

# MECHANICAL DESIGN OF THE 704 MHz 5-CELL SRF CAVITY COLD MASS FOR CeC PoP EXPERIMENT\*

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## Abstract

A 5-cell SRF cavity operating at 704 MHz will be used for the Coherent Electron Cooling Proof of Principle (CeC PoP) system under development for the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory. The CeC PoP experiment will demonstrate the new technique of cooling proton and ion beams that may increase the beam luminosity in certain cases, by as much as tenfold. The 704 MHz cavity will accelerate 2 MeV electrons from a 112 MHz SRF gun up to 22 MeV. Novel mechanical designs, including a superfluid heat exchanger, helium vessel, vacuum vessel and tuner mechanism are presented. Structural and thermal analysis, using ANSYS [1] were performed to confirm the mechanical tuning system structural stability. This paper provides an overview of the design, the project status and schedule of the 704 MHz 5-cell SRF for CeC PoP experiment.

## INTRODUCTION

The BNL3 5-cell 704 MHz SRF linac that is being designed and fabricated in collaboration between BNL and Niowave, will be used as the main 20 MeV accelerator for CeC PoP experiment under construction at IP2 of RHIC at BNL [2]. The 704 MHz SRF linac will be included in Phase II of this experiment which is expected to be completed before the beginning of 2015 RHIC Run. This paper provides an updated overview of the 704 MHz SRF cryomodule layout and components, the structural analysis and design of the tuner, the test results from the vertical test facility (VTF) and the fabrication progress of several components including the helium vessel is presented in this paper.

## 704 MHz DESIGN

### Design Features

The 704 MHz 5-cell cavity cryostat consists of an internal phase separator, control valves, 5-cell cavity [3], two magnetic shields and a helium gas cooled thermal shield, a superfluid heat exchanger and an electrical heater. The helium supply and return lines are bayonet connections for quick assembly [4]. The layout of the 704

MHz SRF 5-cell SRF linac is shown in Fig. 1.

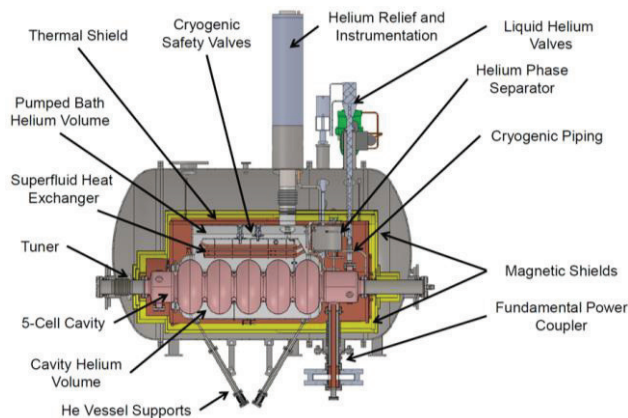


Figure 1: Layout of the 704 MHz SRF cryomodule.

The outside diameter of the ASME stamped cryomodule was increased from 36 to 48 inches in order to provide clearance for the magnetic shields and for welding purposes during assembly.

### Cryogenic Safety Valve

To reduce heat leaks to the cavity helium volume from ambient temperature piping for the pressure relief devices, cold safety valves are designed into the helium vessel to relieve the cavity helium into the pumped bath volume. The reliefs are sized for loss of insulation vacuum. A small helium leak from cavity bath to pumped bath won't affect the cryogenic system operation [4]. As shown in Fig. 2, a prototype was built at Niowave and successfully tested at BNL.



Figure 2: Prototype of the cryogenic safety valve.

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## Mechanical Tuning System

The BNL3 cavity mechanical frequency tuning system was designed based on a tuner that has been successfully implemented by Dresden in Germany for their superconducting RF Photo-Injector [5]. The main reasons to use this design is for the mechanical advantage of the lever arms, the large tuning range, high resolution, hysteresis-free and linear operation. The design was modified to remove any sliding components, to integrate a piezoelectric actuator for fast tuning and to accommodate larger cavity dimensions. A detailed layout of the tuner mechanism is shown in Fig. 3 below.

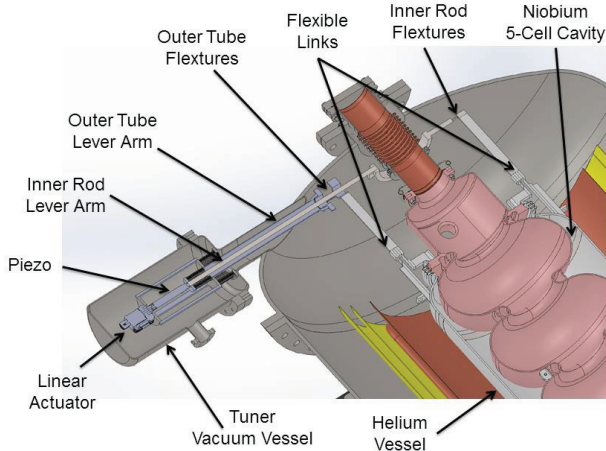


Figure 3: Detail design of mechanical tuning system.

In order to eliminate the effect of the atmospheric pressure on the tuner bellows, that could affect the sensitivity of the tuner by adding noise to the system, the high resolution linear actuator with stepper motor and the piezo actuator are located outside the cryomodule in a separate vacuum vessel. The tuner mechanism consists of an inner rod lever arm and an outer tube lever arm that move in opposite direction, using the linear actuator or the piezo. As a result of the motion described above, a bending moment is applied on each flexible link shown in Fig. 4 below. Via the tuner flexible links, the lateral motion of the rod and the tube is transformed into an axial motion performing the length variation of the cavity cells. The tuning sensitivity of the cavity was calculated to be 171.6 kHz/mm and the tuning range needed is 78 kHz, resulting in a range of 0.454 mm range motion.

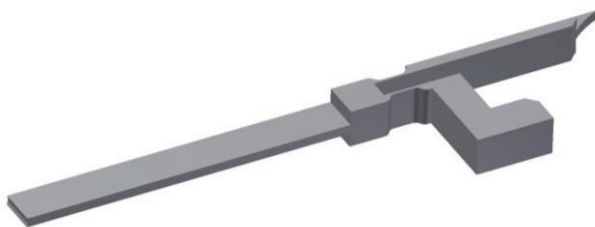


Figure 4: Detail of the tuner flexible link.

## ANALYSIS

### Mechanical Tuning System

As mentioned earlier, structural and thermal analyses were performed to confirm the mechanical tuning system structural integrity. The tuner components were designed using titanium Ti-6Al-4V Grade 5 because of its high tensile yield strength of 120,000 psi. From our previous analysis, the force required to deform the cavity by 0.442 mm is 432 lbs. Using ANSYS, the maximum stress observed was 64,508 psi on one of the flexures of the tuner flexible link shown in Fig. 5.

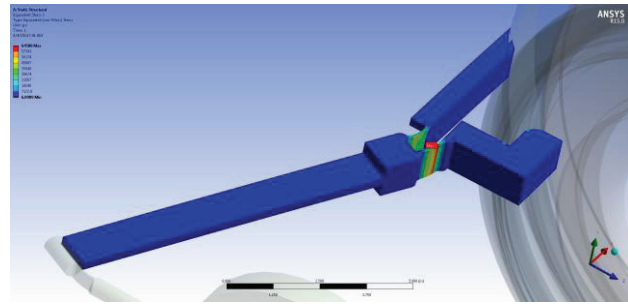


Figure 5: Maximum von-Mises stress on the tuner.

The temperature profile on all the tuner components was also determined and Fig. 6 shows the thermal simulation results for one of the flexible links. The heat intercept will be located near the flexures and the heat leak via the tuner will be intercepted by the heat shield. With the heat stationed by the heat shield, the heat leak to 2.0 K will be reduced to 20 mW range.

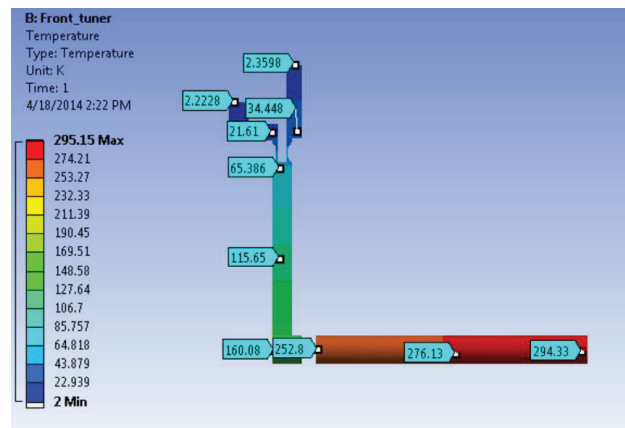


Figure 6: Temperature profile of one tuner flexible link.

### Piping Analysis and Helium Vessel

During the piping analysis, it was determined that the helium vessel would move 3 mm away from the tuner due to thermal contraction during cool down. The result from the simulation is shown in Fig. 7 below. The tuner mechanism is designed to accommodate this displacement and reduce the thermal stresses on the flexible links of the tuner. The piping analysis was done using CAEPIPE [6].

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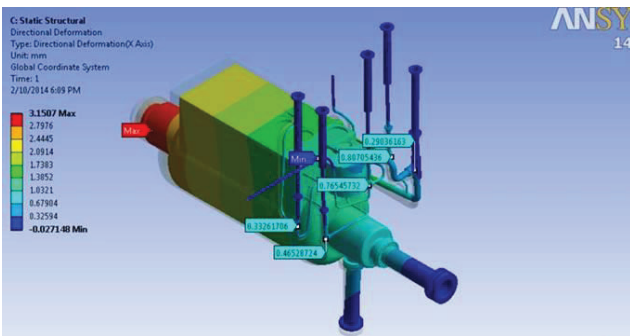


Figure 7: Thermal contraction during cool down.

### CAVITY TEST RESULTS

Two 5-cell Niobium cavities have been fabricated. The first one, BNL3-1 was manufactured by AES [7] and the second one, BNL3-2 by Niowave. The BNL3-1 was tested in a vertical cryostat at BNL and the test results are shown in Fig. 8. Field emission was observed at the cavity gradient above 15 MV/m, initially limiting the cavity performance. We were able to condition it and eventually achieve 17.1 MV/m in CW and 19.7 MV/m in pulsed mode. Further progress was prevented by administrative limits of the BNL facility. However, the test results indicate that the cavity performance is satisfactory. It will be integrated in the cryomodule for the Coherent Electron Cooling Proof of Principle experiment. The BNL3-2 cavity is undergoing additional treatment prior to testing.

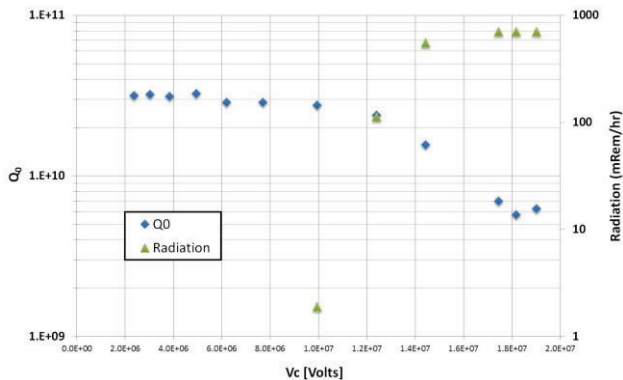


Figure 8: Test results of the BNL3-1 cavity at 2 K.

### FABRICATION

The 704 MHz SRF cryomodule for CeC PoP shown in Fig. 1 above is being built by Niowave. The fabrication and purchasing of many components have been completed. The helium vessel and the superfluid heat exchanger are shown respectively in Fig. 9 and Fig. 10 below. The tuning bellows and the cryogenic valves have been purchased and waiting for installation at Niowave.



Figure 9: Helium vessel with superfluid heat exchanger.

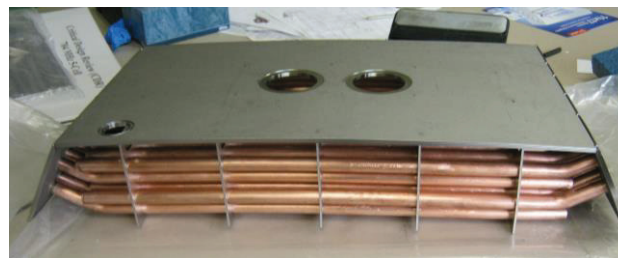


Figure 10: Superfluid heat exchanger.

### CONCLUSION

The superfluid heat exchanger, the tuner system, the cryogenic components and the FPC make the mechanical design a challenging task. A critical design review of the cryomodule was completed in May at Niowave. BNL and Niowave are working closely to finalize the design and integration of the tuner system in the cryostat. The fabrication of the helium vessel is in progress and several components attached to the helium vessel are under construction. The 704 MHz SRF linac is scheduled to be installed during the RHIC summer shutdown 2014.

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