ISBN: 978-3-95450-233-2 ISSN: 2673-5504 doi:10.18429/JACoW-SRF2021-THPCAV008

RESULTS FROM THE PROTON POWER UPGRADE PROJECT CAVITY QUALITY ASSURANCE PLAN *

J. Mammosser†, S.-H. Kim, M. Howell, M. Champion, B. Robertson, S. Stewart,
R. Afanador, D.J. Vandygriff, M. Greenwood, SNS ORNL, TN, USA
C.E. Reece, E.F. Daly, K. M. Wilson, P. Dhakal, K. Macha, K. Davis, D. Forehand, JLab, VA, USA
A. Navitski, L. Zweibaeumer, K.-B. Bolz, A. Bitter, Res. Instrum. Co, Bergisch Gladbach, Germany

Abstract

The Proton Power Upgrade (PPU) Project at Oak Ridge National Lab's Spallation Neutron Source (SNS) is currently under construction. The project will double the beam power from 1.4 to 2.8 MW. This is accomplished by increasing the beam current and adding seven new Superconducting Radio Frequency (SRF) cryomodules. Each new cryomodule will contain four six-cell, beta 0.81, PPU style cavities. A quality assurance plan was developed and implemented for the procurement of 32 PPU cavities. As part of this plan, reference cavities were qualified and sent to Research Instruments Co. for the development and verification of process steps. Here we present the results from this plan to date.

INTRODUCTION

A cavity quality assurance plan was developed early in the PPU project to address the risk for not achieving the designed energy gain in the seven new PPU cryomodules. It was clear from the beginning that the new cavities would be part of a early procurement plan due to the long lead times for the material procurement and fabrication. The accelerating gradient of 16 MV/m was chosen due to its demonstrated performance with beam from some cavities already installed in the SNS linac [1]. From operational experience, it was clear that the High Beta cavity design would be modified to improve its performance, first the end-groups would be fabricated from High-RRR niobium instead of reactor grade material to improve the end group thermal performance. Additionally, the resonant HOM couplers at each end of the cavity design would be removed to reduce the fabrication complexity and increase the effectiveness of the chemistry and cleaning of cavity surfaces. It has been known for some time that the HOM couplers were not needed for SNS operation and have cause additional issues in the past [2]. The concern for operations however, was how to address the risk from early onset of field emission which impacts not only the individual cavity but the entire cryomodule operation due to collective effects [3]. A decision to use electropolishing (EP) as the primary method of surface chemistry was made to increase the effectiveness of the standard cavity cleaning methods, in this case, ultrasonic cavity degreasing, High Pressure Rinsing (HPR) and ethanol rinsing. The original HB cavities surface processing was Buffered Chemical

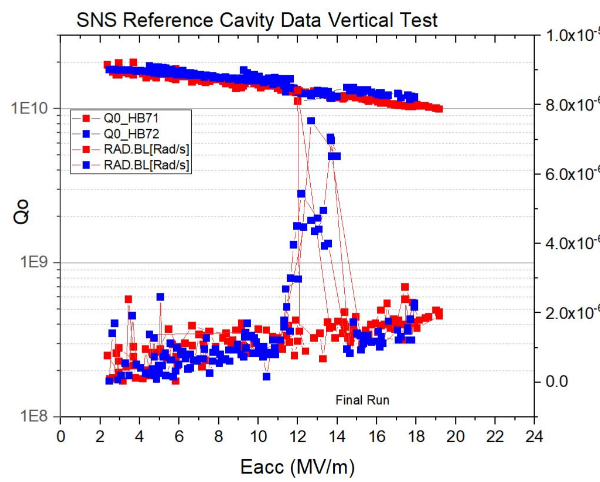

Figure 1: SNS VTA Data from the Reference Cavities.

Polish (BCP), the standard process at the time. Today, electropolishing (EP) of cavities is a well established method by the SRF community [4]. The problem with choosing EP for surface processing is it takes time for a vendor to adapt to the cavity design, resolve issues and gain experience before production. The PPU cavity has about a factor of 2 times the surface area of the 1.3 GHz 9-cell cavities and presents a challenge to maintain the quality of the electropolish electrolyte and cavity surface temperature. During the project planning stage,acceptance criteria were developed for the vendor delivered cavities and for vertical test for the project. The aim of the incoming acceptance was to verify that the cavity vendor followed their internal quality assurance plan as outlined in the contract and the vertical test acceptance was used as to set the pass/fail criteria for the vertical test results on the PPU cavities at JLab. The key criteria for the vertical test was, an administrative limit for the cavity gradient, set at 22 MV/m (not to exceed) to reduce the risk of an emitter degrading the performance at unreasonable gradients and secondly, a field emission limit set at <20 mRem/hr at 16 MV/m to achieve our gradient goal and determine the path for reprocessing of cavities.

THE CAVITY QA PLAN

A quality assurance plan was developed that would define the roles for the cavity vendor, Jefferson Lab who would be building the cryomodules and SNS staff. The focus of the plan was to give the responsibility of the niobium material

* Work supported by UT-Battelle, LLC, under contract DE-AC05-00OR22725
† mammosserjd@ornl.gov

ISBN: 978-3-95450-233-2 ISSN: 2673-5504 doi:10.18429/JACoW-SRF2021-THPCAV008

for the cavity fabrication to the vendor. This included the procurement of the material and all quality assurance steps. The material inspection would include sheet scanning and labeling at DESY, managed by the cavity vendor. JLab would develop a low temperature EP process and apply it to the reference cavities and vertical test each one to qualify them. These cavities would be used to qualify the vendors processes and performance prior to building the PPU cavities. These reference cavities would be sent to the vendor to develop their hardware and verify the process steps. Additionally, this methodology would allow for the testing of qualification hardware, shipping containers and training of the vendors staff processing and assembling these cavities. As a back up to this process the project planned on a reworking of 30 percent of the cavities delivered by applying a second HPR and 10 percent by an additional chemistry.

IMPLEMENTING THE QA PLAN

Research Instruments (RI) Company was awarded the contract to produce, process and assemble 32 PPU cavities. The three cavities, HB71, HB72 and HB73 were chosen at SNS to serve as the reference cavities to help RI develop and verify processes. These cavities were spares from the original production in 2005 and were in storage ever since that time. The cavities already had their bulk chemistry by buffered Chemical Process (BCP) at their time of fabrication. At Jefferson lab, C. E. Reece, led the effort to develop a low temperature EP procedure and EP hardware development [5], SNS developed the shipping boxes, test hardware and RF probes to qualify the cavities. Assembly kits were packaged for the hardware, flanges, valves and seals and shipped to RI. The reference cavities were processed, assembled and Vertical test qualified at JLab and sent to RI. Both JLab and SNS staff visited RI several times during the startup of the EP process to provide some guidance. RI modified their EP setup for the PPU cavity and together we developed the process steps that we felt would achieve the end goal. Reference cavity HB73 was chosen to develop the EP process because it was the weakest performer from JLab VTA qualification data, so it would only be used for this purpose. At RI, HB71 and HB72 were processed for the removal of 60um of niobium as measured by ultrasonic thickness measurements. After EP, the cavities were rinsed to resistivity and transferred, filled with Deionized (DI) water to the cleanroom. In the cleanroom, the cavities were drained and rinsed with ethanol alcohol and drained. Next cavities were High pressure rinsed (HPR) by multiple passes and dried overnight. Then hardware was assembled followed by a final HPR. The final flange was then assembled and a leak check of the cavity and shipping to SNS for vertical test under vacuum. At SNS cavities were received installed into the test stand isolated still under vacuum from RI and inserted into the Dewar. Cavities were then Cooled down to 2.1K and RF tested.

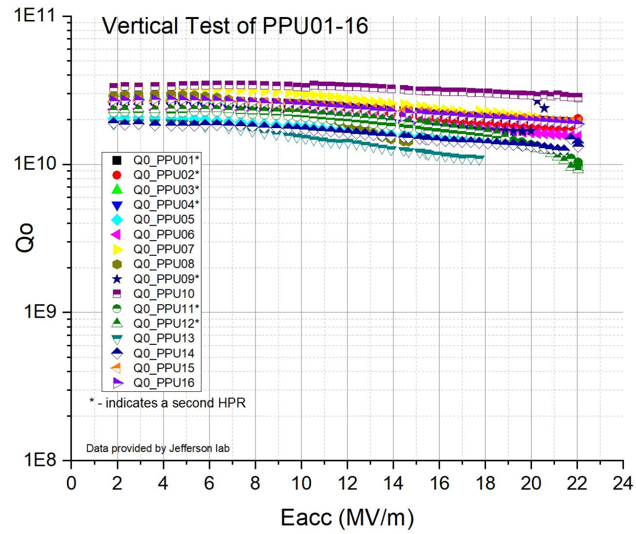

Figure 2: Production RF Data Tested at JLab.

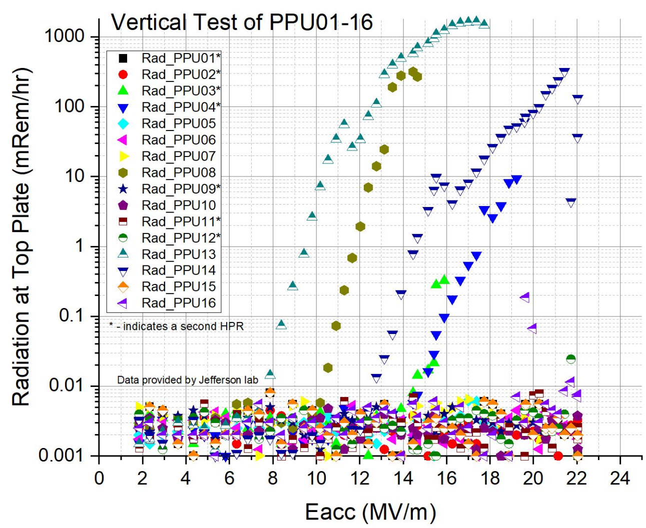

Figure 3: Radiation Data from Production Cavity Testing at JLab.

RESULTS AND DISCUSSION

In figure 1. the vertical test data shows that the reference cavities HB71 and HB72 easily met the PPU gradient (16 MV/m) and field emission onset goals for the project. Additionally the results show clear evidence of the multipacting band of 10-15 MV/m which was always present during the initial production run in 2000-2005 at JLab.

Figure 2. shows the production PPU cavities accelerating gradient data and figure 3., the radiation data from the first 16 cavities delivered from RI. The "*" indicates cavity data after a JLab second HPR due to early field emission. The first two cavities delivered showed early field emission and we decided to review the process and make some changes to the procedures to address future cavities. It was clear after a second HPR that it was clearly surface contamination

ISBN: 978-3-95450-233-2 ISSN: 2673-5504 doi:10.18429/JACoW-SRF2021-THPCAV008

only. After testing cavities PPU01-02, we we added low temperature baking at JLab (was part of the original plan), and discussed the possible risk of contamination from the burst disk which was at the top of the cavity during HPR and determined it should be removed during HPR. We suspected the burst disk was collecting rinse water and recontaminating the cavity during following steps. We decided to remove the burst disk and the first cavity to receive this change was PPU04 all remaining cavities would no longer have a burst disk at RI. We started to see the performance improve on PPU05, which had no field emission as delivered from RI. Another issue was identified by RI was the Fundamental Power Coupler (FPC) probe could also collect HPR rinse water due to its design and location (horizontal mounting). So we adopted a third change of the assembly steps to assemble the FPC probe after final HPR. This change was adopted at PPU10 cavity. Some of the cavities delivered to JLab started showing excellent performance but occasionally early field emission would return. The fourth change was to replace the ethanol rinsing after EP to detergent degreasing and DI water rinsing before HPR, following JLab's successful procedure, all second HPR rinsed cavities at JLab showed little or no field emission up to 22 MV/m . These were all the changes we could make given the time frame for production. Now 30 of the 32 cavities have arrived at JLab and we will have to see if there was any reduction in second HPR's on the remainder of the untested cavities, so far 9 of 16 cavities required additional rinses to remove field emission. What became clear was that the reference cavity effort was not adequate in length (number of cycles) to fully determine the assembly and cleaning issues and fully address early field emission. Both tested reference cavities had no field emission and give us a false impression. This effort however, was adequate to develop the EP process and demonstrate cavity material and fabrication quality which has been excellent so far. Only one sheet at DESY was rejected during their scanning and inspections which showed the quality of the niobium vendors process (Ningxia).

CONCLUSION

A quality assurance plan was developed at SNS to address the risk from not achieving the PPU design gradient and early onset of field emission goals for the 32 new PPU cavities . To date 30 of the 32 cavities have been delivered to JLab and 16 of 30 cavities delivered were vertical tested. The rejection rate for these cavities was 56 percent of due to early onset of field emission, these cavities required a second HPR at JLab to meet our performance goal. This was higher than the expected 30 percent that was planned for in the project. Several process changes were made during production to address early onset of field emission up to completing the processing and assembly of cavity PPU10 and we will have to see if the results from the remaining cavities have reduced the need for a second HPR. Additionally, there has not been any required reprocessing by chemistry which clearly shows that the EP process on these cavities at RI was fully successful and the quality of the niobium and fabrication was also excellent. The gradient and field emission results for all cavities so far (with some second HPR) easily meet expectations for installation into cryomodules at JLab. An additional note is that the typical multipacting as seen from the original production in 2000 and on the reference cavities but was much lighter (could be processed away) on the PPU cavities. Lessons learned from this QA effort are that a larger number of process test cycles is needed to identify contamination sources leading to early onset of field emission, especially on small quantity cavity fabrication runs due to the slow production test result feedback times.

REFERENCES

[1] J. Galambos *et al.*, "SNS Linac Upgrade Plans for the Second Target Station", in *Proc. LINAC'14,* Geneva, Switzerland, 2014, paper MOPP114, p.320. `http://www.jacow.org`

[2] M.Howell *et al.*, "History of Cryomodule Repairs at SNS", *in Proc. LINAC'14,* Geneva, Switzerland, 2014, paper THPP109, p. 1108. `http://www. jacow.org`

[3] S.-H. Kim, "SNS Superconducting Linac Operational Experi-ence and Upgrade Plan", in *Proc. LINAC'08,* Victoria, BC, Canada, 2008, paper MO103, pp. 11-15. `http://www.jacow.org`

[4] Lutz Lilje, "Achievementof 35 MV/m in the TESLA Superconducting Cavities Using Electropolishing as a Surface Treatment", in *Proc. EPAC'04,* Lucerne, Switzerland, July 2004, paper WEOACH03, pp. 129-131.

[5] C.E. Reece, "An Experimental Analysis of Effective EP Parameters for Low-Frequency Cylindrical NB Cavities" in *Proc. SRF2019,* Dresden, Germany, June 2019, paper TUP029, pp. 472-476. `http://www.jacow.org`