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DISCLAIMER

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 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 22 MeV. Novel mechanical designs, including a super fluid heat exchanger, helium vessel, vacuum vessel, tuner mechanism, and fundamental power coupler (FPC) are presented. Structural and modal analysis, using ANSYS were performed to confirm the cavity chamber and helium vessel structural stability and to calculate the tuning sensitivity of the cavity. 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 [1]. Phase II of this experiment is to be completed by the end of shutdown 2014 and will include the 704 MHz SRF linac. At the same time, with this project, BNL is pursuing R&D towards the electron-ion collider (eRHIC). This paper provides an overview of the design and structural analysis of the 704 MHz SRF linac. Two 5-cell Niobium cavities have been fabricated. The first one, BNL3-1 was manufactured by AES and the second one, BNL3-2 by Niowave.

704 MHZ DESIGN

Design Features

The 704 MHz 5-cell cavity cryostat consists of an internal phase separator, control valves, 5-cell cavity, 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 [3]. The layout of the 704 MHz SRF 5-cell SRF linac is shown in Figure 1.

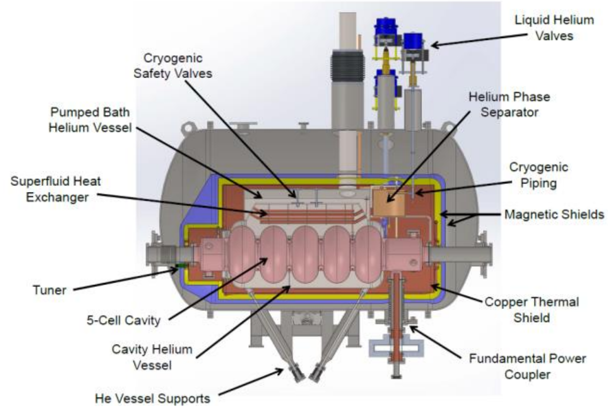

Figure 1: Layout of the 704 MHz SRF cryomodule.

The bottom of the helium vessel is a cylinder that incorporates the 5-cell cavity with the upper section modified to include the superfluid heat exchanger. Due to space constraint at IP2, the helium vessel was designed with the minimum real estate possible in order to keep the cryostat within the available space. The stiffeners shown in Figure 2 were added to the side of the helium vessel in order to reduce the deformation which translates to the cavity by deforming it through the supports attached to the helium vessel.

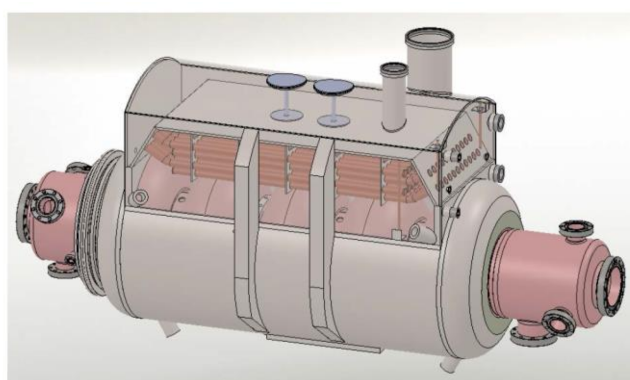

Figure 2: Layout of the 704 MHz cavity in a helium vessel.

Cavity Support

The support for the 5-cell cavity was designed in order to increase the natural frequency of the cavity in the helium vessel. The cavity is supported by three 1/8" Grade 5 titanium rods, symmetrically distributed around

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the beam axis. The support is located after the second cell, closer to the tuning bellows as shown in Figure 1. The support was designed to have no effect on the mechanical tuning of the cavity.

Mechanical Tuning System

The BNL3 cavity mechanical frequency tuning system was adopted from a design that has been successfully implemented by Dresden in Germany for their superconducting RF Photo-Injector [4]. 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 integrate a piezoelectric actuator for fast tuning and to accommodate larger cavity dimensions.

Fundamental power coupler

The fundamental power coupler is used to deliver up to 20 kW CW RF power to the SRF cavity. A cylindrical ceramic window is used to transmit the RF power from a reduced-height WR1150 waveguide to a coaxial line and to seal the cavity vacuum. The outer conductor of the coaxial line will be cooled by 5 K helium gas, and the RF window and inner conductor will be cooled by water. The final model of the fundamental power coupler is shown in Figure 3. The window material is 96% alumina with a dielectric constant of 9.4. The simulated S parameters are shown in Figure 4.

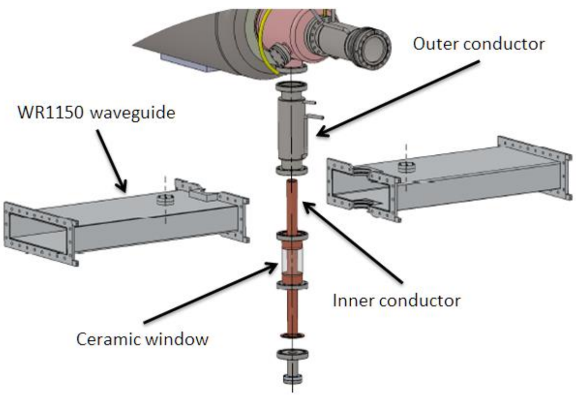

Figure 3: Fundamental power coupler model.

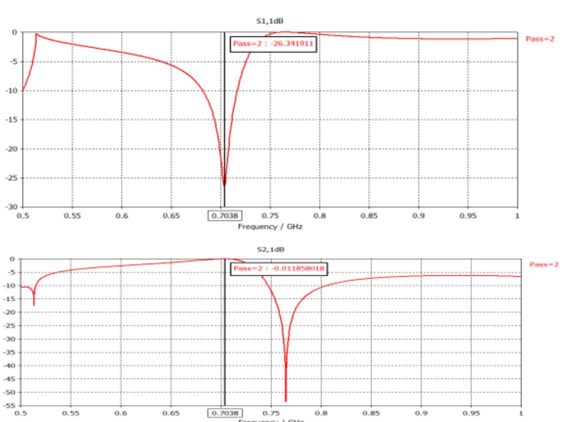

Figure 4: S-parameters for the FPC

ANALYSIS

5-Cell Cavity

As mentioned earlier, structural and modal analyses, using ANSYS were performed to confirm the cavity chamber and He vessel structural stability and to calculate the tuning sensitivity of the cavity. When helium pressure is applied on the cavity, its deformed shape will change the resonance frequency. The sensitivity of the cavity is 10 Hz/mbar bases on the analysis. The location of the stiffeners between the cavities of the 5-cells had to be validated at maximum pressure condition (23 psia relief valve set pressure).

The second part of the analysis was to find the maximum allowable deformation of the cavity before yielding. One end was fixed in all degrees of freedom while allowing the other end to only move in the y direction. A 384 lbs force deformed the cavity by 0.442 mm with a maximum stress of 7507.4 psi. The yield strength of Niobium is 7500 psi. This corresponds to a tuning sensitivity of 171.6 kHz/mm. The relaxed and deformed shapes of the cavity are shown in Figure 5.

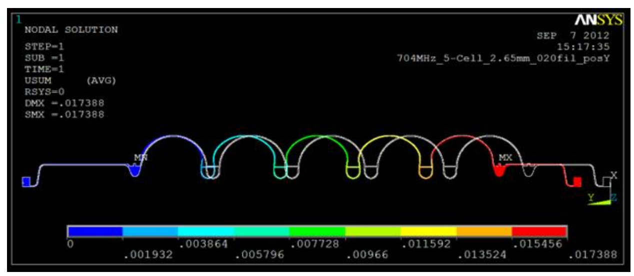

Figure 5: Relaxed and deformed shapes of the cavity.

Tuning Bellows

The tuning bellows was designed using titanium Ti-6Al-4V Grade 5 because of its high tensile yield strength of 120000 psi. The analysis was done at the maximum pressure condition (23 psia relief valve set pressure) applied on the inside of the bellows. The applied pressure resulted in a total deformation of .0065" and a maximum stress of 19927 psi in the convolutions of the bellows. Based on the results from the analysis, the helium vessel is determined to be safe under operating condition (14.7 psi) and the maximum condition (23 psi).

Modal Analysis

The goal was to design the struts to support the helium vessel and 5-cell cavity inside the vacuum cryostat, in order to keep the natural frequency above or close to 90 Hz. In the analysis, the three struts were at a 60^{o} angle from the horizontal, symmetrically placed around the helium vessel about the axis of the beam on each side of the centre plane. Instead of using a solid rod for the struts, they are made of hollow ½" OD 0.022" WT Tube Ti Grade 2 in order to reduce the heat leak into the helium vessel and stiffening the structure. Based on the results from the analysis, the first mode reached 88.3 Hz. Although it is below 90 Hz, it is determined to be sufficient. Table 1 shows the results from ANSYS simulations.

Table 1: Mode frequencies from ANSYS modal analysis

Mode	Frequency [Hz]
1	88.3
2	113.8
3	150.7

Helium Vessel

The deformation of the side of the helium vessel affects the 5-cell cavity by applying a force on it through the cavity support and deforming it. Under the maximum pressure condition (23 psi relief valve set pressure) the location of the stiffeners on the side of the helium vessel, shown in Figure 3, was optimized using ANSYS. The shape and size of the stiffeners was limited to the space available inside the heat shields. The maximum deformation of the helium vessel is 0.015”, which deforms the 5-cell cavity by 0.007” in the radial direction. The maximum stress in all the components affected, are within the allowable limits. The deformed shapes of the helium vessel and 5-cell cavity are shown in Figure 6 and Figure 7.

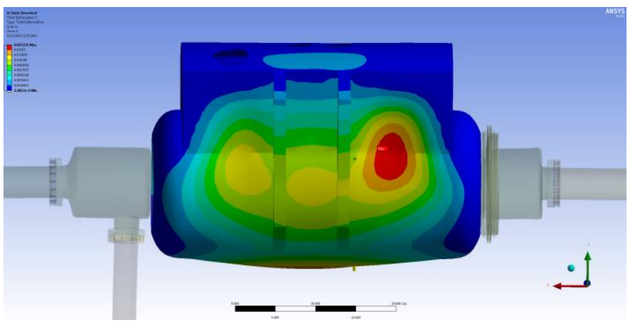

Figure 6: Deformed shape of the helium vessel.

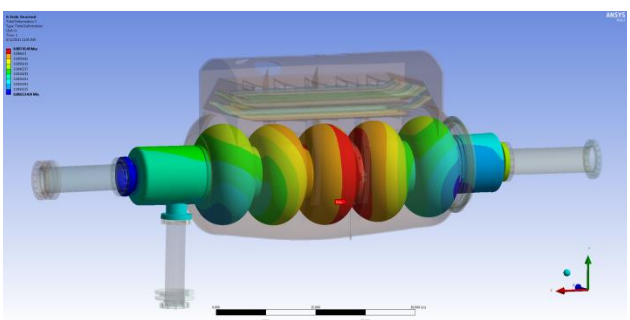

Figure 7: Deformed shape of the 5-cell cavity.

FABRICATION

Bulk buffer chemical polishing (BCP) of BNL3-1 (120 μm) was completed at AES and the cavity was baked at BNL at 600°C for 24 hrs. After baking, the cavity was sent back to AES for light BCP and HPR. BNL3-1 cavity is shown in Figure 8.

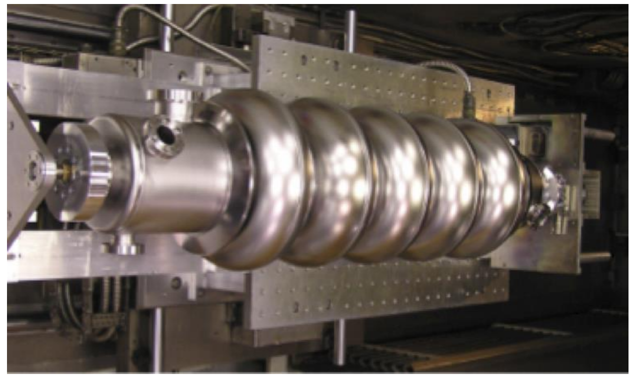

Figure 8: BNL3-1 cavity.

The second cavity, BNL3-2, and a cryomodule for CeC PoP are on order from Niowave. The fabrication and processing (bulk BCP, 600ºC vacuum bake, light BCP and HPR) of the cavity was completed recently at Niowave and BNL. The test in our vertical test facility for both cavities is scheduled for later this year. The better performed one of the two cavities will be integrated in the cryomodule.

CONCLUSION

The superfluid heat-exchanger, the tuner system and the cryogenic components make the mechanical design a challenging task. A preliminary design review of the cryomodule was completed in September at Niowave. We are working closely with Niowave to finalize the design and integration of the tuner system in the cryostat. The fabrication of the helium vessel and several components attached to the helium vessel is schedule to begin within the next couple weeks. The 704 MHz SRF linac is scheduled to be installed during RHIC summer shutdown 2014.

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