

DESIGN AND FABRICATION OF AN FEL INJECTOR CRYOMODULE*

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Abstract

Advanced Energy Systems has recently completed the design of a four cavity cryomodule for use as an FEL injector accelerator on the JLAB Injector Test Stand. Fabrication is nearing completion. Four 748.5 MHz single cell superconducting cavities have been completed and are currently at Jefferson Lab for final processing and test prior to integration in the module. This paper will review the design and fabrication of the cavities and cryomodule.

designed in anticipation of operation at a bunch frequency of 748.5 MHz with every bucket full.

DESIGN REQUIREMENTS

This FEL injector cryomodule is designed as a booster for the DC photocathode gun in use at Jefferson Lab. The physics requirements¹ along with a schematic of the physics geometry for the module are given in Figure 1.

CRYOMODULE DESIGN

Design of the cavities and the cryomodule for this application used the Spallation Neutron Source (SNS) design as a model. In doing so, we took advantage of the development done on the cavity shapes and the module design as well as to take advantage of the existing tools, fixtures, and procedures at JLAB for module integration. This was clearly a minimum cost approach. Figure 2 shows the initial configuration developed from the physics dimensions. Because of the required proximity to the DC Gun, the supply end can cold box was oriented to the side of the module rather than on the end as was done for SNS. Figure 3 shows the final configuration of the module without the gun or end cans.

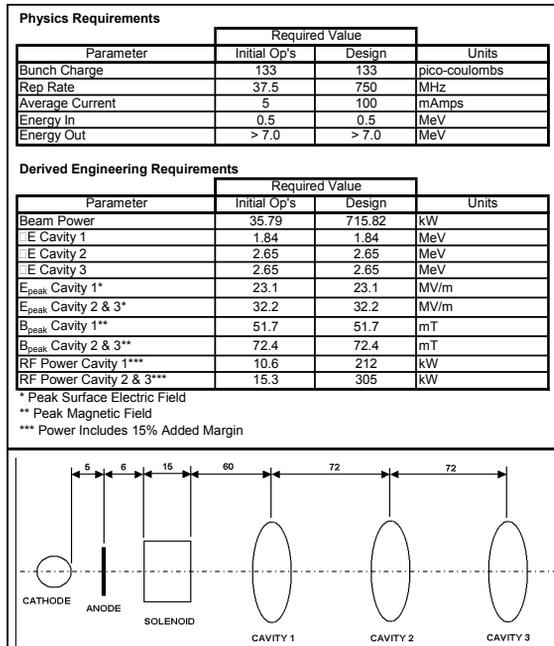


Figure 1: Booster Cryomodule Design Requirements

The fundamental operating frequency of the cavities in the booster module was chosen as 748.5 MHz (~750), the first sub-harmonic of the JLAB FEL cavity frequency of 1497 MHz. The lower frequency is required with the high bunch charge. It should also be noted that the initial requirements for operation were at full bunch charge but a bunch repetition frequency of only 37.5 MHz making the required power to the cavity a modest 15 kW. Despite this, the cavities and balance of the cryomodule were

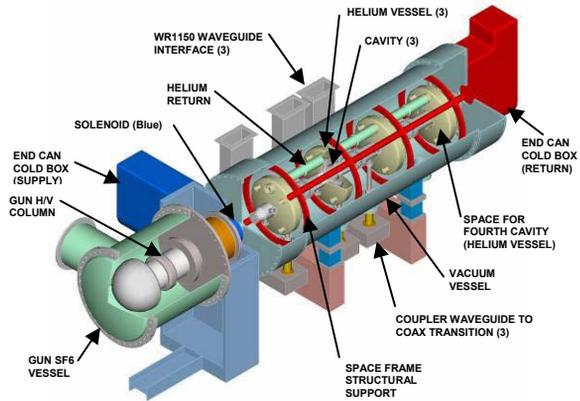


Figure 2: Initial Cryomodule Concept with DC Gun

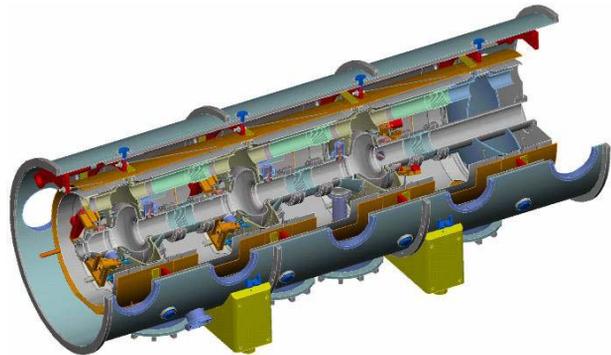


Figure 3: Final Cryomodule Assembly

Because of the expectation that a fourth cavity may be desired in this cryomodule it was designed with a fourth location available. This space was occupied by a helium

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 ** On leave from DESY

vessel that would serve to increase the helium inventory of the module and improve the control characteristics. Recently however, this project has been directed to incorporate a 2245.5 MHz, 3rd harmonic correction cavity into this module. To accomplish this we will move the second and third fundamental cavities to slots #3 and #4 and install the 3rd harmonic cavity in slot #2. Figure 4 shows a rendering of the module core with the 3rd harmonic in place.

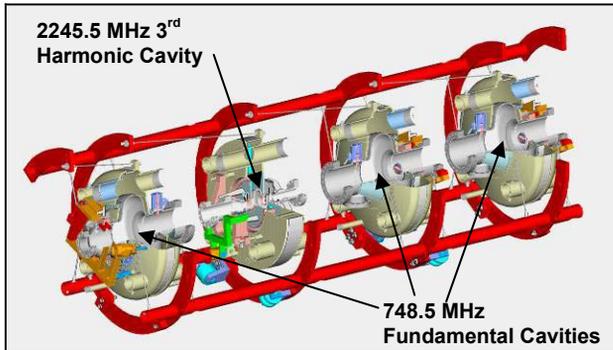


Figure 4: Upgraded Cold Mass with 3rd Harmonic Cavity

As mentioned earlier, this cryomodule design borrows heavily from the SNS design and in most cases components will interface directly to the same assembly tools and fixtures that already exist at JLAB for SNS assembly. The helium vessels surrounding the cavities are the same diameter as SNS and the design employs inner and outer magnetic shields, a 50K thermal shield, a structural space frame, and a vacuum vessel that are all the same diameter as the corresponding SNS components. Further, the power couplers are near duplicates of the SNS couplers with an identical cryomodule interface.

The helium distribution system inside the module is largely the same as SNS with 2K helium feeding the cavity string at one end with the individual helium vessels connected at the bottom with crossover feed lines and at the top with a two-phase helium return line. The interface of the end can cold boxes differs from SNS because of space considerations for the photocathode gun. We also use 4K helium to cool the beamline flanges, the power coupler flange, and the power coupler outer conductor.

CAVITY DESIGN

The cavity design was done by starting with the SNS $\beta=0.81$ cavity shape and scaling to achieve the desired frequency of 748.5 MHz. This was not a direct scaling because the beam pipe diameter was kept at 13cm. Because of concerns surrounding Higher Order Mode (HOM) power at these high bunch charges, the beam pipe diameter was maintained at 13cm for the full length of the cryomodule to allow transport of most of the HOM's to loads that would be placed outside the module at room temperature. The cavities also incorporate DESY/SNS style HOM filters modified for operation at 748.5 MHz. However, concerns over their ability to handle the power with these CW fields led to a conservative approach to HOM damping. With incorporation of the 3rd harmonic

cavity in slot #2 the issue of trapped modes is again being reviewed for cavity 1.

Figure 5 shows cutaway views of a fundamental cavity with helium vessel and frequency tuner. The tuners are a scaled version of the SNS tuners and are being provided by JLAB.

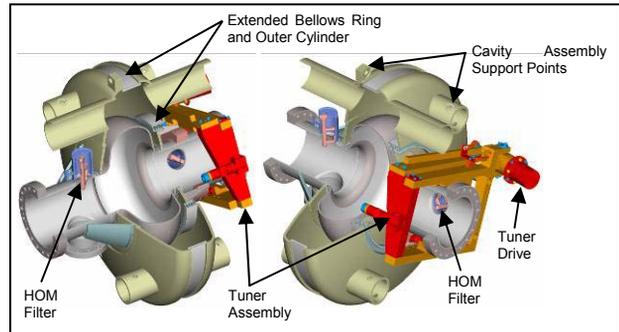


Figure 5: Cavity Cutaway

Engineering Analysis

Engineering analysis was performed on the cavities to evaluate thermal performance and structural performance. Figure 6 shows an ANSYS finite element model of the cavity with the different materials of construction identified. Table 1 presents the material structural properties used in the analysis.

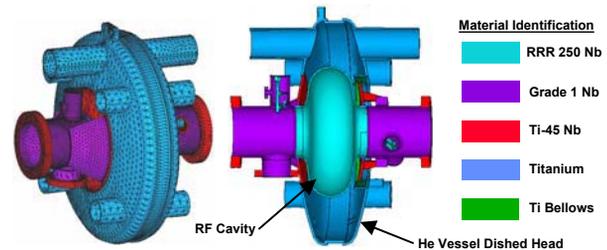


Figure 6: FEA Model and Materials - 748.5 MHz Cavity

Table 1. Material Properties for Analysis

Material	Young's Modulus MPsi	Poisson's Ratio	RT Yield* kPsi	4K Yield kPsi
Niobium RRR 250	14.9	.39	9.7	95.4
Titanium	16.6	.32	51.9	136.
Titanium/Niobium	9.0	.35	69.6	69.6**
Niobium RRR 40 reactor grade	14.9	.39	11.0	64.2 @ 77K

* Values are found in R. P. Walsh, et.al., "Low temperature Temperature and Fracture Toughness Properties of SCRF Cavity Structural Materials," Proceedings of the 9th Workshop on RF Superconductivity, Santa Fe, NM 1999. These values are typical, design allowable may be less, i.e., 7.0 ksi is often used for RRR 250 niobium.

** Titanium/Niobium RT values are used at 4K. Fracture toughness may be significant at low temperature.

Thermal analysis was performed using the RF heat loads and thermal boundary conditions of 5K at the actively cooled flanges. Radiation load from the power coupler center conductor was also added assuming operation at 60° C. Heat removal is via the 2K helium contained within the helium vessel. The calculations fully account for the effect of temperature on material

properties and the effect of local heat flux on the Kapitza resistance to the 2K fluid. Figure 7 shows the results for the thermal case indicating suitable temperatures throughout the structure.

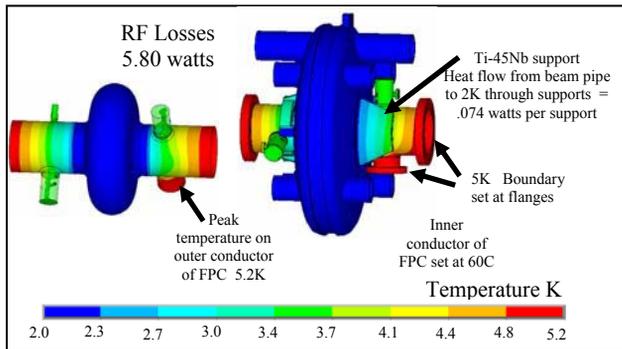


Figure 7. Thermal Results

Analysis was also performed to evaluate the tuner performance and the loads and stresses associated with the tuner at full stroke. To do this an FEA model of the RF space of the cavity was created that shares a common set of surfaces with the thermal/structural model. Distortions calculated in the structural model are then applied to the original RF model geometry to determine the Δf . Figure 8 shows the results of tuner load versus frequency shift in the cavity.

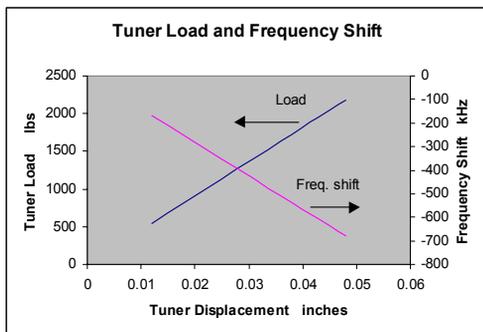


Figure 8. Tuner Load vs. Frequency Shift

Figure 9 shows the stresses associated with the tuner displacement of .036" which is the amount required to produce -500 kHz tuning. The maximum stress in the

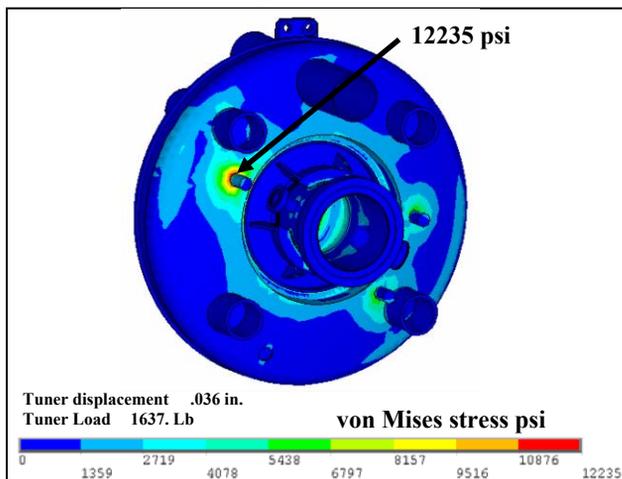


Figure 9. Stresses Due to Tuner Load

cavity under these tuner loads is 9900 psi and is restricted to a very local area near the iris. Indeed, during bench tuning of the cavities² it was found that more than 3,000 pounds was required to induce permanent deformation at room temperature.

CAVITY FABRICATION

Four 748.5 MHz single-cell cavities have been fabricated for this project (figure 10). The fourth cavity, originally intended to be used with the 3rd harmonic cavity in a separate test, is now a spare. The cavities were fabricated at AES with the electron beam welding done at Sciaky, Inc. in Chicago under direct AES supervision. The cavity halves and many details were hydroformed using equipment at a local supplier and all other work including pre-weld BCP were done in the AES facilities. The cavities were tuned at AES prior to delivery to JLAB where they have now undergone bulk chemistry and are being prepared for testing at 2K in the VTA.

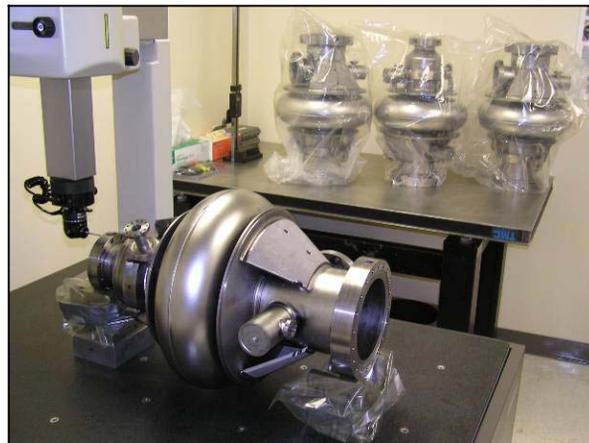


Figure 10: Four Cavities in Final Mechanical Inspection at AES

CONCLUSION AND STATUS

A booster cryomodule for the FEL injector at Jefferson Lab has been designed and is nearing completion of the fabrication phase. The 748.5 MHz accelerating cavities are complete and have been delivered to JLAB and the 3rd harmonic cavity is complete and will be delivered in June 2005. The balance of the cryomodule hardware will be procured in summer 2005 and integration and assembly will take place at JLAB in late 2005.

REFERENCES

- [1] H. P. Bluem, A. M. M. Todd, et al., "Electron Injectors for Next Generation X-Ray Sources", to appear in "Fourth Generation X-Ray Sources", *Proc. SPIE 5534* (2004).
- [2] M. Cole, et al., "Fabrication Tuning of Four 748.5 MHz Single Cell SRF Booster Cavities for a 100 mA SRF FEL Injector," these proceedings.