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3.9 GHz PRODUCTION CAVITIES FOR LCLS-II *

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Abstract

The main part of the SRF linac for the Linac Coherent Light Source II (LCLS-II) at SLAC will consist of 35 cryomodules with superconducting RF cavities operating at 1.3 GHz. In addition, two cryomodules with 3.9 GHz cavities will be installed and help to linearize the longitudinal phase space of the beam. During the design verification phase, four prototype 9-cell 3.9 GHz cavities had been built by industry and then processed, including chemical surface removal and heat treatment, and tested at Fermi National Accelerator Laboratory. Based on the resulting cavity treatment recipe, 24 cavities (for two cryomodules to be installed in the linac and one spare cryomodule) have been built by industry and tested at Fermilab prior to cryomodule string assembly. We present an overview of the cavity production and the results of the vertical acceptance tests for the LCLS-II 3.9 GHz cavities.

INTRODUCTION

Fermilab is building three 3.9 GHz cryomodules for the Linac Coherent Light Source II (LCLS-II). Two will be installed in the accelerator and one will serve as a spare. The surface treatment recipe for the cavities has been developed during the design verification phase and was chosen to be buffered chemical polish (BCP) in combination with 120 C bake. The main production of 24 cavities is done by RI Research Instruments (RI) and 75% complete. After delivery to Fermilab the cavities undergo the vertical acceptance test and if they meet the performance requirements are qualified for string assembly.

DESIGN VERIFICATION PHASE

The design of the 3.9 GHz cavities for LCLS-II is based on the 3rd harmonic cavity originally designed at Fermilab for use in the FLASH accelerator at DESY [1], adapted for CW operation. The design verification phase aimed to validate these changes, develop the surface processing recipe and test the cavity together with ancillaries like high power fundamental power coupler and tuner.

Four cavities were built by RI and delivered after completion of mechanical fabrication, without chemical surface treatment or welding to a helium vessel. Surface processing by BCP and heat treatments (800C degassing/annealing and 120C bake) were performed at Fermilab and Argonne National Lab. One of the bare cavities during incoming inspection after arrival at Fermilab is shown in Fig. 1.

Figure 1: Bare cavity during incoming inspection at Fermilab.

Performance tests in the vertical dewar (VTS) were done before and after 120C bake and results are shown in Fig. 2. The average Q_0 at 13.4 MV/m was $3.5 \cdot 10^9$ pre-120C bake and $4.5 \cdot 10^9$ post-120C bake. Due to the additional margin gained in Q_0 compared to the specification, 120C bake was adopted for the production.

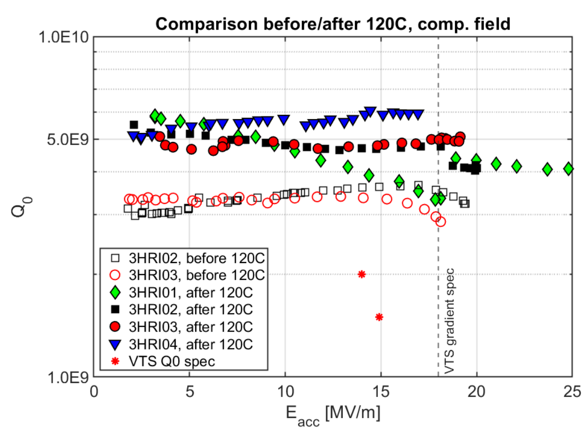

Figure 2: Q vs E performance in VTS for the four design verification cavities before and after 120C bake.

After being welded into a helium vessel cavity 3HRI03 was tested in the horizontal test stand (HTS). For this test the cavity was equipped with a high power fundamental power coupler, tuner and hybrid internal and external magnetic shielding. The performance of all components was tested successfully. The hybrid approach with a magnetic shield inside the helium vessel covering the cells and external shield caps covering the end groups worked well. In addition the heat load limit of the helium vessel chimney was determined to be consistent with the expectations.

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More details and results from the design verification phase can be found in [2].

CAVITY PRODUCTION

The main production of 3.9 GHz cavities for LCLS-II consists of 24 cavities that were ordered from RI. As for the the LCLS-II 1.3 GHz cavity production all mechanical fabrication steps, chemical surface processing, heat treatment and assembly for VTS are done at the vendor. The cavities arrive at Fermilab under vacuum and ready for acceptance testing.

Cavity Types

One distinctive feature of the LCLS-II 3.9 GHz cryomodule is that the fundamental power couplers of neighboring cavities are on opposite sides of the cryomodule with respect to the beam axis. This serves the purpose of minimizing the coupler kick. As a result the total number of cavities is equally split into type "A" and type "B". The bare cavities are all identical, becoming type "A" or "B" by a 180 degree rotation along the beam axis during the step of welding to the helium vessel, so that the power coupler flanges are on opposite sides while the chimneys on the helium vessel are all aligned allowing for one continuous 2-phase pipe. More details about the design of the LCLS-II 3.9 GHz cryomodules can be found in [3].

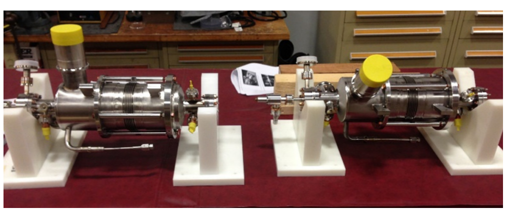

Figure 3: Two dressed cavities during incoming inspection at Fermilab.

Figure 3 shows two dressed cavities during the incoming inspection at Fermilab. The incoming inspection includes visual checks of the cavity and all assembled components, RF measurements at room temperature and a vacuum leak check of the helium space of the cavity tank. To date the cavity production is 75% complete and 18 cavities have been delivered to Fermilab.

Cavity Surface Processing Recipe

Based on the experience in the design verification phase the following recipe has been used for the main cavity production. After completion of the mechanical fabrication bulk BCP of 120 µm is done to remove the damage layer on the inside of the cavity. The total removal is split into two steps of 60 µm each with a change of the cavity orientation by 180 degrees in-between in order to minimize non-uniform removal. Figure 4 shows the average removal amount, determined by weight of the cavity before and after the BCP. Cavities are shown in chronological order of their treatment. For the first three cavities (3HRI08, 3HRI05 and 3HRI06) the overall removal amount is larger since the process parameters were still in development, including a trial not to split the overall removal into two equal steps but into a larger and a smaller amount. From 3HRI15 on removals of 60 µm per step were done.

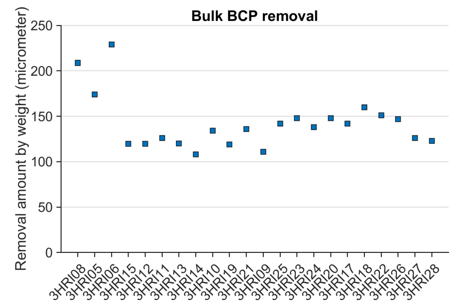

Figure 4: Bulk BCP removal by weight, cavities in chronological order of surface treatment.

The bulk BCP is followed by a three hour furnace treatment at 800 C for annealing and hydrogen degassing. Then the final BCP of 15 µm is performed. Final preparation for vertical acceptance testing includes installation of all flanges and RF antennas and high pressure water rinse (HPR) with ultra pure water in the cleanroom. Once the cavity is fully assembled, sealed and under vacuum it is baked at 120 C for 48 hours. Afterwards the cavity is ready for shipment to Fermilab.

VTS ACCEPTANCE TESTING

After completion of the incoming inspection at Fermilab the cavities proceed to the acceptance test in the vertical test stand (VTS). The acceptance tests for the LCLS-II 3.9 GHz production cavities are done in dewar VTS2. This dewar is equipped with one radiation sensor on the bottom and one on top, so that radiation created by field emission in the cavity can be detected in upwards and downwards direction. More details about the Fermilab vertical test facility can be found in [4].

Typically three cavities are cooled down to 2 K at a time and tested one after the other. Figure 5 shows three cavities assembled to the test insert. All RF cables are connected and the insert is ready to be lowered into the dewar for testing.

Cavity Performance Requirements

The nominal operating gradient for the 3.9 GHz cryomodules in LCLS-II is 13.4 MV/m. Furthermore there are potential operating modes with a maximum gradient of 14.9 MV/m. Adding a 20 % margin to this value to account for measurement uncertainties in VTS and potential degradation that may occur between vertical acceptance test, cryomodule assembly and ultimately operation in the tunnel, the acceptance limit for the gradient in VTS has been set at 18 MV/m. The quality factor Q_0 has to surpass $2 \cdot 10^9$ at 13.4 MV/m and $1.5 \cdot 10^9$ at 14.9 MV/m. Only field emission free cavities are qualified for string assembly. No sustained

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Figure 5: Three 3.9 GHz cavities assembled to the insert, ready for testing in VTS.

detectable radiation above background is allowed. The performance requirements are summarized in Table 1.

Table 1: Performance Specification for LCLS-II 3.9 GHz Cavities

Parameter	Value	Unit
nominal E_{acc} in linac	13.4	MV/m
max. E_{acc} in linac	14.9	MV/m
min. E_{acc} in VTS	18	MV/m
Q_0 (at 13.4 MV/m)	$\geq 2 \cdot 10^9$	
Q_0 (at 14.9 MV/m)	$\geq 1.5 \cdot 10^9$	
Field emission	none	

Test Results

At the time of this conference RF acceptance testing has been completed for 14 cavities. One more cavity had been cooled down, but was found to have a cold leak and could not be tested. In total of 9 cavities have been accepted for string assembly, the other 5 need re-processing. Among the accepted cavities 3HRI21 and 3HRI25 were close enough to the gradient specification with 17.5 MV/m and 17.9 MV/m to be deemed acceptable after their first test. 3HRI23 was accepted despite its lower quench gradient of 15.5 MV/m since it was the last cavity needed for a complete string and string assembly would have been delayed otherwise.

The Q_0 vs E curves for all accepted cavities are shown in Fig. 6 and Table 2 summarizes their test results. The average for the maximum E_{acc} is 19.7 MV/m. The median for the quality factor Q_0 is $2.8{\cdot}10^9$ at 13.4 MV/m and $2.7{\cdot}10^9$ at 14.9 MV/m.

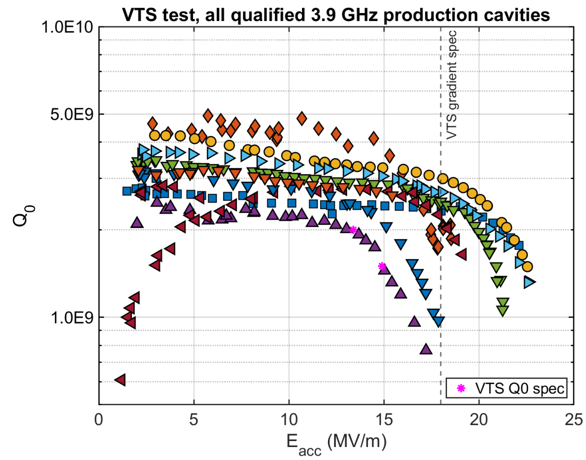

Figure 6: Q_0 vs E performance for all cavities that were accepted for string assembly.

In the beginning of the production cavities suffered from severe field emission. 3HRI05 is one example for this. The Q_0 vs E curves for two tests, before and after re-HPR at Fermilab, are shown in Fig. 7. In the first test radiation onset was around 12 MV/m and the maximum radiation detected at the bottom detector was 1.2 R/hr. After the re-HPR the cavity tested field emission free in the second test and ultimately quenched at 22.1 MV/m. Clean room procedures for final assembly and the HPR setup for 3.9 GHz cavities at RI were audited and improved.

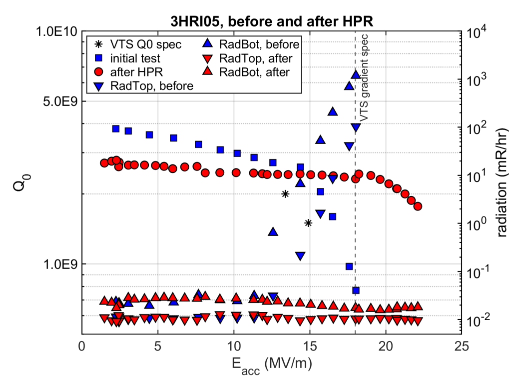

Figure 7: Q_0 vs E performance in VTS for cavity 3HRI11, before and after re-HPR.

SUMMARY

The production of 3.9 GHz cavities for LCLS-II is ongoing at RI and 18 of the 24 cavities have been delivered to Fermilab. Vertical acceptance testing has been completed for 14 cavities and 9 are accepted for string assembly. Their average for the maximum E_{acc} is 19.7 MV/m. The median for the quality factors Q_0 is $2.8{\cdot}10^9$ at 13.4 MV/m and $2.7{\cdot}10^9$ at 14.9 MV/m.
String assembly for the first cryomodule has started at Fermilab.

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Table 2: Cavities Accepted for String Assembly

Cavity name	Cavity type	E_{acc} in VTS	Limitation	Q_0 @ 13.4 MV/m	Q_0 @ 14.9 MV/m
3HRI05	A	22.1	quench	$2.4 \cdot 10^9$	$2.4 \cdot 10^9$
3HRI10	A	19.3	quench	$2.8 \cdot 10^9$	$2.7 \cdot 10^9$
3HRI11	A	22.6	power	$3.3 \cdot 10^9$	$3.3 \cdot 10^9$
3HRI13	A	22.6	power	$3.1 \cdot 10^9$	$3.1 \cdot 10^9$
3HRI14	A	21.3	quench	$2.9 \cdot 10^9$	$2.9 \cdot 10^9$
3HRI17	B	18.6	quench	$4.0 \cdot 10^9$	$4.0 \cdot 10^9$
3HRI21	B	17.5	quench	$2.0 \cdot 10^9$	$1.5 \cdot 10^9$
3HRI23	B	15.5	quench	$2.7 \cdot 10^9$	$2.6 \cdot 10^9$
3HRI25	B	17.9	quench	$2.5 \cdot 10^9$	$2.2 \cdot 10^9$

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