

LCLS-II 1.3 GHZ DESIGN INTEGRATION FOR ASSEMBLY AND CRYOMODULE ASSEMBLY FACILITY READINESS AT FERMILAB*

T. Arkan[#], C. Ginsburg, Y. He, J. Kaluzny, Y. Orlov, T. Peterson, K. Premo
Fermi National Accelerator Laboratory, Batavia, USA

Abstract

LCLS-II is a planned upgrade project for the linear coherent light source (LCLS) at Stanford Linear Accelerator Center (SLAC). The LCLS-II linac will consist of thirty-five 1.3 GHz and two 3.9 GHz superconducting RF continuous wave (CW) cryomodules that Fermilab and Jefferson Lab will assemble in collaboration with SLAC. The LCLS-II 1.3 GHz cryomodule design is based on the European XFEL pulsed-mode cryomodule design with modifications needed for CW operation. Both Fermilab and Jefferson Lab will each assemble and test a prototype 1.3 GHz cryomodule to assess the results of the CW modifications. After prototype cryomodule tests, both laboratories will increase cryomodule production rate to meet the challenging LCLS-II project installation schedule requirements of approximately one cryomodule per month per laboratory. This paper presents the 1.3 GHz CW cryomodule design integration for assembly at Fermilab, Fermilab Cryomodule Assembly Facility (CAF) infrastructure modifications for the LCLS-II cryomodules, and readiness for the required assembly throughput.

INTRODUCTION

The LCLS-II main linac 1.3 GHz cryomodule is based on the XFEL design, including TESLA-style superconducting accelerating cavities, with modifications to accommodate CW (continuous wave) operation and LCLS-II beam parameters.

Two prototype cryomodules will be assembled between September 2015 and March 2016 at Fermilab and JLab. At Fermilab, Cryomodule Assembly Facility (CAF) will be used to assemble the prototype cryomodule and 16 production cryomodules. For the prototype cryomodule, 8 ILC style bare cavities were processed with High Q0 recipe [1, 2] and then qualified in one of Fermilab's large test dewars, Vertical Test Stand (VTS) [3]. The qualified bare cavities are jacketed with their helium vessel at CAF glove box welding infrastructure [4]. The dressed cavities are tested and qualified for cavity string assembly either in VTS and/or at Horizontal Test Stand (HTS) [5].

For the 16 production cryomodules, the cavities will be fabricated, processed, jacketed with helium vessel and assembled (ready to be tested in vertical test stand) at cavity vendors. The cavities will be shipped from vendors

to Fermilab for vertical testing. Qualified cavities will arrive to CAF for string assembly. Procurement responsibilities of the cryomodule components for the prototypes and production cryomodules are divided between Fermilab and JLab. Each laboratory is responsible to procure a specific component for all 35 cryomodules. The half of the components will be drop shipped from vendor(s) to each partner laboratory. The incoming quality control and acceptance of the component will be done by each laboratory before the component is accepted and can be fed to the assembly workflow. The procurement strategy is chosen to eliminate the schedule competition with a specific vendor. JLab developed sub-contracting officer technical representative (SOTR) scheme is being used to manage the procurement. Two SOTRs (one from each partner laboratory) are identified. SOTR from the laboratory who has the main responsibility of a specific procurement oversees the procurement specifications development, assists the preparation of the request for procurement (RFP), reviews the bids, forms a technical evaluation criteria and review team for evaluation of the bids and finally chooses the best value vendor to award the contract. The second SOTR from the other laboratory has the role of helping the main SOTR as needed and two SOTRs have to work closely to ensure qualified components are fabricated and delivered to each laboratory on time and on budget.

DESIGN INTEGRATION FOR ASSEMBLY

The overall structural design of the LCLS-II cryomodule is similar to that of the TESLA-style module [6]. Fermilab has assembled two 1.3 GHz pulsed Tesla type 3+ cryomodules in the last years. CM2, the second cryomodule assembled at CAF, has achieved world record gradient results [7, 8].

LCLS-II CW cryomodule cavity string is very similar to CM2 design, which consists of 8 dressed cavities, a beam position monitor (BPM) with a magnet spool tube and a gate valves at each end of the cavity string. The only difference between CM2 and LCLS-II cavity string is the BPM and magnet package assembly. In the cleanroom, BPM is assembled with a magnet spool tube and downstream gate valve. The conduction cooled split magnet will be assembled later during cold mass assembly; it does not need to be in the cleanroom. A beamline vacuum monitoring manifold will be assembled to the downstream end gate valve in order to monitor the beamline vacuum integrity from CAF to testing of the cryomodule, during shipping to SLAC until cryomodules are installed and interconnected in the linac tunnel. The

*Work supported, in part, by Fermi Research Alliance, LLC under Contract No. DE-AC02-07CH11359 with the United States Department of Energy and the LCLS-II Project
#arkan@fnal.gov

configuration of the BPM/Magnet package is shown in Figure 1.

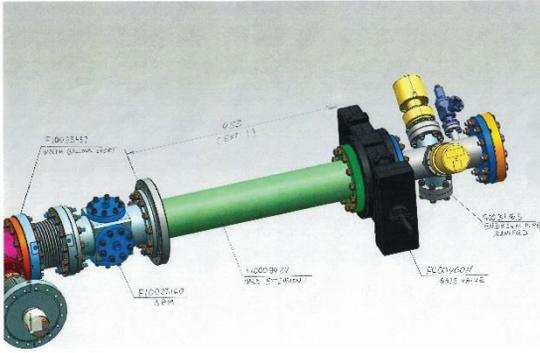


Figure 1: BPM/Magnet package.

Fixtures to align and assemble the BPM to the magnet spool tube and to the downstream gate valve are designed and fabricated. See Figure 2.

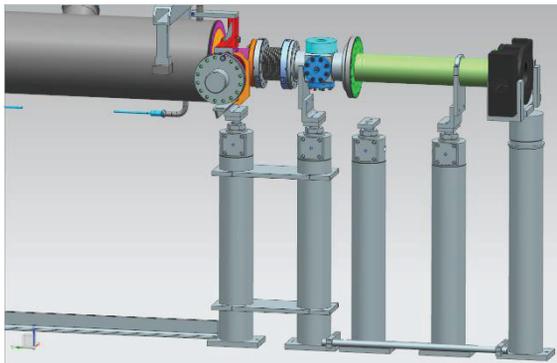


Figure 2: BPM/Magnet package assembly fixtures in the cleanroom.

The cavity string will be assembled using the CAF cleanroom infrastructure in Class 10 (ISO 4) cleanroom. Cavities will be aligned (X-Y and rotationally) and then assembled into the string using slightly modified version of the fixtures used for CM2 cavity string assembly. (See Figure 3.) The only modification was done to the cavity support bracket on the end lever tuner side. (blade tuner for CM2 cavity versus end lever tuner for LCLS-II cavity).



Figure 3: LCLS-II dressed cavity installed on the cleanroom assembly fixture.

LCLS-II CW cold mass has significant design changes compared to CM2 due to CW cryogenics, thermal requirements and SLAC linac tunnel boundary conditions. Therefore, the assembly and design teams worked together that the modified design can be efficiently assembled using the CAF infrastructure. Some new fixtures are designed for the assembly such as split magnet installation fixture (See Figure 4) and some new fixtures and equipment such as tube centralizer (See Figure 5) for welding. Automated welding machine heads are purchased to weld the 2-phase circuit of the LCLS-II CW cryomodule.

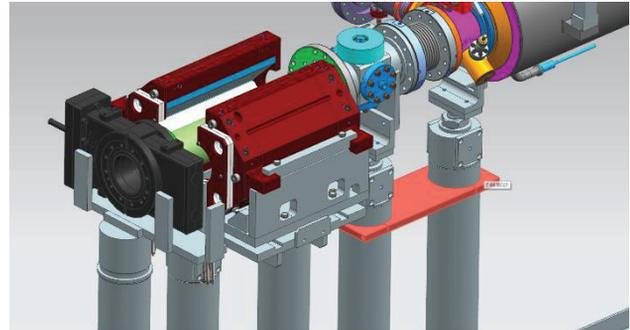


Figure 4: Split magnet assembly fixture.

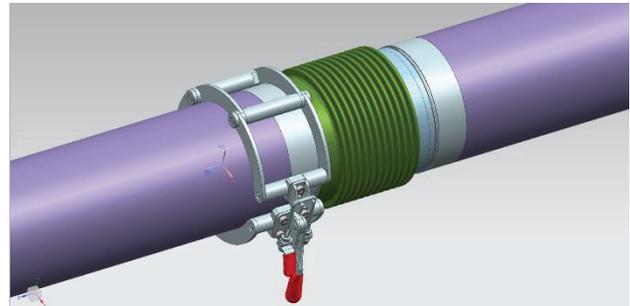


Figure 5: 2-phase pipe centralizer fixture during welding.

The 2-phase circuit of the LCLS-II CM cryomodule consists of a 4 inch OD stainless steel tube (compare to 2.750 inches OD titanium pipe for CM2), connection of the 2-phase pipe to the 300 mm helium gas return pipe (HGRP) in the middle of the cryomodule (at each end for CM2), two welded fill lines (one flanged fill line for CM2) and closed 2-phase pipe ends due to SLAC tunnel slope (open flanges ends for CM2). The 2-phase circuit assembly, welding, and quality assurance procedures will be developed in detail during prototype cryomodule assembly.

Other LCLS-II CW cryomodule cold mass assembly components such as magnetic shielding, end lever tuner, instrumentation, multi-layer insulation (MLI) scheme, thermal intercepts, cryogenic valves, and tuner access ports have significant design changes compared to CM2. Assembly team has worked closely with the design team for seamless integration of the design to the actual assembly. Detailed assembly procedures will be developed during actual prototype cryomodules assembly.

During the prototype cryomodule assembly at CAF, all the infrastructures upgrades done at CAF will be tested

and shaken down as needed for the readiness of the 16 production cryomodules assembly. Due to tight schedule pressure for the production cryomodules assembly, most of the production modules components will be procured before the completion and test of the prototype cryomodule. Therefore, real-time feedback of the lessons learned during the actual prototype cryomodule assembly shall be communicated with the vendors (via SOTRs) during the production cryomodules components fabrication.

CRYOMODULE ASSEMBLY

Cavity String Assembly

The assembly of the cavity strings will be done in the CAF cleanroom situated in the CAF-MP9 building. Eight qualified dressed cavities, a BPM, a magnet spool tube and two gate valves with beamline monitoring manifold will be interconnected using copper plated bellows in the Class 10 (ISO 4) cleanroom. CW cryomodule design requires specific requirements for the magnetic properties of the components and assembly hardware used during string assembly. Components that are inside of the magnetic shielding of the dressed cavities need to be scrutinized for magnetic properties and need to conform to the magnetic hygiene protocols developed for LCLS-II CW cryomodules. The assembly of the cavity string is the most important step throughout the cryomodule assembly to ensure that the measured parameters (gradient and quality factor) of the qualified cavities are preserved. Particulate-free-flange-assembly techniques were developed and optimized throughout the years at various institutions working on SRF R&D. CAF cleanroom technicians have over 10 year experience in particulate free ultra-high vacuum applications. LCLS-II cryomodule cavity strings will be assembled while following the assembly travelers (will be finalized during prototype cryomodule assembly) and working with strict adherence to the CAF cleanroom working protocols.

Cold Mass and Final Assembly

After the string assembly is completed, the string will be rolled out of the cleanroom into the cold mass assembly area at CAF-MP9 using the assembly rail. The 2-phase circuit will be welded using an automated orbital welding machine and manual welding conforming to the ASME piping code. The dressed cavities are then outfitted with instrumentation, MLI and magnetic shielding. The cavity string is then lifted from the cleanroom assembly fixtures and married to the HGRP assembly (cold mass upper) forming the cold mass assembly. The cold mass assembly is then transported to CAF-ICB building. The X-Y axis alignment of the cavities to 150 microns will be done using a laser tracker instrument. End lever tuners will be assembled post alignment. The cold mass is then transferred to the Big Bertha cantilever fixture for the welding of lower heat shields and MLI installation. The cold mass is then moved to the final assembly area in CAF-ICB where the

warm end high power couplers and waveguides are assembled.

CRYOMODULE ASSEMBLY FACILITY

CAF infrastructure consists of two assembly/production floors CAF-MP9 and CAF-ICB. CAF-MP9 (See Figure 6) houses the cleanroom which consists of a ~250 square meter cleanroom complex which has Class 10 (ISO 4), 100 (ISO 5) and 1000 (ISO 6) areas. See Figure 7. There are two workstations (WS) setup in the cleanroom. WS0 is for the cold end of the coupler assembly to the qualified dressed cavity and WS1 is for the cavity string assembly.

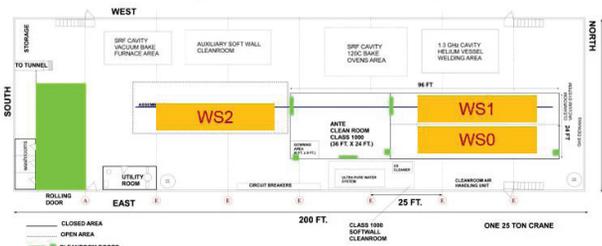


Figure 6: CAF-MP9 production floor.



Figure 7: CAF-MP9 cleanroom (Class 10 and Class 100 areas).

Adjacent to the cleanroom, WS2 is the cold mass phase-I assembly area outside of the cleanroom. The workflow planned at CAF-MP9 workstations is:

1. Receive qualified cavities from VTS or HTS Cleanroom:
2. WS0: Cold End Coupler Assembly (if the last qualification test is done at VTS)
 - Incoming QC and handling of the cold end couplers
 - Assembly of the cold end couplers to qualified LCLS-II dressed cavities
3. WS1: Cavity String Assembly
 - Receive qualified dressed cavities (removal of tuner, installation of safety brackets, cleaning of exterior surfaces of the cavities)
 - Alignment & Assembly of 8 cavities, magnet/BPM package and 2 gate valves with interconnecting bellows

Production floor:

4. WS2: Cold Mass Assembly Part-1

- Reception of the cavity string from the cleanroom and alignment to the GRHP sub-assembly
- Split magnet assembly
- 2-phase pipes cutting, interconnect bellows/pipes/helium level housings welding; leak checking
- Instrumentation installation and QC check
- Magnetic shielding assembly
- RF checks and HOM notch frequency tuning
- Assembly of the cavity to HGRP (cold mass upper sub-assembly with needle bearing and C clamps)
- Warm-up/Cool down lines welding to the cavities helium vessel
- Leak Check & Pressure test the helium circuit after all the welding is completed
- Gate valve supports assembly
- Cooling straps assembly (2-phase and 5K intercepts)
- Cold Mass Prep for Transport
- Transport from MP9 to ICB

CAF-ICB production floor (see Figure 8) houses the cold mass assembly Part-2 and Part-3 assembly workstations.

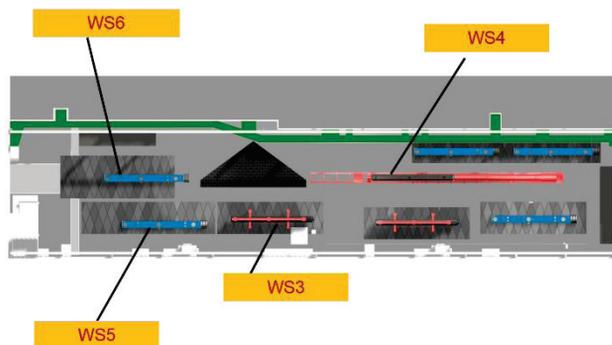


Figure 8: CAF-ICB production floor.

The workflow planned at CAF-MP9 workstations is:

Production floor:

5. WS3: Cold Mass Assembly Part-2a

- Current leads to the magnet assembly
- RF cables installation
- RF checks
- Alignment (cavities to cold mass)
- Locking the cavities positions post alignment
- Tuner system installation / Tuner stepper motors checks
- RF checks
- Couplers cooling straps assembly
- Instrumentation assembly and harness arrangements
- Prep and move cold mass to WS4 (Big Bertha fixture)

6. WS4: Vacuum Vessel Assembly Part-2b

- Installation of cold mass to Big Bertha fixture
- Final QC checks before 50K lower shields assembly & welding
- 50K lower shields assembly and welding
- MLI assembly and post MLI work (cutting MLI to give access to the FPC ports, instrumentations ports, tuner access ports etc.)
- RF checks, instrumentation checks, tuner motors/piezos checks
- Vacuum vessel assembly
- Cryogenic valves weldment, leak check & pressure test 2-phase circuit
- Alignment (cold mass to vacuum vessel)
- Prep and move the module to WS5

7. WS5: Final Assembly Part 3

- Warm end couplers/waveguides assembly
- Coupler pumping lines & pumps assembly & leak check & leave under vacuum
- Instrumentation flanges assembly
- RF checks
- Insulating vacuum pumping & leak check & backfill
- Beamline pumping & leak check & leave under vacuum
- Final QC checks

8. WS6: Prep, Transport & Shipping

- Prep and Transport from ICB to CMTS (cryomodule test stand at Fermilab)
- Prep and Shipping to SLAC
 - Reconfigure beamline gate valves ends configuration for shipping
 - Prepare CM for shipping

The prototype cryomodule will be assembled between September 2015 and March 2016. The objective with this cryomodule is to finalize the assembly travelers, debug the design and design integration for assembly as needed, shake down the infrastructure (and upgrades) planned for cryomodule assembly, train the new contract technician personnel to work on cryomodule assembly and test the planned production workflow. For the production cryomodule, first three cryomodules will be ramp-up phase and will be assembled in series during CY2016. Remainder of twelve cryomodules will be assembled with an assembly throughput of 1 cryomodule per month (4 weeks) during steady state phase. It takes ~12 (60 days) weeks to assemble a module. Excluding any sick modules that need to be reworked, there will be max 3 modules in the production line at the same time to satisfy the required throughput (1 module per 4 weeks). See Figure 9.

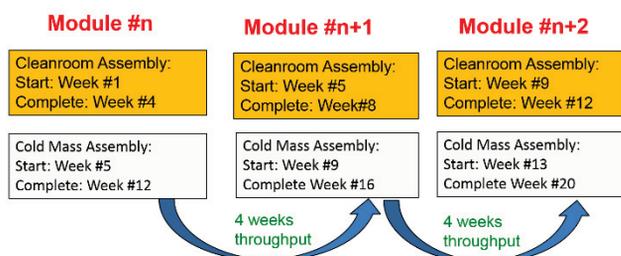


Figure 9: Planned production throughput for LCLS-II cryomodules assembly during steady-state phase.

CONCLUSION

CAF infrastructure is ready to start the assembly of the prototype cryomodule. Core personnel are fully trained and experienced with assembly of similar design cryomodules. New contract mechanical technicians (cleanroom and cold mass) were hired and are being trained during the prototype cryomodule cavities qualification preparation. Actual training will be done during prototype and ramp-up production cryomodules assembly. Additional technician staff needs to be added to the CAF team in order to achieve the required assembly throughput. Core team will train the new personnel and also will conduct industrial time studies during the prototype and ramp-up production cryomodules assembly. These studies will be used to adjust the manpower requirements and the workflow plans for the assembly of the steady state production cryomodules with the required throughput. CAF team is also working closely with the design team during the procurement of the components and will continue to work during

cryomodules assembly so that we can achieve the planned workflow and the required assembly throughput.

REFERENCES

- [1] M. Merio, “Details of Nitrogen Doping of SRF Cavities at Fermilab,” MOPB111, *these proceedings*, Proc. SRF2015, Whistler, BC, Canada (2015).
- [2] G. Wu, “Cooling Optimization for High Q Dressed Cavities in Cryomodules,” THPB111, *these proceedings*, Proc. SRF2015, Whistler, BC, Canada (2015).
- [3] A. Melnychuk, “Vertical Test Facility at Fermilab,” TUPB004, *these proceedings*, Proc. SRF2015, Whistler, BC, Canada (2015).
- [4] C.J. Grimm, “Welding a Helium Vessel to a 1.3 GHz 9-Cell Nitrogen Doped Cavity at Fermilab for LCLS-II,” THPB027, *these proceedings*, Proc. SRF2015, Whistler, BC, Canada (2015).
- [5] N. Solyak, “Integrated High-Power Tests of Dressed N-doped 1.3 GHz SRF Cavities for LCLS-II,” MOPB087, *these proceedings*, Proc. SRF2015, Whistler, BC, Canada (2015).
- [6] T. Peterson et al., “LCLS-II 1.3 GHz Cryomodule Design – Modified Tesla-style Cryomodule for CW Operation,” THPB119, *these proceedings*, Proc. SRF2015, Whistler, BC, Canada (2015).
- [7] E.R. Harms, “High Gradient Performance in Fermilab ILC Cryomodule,” FRAA03, *these proceedings*, Proc. SRF2015, Whistler, BC, Canada (2015).
- [8] T. Arkan et al., “CM2, Second 1.3 GHz Cryomodule Fabrication at Fermilab,” WEPAC29, Proc. PAC2013, <http://jacow.org/>