CHALLENGES ENCOUNTERED DURING THE PROCESSING OF THE BNL ERL 5 CELL ACCELERATING CAVITY*

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Abstract

One of the key components for the Energy Recovery Linac being built by the Electron cooling group in the Collider Accelerator Department is the 5 cell accelerating cavity which is designed to accelerate 2 MeV electrons from the gun up to 15-20 MeV, allow them to make one pass through the ring and then decelerate them back down to 2 MeV prior to sending them to the dump. This cavity was designed by BNL and fabricated by AES in Medford, NY. Following fabrication it was sent to Thomas Jefferson Lab in VA for chemical processing, testing and assembly into a string assembly suitable for shipment back to BNL for integration into the ERL. The steps involved in this processing sequence will be reviewed and the deviations from processing of similar SRF cavities will be discussed. The lessons learned from this process are documented to help future projects where the scope is different from that normally encountered.

Introduction

The BNL 5 cell accelerating cavity has been designed[1] for use in our high average current Energy recovery linac, which is being built as a proof of principle system for the future RHIC II upgrade.[2] The cavity is designed to operate at 20 MV/m and a Qo of $1e^{10}$. This paper will cover the progress and technical challenges encountered during the processing of the cavity at Jefferson Lab. The cavity was built by Advanced Energy Systems of Medford NY and was then shipped to JLAB for chemical treatment and RF testing in the Vertical Test Dewar, VTA. The initial plan was to carry out the cleaning, verify the cavity performed as expected, and then assemble the cavity into a He vessel and a hermetic string assembly for shipment back to BNL to complete the string assembly build-up and begin cold emission testing. The initial cavity testing did not go as planned, and a number of course adjustments and corrections were required in order to obtain the desired performance level. These items will be covered here with the idea of providing a brief overview of what is really involved in obtaining a high performance SRF cavity, and some of the technical issues that can be easily solved using understood, but not always well documented techniques.

Cavity Processing

The initial cavity processing plan was to be as follows:

1. CMM measurements of the cavity dimensions. (see figure 1)
2. RF beadpull to determine frequencies of cavities modes as well as field flatness in the 5 cells, followed by calibration of the input and field probes.
3. 200 um buffer chemical polishing (1:1:2 conc. hydrofluoric, conc. nitric, phosphoric acid)(figure 2)
4. 600 ºC bake for 10 hours to remove hydrogen following heavy chemistry
5. Degreasing of the cavity for 1 hour
6. Light BCP, typically 20 um
7. High pressure water rinse (HPR) 6 hours
8. Initial assembly of one half of the cavity flanges
9. Second HPR for 6 hours
10. Final assembly and leak check of cavity
11. Testing in VTA to determine RF performance
12. Repeat steps 5-10 until desired performance is achieved.
13. If the desired performance is not reached via these steps implement new plan.

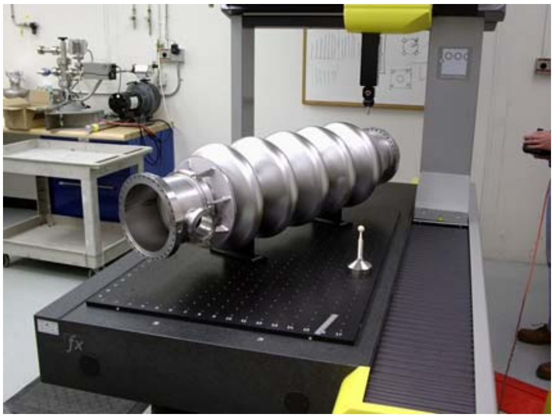

Figure 1. Dimensional Analysis on the CMM machine, the cavity needed to be placed on an angle due to its size.

This plan was based on past experience processing SRF cavities at JLAB, and was based on no new challenges arising. As with any unique cavity test there were unforeseen hurdles to be dealt with. The first was encountered when the initial RF measurements did not yield the desired result. The power that was being applied to the cavity was not yielding the expected results,

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limiting the gradient that could be reached to a few MV/m. As the phenomena was highly reproducible and did not produce any radiation it was determined there was heating taking place in the cavity which was initially attributed to the AlMg gaskets used on the large diameter flanges. Microwave studio analysis did not show this to be plausible and further investigation led us to find the problem was coming from one of the NbTi flanges that was used to blank off the cavity beampipe. One of the 24 cm diameter beampipe flanges, was fitted with two Titanium half-nipples for vacuum pumping and RF power input. It was discovered that due to the dimensions of the beampipe, there was still appreciable magnetic field at the flange, and the titanium half-nipples were found to be heating up. This was further confirmed using microwave studio, and new all Nb flanges were built, one of which used an existing all Nb flange with input ports which was graciously provided by Peter Kneisel.

Figure 2. The closed chemistry, BCP, cabinet is used to acid etch the inner surface of the cavity at a controlled etch rate and temperature.

With the new flanges installed the cavity was again tested and yielded better results, reaching 12 MV/m before running out of RF power. The cavity was still not at its design specification, and there was significant field emission during testing. In order to help improve the cavity performance, helium processing was carried out. This is technique which in the past has provided mixed results, not always improving cavity performance, but due to the fact we had not reached our design specification it was decided to move forward with this technique. He processing is carried out by introducing a small amount of He gas into the cold cavity and then applying RF power. The He gas freezes out on the cavity walls and as power is applied some gas is ionized by electron bombardment as a result of field emission. The He ion then returns to the site of the electron origination, impacts the field emission site and effectively smooth the cavity surface. For this cavity numerous He processing cycles were undertaken over the course of several days with very good results as shown in figure 3.

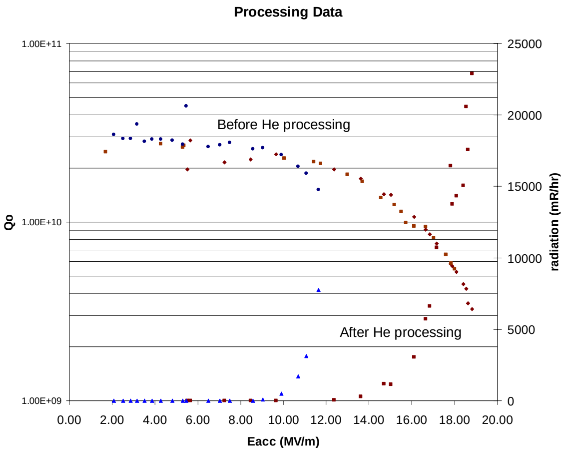

Figure 3. The RF performance before and after He processing is shown above. The data in blue was collected before He processing and the data in red after He processing. The significant improvement in field is obvious, but the radiation levels are still very high.

As the cavity was still not at the designed specification further performance improvement were needed. In order to improve the cavity performance the cavity was baked at 110°C for 48 hours. The low temperature bake is designed to help improve the low field Q, usually by a factor of 2, slightly increase or flatten the medium field Q slope, and strongly improve the high field Q slope, the third statement is more applicable to electropolished cavities. The low temperature bake technique is understood to work by lowering the R_{BCS} by 50% while slightly increasing the R_{res}, and has been implemented on a number of different cavities[3,4] The bake-out box used for the low temperature bake is shown in figure 4.

Figure 4. The low temperature bake-out box used for the 5 cell cavity 110 degree bake.

In its original configuration the heating element was too close to the bottom cavity flange, which was sealed using indium. As such the bottom seal was compromised during the first bake run, causing a large vacuum leak, and the introduction of indium into the cavity. This caused a considerable removal processes to be undertaken, but it turned out to actually be quite straight forward.

Concentrated Nitric acid was used in the closed chemistry cabinet, shown in figure 2, and was circulated through the cavity for 1 hour. Conc. Nitric acid dissolves indium, but has no affect on the Nb surface. This allowed for the removal of all of the indium contamination and we proceeded with a second low temperature bake of the cavity. For this bake a baffle was introduced into the bake-out box and 7 thermocouples were placed on the cavity to measure the temperature and ensure a uniform heating. The thermocouple readings for the bake-out are shown in figure 5.

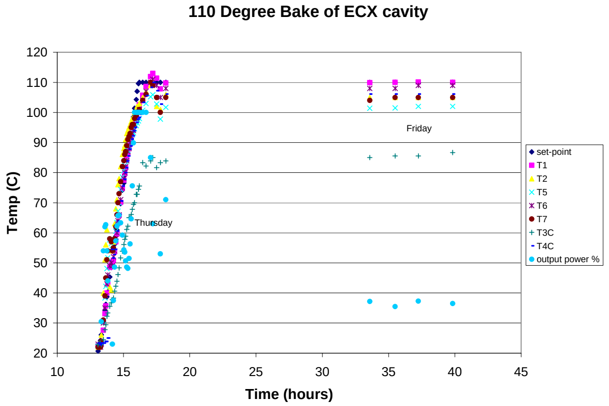

Figure 5. A plot of the thermocouple readout during the low temperature cavity bake. All thermocouples placed inside the box were within 5 degrees of one another.

Following this low temperature bake the cavity was again tested and significant performance improvement was seen. At this point the cavity was very near its specification of 20 MV/m at a Q of 1e^{10} so it was decided that the He vessel would be attached and the cavity tested again. As we wanted to save time by not having to disassemble and clean the cavity before and after welding the helium vessel, it was decided we would leave the cavity under vacuum and attach the He vessel. This worked quite well, and subsequent testing after He vessel attachment yielded the best results yet as shown in figure 6.

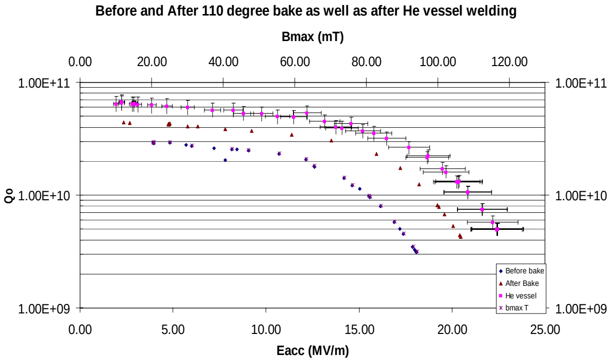

Figure 6. The plot of Qo vs Eacc for three tests on the 5 cell cavity. The blue circles are before the 110 degree bake, the red triangles are after the 110 degree bake and the red squares are with the He vessel attached.

Now that the cavity has met its specification it will be assembled into a hermetic string and shipped back to BNL for commissioning and subsequent use in the ERL.

Conclusions

After a great deal of effort the 5 cell cavity has met its design specification of 20 MV/m at 1e10 and performs very well with no signs of field emission. A collection of cavity processing techniques have been implemented with good results, and the future use of this cavity and the ERL is anxiously awaited.

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