

SUPERCONDUCTING QUARTER-WAVE RESONATORS FOR THE ATLAS ENERGY UPGRADE

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Abstract

A set of six new 109 MHz $\beta=0.15$ superconducting (SC) quarter-wave resonators (QWR) has been built at ANL as part of an upgrade to the ATLAS superconducting heavy-ion linac at Argonne National Laboratory. The final cavity string assembly will use most of the techniques needed for the next generation of large high-performance ion linacs such as the U.S. Department of Energy's FRIB project. Single-cavity cold tests at $T=4.5$ K have been performed for 5 of 6 cavities. Tests were performed with a moveable coupler, rf pickup, and VCX fast tuner as required for the full 5-meter cryomodule assembly. The average maximum accelerating gradient of 6 cavities (5 new + 1 prototype), is $E_{ACC}=10.6$ MV/m ($B_{PEAK}=62$ mT). Assembly of the clean cavity string has just begun using techniques which are fairly well developed based on many single cavity clean assemblies and one assembly of the entire string performed under non-clean conditions. Details on single cavity performance including high-field cw operation, microphonics and fast tuning are presented.

INTRODUCTION

Advances in the last decade in SC cavity performance achieved using clean processing and assembly techniques at KEK, DESY and JLab for elliptical cavities have been adapted for TEM-cavities at Argonne and elsewhere. TEM cavity field performance with $B_{PEAK}\sim 100$ mT or higher in single cavity tests is often achieved and is comparable to surface magnetic fields found in today's state-of-the-art elliptical cell cavity linacs. The ANL 7-cavity cryomodule, shown partially assembled in Figure 1, will be the first section of TEM-cavity linac incorporating all of the essential features found in clean elliptical cavity string assemblies. Features include electropolished high RRR bulk niobium cavities cleaned using high-pressure water rinsing and assembled in a clean room into a single sealed cavity string assembly. Isolation of the cavity rf volume from the cryomodule insulating volume greatly reduces the number of components assembled in the clean room and should help maintain cavity cleanliness.

CAVITIES AND CRYOMODULE

Specifications

Primary specifications for the upgrade cryomodule are shown in Figure 2. Initially the module was to hold seven $\beta=0.15$ quarter-wave resonators and one $\beta=0.24$ half-wave resonator, however, the half-wave requires additional work and will not be included in the initial assembly. This cw SC cryomodule is designed for a "real

estate gradient" 3 MV/m which is now higher than achieved in pulsed normal conducting linacs for this velocity range.

Fabrication

The quarter-wave prototype and six production cavities were fabricated from RRR ~ 250 3-mm thick niobium sheet purchased from Wah Chang. Parts were die hydroformed at Advanced Energy Systems and then electropolished at ANL to remove at least 100 μm of niobium from the rf surface. To perform the initial rough tuning of the cavity, the niobium subassemblies were clamped together and the frequency was measured. The cavity housing and center conductor were then trimmed along the length using a wire EDM. Ref. [1] contains many additional details on fabrication and tuning. The niobium subassemblies were then electron beam welded together at Sciaky Inc. and the complete niobium cavity was enclosed in an integral stainless steel helium vessel. Details of the critical niobium-to-stainless steel braze transition have been presented [2]. In order to remove residues from electron beam welding, a final five minute

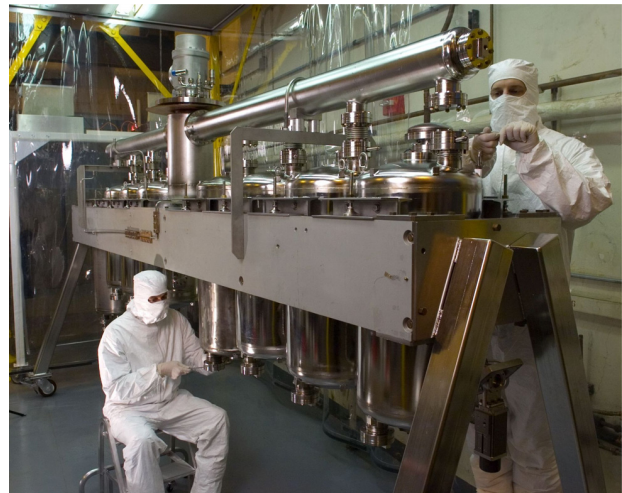


Figure 1: Partial assembly of the quarter-wave cavity string in the clean room.

physical length	4.62 meters
# cavities	7
L_{eff}/cavity	0.25 cm
required gradient	8.4 MV/m
total voltage	14.7 MV
static load (4.5 K)	15 Watts
rf load/cavity (4.5 K)	12 Watts
total heat load (4.5 K)	100 Watts

Figure 2: Primary specifications for the ATLAS upgrade cryomodule.

chemical etch was performed using standard 1:1:2 buffered chemical polish solution at T=15-17 °C.

High-Pressure Rinsing and Clean Assembly

For single-cavity tests reported here, high-pressure water rinsing (HPR) was performed for each cavity. The rinsing system uses 0.04 μm filtered deionized water flowing at 16 liters/minute through a nozzle with eight jets at a pressure of 120 bar. HPR was done in a class 100 clean area using an automated spray wand and rinsing through each of the three cavity coupling ports for 45 minutes. By design, the coupling ports are located so that the high-pressure water spray has line-of-sight to the entire cavity rf surface.

Major subsystems including the rf power coupler, VCX fast tuner, rf pickup loop, and vacuum pumping lines were also high pressure rinsed in a class 100 clean area using a manual spray wand. The sealed cavity and subsystems were moved to a larger class-100 clean area for assembly. A model of a cavity, coupler and VCX tuner is shown on the left hand side of Figure 3.

Clean Cavity String Assembly

Due to the cost and difficulty associated with assembly of hardware in a class-100 environment, a primary design goal was to minimize the number and complexity of the parts requiring clean assembly. A Pro/Engineer solid model of the clean assembly is shown on the right side of Figure 3. Major components include a pumping manifold to evacuate the cavity rf volume, the seven dressed cavities with coupler, VCX fast tuner and rf pickup. The string is supported on an anodized aluminum frame and a pair of gate valves (one is visible in Fig. 4) seals the string before it is removed from the clean room.

In order to avoid unforeseen difficulties during the first clean string assembly, a mock assembly was performed using all components with no high-pressure rinsing. The string has now been disassembled and is being reassembled after high-pressure rinsing. Manpower required for assembly was three man-months. An additional three man-months will be required for ultrasonic cleaning and high-pressure rinsing of all of the

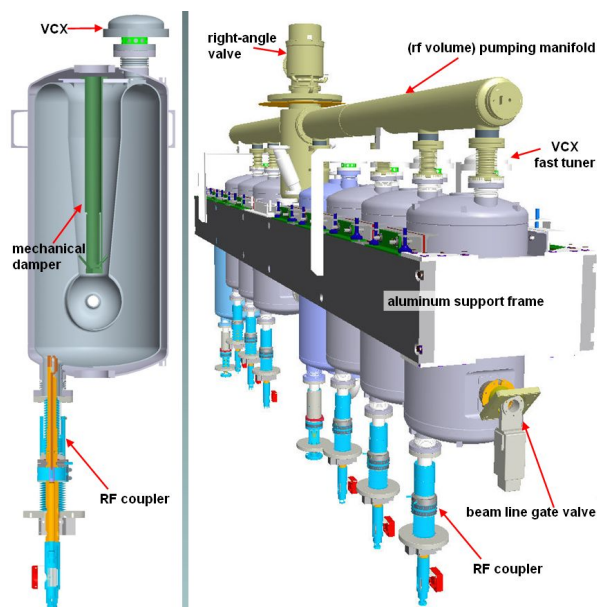


Figure 3: A 109 MHz quarter-wave resonator (left panel) as dressed in the clean room with rf power coupler and a VCX fast tuner. The right panel shows the sealed clean room cavity string assembly.

components based on experience from the single cavity testing work.

COLD TEST RESULTS

Prototype QWR Cavity

A prototype QWR cavity has been tested in the single-cavity test cryostat nearly a dozen times over a period of 4 years. In many tests the cavity operated with little or no field emission. An example is shown in Figure 5. The cavity has not been baked at high temperature in order to degas hydrogen, so it is necessary to cool rapidly (~1 hour) from 150 K to 80K in order to avoid hydride precipitation. The maximum gradient is limited to approximately $E_{ACC}=12$ MV/m by thermal-magnetic quench and is repeatable after cycling to room temperature.

The operating temperature for the upgrade cavities is set by the ATLAS refrigerator supply pressure of 20 PSIA, corresponding to T=4.5 K. Cavity performance at T=4.5 K is given by the red curve in Figure 4. Data in Figure 4 indicate there would be little benefit to 2 K operation in terms of wall plug power, however, hydrogen degassing, not performed here, would be likely to increase 2 K performance.

Production Quarter-Wave Cavities

Five of the six production cavities have been cooled to 4.5 K in the ANL single-cavity test cryostat in order to measure cavity field performance and operation of the rf power coupler and VCX fast tuner. The last cavity has been cold tested in the upgrade cryomodule but with no high-pressure rinsing or clean assembly. The goal was to understand the operation of the helium and nitrogen cryogenics systems. Field testing of this cavity will be

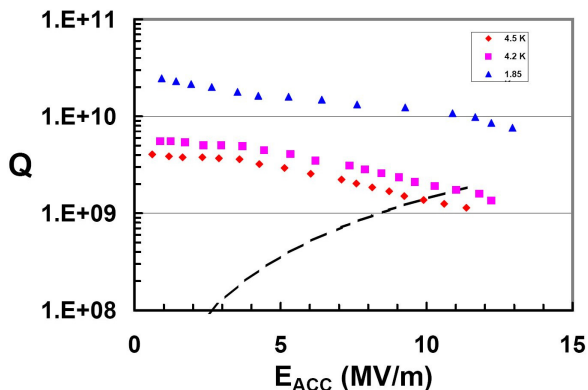


Figure 4: Q-curve measurements for the 109 MHz $\beta=0.15$ prototype quarter-wave cavity at T = 1.9, 4.2 and 4.5 Kelvin. The dashed line represents 8 Watts of rf power dissipated into the liquid helium cooling bath.

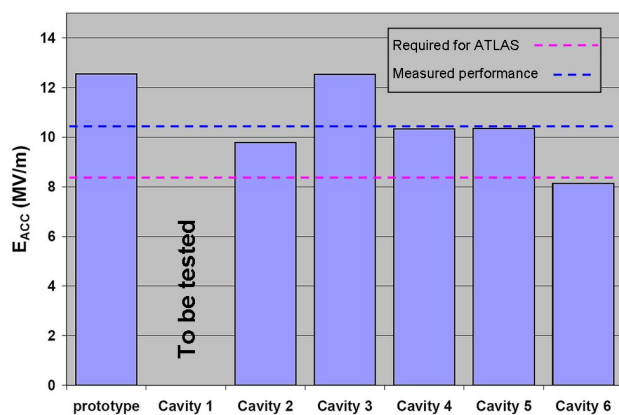


Figure 5: Measured maximum accelerating gradients at $T=4.5$ K in the vertical test cryostat for the prototype and five of the six production cavities.

performed with the cavity assembled onto the full clean cavity string.

Measured maximum accelerating gradients for 6 of the 7 cavities are shown in Figure 5 with average value of $E_{ACC}=10.6$ MV/m. Cavity #2, #3, #4 and #6 tests included a VCX fast tuner.

After several cold tests, a nominal VCX tuning window of 40 Hz with $Q_{EXT}\sim 2\times 10^8$ was chosen for the upgrade. With these parameters the VCX was found to be thermally stable up to $E_{ACC}=8$ MV/m. In order to make use of the highest gradients achieved here, ~ 12 MV/m, future ion linacs may replace the VCX with a piezoelectric or magnetostrictive fast mechanical tuner.

The rf power coupler for the ATLAS upgrade is similar to the coupler reported on in Ref. [3], the primary difference being $\sim 3X$ larger inductive loop area. The need for stronger coupling is due to the relatively low magnetic field at the quarter-wave cavity coupling port.

Coupler heating was experimentally measured using a silicon diode thermometer placed on the cavity coupling port flange and was not problematic under normal operating conditions. With the coupler positioned for $\beta\sim 1$ (critically coupled) with $E_{ACC}=10$ MV/m and $P_{IN}=70$ Watts (10% into cavity walls, 90% in VCX LN₂), heating at the coupling port was ~ 1 degree Kelvin. Operation was stable over a period of several hours.

Microphonics

Microphonics measurements have been made during many single cavity tests and one time in the upgrade cryomodule. In the test cryostat, rms frequency deviations of 2-4 Hz were observed mostly due to 10 Hz vibrations resulting from thermal-acoustic oscillations in the helium bath. Cryomodule test data, shown in Figures 6 and 7, had very low microphonics with $\sigma_{rms}\sim 1$ Hz. Frequency deviations due to the peak at 80 Hz in Fig. 7 are well within the planned 40 Hz VCX tuning window.

CONCLUSION

Assembly of a 5-meter 7 quarter-wave cavity clean string has begun. The new cryomodule is the first TEM

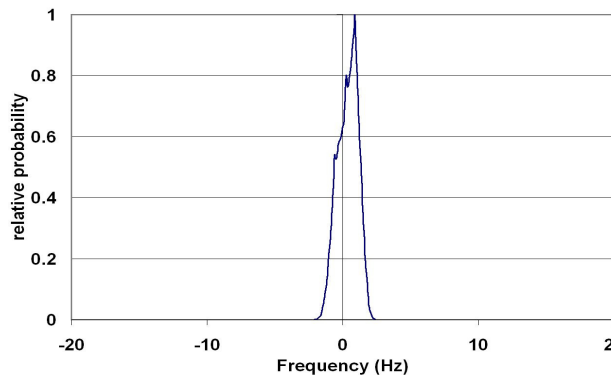


Figure 6: Probability density for eigenfrequency shifts for one of the six production cavities as measured in the upgrade cryomodule.

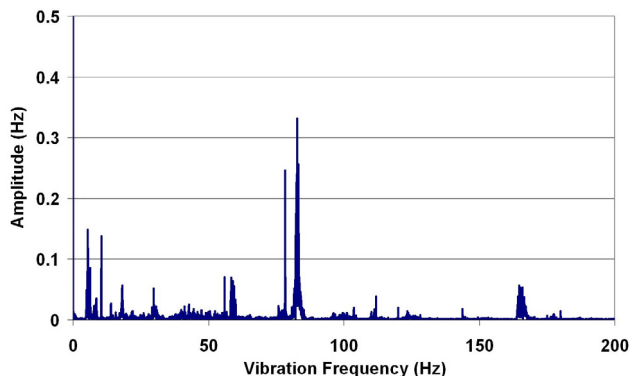


Figure 7: Power spectrum distribution of microphonics for one of the six production cavities as measured in the upgrade cryomodule.

cavity linac to use all of the essential clean techniques used in elliptical cavity linacs. Performance in single cavity tests shows $E_{ACC}=10.6$ MV/m, exceeding by 20% the requirement for ATLAS. Final assembly of the clean string is planned for late 2008 with installation of the module into the ATLAS tunnel in early 2009.

ACKNOWLEDGEMENTS

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