DESIGN AND FABRICATION OF THE RHIC ELECTRON-COOLING EXPERIMENT HIGH BETA CAVITY AND CRYOMODULE

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Abstract

Advanced Energy Systems is currently under contract to BNL to design and fabricate a five cell superconducting 703.75 MHz cavity and cryomodule for the RHIC e-Cooler SRF Energy Recovery Linac (ERL) program. The superconducting cavity fabrication is complete while fabrication of cryomodule components has begun. The cryomodule component design facilitates a build-in-place integration approach of the cavity string with the other major components of the cryomodule, helping to minimize assembly tooling requirements. This paper will review the design, analysis and fabrication of the e-Cooler cavity and cryomodule.

DESIGN REQUIREMENTS

This cryomodule is designed to incorporate a 703.75 MHz, 5-cell superconducting linac cavity developed to accelerate high electron current in an energy recovery mode. The physics requirements of the cavity are given in Table 1 [1].

Table 1. Parameters of ERL Cavity

	High charge	High current	Units
Energy In(kinetic)	2.0	2.0	MeV
Energy out	20	20	Mev
Beam Current	0.2	0.5	A
Bunch charge	~20	~1-3	nC
Rep rate	9.38	703.75	MHz

CAVITY DESIGN

The cavity physics design developed by BNL is a 5-cell, β=1 structure capable of accelerating ampere-level current at a frequency of 703.75 MHz as this is a harmonic of the RHIC frequency [2]. The cavity design has no trapped Higher Order Modes (HOMs) allowing them propagate out of the cryomodule to ferrite absorbers at room temperature [3]. As a result the cavity has a large 17 cm diameter iris and end groups with expansion sections increasing the beam pipe diameter from 17 cm at the iris to 24 cm. Figure 1 of the cavity geometry in section shows the RF field profile as calculated by SUPERFISH.

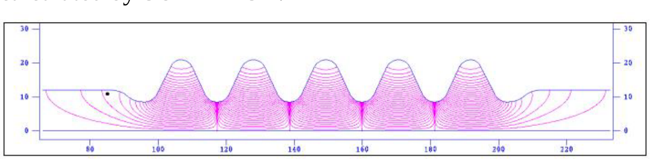

Figure 1. SUPERFISH RF field profile

RF parameters of the cavity as calculated by SUPERFISH are given in table 2.

Table 2. SUPERFISH Parameters

Cavity Frequency	703.781 MHz
Energy Gain (E0TL)	15 MV
E0 (Iris to Iris, L = 1.065m)	20.356 MV/m
Max Design E Field at Iris, Epeak	27.861 MV/m
Max Design H Field at Wall, Hpeak	6.487 mT
Avg Design H Field over Walls, Havg	6.189 mT
Design Stored Energy	126.931 Joules
Residual Resistivity used in SUPERFISH	10 nOhms
2K heat load	37.2 watts
Q_0 at 2K	1.51×10^{10}

Engineering Analysis

Initial structural analysis of the cavity shape was performed to assess the inherent stiffness of the cavity cell geometry having a 25 degree face angle for the cells conical section between the iris and equator. This trade study considered 3mm and 4mm thick niobium walls for the cavity and the use of iris stiffeners positioned at several different radial locations to evaluate their effect. Due to the high inherent stiffness of the cavity geometry, the cavity was manufactured from 3mm thick niobium sheet with no iris stiffeners. Figure 2 shows the results of the ANSYS Finite Element Analysis (FEA) of the mechanical resonant modes of the cavity calculated in the trade study.

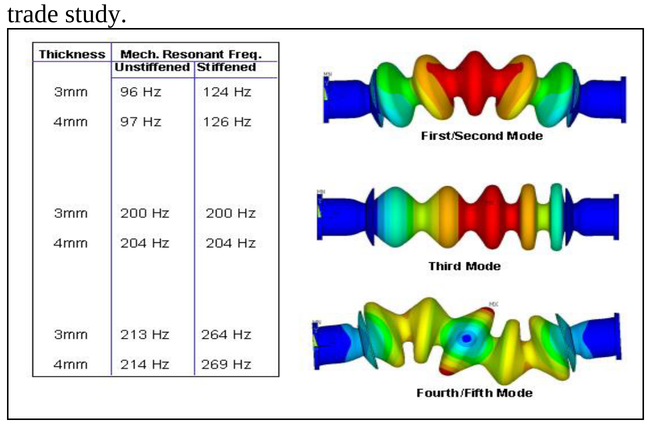

Figure 2. Cavity mechanical resonant modes

FEA analysis was also performed to evaluate the cavity axial stiffness and RF tuning coefficient to assess the loads and stresses associated with the tuner acting on the cavity. The analysis indicates that a cavity axial displacement of

.162” results in a frequency shift of 400 kHz and a maximum cavity stress of 11,700 psi in a very localized area of the iris region. Figure 3 shows the axial load verses frequency shift of the cavity.

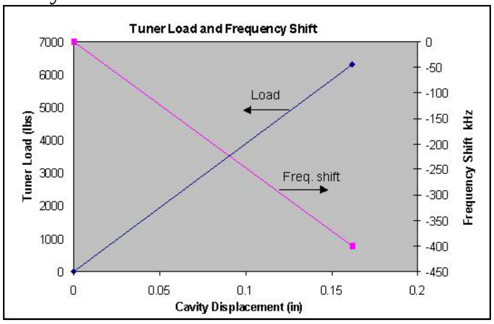

Figure 3. Cavity load vs. Frequency shift

Other analysis performed evaluated cavity RF behavior due to helium pressure variations and Lorentz force detuning. Table 3 shows these cavity parameters.

Table 3. Cavity Parameters	
Cavity tuning coef.	100 kHz/mm
Helium press. detuning coef.	73 Hz/mbar
Lorentz detuning coef.	1.5 Hz/(MV/m)^2

CAVITY FABRICATION

Two low power copper cold model cavities (Figure 4 & 5) were manufactured for this project prior to fabricating the niobium cavity. The copper cavities were manufactured from sheet material in a similar manner planned for the niobium cavity to prove out all tooling used for the niobium cavity fabrication.

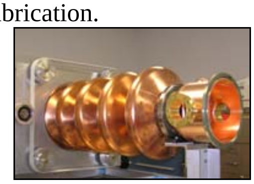
Figure 4. CM1

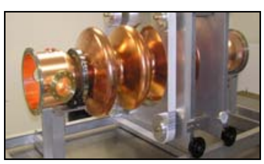
Figure 5. CM2

Fabrication of the niobium cavity shown in figure 6 has also been completed. All three cavities were manufactured at AES with the electron beam welding done at EBTEC located in Agawam, Massachusetts with direct AES supervision.


Figure 6. Niobium 5-cell cavity

CRYOMODULE DESIGN

The design of this cryomodule largely used the Spallation Neutron Source (SNS) as a model. Figure 7 shows the cryomodule in cross section.

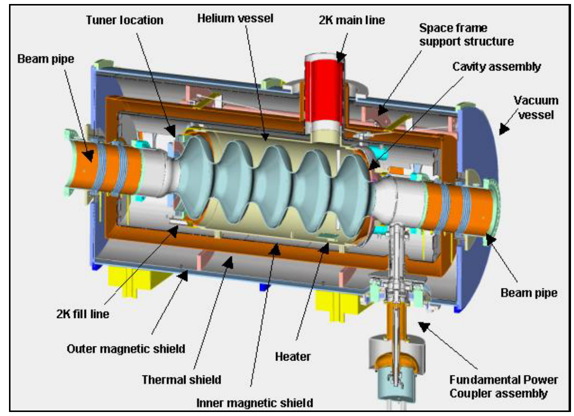

Figure 7. Cryomodule Assembly

This figure shows the helium vessel around the cavity followed by an inner magnetic shield and a thermal shield all located within space frame support structure. An outer magnetic shield surrounds the space frame located just inside the insulating vacuum vessel structure. Beam pipe assemblies extend from both ends of the cold cavity to outside of the cryomodule where they interface with room temperature ferrite HOM absorbers. The coaxial Fundamental Power Coupler (FPC) enters through the bottom of the cryomodule into an end group of the niobium cavity. Space is allocated around the niobium cavity end group opposite the FPC for the cavity tuner assembly. BNL is designing and manufacturing a cavity tuner that will be integrated into the cryomodule assembly at this location.

This cryomodule is designed so that the cavity can be cooled to 2K with a liquid helium dewar-style system located directly above the cryomodule. A large 2K main line connects the helium vessel surrounding the cavity to the dewar above and acts as a conduit for the 2K thermal load from the cavity to the helium dewar where helium boil-off occurs. A dedicated helium fill line enters the bottom region of the helium vessel.

CRYOMODULE INTEGRATION

JLAB will be performing the cavity RF surface treatment, initial cavity RF testing, helium vessel integration and hermetic cavity string buildup for this cryomodule. As mentioned earlier, this cryomodule design borrows heavily from the SNS design allowing the use of assembly tooling, fixtures and procedures on hand at JLAB during these tasks. The hermetic string assembly will be shipped from JLAB to BNL where it will be integrated into the cryomodule. The hermetic string assembly extends out to the vacuum gate valves to maintain internal vacuum. These valves are located outside the HOM absorbers and tapered sections allowing smaller RF gate valves to be used. Figure 6 shows the hermetic string assembly supported on tooling support stands.

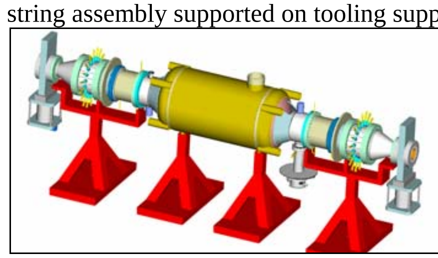
Figure 6. Hermitic cavity string

Once the cavity string arrives at BNL it will be integrated into the cryomodule. In an effort to minimize cryomodule integration tooling requirements, the shields, space frame and vacuum vessel are designed to facilitate a build-in-place assembly scheme. The first integration step is to assemble the inner magnetic shield onto the cavity string and run all cooling lines and instrumentation wiring as required. This is shown pictorially in figure 7.

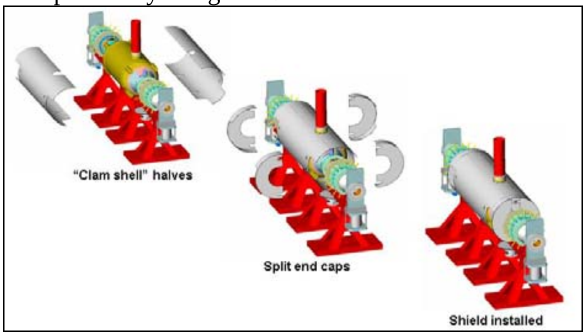

Figure 7. Inner magnetic shield installation

The next assembly step is to install the space frame and main thermal shield onto the cavity string by lowering it down over the string from above. This process calls for first mounting the main portion of the thermal shield into the space frame. Once positioned relative to the cavity, the space frame assembly is supported in place with tooling support stands located outboard of the frame. The cavity string is then attached to and supported from the space frame allowing the removal of the center tooling supports as depicted in Figure 8.

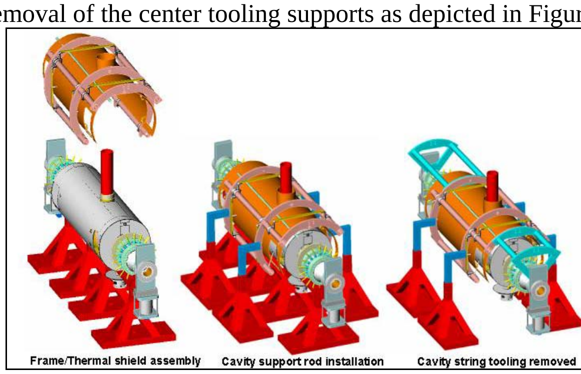

Figure 8.Thermal shield/ space frame assembly

With the cavity string supported from the space frame, the rest of the thermal shield is installed followed by the lower portions of the outer magnetic shield and vacuum vessel as shown in Figure 9.

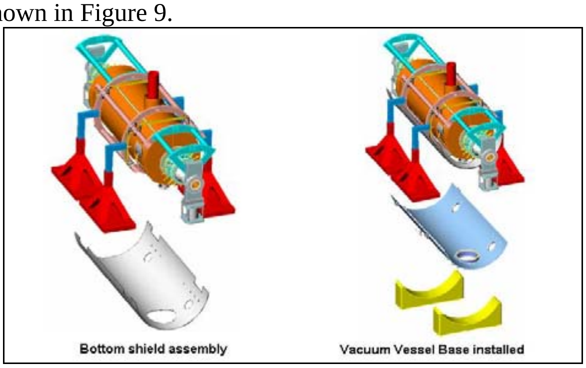

Figure 9.Vacuum vessel base assembly

A large portion of the cryomodule instrumentation and cooling line vacuum feedthroughs are located in the lower vacuum vessel segment. This allows these circuits to be wired or plumbed and checked for continuity or leaks prior to closing up the vacuum vessel. The feedthroughs are identified in Figure10.

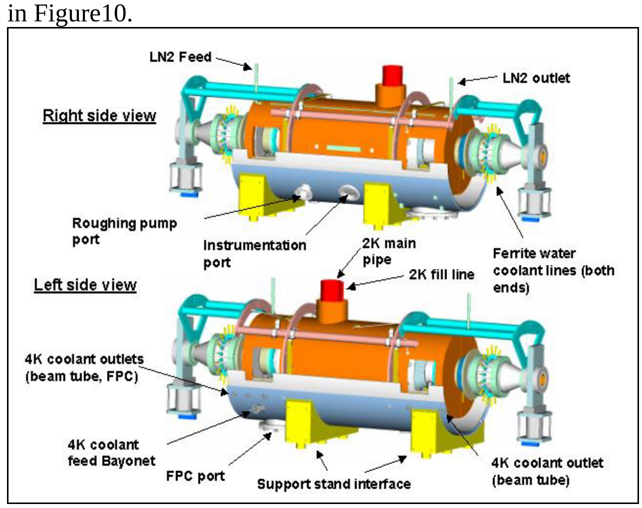

Figure 10. Cryomodule feedthroughs

The final cryomodule assembly step of installing the upper portions of the outer magnetic shield and vacuum vessel yield a system as shown in Figure 11.

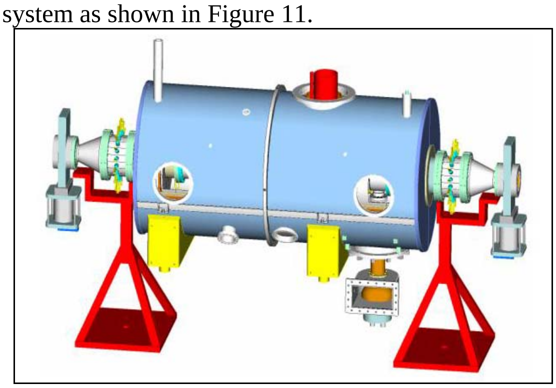

Figure 11. Cryomodule Assembly

CONCLUSION

The RHIC e-Cooling Experiment cryomodule is designed and manufacturing of the cryomodule components is well under way. The accelerating cavity is complete and has been delivered to BNL while all other cryomodule subcomponents will be manufactured by early 2006 in time for cryomodule integration scheduled for Spring 2006.

REFRENCES

[1] V. N. Litvinenko et al., Proceedings of the 2004 FEL Conference, p. 570, http://accelconf.web.cern.ch/AccelConf/f04

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[3] R. Calaga et al., High Current Superconducting Cavities at RHIC, TUPKF078, Proceedings of EPAC-2004, Geneva, Switzerland, July 5-9, 2004