# DEDICATE SRF CRYOMODULE TEST FACILITIES FOR S³FEL

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## *Abstract*

Shenzhen Superconducting Soft-X-Ray Free Electron Laser (S³FEL) has been proposed to build a continuous wave (CW) superconducting linear accelerator and produce FEL in the soft X-ray wavelength region. The proposed S³FEL LINAC consists of twenty-eight SRF cryomodules to accelerate beam energy up to 2.5 GeV. Prior to the cryomodules installed in the tunnel, SRF cavities and cryomodules will be conditioned and tested at a dedicate SRF Cryomodule Test Facility (SMTF).The SMTF for S³FEL is currently under design which equipped with two vertical cryostats and three horizontal test benches. R&D work for the SMTF and its corresponding cryomodule assembly procedure is now on going. This paper describes the full set of layout design and implementation of the SMTF for S³FEL project as well as its latest status.

## INTRODUCTION

Institute of Advanced Science Facilities, Shenzhen (IASF) is a multi-disciplinary research institute responsible for Shenzhen's large-scale science facilities' whole life cycle planning, construction, operation, and maintenance [1]. So far, one of two active infrastructure projects proposed by IASF, Shenzhen Superconducting Soft-X-Ray Free Electron Laser (S³FEL) is officially approved and is in the stage of designing and construction. S³FEL is a 6-year-construction-period project which will locates in Guangming science city, Shenzhen, China.

S³FEL is a high repetition rate soft-X-ray free-electron laser facility that consists of a CW superconducting linear accelerator, four FEL amplifiers, four beamlines, and eight end stations at the first stage. More beamlines and end stations will add on at next step. Bright electron pulses will be generated efficiently on a photocathode, through the photoelectron effect, using a high-repetition laser. The electron pulses are then accelerated to 2.5 GeV by a superconducting linear accelerator. The high brightness electron pulses are then split and injected into long undulator FEL amplifiers to generate soft X-ray light from 0.5 to 30 nm with extremely high brightness. Figure 1 shows the layout of S³FEL facility.

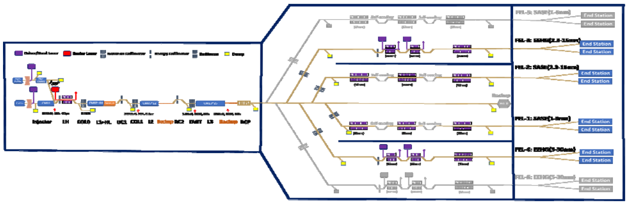

Figure 1: The layout of S³FEL facility.

The photon energy of S³FEL ranges from 40 eV to 1 keV, which covers wavelengths from EUV to soft X-ray with pulse energy up to 500 μJ. The key performance parameters of S³FEL are listed in Table 1.

Table 1: Key Parameters of S³FEL

| Parameters | Design Value |
|---|---|
| Electron beam energy | 2,5 GeV |
| Charge per bunch | 200 pC |
| Bunch Repetition rate | 1 MHz |
| Photon energy | 40 eV-1 keV |
| Pulse energy | 500 μJ @1 keV |

The development of multiple FEL beamlines will provide abundant opportunities for future scientific research in numerous diverse and important fields, such as quantum materials, energy research, dynamics of biological systems, combustion, atmospheric and interstellar chemistry, frontiers in atomic and molecular physics, as well as new developments in technology. The application of the FEL capabilities towards research and development efforts in these fields will significantly enhance the competitive edge of both academic and industrial institutions in Shenzhen and the greater bay area, and facilitate the development of top research universities, as well as high tech companies.

## S³FEL LINAC

S³FEL will use a total of 224 TESLA-type elliptical cavities operating in a CW mode in its superconducting LINAC section, which will be installed in twenty-six 1.3 GHz and two 3.9 GHz cryomodules (with 8 cavities integrated into one cryomodule), in order to accelerate the electron beam up to 2.5 GeV. The overall design of S³FEL LINAC is similar to LCLS II and SHINE facility, which are also CW FEL [2, 3]. Figure 2 shows the layout of the main LINAC.

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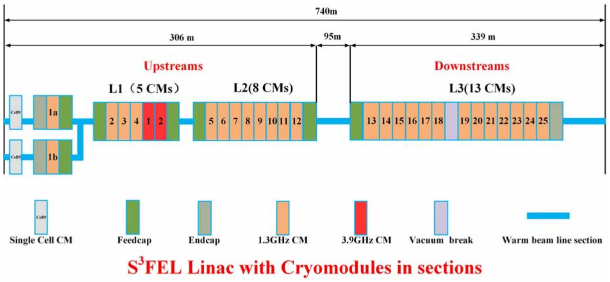

Figure 2: The layout of the main LINAC.

The L1 acceleration segment consisting of three sets of 1.3 GHz modules, works in front of the peak phase to provide an energy chirp for compression. The energy increases from the head to tail within the electron bunch. In order to realize linear compression, the L1 acceleration segment must also be followed by two sets of 3.9 GHz cryomodules which act as a high harmonic decelerator to compensate for the secondary longitudinal correlation energy distribution imprinted by the former three 1.3 GHz cryomodules. After compensation, the electron bunch with linear energy chirp enters the first-stage magnetic bunch compressor (BC1) and is compressed from 3 ps to 0.5 ps. Hence, the peak current is raised from 12 to 80 A, accordingly. The L2 acceleration segment consists of eight sets of 1.3 GHz cryomodules, which also work in the front of the peak phase, providing less energy chirp to the electron bunch. After the second-stage magnetic bunch compressor (BC2), the length of the electron bunch is compressed to 40 fs, and the peak current is increased to 800 A. Then, the electron bunch enters the L3 acceleration segment. This segment includes 13 sets of 1.3 GHz cryomodules, working on the crest. After this segment, the energy of electron bunch increases from 1.2 to 2.5 GeV.

## DEDICATE SRF CRYOMODULE TEST FACILITIES

The cryomodule (CM) and its corresponding low level radio frequency system (LLRF) become key technologies for the whole project. To ensure the smooth progress of $S^3$FEL project, R&D work for prototype cryomodule and key systems has been launched. A dedicate superconducting cryomodule test facility (SMTF) is designed and will be used for the critical mission of CM acceptance test. The site of the SMTF is decided to be placed adjacent to the $S^3$FEL LINAC, as shown in Fig. 3. The total area of the SMTF is about 10000 $m^2$, which is about 200 m long and 50 m wide. The preliminary design of the SMTF is to apply half of the hall for cryomodule assembly, integration and test that covers the whole CM production chain. The 3D layout is shown in Fig. 4, while the other half hall will be used as a storage area for various components.

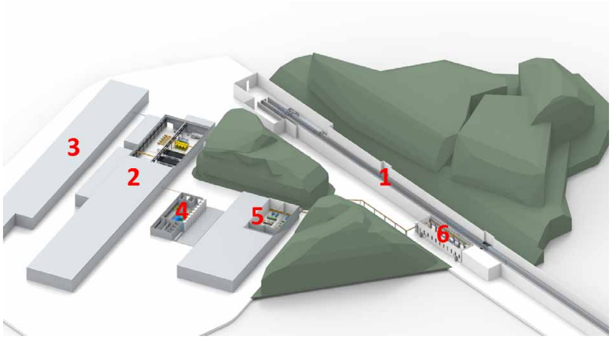

Figure 3: The site layout of the S3FEL facility Building.#1 represents S3FEL, building #2 represents SRF Cryomodule Test Facility (SMTF ), building #3 represents Prototype Accelerator Test Facility (PATF), building #4 represents Cryo-hall A (TFCP & PACP Warm Compressor System), building #5 represents Cryo-hall B (ACCP Warm Compressor System), and building #6 represents (ACCP Cold Boxes and Valve Boxes).

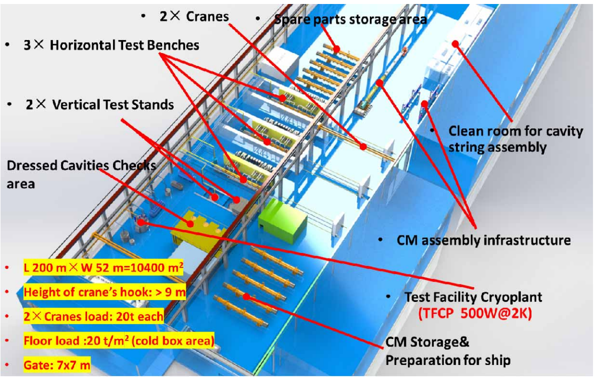

Figure 4: 3D Layout for SMTF.

The scope of S3FEL SMTF is mainly to cover capabilities: 1) to test 1.3 GHz 9-cell cavities, construct the cavity string in a class 10 cleanroom environment, assemble into the cryomodule, and prepare cryomodules for overall cryogenic performance test; 2) R&D work for key components, such as SRF magnet, multi-purpose cryogenic test cryostats etc., and 3) temporary storage for CMs and magnets before the tunnel installation.

To fit the intensive project schedule, the SMTF will be equipped with:

- Three Cryomodule Test Benches (CMTB) which allows to test CMs in parallel;
- Two Vertical Test Benches for SRF cavity test (VTB);
- One Superconducting Magnet Test Bench (SMTB);
- One multi-purpose Cryogenic Test Bench (CTB).

Some other necessary supply systems are also considered and designed from the first beginning, such as a Test Facility Cryoplant (TFCP) with 500 W cooling capacity at 2 K, a class 10 cleanroom, cold mass assembly fixtures, and two cranes with 20 t capacity.

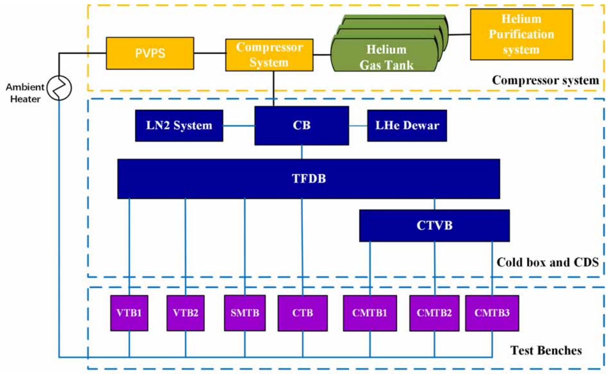

Figure 5: The Block diagram of the TFCP.

The system architecture is presented in the TFCP block diagram of the Figure 5. A centre cryoplant will provide the helium to a main distribution box (TFDB), which will feed the VTBs, SMTB and CTB directly. A dedicate valve box (CTVB) via the TFDB will serve the three CMTBs. With this system, CMTB allows 2 CMs under RF test at the same time while the other CM stays at 2 K standby.

## CRYOMODULE PRODUCTION STRATAGE

The workflow of the cryomodule production includes key activities such as cavity qualification from vendors, various stages of CM assembly and acceptance testing.

At the SMTF, the cryomodule moves through five workstations during the fabrication process, as presented in Fig. 6. Each station brings the cryomodule one step closer to completion. After assembly is completed, the cryomodule makes its way to the CMTB, where the performance is qualified finally.

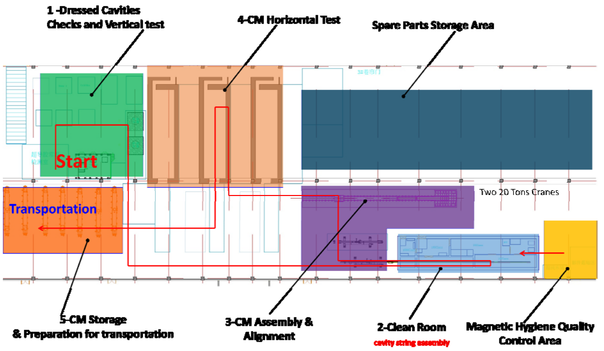

Figure 6: The Workflow for the CM Production at SMTF.

According to the experience from worldwide accelerator similar projects such as FLASH, European XFEL and LCLSII [4-7]. The plan of CM production rate is listed in Table 2. Meanwhile, R&D work for cryomodule assembly and integration is on-going, which the workflow is shown as Fig. 7.

Table 2: Plan of CM Production Rate

| Parameters | Expected period |
|---|---|
| Vertical Testing of Naked/Dressed Cavities | 8 cavities per week |
| Cavity String Assembly | 1 strings per 2 weeks |
| Cold Mass and Vacuum Vessel Assembly | 1 CMs per 2 weeks |
| Cryomodule Testing | 1 CM per 4 weeks |

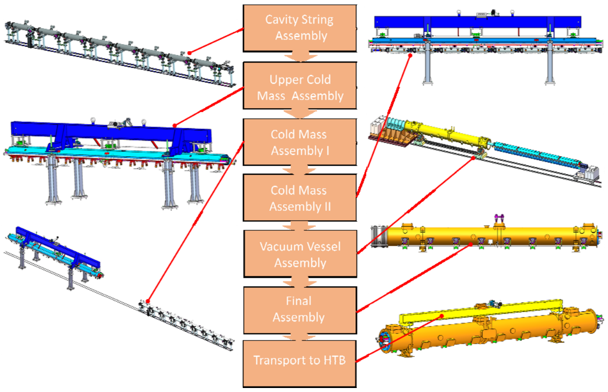

Figure 7: Cryomodule assembly and integration workflow.

The strategy before the CM production could be divided into 5 stages. The first stage is to develop the 1.3 GHz and 3.9 GHz prototype CM with purpose: 1) verify the cryomodule design as soon as possible; 2) qualify the performance of cavities in a realistic environment; 3) prove out the assembly and integration; 4) develop procedures for transportation and staff training, etc. The second stage is the design optimization, where the CM design could be optimised thanks to the feedback from prototype cryomodule's experience and lessons learnt. The third stage is Low-rate initial Production (LRIP), which will start the cryomodule production in small scale, develop and stabilize the engineering procedures. The final cryomodule design and production procedure will be confirmed in the fourth stage before the launch of the mass production. In the last stage, CMs can be put into the mass production.

## CONCLUSION

Shenzhen Superconducting Soft-X-Ray Free Electron Laser, proposed by Institute of Advanced Science Facilities, Shenzhen (IASF), China, is officially approved and is under design and construction. $S^3$FEL will use a total of twenty-six 1.3 GHz and two 3.9 GHz cryomodules (with 8 cavities integrated in one cryomodule) operating in a CW mode in its superconducting LINAC section to accelerate the electron beam up to 2.5 GeV.

A dedicate superconducting cryomodule test facility (SMTF) is designed and will be used for the critical mission of CM acceptance test. Within the preliminary design, this SMTF supplies three cryomodule test benches, two vertical cryostats, one superconducting magnet test bench and one multi-purpose cryogenic test bench. So far the conceptual design is finished and the corresponding R&D work is launched.

## ACKNOWLEDGMENT

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