

LCLS-II CRYOMODULES PRODUCTION AT FERMILAB*

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Abstract

LCLS-II is an upgrade project for the linear coherent light source (LCLS) at 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 (JLab) 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. Fermilab and JLab will each assemble and test a prototype 1.3 GHz cryomodule to assess the results of the CW modifications, in advance of 16 and 17 production 1.3 GHz cryomodules, respectively. Fermilab is solely responsible for the 3.9 GHz cryomodules. After the prototype cryomodule tests are complete and lessons learned incorporated, both laboratories will increase their cryomodule production rates to meet the challenging LCLS-II project requirement of approximately one cryomodule per month per laboratory. This paper presents the Fermilab Cryomodule Assembly Facility (CAF) infrastructure for LCLS-II cryomodule production, the Fermilab prototype 1.3 GHz CW cryomodule (pCM) assembly and readiness for production assembly.

INTRODUCTION

The LCLS-II main linac 1.3 GHz cryomodule (CM) 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 [1]. Two prototype cryomodules (pCM) were planned for assembly at Fermilab and JLab to confirm the design modifications. The 3.9 GHz CM assembly will follow the 1.3 GHz CMs, for efficiency.

At Fermilab, the pCM was assembled between September 2015 and June 2016. For the prototype cryomodule, 8 ILC style bare cavities were processed with a high-Q0 recipe and then vertical-test qualified at Fermilab’s Vertical Test Stand (VTS) [2]. The qualified bare cavities were jacketed in a helium vessel at the CAF TIG welding glove box [3]. The dressed cavities were tested and qualified for cavity string assembly at VTS and/or at Fermilab’s Horizontal Test Stand (HTS) [4]. For the 16 production cryomodules, the cavities will be fabricated, surface processed, jacketed with a helium vessel, and assembled (ready to be tested at VTS) at the cavity vendors. Qualified cavities will arrive at the CAF for string assembly. To date, Fermilab has received eight cavities from the cavity vendors, and five of those cavities

were vertical test qualified and delivered to the CAF to start cavity string assembly of the first production module.

The procurement responsibilities for cryomodule components for the prototypes and production cryomodules are divided between Fermilab and JLab. SLAC is managing the fundamental power couplers procurement. Each laboratory is responsible for procuring a specific component for all 35 cryomodules. The components for 16 and 17 CMs will be drop shipped from vendor(s) to Fermilab and JLab, respectively. Acceptance Criteria Strategy (ACS) documents have been jointly developed for each major component procurement to establish common incoming QC guidelines. The incoming QC and acceptance of the component is done by each laboratory. At Fermilab, an LCLS-II CM supply chain manager coordinates the life cycle of the procured components from receipt, acceptance, storage, and kitting, to delivery to CAF production floors.

CRYOMODULE ASSEMBLY FACILITY

The CAF consists of two assembly/production floors: CAF-MP9 and CAF-ICB. CAF-MP9 (see Figs. 1 and 2) 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. There are two workstations (WS) setup in the cleanroom: WS0 is for coupler cold end assembly to the qualified dressed cavity and WS1 is for cavity string assembly. After the string is assembled, it is rolled to WS2 for cold mass assembly phase-I.

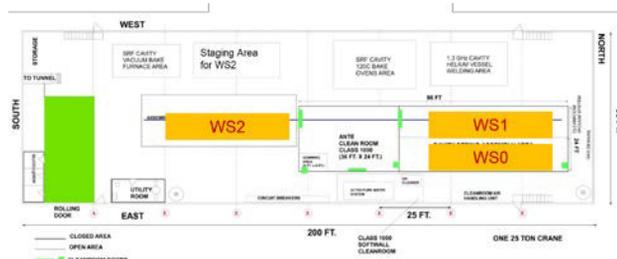


Figure 1: CAF-MP9 layout.



Figure 2: CAF-MP9 cleanroom.

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CAF-ICB (see Fig. 3) houses the cold mass assembly work stations WS3, WS4, WS5 and WS6, i.e., all remaining assembly steps and preparation for shipment. CAF-ICB is approximately 2 km away from CAF-MP9.

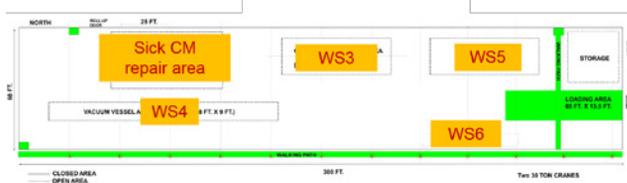


Figure 3: CAF-ICB layout.

PROTOTYPE MODULE ASSEMBLY

The pCM assembly was completed at the CAF in July 2016 and the module is currently undergoing test at the Cryomodule Test Stand (CMTS). The assembly workflow and details are:

0. WS0: Cold End Coupler Assembly [CAF-MP9]
 - WS0 omitted if final qualification test at HTS
 - Incoming QC and handling of cold end couplers
 - Assembly of the cold end couplers to qualified dressed cavities (see Fig. 4)



Figure 4: Cold end coupler assembly.

1. WS1: Cavity String Assembly [CAF-MP9]
 - Receipt of qualified dressed cavities
 - Alignment & assembly of 8 cavities, magnet/BPM package and 2 gate valves with interconnecting bellows and spools (see Figs. 5 and 6)

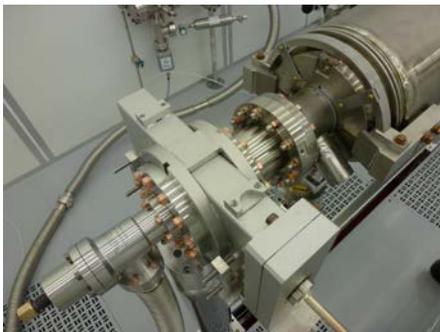


Figure 5: Upstream end gate valve assembled to Cavity #1.

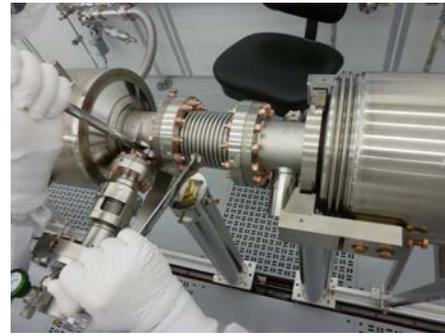


Figure 6: Interconnecting bellows assembly.

2. WS2: Cold Mass Assembly Phase-I [CAF-ICB]
 - Split magnet installation (see Fig. 7)
 - 2-phase circuit pipe cutting and welding
 - Instrumentation installation
 - Cavity magnetic shield installation
 - Cavity helium vessel MLI installation
 - Cavity helium vessel lugs to needle bearings and housings installation. This is the step to marry the cold mass upper to the cavity string (see Fig. 8)
 - GHRP to 2-phase circuit welding
 - Cool down lines to helium vessel welding
 - Various leak checks of the helium circuit
 - Various electrical checks
 - Various RF checks & HOM notch frequency tuning



Figure 7: Split Magnet Assembly.



Figure 8: Upper cold mass to cavity string assembly.

3. WS3: Cold Mass Assembly Phase-II [CAF-ICB] (see Fig. 9)

- Cavity axial alignment
- Magnet & current leads thermal intercept installation
- Cavity string alignment to cold mass (laser tracker)
- End lever tuner system assembly
- Thermal intercept assembly completion
- RF cable installation
- Magnetic shielding end-cap assembly
- Harnessing of the wires & cables
- Thermal intercepts installation for RF cables
- Electrical & RF Checks



Figure 9: Cold Mass Assembly at WS3.

4. WS4: Vacuum Vessel Assembly [CAF-ICB] (see Fig.10)

- Installation/welding lower 50K aluminum shields
- Installation of 30 layers of MLI around cold mass
- Electrical & RF checks
- Vacuum vessel installation onto the cold mass
- Cold mass support installation
- Cold mass alignment to the vacuum vessel



Figure 10: Cold Mass Assembly at WS4.

5. WS5: Final Assembly [CAF-ICB]

- Weld JT/Cooldown valves
- Leak check, X-ray QC, and pressure tests
- Installation of coupler warm parts and waveguides
- Routing & termination of instrumentation wires and RF cables to the feedthrough flanges
- Installation of coupler pumping lines, pumps & leak check

- Beamline vacuum leak check
 - Insulating vacuum pump down and leak check
6. WS6: Preparation for shipping [CAF-ICB]
- Preparation and shipment of CM to/from CMTS or to SLAC

PRODUCTION ASSEMBLY READINESS

The pCM assembly has been very useful preparation for production assembly readiness. At this point, the CAF infrastructure is complete and ready. The pCM assembly travelers and parts kits are complete and ready. All discrepancy (non-conformance) reports have been closed. The production CM design drawings have been updated based on pCM experience, and the production CM components were ordered with the revised drawings.

Lessons learned meetings were held with the assembly team, sub-systems leads, subject matter experts, process engineering. Meeting minutes resulted in action items which primarily addressed revisions for production cryomodule assembly travelers.

The pCM task durations have been carefully analysed and considered for optimization during the production CM assembly. The first three production CM's will be assembled in pseudo-parallel mode during a ramp-up phase. The ramp-up phase will also be used to train additional contract mechanical technicians. The remaining thirteen cryomodules will be assembled with an assembly throughput of one CM per five weeks and a duration of ~12 weeks (60 days) (peak-rate). Excluding any sick modules that need to be reworked, there will be three modules in the production line at the same time to satisfy the required throughput. Since the tooling and assembly steps for the 3.9 GHz CMs are by design as similar as possible, after a brief preparation period, the 3.9 GHz CM assembly will proceed with similar throughput.

CONCLUSION

CAF infrastructure is a proven, fully operational facility to assemble 1.3GHz and 3.9GHz cryomodules. With the successful assembly completion of pCM, we are ready to start the LCLS-II production cryomodule assembly.

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