200 MV RECORD VOLTAGE OF vCM AND LCLS-II-HE CRYOMODULES PRODUCTION START AT FERMILAB

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LCLS-II-HE cryomodule (CM) production started at Fermilab with the assembly and testing of the verification cryomodule (vCM). The vCM design is the same as the LCLS-II CM; one major difference is that the superconducting radio frequency (SRF) cavities are treated with a new processing protocol for the required performance specifications. vCM was successfully tested at Fermilab with a 5-month test program and achieved an acceleration voltage of 200 MV in continuous wave mode, corresponding to an average accelerating gradient of 24.1 MV/m, significantly exceeding the specification of 173 MV. The average Q_0 (3.0×10^{10}) also exceeded its specification (2.7×10^{10}).

VERIFICATION CM ASSEMBLY & TEST

vCM is assembled using eight of the best performing cavities fabricated with the new processing protocol. R&D to develop the new processing protocol, transfer the technology to industry, test and qualify the cavities processed with the new protocol is the first part of the equation to declare success. The second part is to assemble these cavities into the cryomodule and prove that the performance of the cavities can be preserved. vCM was assembled very soon after completing the last LCLS-II CM (keeping the momentum). Based on lessons learned from our successes and from unwanted outcomes of LCLS-II cryomodules production, some infrastructure upgrades were done and validated

- Beamline slow vacuum pumping & nitrogen gas backfill / purge systems upgrades
- Leave beamline under active vacuum during CM assembly, pumping with NEG/ion pump
- Eliminate fundamental power cold coupler (FPC) assembly workstation in the cleanroom and combine the cavity interconnect bellows and cold end FPC assembly into one workstation.

Cavity String Assembly in the cleanroom

After the string assembly is completed and rolled out of the cleanroom, cold mass and cryomodule assembly was assembled in four months. We again had to ensure that the new procedures, tooling, and infrastructure upgrades are fully understood and utilized by the team. One of the biggest concerns was assembling the beamline under vacuum. The Fermilab CM assembly team visited JLab to learn and transfer the knowledge for the beamline assembly. We introduced new tooling and procedures to eliminate any risk to the cavity string bellows and unintentional collapse due to beamline vacuum forces. A Failure Mode and Effects Analysis (FMEA) was written to complement the travelers.

Cold mass and Cryomodule Assembly

In-situ Leak repair

During the cold mass assembly at WS2 after the 2-phase circuit welding leak check, a helium vessel leak was found on an SRF cavity. This leak opened during cold test at the vertical test stand. The leak was repaired in situ. We revised the production workflow and introduced a new cavity jacket leak check step post vertical test.

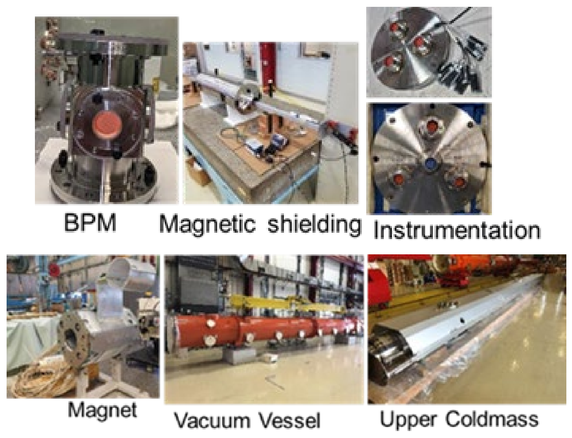
Cavity performance results look excellent. This is a world record CW CM. Gradient and Q_0 in all eight cavities exceed the LCLS-II-HE specification and are well above average compared to LCLS-II production. The CM is field emission free. We also applied plasma processing to this cryomodule even though it was field emission free. Post plasma processing results showed that no new field emission was introduced to the CM. One benefit observed after plasma processing was the elimination of multipacting quenches.

These excellent results prove that all the work done to prepare for LCLS-II-HE CM assembly, keeping the momentum from LCLS-II and applying the lessons learned, was an effective strategy. vCM has successfully shipped and delivered to SLAC in February 2022.

vCM at SLAC

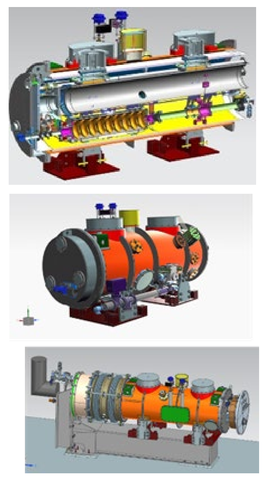
SERIES PRODUCTION

Procurement of parts for series cryomodules production is nearing completion. Fermilab plans to produce and deliver all series production CMs by the end of 2025.



BUNCHER CAVITY CRYOMODULE

The LCLS-II-HE project scope includes the construction of a 100 MeV low emittance injector (LEI). The LEI includes two SRF cavities: an electron gun cavity and a 1.3 GHz, 9-cell buncher cavity. The latter is housed in the Buncher Cavity Cryomodule (BCC) that includes a solenoid magnet package. Fermilab will design, build, test and deliver the BCC to SLAC in early 2026.



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