PROCESS DEVELOPMENTS FOR SUPERCONDUCTING RF LOW BETA RESONATORS FOR THE ReA3 LINAC AND FACILITY FOR RARE ISOTOPE BEAMS*

L. Popielarski#, C. Compton, L. Dubbs, K. Elliott, A. Facco(*), L. Harle, I. Malloch, R. Oweiss, J. Ozelis, J. Popielarski, K. Saito

Facility for Rare Isotope Beams (FRIB), Michigan State University (MSU), East Lansing, MI 48824, USA (*) INFN-Laboratori Nazionali di Legnaro, I-35020 Legnaro, Padova, Italy

Abstract

The Facility for Rare Isotope Beams (FRIB) will utilize over 330 superconducting radio frequency (SRF) low beta cavities for its heavy ion driver linac. The SRF department will process and test all cavities prior to string assembly in the cleanroom. The baseline processing procedures have been established. The methods are being optimized for production rate benchmarking. Additional processes are being developed to increase flexibility and reduce technical risks. This paper will describe developments and experimental results. Topics include high temperature heat treatment for hydrogen degassing, selective chemical etching for cavity frequency tuning, low-temperature bake out and process quality control.

INTRODUCTION

The ReAccelerator (ReA) and FRIB projects at MSU both utilize a 80.5 MHz β=0.085 quarter wave resonator (QWR) design [1]. For the ReA3 project eleven cavities have been fabricated and eight need to be certified, while for the FRIB project, 126 cavities need to be fabricated with 94 qualified for use in a cryomodule. The ReA project allows for the chance to gain valuable production experience. To meet the ReA3 cavity frequency specifications a differential etching technique with Buffered Chemical Polish (BCP) was developed for post fabrication tuning. The technical risks regarding cavity performance for ReA linac operation were reduced by establishing a low temperature bakeout method and a high temperature heat treatment - both of which improved cavity Q_0 values. The process steps for the ReA3 cavities are shown in Table 1. The process procedures will be optimized from lessons learned during the ReA cavity production.

Table 1: Summary of process steps for ReA3 cavities.

Step	Cavity Process Steps
1	Degrease, bulk BCP, dry, frequency measurements
2	Differential BCP, dry, frequency measurement
3	Degrease & hydrogen degas
4	Degrease, light BCP, High Pressure Rinse (HPR)
5	Clean assembly, evacuation, 120°C low temperature bake
6	*Test preparations and RF Dewar testing*
7	Clean removal from test stand and install to coldmass

*Work supported by the U.S. Department of Energy Office of Science under Cooperative Agreement DE-SC0000661.
#lpopiela@frib.msu.edu

In preparation for FRIB production, a comprehensive program is in place to improve process quality control and documentation. Innovative diagnostic tools allow for the quantification of process and assembly parameters for quality control [2]. The cavity fabrication, processing and vertical test parameters are recorded in a computer database (electronic traveler system), for cavity characterization and analysis. The database is accessible through a web-based interface, and will ease the analysis of 50 cavities before FRIB production.

HYDROGEN DEGASSING

The risk of Q-disease has been mitigated by implementing a hydrogen degassing step to the cavities after the bulk chemistry. The cavities are fired in a high temperature vacuum furnace for 10 hours at 600°C, while maintaining vacuum less than $5X10^{-6}$ Torr. The heat treatment removes much of the hydrogen from the bulk niobium material. Multiple QWRs and half wave resonators (HWRs) have been heat treated, using furnaces at Jefferson Lab and Fermilab, in an effort to quantify the benefits of the treatment both at 4.2 K and 2 K. The furnace design and heat treatment cycle have been optimized for production, considering both mechanical impacts to the cavity structure and overall schedule constraints. The current FRIB cavity furnace cycle is about 40 hours and includes pump down, temperature ramp up, steady state bake at 600 °C and cool down.

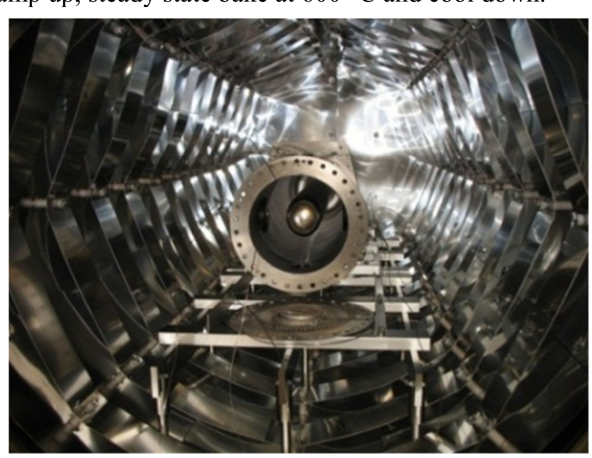

Figure 1: T-M Vacuum® high temperature vacuum furnace commissioned and being used to heat treat cavities at MSU.

The FRIB baseline calls for all SRF cavities to receive heat treatment. A high temperature vacuum furnace, shown in Figure 1, was procured from T-M Vacuum® in 2011 and installed and commissioned at MSU in 2012. The furnace fits two FRIB cavities per cycle.

DIFFERENTIAL REMOVAL AND TUNING

In an effort to compensate for frequency shifts during β=0.085 QWR fabrication, a program of frequency tuning by targeted material removal was undertaken. Removing material from the magnetic field region of the β=0.085 QWR will reduce the cavity frequency, while removing material from the electric field region (Fig. 2) will increase the cavity frequency. The process used to remove material from the RF surface must be reproducible, in order to accurately tune to the desired frequency goal after fabrication.

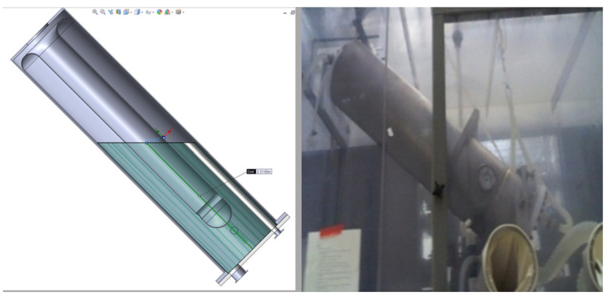

Figure 2: Differential etching setup for removal in high electric field region of the β=0.085 to increase frequency.

Etching with BCP was chosen to remove material because it was most likely to be uniform and repeatable. Simulations were performed to predict the expected amount of frequency shift per micron of niobium removed from the surface. The simulation predicted the cavity frequency would shift by 0.9 kHz/μm when etched in the high electric field region. A custom flange was fabricated to allow BCP circulation, while maintaining a specific fill height. After three trials an empirical tuning factor, kHz/μm, was calculated. The factor is recalculated after each custom etch for increased accuracy (Fig. 3).

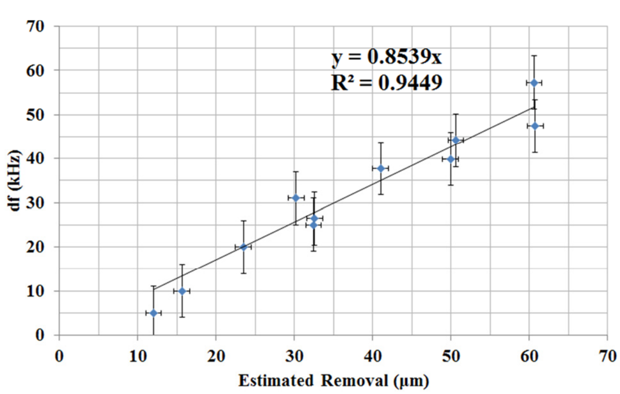

Figure 3: Measured frequency shift (kHz) versus the estimated material removal (microns).

Eight of the β=0.085 QWRs for ReA3 required a frequency increase and have been successfully tuned with this method. The current tuning factor is 0.8539 kHz/μm for removal in the electric field region. The average error is within 6 kHz of the desired frequency before the degassing procedure, which can cause unpredictable shifts up to 7 kHz. After degassing, the final frequency is set, to within 5 kHz (well within the operational fine tuning range) by attaching a custom length "puck" to the demountable niobium tuning plate with an e-beam weld which does not disturb the prepared cavity.

LOW TEMPERATURE BAKEOUT

Performing a 48-hour long 120ºC bakeout procedure, prior to cavity testing, has proven to be beneficial in improving the performance of the β=0.085 QWR at 4K (Fig. 4).

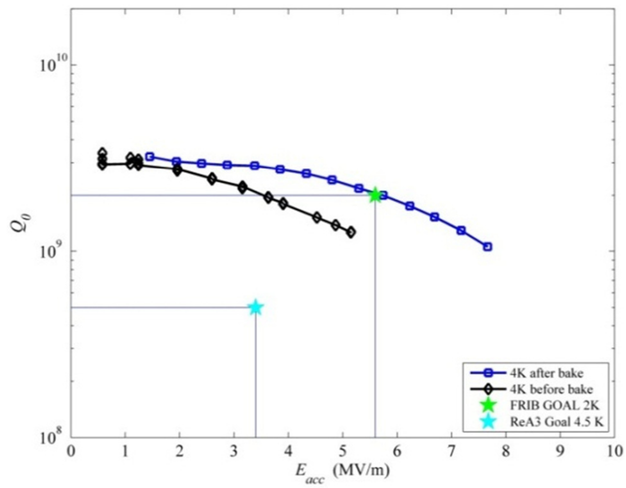

Figure 4: Q_0 versus E_a showing improvement in cavity performance after low temperature bakeout application.

After clean cavity assembly to the test stand and evacuation, the stand is removed from the cleanroom. The cavity is then wrapped in fiberglass heat tape and a gas heater is attached to the helium return flange on the vessel. Twelve thermocouples, five of which are connected to controllers, monitor the internal and external cavity temperatures to ensure that the temperature does not exceed 120ºC. Especially important to monitor is the bottom flange of the cavity, which cannot exceed 156ºC, the temperature at which the indium wire used in the vacuum seal will begin to melt. The cavity is wrapped in foil for insulation, and the temperature is slowly ramped up to 120ºC and then monitored for 48 hours. Residual gas analyzer scans are taken during the baking cycle to monitor the pressure in the cavity and to allow for the presence of any potential contaminants to be determined. The gradual stabilization of the pressure over time is indicative of the removal of water and other low-boiling contaminants in the vacuum space. The bakeout process has proven itself to be a low cost method by which to quickly improve the low field quality factor and somewhat recover the higher field Q-slope in an underperforming cavity. The bake application is being

ISBN 978-3-95450-122-9

considered as an optional process step for FRIB cavities exhibiting slightly low Q_0 during vertical test. A test stand bake oven is under development which will minimize the process time.

PROCESS QUALITY CONTROL & DOCUMENTATION

Overall cavity performance and certification rate in both the vertical Dewar and final cryomodule testing is improved by continuous documentation and aggressive quality control. Diagnostic tools are used to monitor and quantify the process data [2] and to discover problems quickly so they can be corrected. Documented process parameters include: water quality identifiers, niobium concentration in BCP, High Pressure Rinse (HPR) liquid particle counts, and surface particle counts of cavity RF surfaces and associated vacuum hardware. An inclusive process and maintenance management system, the electronic traveler (e-traveler), is used to record fabrication, process and test data for various devices (Fig. 5) and control process steps. The data can be searched, extracted, and analysed for correlations and post failure analyses (Fig. 6). Scheduled reports can be produced for various data fields or parameters and specified devices, being helpful to track trends and provide feedback.

Traveler Reporting

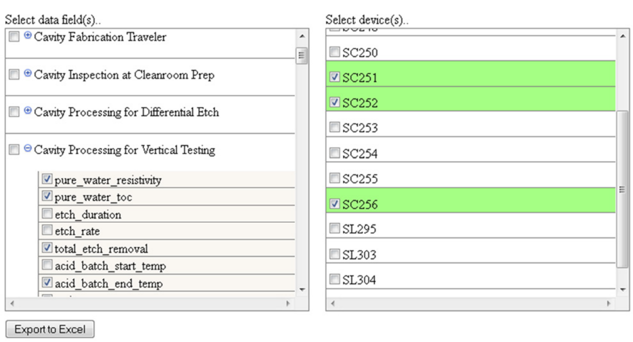

Figure 5: Screenshot of the reporting function which quickly exports any selected data field and device to an Excel® file.

Device SN	nb_concentration_solution	particle_count_end	spc_tuning_plate	initial_field_emission	low_field_q0	q0_120	xray_count_120
SC251	2.1	936	0	6.12	2.60E+09	1.50E+09	0.5
SC252	13	1775	0	5.32	2.80E+09	1.30E+09	0.8
SC256	13.3	1146	1.33	5.48	5.00E+09	3.25E+09	0.52

Figure 6: Sample of an e-traveler report for selected data fields and devices (in this case ReA3 cavities).

The initial release of the e-traveler system allows for its use during the ReA3 coldmass production. This has been beneficial to streamline the system and move toward production operations. The e-traveler reporting function reduces the time to identify the correlations between cavity process parameters and the cavity RF test results. These trends guide the optimization of the process procedures to ensure that they are effective, yet efficient.

Device routers, assembly work instruction and standard operating procedures are written and controlled as FRIB documents by the FRIB Manufacturing Engineering group and will eventually be embedded as links in each e-traveler form.

CONCLUSION

The recently developed procedures presented here have been applied to ReA3 cavities. Three of the cavities have been successfully RF tested, certified and installed to the coldmass string. The processing procedures and quality control techniques have proven to be effective at producing the required performance specifications for ReA3 cavities during vertical Dewar testing (Fig. 7).

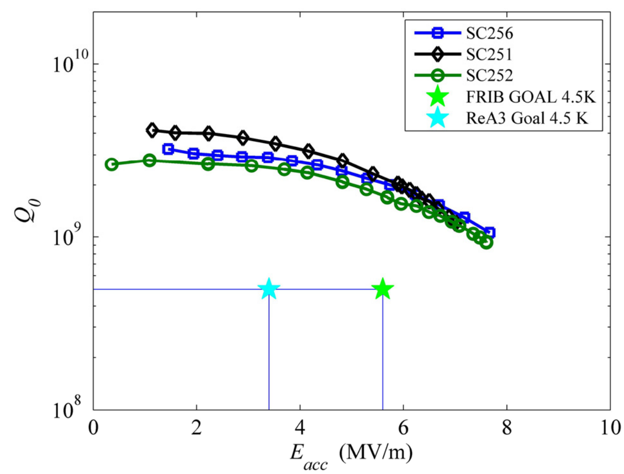

Figure 7: Q_0 vs. E_{acc} at 4K for ReA3 β=0.085 QWRs

ACKNOWLEDGEMENTS

The authors would like to thank the members of the NSCL & FRIB staff whose effort has made a significant contribution to this progress. In particular, Ed Bernard, Steve Bricker, Byambatsogt Enkhbat, Robert Gaul, Lee Harle, Matt Hodek, Doug Miller, Dave Norton, Sheng Peng, Nicholas Putman, Greg Velianoff, Michael Williams, Daniel Victory, Vasu Vuppala, Andy Wisniowiecki and Ken Witgen. We would like to acknowledge the impact of our weekly SRF teleconference on the overall success of our program with special thanks to Bob Laxdal and Peter Kneisel for their continued contributions. We thank our collaborators at JLab, Tony Reilly, and at Fermilab, Allan Rowe, for allowing us the use of their furnace while the MSU furnace was procured, installed and commissioned.

REFERENCES

[1] A. Facco et al., "Superconducting Resonators Development for the FRIB and ReA LINACS at MSU: Recent Achievements and Future Goals", Proc. in IPAC2012, New Orleans, USA, p.61

[2] R. Oweiss et al., "Quality Control of Cleanroom Processing Procedures of SRF Cavities for Mass Production", These proceedings, MOPB070.