structures. The C-band accelerating structure is optimized to work at a 4π/5 mode with a round cell shape for obtaining high shunt impedance and low short-range wakefields [4]. The structure design of a 1.8 m C-band accelerating structure is shown in Fig. 10. Prototype has been developed successfully. High power tests show that the average accelerating gradient of the prototype structure reaches 47 MV/m, and the breakdown rate is about 0.01% on average in over 24 hours at 42.7 MV/m gradient. The beam tests have also been successfully performed in SDUV-FEL, as shown in Fig. 11.

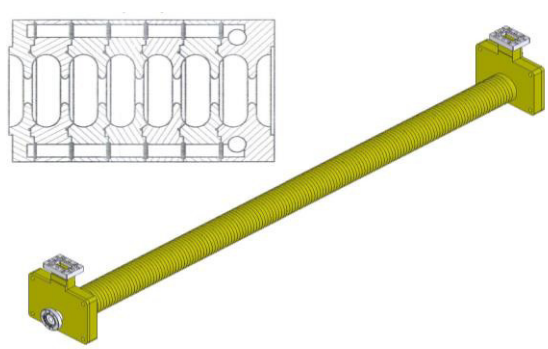

Figure 10: Design of the C-band structure.

The final FEL output from SXFEL will be at 8.8 nm with peak power greater than 100 MW. The two-stage undulator line is comprised of a seed laser system, stage-1 modulators and radiators, stage-2 modulator and radiators, as well as a couple of chicanes. The 8.8 nm radiation will be generated by the fresh bunch in the radiators of the second stage. The total harmonic conversion number of the two stages is 6×5 (264nm→44nm, 44nm→8.8nm).

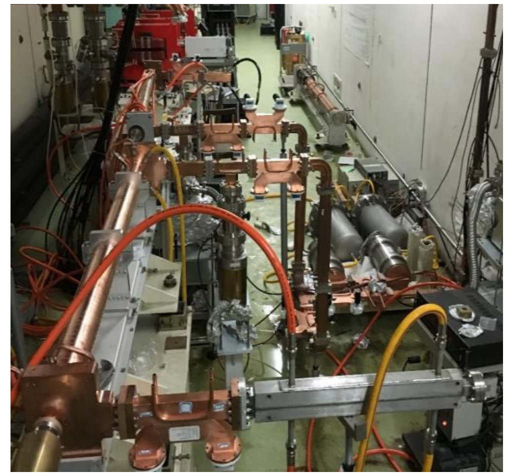

Figure 11: C-band structure beam test.

A proposal about upgrading the SXFEL test facility to a user facility was approved in 2016. This would be accomplished by having the radiation wavelength extended to cover the "water window" region by boosting the electron beam energy to 1.6 GeV with more C-band accelerating structures and by making the FEL output saturation with more undulators in the second stage.

SUMMARY

A series of achievements on new FEL principles and techniques have been obtained based on the SDUV-FEL source. The DCLS user facility is under commissioning and will have wide applications in the frontier researches of molecular photochemistry, combustion chemistry, etc. The SXFEL test facility with the output of 8.8 nm radiation is under construction and will be commissioned at the beginning of 2017. By adding more accelerating structures and undulators, the machine will be upgraded to a user facility with saturated 3 nm output wavelength in the future.

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