JLAB CRYOMODULE ASSEMBLY INFRASTRUCTURE MODIFICATIONS FOR LCLS-II*

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Abstract

The Thomas Jefferson National Accelerator Facility (TJNAF, aka JLab) is currently engaged, along with several other DOE national laboratories, in the Linac Coherent Light Source II project (LCLS II). The SRF Institute at Jefferson Lab will be building 1 prototype and 17 production cryomodules based on the TESLA / ILC / XFEL design. Each cryomodule will contain eight nine cell cavities with coaxial power couplers operating at 1.3 GHz. New and modified infrastructure and assembly tooling is required to construct cryomodules in accordance with LCLS-II requirements. The approach for modifying assembly infrastructure included evaluating the existing assembly infrastructure implemented at laboratories world-wide in support of ILC and XFEL production activities and considered compatibility with existing infrastructure at JLab employed for previous cryomodule production projects. These modifications include capabilities to test cavities, construct cavity strings in a class 10 cleanroom environment, assemble cavity strings into cryostats, and prepare cryomodules for cryogenic performance testing. This paper will give a detailed description of these modifications.

INTRODUCTION

The Linac Coherent Light Source (LCLS)-II project at the SLAC National Accelerator Laboratory (SLAC) requires a 4 GeV continuous-wave (CW) superconducting radio frequency (SRF) linear accelerator in the first kilometer of the SLAC tunnel. The aim is to operate a high repetition rate X-ray free-electron laser, i.e. with electron pulses at rates approaching 1 MHz delivered to two new undulators covering the spectral ranges of 0.2-1.2 keV and 1-5 keV, respectively. The collaborative project brings together six US institutions, which in alphabetical order are Argonne National Laboratory (ANL), Cornell University, Fermi National Accelerator Laboratory (FNAL aka Fermilab), Thomas Jefferson National Accelerator Facility, Lawrence Berkeley National Laboratory (LBNL), and SLAC [1].

As part of shared responsibilities Fermilab and JLab will build the 1.3 GHz accelerating cavity cryomodules (CMs) concurrently in two assembly lines in order to meet the overall project schedule. In preparation for CM assembly, Fermilab has been leading the CM design efforts based on extensive experience with TESLA-style CM design and assembly. The starting point for design is existing models and drawings of similar ILC CMs (e.g. Type III+) with modifications to enable continuous-wave (CW) operation [2]. JLab and Cornell are partners in R&D and design contributing to development activities, design reviews, integration, cost estimation and production. Both Cornell and JLab have valuable CW CM design experience. JLab has directly applicable recent 12 GeV Upgrade production experience. Experienced SRF and cryogenic personnel at ANL are participating in cryostat design beginning with system flow analyses and pipe size verification and may be available for other collaborative tasks. The procurement of CM components is distributed between Fermilab and JLab, with the exception of SLAC who will procure the main RF power couplers [3, 4].

Currently, activities and preparations are underway for assembling two prototype CMs, one at each laboratory. Following the prototyping efforts, thirty-three production CMs are planned - sixteen at Fermilab [5], seventeen at JLab – for a total of thirty-five CMs in order to provide reliable 4 GeV energy gain.

STRATEGY – ONE DESIGN, TWO PRODUCTION LINES

CM designs currently under development for the prototype and production CMs are intended to satisfy LCLS-II Project Requirements [6] as well as the CM Functional Requirements Specification [7]. The two prototype CMs will be identical and utilize as much existing hardware as possible in order to reduce schedule risk and reduce overall cost while achieving the same performance as the production CMs. The production designs will utilize as much of the DESY/XFEL design as practically possible in order to reduce schedule risk and reduce overall cost.

The two partner labs plan to receive identical parts and sub-assemblies based on final drawing packages, requirements and specifications that are well-developed. This is accomplished through concurrent reviews within LCLS-II project. Procurement activities are coordinated between technical leads at Jlab, Fermilab and SLAC who work together during all phases of the procurement process. The interfaces between CM hardware and

* Authored by Jefferson Science Associates, LLC under U.S. DOE Contract No. DE-AC05-06OR23177 with supplemental funding from the LCLS-II Project U.S. DOE Contract No. DE-AC02-76SF00515. The U.S. Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce this manuscript for U.S. Government purposes.

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tooling are identical at both labs in order to avoid adding custom features to the CM. Existing infrastructure and tooling utilized for CM production at JLab has been adapted to accommodate the LCLS-II 1.3 GHz CM.

For each production line, equivalent processes will be developed in order to yield equivalent performance. It is recognized that some tools are different at each lab such as the high-pressure rinsing cabinets, cavity vertical and horizontal testing systems and vacuum leak checking equipment. Each laboratory has developed operational procedures for their equipment over time and in recent years has processed cavities that meet LCLS-II performance requirements. In order to ensure consistency between production lines, common acceptance criteria will be defined (e.g. acceptable vacuum leak rates) and key process variables will be monitored.

LEVERAGING XFEL/ILC CM EXPERIENCE

A very important part of the CM production plan is to leverage XFEL's existing CM experience ("know-how") gained during production [8]. DESY has entered into licensing agreements to share their successes, current issues and supply-chain challenges for key areas of cavity, main coupler and cryomodule production. This allows LCLS-II to learn from DESY's experiences and to adjust procurement and production plans accordingly.

In addition, CEA Saclay colleagues responsible for production of ~100 XFEL CMs [9] have hosted workshops for the SRF community and several focused meetings with LCLS-II staff to share their experiences with production in order to understand the staffing, technical and logistics issues related to such a large scale production effort.

Finally, LCLS-II can leverage Fermilab's ILC-style CM production development activities and experience that resulted in a set of assembly tools installed at Fermilab. These tools were utilized to develop procedures, train staff and ultimately to build two pre-production CMs – CM1 and CM2 – from kits of subassemblies and components provided by DESY. Technical staff at Fermilab have reviewed and discussed the assembly travellers that were developed with JLab staff in an effort to describe the detailed assembly procedures for CM2 in particular.

SRF INFRASTRUCTURE MODIFICATIONS

In order to assemble and tests LCLS-II CMs, a series of improvements and modifications are underway at JLab. These modifications include capabilities to test 1.3 GHz 9-cell production cavities, construct cavity strings in a class 10 cleanroom environment, assemble cavity strings into cryostats, and prepare cryomodules for cryogenic performance testing. JLab has significant existing infrastructure that has been utilized to assemble and test CMs for the original Continuous Electron Beam Accelerator Facility (CEBAF), the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory and the 12 GeV Upgrade at JLab.

This existing infrastructure has been adapted to accommodate LCLS-II CM assembly and testing. The work flow (Figure 1) includes key activities such as cavity qualification from vendors, various stages of CM assembly and acceptance testing. The work areas for CM production (Figure 2) include the following throughput capacities to achieve a rate of 1 CM per six weeks:

Testing of Dressed Cavities - four cavities per week,
Cavity String Assembly - two CMs per month,
Cold Mass Phase I – two CMs per month,
Cold Mass Phase II – two CMs per month,
Vacuum Tank Installation – four CM per month,
Final Assembly – two CMs per month,
CM Testing – 1 CM per ~ six weeks, and
CM Preparation for Shipment – two CMs per month.

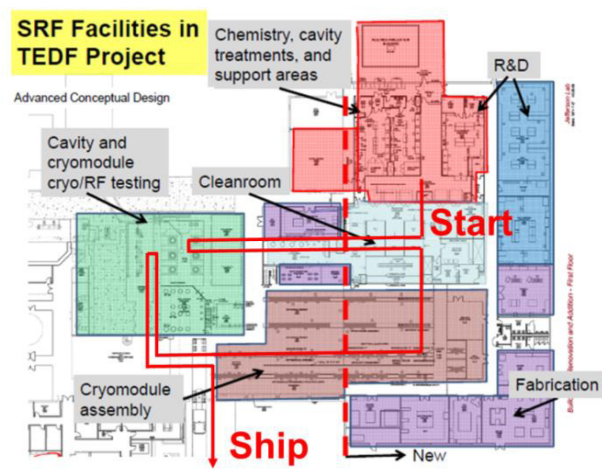

Figure 1: Work Flow for CM Production.

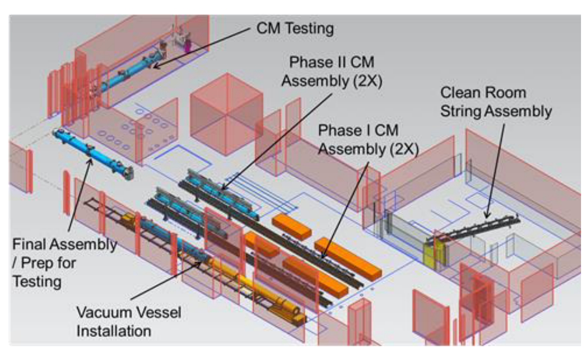

Figure 2: Work Areas for CM Production.

Vertical Test Area (VTA)

Up to four test stands are available for production acceptance testing capable of testing one cavity at a time. The plan for the prototype cavity qualification is to utilize the same cavity hardware (test flanges, feedthroughs, etc.) provided by project to cavity suppliers. Small modifications required to existing supports have been completed to enable LCLS-II dressed cavity testing. The cavity testing systems, both low-level RF (LLRF) and

ISBN 978-3-95450-178-6

cryogenic controls [10], have been upgraded as part of a VTA improvement effort. The magnetic environment is monitored to ensure that a low magnetic field environment, less than 3 mGauss, is maintained during testing.

Horizontal Test Bench (HTB)

The HTB has been modified to support high-Qo development efforts and now includes the capability to test a single LCLS-II cavity either critically coupled or with a fundamental power coupler (FPC). The modifications have been mainly to the top hat area to accept the XFEL-style FPC, and several other modifications have been implemented. The return header has been rolled by 45° to emulate the position of the two-phase line. To support rapid cooldown studies, a cold valve and several orifices have been added to mimic the piping arrangement in the LCLS-II CM forcing flow through the supply lines, into the cavity and exiting via the chimney. Instrumentation feedthroughs have been added to allow readback of temperature sensors and flux gate magnetometers to investigate flux expulsion and the magnetic field environment during cooldown and steady state operations. Finally, some minor modifications to the existing supports have been implemented to accommodate the new helium vessel design. The production plans include the possibility of conducting five tests during the production effort to provide feedback on the cavity assembly process or for production development activities if needed.

Clean Room Modifications

The ISO-4 clean room that was used for 12 GeV cavity string has been reconfigured to support LCLS-II cavity string assemblies which are approximately twelve meters long. The clean room has 100% ultra-low particulate air (ULPA) coverage, laminar flow, 100% perforated raised modular flooring (RMF), and a side wall return. The LCLS-II string occupies the majority of the clean room (1800 sq. ft.), and is segregated from the process tools using clean room curtains and soft walls. Areas for preparing components and sub-assemblies have been designated along with an area for cold coupler pre-assembly. The air-lock door has been modified to allow roll-out into the CM assembly area.

Assembly Tools

In the clean room, the stainless steel mobile rail will be used for cavity string assembly. The interfaces to the cavity are identical to those used for XFEL CM production. The lower portion of the cavity carriages have been adapted to fit on the mobile rail. The rail has helium supply installed for leak checking and nitrogen supply installed for purging during assembly activities. There are number of small fixtures fabricated that are intended for coupler installation, cavity bellows restraint and flange alignment. Four dedicated cavity handling cages used for processing and VTA testing have been fabricated along with two clean dressed cavity storage racks. Two sets of carriages for cavity string assembly have been constructed, and are used to support the cavity strings during transfer from the mobile rail to the fixed rail systems outside the clean room.

Outside the clean room, there are two cold mass spreader bars that are used to support and position the cold mass during cavity string attachment, one fixture for cold mass installation into the vacuum tank, and a spreader bar for lifting vacuum tanks, completed CMs and CMs with testing end caps installed. These tools are identical to those used for the XFEL CM assembly currently. Calculations have been performed to ensure that the installation meet load specifications. All tooling will undergo load testing to confirm load carrying capabilities. An automated welding system will be used to complete welds on the two-phase and fill lines after the cavity string is rolled out from the clean room. A pair of 25-ton cranes provides lifting capability in the high-bay for moving installing CMs in the Cryomodule Test Facility (CMTF) and onto shipping fixtures.

Cryomodule Test Facility

The CMTF is an integrated facility whose main function is to perform acceptance testing of CMs, and is occasionally used for HTB testing activities. It has an installed magnetic shielding that encloses the testing volume reducing external fields to less than 50 mG. Cryogens are provided by the Cryogenic Test Facility (CTF) to both the VTA for cavity qualification and CMTF for CM acceptance testing. Cryogenic capacity of 100 W at 2K and 0.031 atm is available for testing individual cavities in CW mode. To improve refrigeration efficiency, a 4K-2K heat exchanger (HX) is being added to the CTF and will be located in the CMTF near the CM.

Improvements to the CMTF include a high-power RF (HPRF) system suitable for testing an individual cavity or eight cavities in short duration steady state. Solid-state amplifiers (SSAs) that provide up to 3.8 kW of RF power are supplied by SLAC and will be returned at the completion of production. For steady-state eight-channel operations, JLab has procured circulators, directional couplers, rectangular and coaxial waveguide to be installed between the SSAs and the CMTF. Line power has been run to the area where the SSAs will be installed. Upgraded LLRF controls, HPRF controls and software are being developed including new digital controls for the CMTF control room. Interlocks such as arc detectors and infra-red sensors are being developed and installed. In addition, an integrated test system providing 50 A maximum current, quench detection and temperature readback for the superconducting magnet will be supplied by SLAC.

Two sets of LCLS-II CM testing end cans are being fabricated in-house and will support the CM production rate. The bayonet box provides the interface between internal CM piping and the existing junction box, connects the CM to CTF junction box via removable u-tubes, and helps to close the insulating vacuum space.

The bayonet box consists of valves, a 4K-2K heat HX, liquid level readback and diodes to monitor and control helium flow and liquid inventory. In addition, the bayonet box provides pressure reliefs for the primary circuits, the shield circuit and the insulating vacuum space. The end cap provides a turn-around for the cryogenic circuits, access for pumping the cavity beamline vacuum volume, and helps to close the insulating vacuum space. Once the bayonet box and end cap are installed on the CM, the entire assembly is moved into the CMTF for testing (Figure 3).

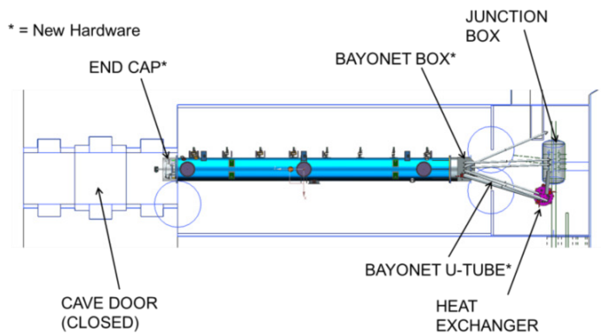

Figure 3: CMTF Layout of CM with U-tubes and HX.

SCHEDULE

The infrastructure for cavity testing is complete and has been used for cavity qualification activities. The cavity string assembly is ready for use; the prototype cavity string assembly is planned to occur in September/October 2015. The assembly tools have been received at JLab, are being installed currently and will be ready for prototype CM assembly within one month. The CMTF activities are in progress with the goal of completion prior to prototype CM testing which is currently scheduled for February 2016.

SUMMARY

Through a strong collaboration with XFEL and Fermilab colleagues, JLab has developed and implemented a plan for infrastructure to enable assembly and testing of LCLS-II CMs. The goal for production of CMs at JLab and Fermilab is "identical design, identical parts, equivalent processes to yield equivalent performance". The infrastructure development supports this goal with a planned production rate of one CM every six weeks.

ACKNOWLEDGEMENTS

We wish to thank the team at Fermilab, and in particular Tug Arkan and Yuri Orlov, who contributed their time, experience and knowledge regarding the existing infrastructure installed onsite at FNAL. We would also like to express our sincere gratitude to DESY and CEA Saclay colleagues for their generosity providing insight and experience related to the monumental XFEL CM production efforts.

Finally, we are especially grateful to the excellent team in SRF Operations that supports the installation of this infrastructure and will utilize it to build LCLS-II CMs.

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ISBN 978-3-95450-178-6