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INSTALLATION OF LCLS-II CRYOMODULES*

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Abstract

The Linac Coherent Light Source II (LCLS-II) superconducting accelerator is fully installed and operational. Cryomodules were designed and manufactured by Fermi National Accelerator Laboratory (FNAL) and Thomas Jefferson National Laboratory (JLab) during 2017-2020. From November 2018 through March 2021, SLAC National Accelerator Laboratory installed 37 Cryomodules. Full system cooldown was completed in March 2022.

Installation processes were optimized at SLAC for best quality, especially during particle-free and UHV assembly. These processes and successful Cavity and Cryomodule manufacturing resulted in installed gradient exceeding design requirements by more than 20%. No statistical variation in field emission onsets or magnitudes were observed between manufacturing and site testing. This paper summarizes SLAC experience during installation, and relevant testing results.

CRYOMODULE INSTALLATION PROCESS OVERVIEW

Following delivery to SLAC and acceptance testing, the Cryomodule installation sequence consisted of first rigging Cryomodules onto stands in the SLAC tunnel. Custom dollies were used, which were pulled by an electric tugger at low speeds. To protect sensitive components from tight tunnel clearances during transit, guide rollers kept the Cryomodule couplers at a safe distance from the accelerator tunnel wall. Cryomodules were then rigged onto their stands and aligned to the proper position (Figure 1).

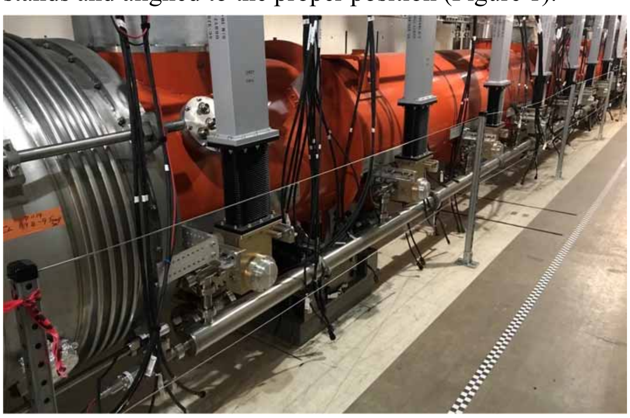

Figure 1: Cryomodule installed in the SLAC tunnel.

Once in place, Cryomodules were then connected, starting with joining helium process pipes together using orbital welding. The joints were verified with visual examination, ultrasonic examination, and helium mass spectrometer leak check. Once all helium lines were connected and inspected, a pressure test of the entire line served as a final validation of joints. For the pressure test, lines were filled with a mixture of air and helium at a closure weld prior to connecting the Cryomodule string to the Cryo Plant. This allowed the team to stay well away from pressure piping during testing.

Next the particle-free and UHV beamline connection was made with flanges. This was left until validation of helium process pipes was complete to avoid removing components in the event weld repair was needed in an interconnect. This also reduced the risk of work above the beamline causing dents or an uncontrolled vent to the Cryomodule string. After beamline interconnect pieces were installed, helium process pipes are wrapped in several layers of MLI. Lastly, heat shields and a final MLI blanket were installed before the vacuum vessel is closed over the interconnect.

After all Cryomodules in a string were connected, the insulating vacuum was prepared for cooldown with three cycles of pumping and purging with dry nitrogen. After the final purge, turbo pumps were installed to reduce insulating vacuum pressure to meet spec for cooldown.

While all installation steps required cautious handling due to shock sensitivity and exposed parts, the particle-free installation of beamline components was developed with the most care under SLAC's enhanced rigor policy. As the cavity string of the Cryomodules are critical to accelerator performance, beamline installation practices will be looked at in more detail. See Fig. 2 for full process flow diagram.

PARTICLE-FREE TOOLING

Cryomodules were connected to each other and surrounding beamlines with either Beamline Absorbers (BLA) or spool pieces. All particle-free connections of vacuum components must take place in an ISO Class 5 Cleanroom (FED-STD Class 100) or Clean Zone per ISO 14644-1, in the operational state, for 0.5 micron and 5.0 micron particles. Custom tools were developed to manage these conditions and to create a successful installation environment.

Custom Installation Clean Zones

The small amount of space between the Cryomodules and wall of the accelerator housing made an overhead cleanroom impractical for installation. Instead, a custom clean zone was designed to fit underneath the helium process pipes to keep the working area clear of debris and unexpected air currents (Figure 3). With no space to place an air filter above the beamline, the air filter provided laminar air flow from the bottom to the top of the zone. Curtains on either end allowed technicians to reach in from the two sides of the working area. Airborne particle counters were continuously used when beamline components were

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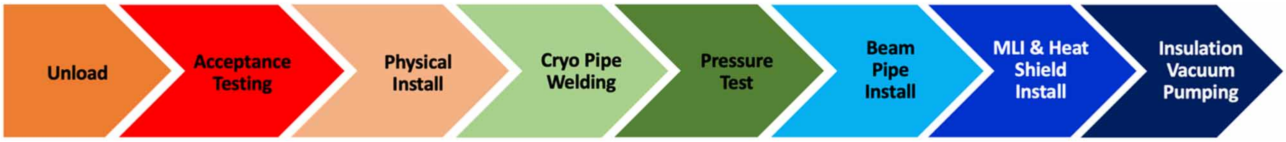

Figure 2: Installation process flow diagram.

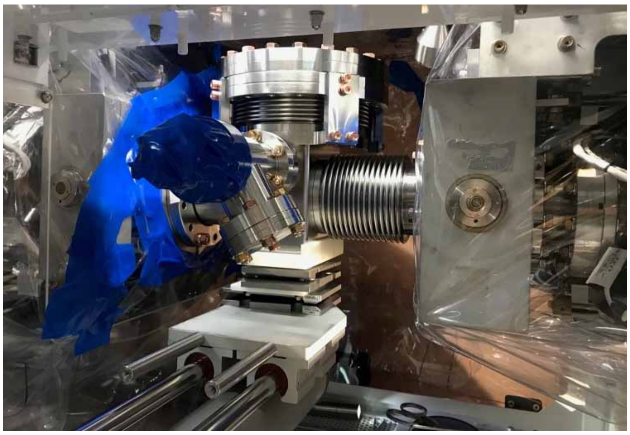

Figure 3: BLA assembly installed between cryomodules.

exposed. Optimized tooling and installation processes resulted in very few instances where particle counters showed any particles above 0.1 µm.

The clean zone was also designed to manage the 40 pound weight of the BLA during installation (Figure 4). A custom, moveable cradle was designed to adjust alignment in the clean zone. This allowed technicians to slowly and accurately adjust the position and angles of BLA flanges to align with Cryomodule gate valves. To minimize debris generation in the clean zone, technicians adjusted the height and lateral movement of the BLA with a series of actuators outside of the clean zone. They would only reach inside to move the BLA to the center of the clean zone and adjust its angle, keeping internal moving parts to a minimum. To install hardware with minimal adjustment, alignment pins were used to line up bolt holes on BLA and gate valve flanges.

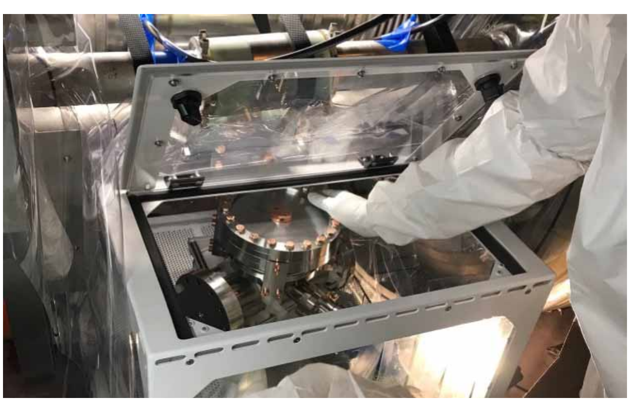

Figure 4: Tight space available inside clean zone.

Laminar Flow Bench

The clean zone maintained particle-free conditions for the interconnect installation zone, but it was not big enough to provide a working space to prep the BLA and hardware. Instead, technicians used a laminar flow bench directly to the side of the interconnect to unpackage and inspect the interior of the BLA and to unpackage and inspect gaskets and hardware before installation.

Pump Carts

SLAC worked with a vendor to develop particle-free turbo-molecular pump carts. A slow pump-down was implemented using a mass flow controller to maintain laminar flow at pressures above 0.1 Torr. State-machines were used to transition between pressure regimes. RGA testing validated each connection.

PARTICLE-FREE INSTALLATION

Best Practices

Particle-free procedures for interconnects were developed as Category 1 tasks under SLAC's enhanced rigor policy. A FMEA was developed to identify and mitigate possible risks during installation and plan for field work.

BLA installation crews consisted of two, particle-free trained vacuum technicians to perform work, and a quality assurance representative to verify that all steps were followed as planned. Each step was initialed and signed. Record of beamline vacuum and particle counts before and during installation were recorded.

The procedure was developed to protect equipment and technicians with SLAC's ergonomic safety team. The installation area was challenging to work within. The beamline sits at a nominal height of 27 inches above the ground, which is a lower working height than is comfortable for most technicians. There is ample working space on the aisle side of the Cryomodule, but the wall side has 12 inches of clearance at its tightest point. Both technicians must reach inside the clean zone and work for considerable periods of time with arms outstretched to the center of the box. To reduce ergonomic strain and avoid sudden, accidental movements during installation, yoga blocks and knee pads were used to keep technicians comfortable during long hours of installation. Micro breaks were included in the procedure to allow technicians to stand and stretch before critical steps with exposed vacuum components.

More than 6 months prior to installation, a mock-up space of a Cryomodule-to-Cryomodule interconnect was created for installation teams to verify procedures and tooling prior to the first field work. Once work started in the tunnel, coordination with other groups was essential. The equipment set-up and particle-free practices blocked tunnel access for other working groups in the LCLS-II project.

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At the start of the BLA installation process, Cryomodule gauge trees and right-angle valves had already been removed from the beamline. Without instrumentation, the beamline pressure was unknown. Particle-free connection of Cryomodules must start at a portion of the beamline with an ion pump and gauge to monitor the string of Cryomodules as they are connected. In every interconnect, the beamline pressure of only one device is known. Once a BLA is installed, the gate valve to the Cryomodule with unknown pressure is opened to the interconnect first. Its pressure is confirmed with a particle-free cart connected to the BLA right-angle valve. It can then be pumped down if needed before introduction to the rest of the string. The Cryomodules are carefully and linearly introduced to the string using this strategy.

Particle-Free Installation Procedure

Particle-free work in the accelerator housing started with a thorough cleaning of the work area. The walls and floor were masked with polyethylene sheeting to prevent dust from surrounding walls from impacting installation. The gate valves on either end of the interconnect had already been covered with plastic caps and bagged for cleanliness. Then the clean zone, laminar flow bench, particle counters and ergonomic equipment were put in place. The clean zone and laminar flow bench fan filter units were run overnight and tested with particle counters.

Once the particle-free working areas were validated, the BLA was transported to the interconnect and placed in the laminar flow bench. Technicians then removed end flange blanks and conducted a visual inspection of the interior. The Cryomodule gate valves on either side of the interconnect were also inspected with a nitrogen blow-off test in the clean zone. With flanges of Cryomodules and BLAs clean, the BLA was then placed in the clean zone, and secured to the cradle. Next, the empty laminar flow bench was used to prepare hardware. Hexagonal, aluminum gaskets used in beamline joints underwent thorough examination before use to identify any dents or scratches that could compromise flange seals. Hardware was then placed in the clean zone.

With hardware and equipment prepped, the technicians were ready to line-up and install the BLA. The fixed connection to the upstream Cryomodule was done first. On both sides, an initial dust seal is created with four fasteners to close exposed beamline surfaces. The remaining hardware was then installed on both sides and tightened.

After BLAs were secured in place with hardware, a particle-free pump cart was connected to the right-angle valve to pump down the BLA and leak check flange connections. Once installation was verified to be leak tight, both gate valves were opened, starting with the Cryomodule of unknown vacuum. The pump cart was disconnected, and a pinch-off was installed on the right-angle valve. Large interconnect heat shields were immediately installed around the BLA to protect the area from surrounding work.

SYSTEM PERFORMANCE AND TESTING RESULTS

These processes and successful Cavity and Cryomodule manufacturing resulted in the installed gradient exceeding design requirements by more than 20%. Total commissioned cavity voltage is 4.9 GV. All testing is complete, and 97% of cavities are now fully operational, exceeding the planned 94%. Figure 5 shows a statistical review of the onset of Cavity field emission, which shows no change compared with initial testing from partner laboratories (FNAL and JLab). Full commissioning details are available from Gonnella et al [1].

All testing data indicates field installation and SLAC particle-free processes effectively maintained the best quality of the LCLS-II Cryomodules.

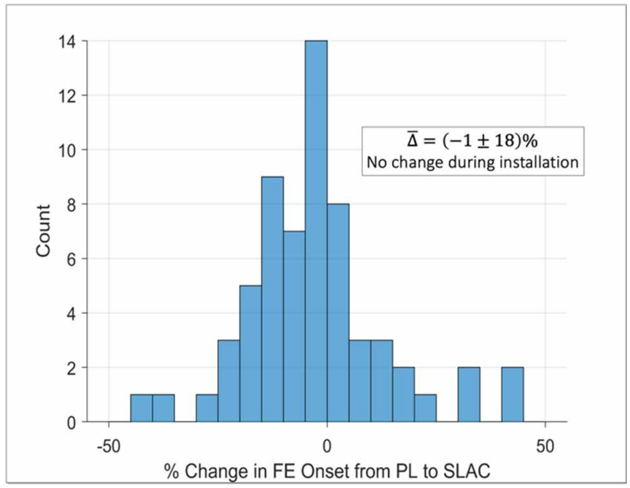

Figure 5: Change in field emission onset.

CONCLUSION

The LCLS-II project installed 37 Cryomodules at SLAC National Accelerator Laboratory built by Fermi National Accelerator Laboratory (FNAL) and Thomas Jefferson National Laboratory (JLab). The Cryomodules were connected in the accelerator housing by welded helium process pipes and beamline particle-free flange connections.

The particle-free installation work proved to be the most challenging due to environmental and ergonomic factors, but the quality of the particle-free connections has the greatest impact on accelerator performance. The challenges were mitigated with custom tooling, technician training, and a well-developed procedure. Once installed, testing data indicated these processes effectively maintained the best quality of the LCLS-II Cryomodules.

REFERENCES

[1] D. Gonnella *et al.*, "Commissioning of the LCLS-II Superconducting Linac", presented at the SRF'23, Grand Rapids, MI, USA, Jun. 2023, paper MOPMB088, this conference.