ISBN: 978-3-95450-232-5 ISSN: 2673-7000 doi:10.18429/JACoW-NAPAC2022-WEPA19

He PRODUCTION UPDATE AT JLab – INTRODUCING AN ENHANCED NITROGEN PURGE FOR CLEAN STRING ASSEMBLY

P. Owen, Thomas Jefferson National Accelerator Facility, Newport News, VA, USA

Abstract

A major limitation to cryomodule performance is field emission caused by particulates within the superconducting cavities. To reduce contamination of the inner surfaces during assembly in a cleanroom, the whole string can be connected to a purge system which maintains a constant overpressure of dry, clean nitrogen gas.

Following the successes of similar systems at XFEL and Fermilab, Jefferson Lab followed this example for the production of LCLS-II-HE cryomodules. Implementing this system required new procedures, infrastructure, and hardware, as well as significant testing of the system before use in actual production. This poster summarizes the implemented controls and procedures, including lessons learned from Fermilab, as well as the results of mock-up tests.

Based on the latter, the system was used for the assembly of the first article string in April 2022, as well as during a rework required due to issues with cold Fundamental Power Coupler (FPC) ceramics two months later. The benefits of using a purge system with regards to procedure, time savings, and added flexibility for potential rework have already proven to provide a significant improvement for the production of LCLS-II-HE cryomodules at Jefferson Lab.

INTRODUCTION

LCLS-II-HE cryomodules share most of their same design with the LCLS-II modules. Likewise, production of these modules is split between Jefferson Lab and Fermilab. Once received from the vendor, each cavity is kept under vacuum and tested in a vertical dewar. Along with other qualifying criterion, if the test produces no field emission (detectable above background levels), the cavity is cleared for assembly. Because the interior of the cavity has therefore been proven to be clean, great care is taken to preserve the state. Cavities are taken into an ISO-4 cleanroom and undergo a thorough external cleaning.

For assembly, the interior space must be backfilled from vacuum to atmospheric pressure. The temporary input antenna for vertical testing is replaced, and eight cavities are joined together to form a string. These three steps pose the greatest risk in introducing particulate to the inner surface of the cavity, potentially causing field emission during cryomodule test and in later operation. This preservation of cleanliness was a key issue during LCLS-II production at both partner labs. Following an extensive audit, Fermilab implemented a nitrogen-purge system to be used during the stages of string assembly [1]. Combined with other improvements, the system was successful in reducing field emission in later cryomodules.

For LCLSII-HE production, Jefferson Lab was instructed to develop a similar system and procedures for string assembly. Due to fundamental differences in cleanroom infrastructure from Fermilab, a new design of gas supply, control, and tubing was needed.

SYSTEM DESIGN

Throughout the assembly process, there will be a flow of nitrogen available to keep the interior of the cavity clean. The supply is boil-off gas from a nitrogen dewar which is then passed through several filters before reaching the cavity. The final filter is placed as close as possible to the cavity to avoid the gathering of moving particulate from bellows flex hoses or valves into the cavity (Fig. 1).

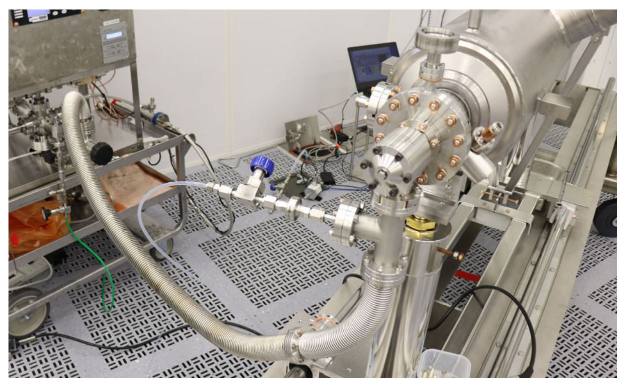

Figure 1: Filtered nitrogen supply and vacuum hose connected to cavity in the cleanroom.

Control and Instrumentation

The nitrogen flow must be carefully controlled for three main reasons. A flow rate that is too small will be ineffective in keeping particulate out of the cavity. Too much flow could lift and redistribute particles in the cavity, potentially leaving particulate on a more critical surface. Finally, once the flange is sealed and the assembly is completed, the flow must be shutoff to prevent overpressure and harm to any component.

To meet these flow criteria, each line of nitrogen supply was designed with a mass flow controller (MFC), pressure gauge, and pneumatic shutoff valve. A cRio system from National Instruments was programmed to communicate with and control these three elements for each of the three nitrogen supply lines. A test fit of this control hardware is shown in Fig. 2.

ISBN: 978-3-95450-232-5 ISSN: 2673-7000 doi:10.18429/JACoW-NAPAC2022-WEPA19

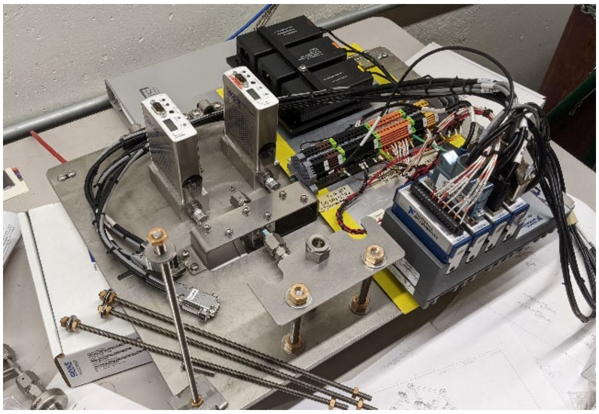

Figure 2: Test fit of MFCs and control hardware outside the cleanroom.

The MFC sets the flow in the cavity based on user input and the stage of assembly. Because this system is used to backfill the cavity from vacuum as well as purge during assembly, different flow rates need to be set and regulated. These are controlled by the user through a LabView software interface. The differential pressure gauge measures pressure in the nitrogen supply line relative to ambient pressure in the cleanroom environment. This ensures that the cavity will always be above ambient pressure which is necessary to keep airborne particulate away from the cavity opening.

When the cavity pressure reaches a threshold equal to 50 mbar above atmosphere, the cRio shuts off flow using the pneumatic valve and MFC flow rate. If the pressure drops below the threshold, the flow will slowly ramp back up to the desired rate. After initial testing, this control scheme was found to be very 'jerky' at pressures close to the threshold. Hence, a more relaxed control system was implemented before the first string assembly. Further control improvements, such as PID control, may be implemented in the future. Following the precedent set by Fermilab, the flow rate during purge was selected to be 1000 sccm [1]. This rate can be increased or decreased with a simple setting in the software.

Vacuum and Backfill

Before any gas flow is introduced to the cavity space, the right angle valve must be opened. Because the cavity is kept under vacuum after vertical RF test, the exterior side of the valve must also be under vacuum when the valve is opened. The exterior side of the valve is connected to the Nitrogen purge and the line is evacuated to a pressure of 10^{-5} Torr or lower. While monitoring the pressure in the line, the valve is then slowly opened. Then the MFC begins to slowly backfill the cavity with Nitrogen. At a flow rate of 300 sccm, reaching atmospheric pressure takes approximately 90 minutes.

Through software, the user has the ability to control and monitor the flow in each supply line, monitor the pressure of each line, as well as the upstream pressure of the nitrogen supply.

QUALIFICATION TESTS

A preliminary test of the purge system was conducted on a small assembly rail outside the cleanroom. Because of the 'dirty' nature of this test, cavities that did not qualify for production use were attached to the system. This was the first opportunity to test the hardware, software, and receive feedback on new tooling.

The next test was performed inside the cleanroom on two cavities that were already qualified as meeting all specification for production use. With the purge system attached, components were removed and replaced as a mock-up of a portion of the string assembly process. When the mock-up was done, the cavities were tested again at 2 K, with identical performance to the pre-purge test. They key results are listed in Table 1. This mock-up was a prime learning and training opportunity for cleanroom technicians, as well as an important test of the purge system hardware inside the cleanroom.

Table 1: Vertical RF Test Performance of Cavities Used in First Mock-up Assembly

Test Criterion	**CAV0295**	**CAVR023**
	Before Purge Assembly	
E_{max} (MV/m)	23.5	25.3
Q_0 at 20.8 MV/m	2.6e10	2.5e10
Field Emission Onset Gradient (MV/m)	N/A	N/A
	After Purge Assembly	
E_{max} (MV/m)	24.45	24.9
Q_0 at 20.8 MV/m	2.6e10	2.7e10
Field Emission Onset Gradient (MV/m)	N/A	N/A

A major change in string assembly from the LCLS-II procedure was attaching the inter-cavity bellows to the cavities when they are horizontal on the rail, rather than hanging vertically. Validating the new installation procedures and tooling was a critical step in qualifying the purge system, so a second mock-up was performed on two new cavities. As in the first mock-up assembly, the test antenna was removed and reinstalled on each cavity. This time, the cavities were also joined by a beamline bellows, which is shown in Fig. 3.

In order to validate the two-sided purge, required for joining two cavities, a second right angle valve was connected to the upstream beamline flange of CAVR022 in a non-standard production configuration. This valve was kept on during the vertical test. When the mock-up assembly was completed the same cavity had a small leak while pumping down to vacuum. A combination of these factors likely caused field emission during the 2 K vertical test. Full test results are in Table 2.

ISBN: 978-3-95450-232-5 ISSN: 2673-7000 doi:10.18429/JACoW-NAPAC2022-WEPA19

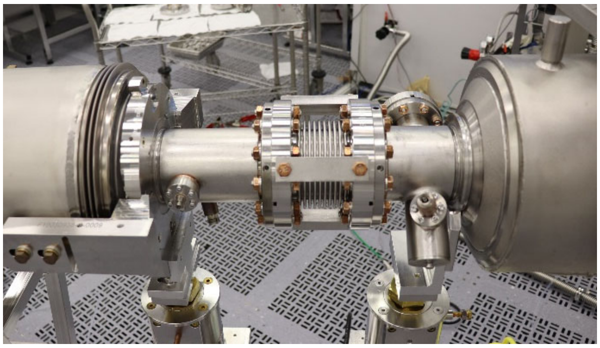

Figure 3: Cavities joined by beamline bellows with stiffeners as part of the second mock-up.

Table 2: Vertical RF Test Performance of Cavities Used in Second Mock-up Assembly

Test Criterion	CAVR012	CAVR022
	Before Purge Assembly	
E_{max} (MV/m)	22.3	24.9
Q_0 at 20.8 MV/m	3.5e10	2.7e10
Field Emission Onset Gradient (MV/m)	N/A	N/A
	After Purge Assembly	
E_{max} (MV/m)	22.5	10
Q_0 at 20.8 MV/m	3.5e10	N/A
Field Emission Onset Gradient (MV/m)	N/A	6.8

In summary, three out of four cavities that were involved with the purge system mock-ups maintained their vertical test performance. And of the cavities that did not have complicating factors, 100% were still qualified for production use after the purge system. These statistics were satisfactory to implement the purge system during LCLS-II-HE string assembly.

ADDITIONAL USE FOR REWORK

After the first string was constructed and rolled out of the cleanroom, issues with the FPCs were found relating to cleanliness and quality control of the cold RF window. The decision was made to replace all eight couplers inside the cleanroom. The purge system was used to slowly bleed-up the string. As was done during string assembly, Nitrogen was purged through each FPC flange during the process. Such a replacement procedure introduced a much higher risk of contamination during LCLS-II due to the lack of a purge to block particulates.

CONCLUSION

A nitrogen purge system has successfully been installed in the Jefferson Lab cleanroom for cryomodule production. Based on initial testing, the system is able to preserve the vertical test performance of a cavity throughout string assembly. In early 2023, the first LCLS-II-HE cryomodule will be tested at Jefferson Lab, J1.3-21. If no field emission is detected, this will complete the qualification of the purge system. The purge system may be adapted for other projects at Jefferson Lab such as CEBAF refurbishment.

ACKNOWLEDGEMENT

I would like to thank the LCLS-II-HE project management and staff at Jefferson Lab, Fermilab, and SLAC for their support throughout the design, complications, and implementation. Additional thanks to Tiffany Ganey, Danny Forehand, and Chris Dreyfus for their contributions to the design and procedures to use the system.

REFERENCES

[1] G. Wu *et al.*, "Optimization of Clean Room Infrastructure and Procedure During LCLS-II Cryomodule Production at Fermilab", in *Proc. SRF'19*, Dresden, Germany, Jun. 2019, pp. 695-697. doi:10.18429/JACoW-SRF2019-TUP096