DESIGN AND CONSTRUCTION OF THE PROTOTYPE CRYOMODULE *RENASCENCE* FOR THE CEBAF 12 GEV UPGRADE*

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Abstract

During 2002 and 2003, the design of the cryomodules for the anticipated CEBAF 12 GeV upgrade has evolved considerably. While maintaining compatibility with existing infrastructure, several modifications have been made which are expected to improve both gradient and 2 K heat load performance and to simplify assembly. Two versions of improved cavity design have been prototyped, a new tuner design has been developed, new flange sealing hardware has been developed, and refinements to the cryogenic design promise to extend the usable net cw voltage from the eight-cavity cryomodule to about 110 MV with 250 W load to 2.1 K. The final prototype cryomodule, *Renascence*, is under construction and scheduled for completion in summer of 2004. System improvements, problems encountered along the way, and present solutions are presented.

CEBAF UPGRADE REQUIREMENTS

The planned upgrade of the CEBAF accelerator to 12 GeV[1] requires cryomodules with significantly improved performance over the original CEBAF construction. The principal requirements call for 10 additional cryomodules, each capable of >108 MV, fitting within the existing CEBAF infrastructure and presenting a low dynamic 2 K heat load. BBU simulations have established modest HOM shunt impedance limitations on several dipole modes, requiring loaded Q's of $<\sim 2\times10^6$.

The second-generation prototype cryomodule, dubbed *Renascence*, is presently under construction at JLab and is expected to be completed in summer 2004.

NEW DESIGN FEATURES

These primary constraints have led to an evolution of the CEBAF upgrade cryomodule design. The first step was the design and construction of two "70 MV" cryomodules.[2,3] An overall project cost optimization subsequently increased the performance requirements to the +100 MV range.

Several design changes had to be made to accommodate the requirement changes, and several additional modifications are being incorporated based on experience during fabrication, construction, and commissioning of the first prototype units.[4,5]

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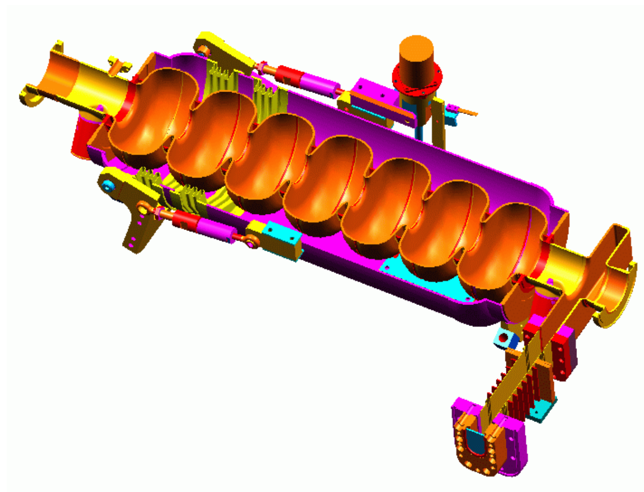


Figure 1: Cross-section of *Renascence* cavity, couplers, helium vessel, and tuner.

SRF Cavities

1. Each cryomodule houses eight 7-cell 1497 MHz cavities with half-height waveguide input couplers and two DESY-style HOM couplers at both ends of each cavity.
2. A new "High Gradient" (HG) cavity cell design was developed as an optimization to minimize risk of field emission limitations by minimization of E_{pk}/E_{acc}.
3. A new "Low Loss" (LL) cavity cell design was developed as an optimization to attain the greatest voltage/cryo-watt by accepting some increase in E_{pk}/E_{acc}.[6]
4. *Renascence* will employ four HG and four LL cavities for evaluation. The cavities are identical except for the cell shapes.
5. The anticipated central LHe refrigerator capacity and the installed cryogenic valving capacity constrain the dynamic 2.1 K heat budget to 250 W per cryomodule. This, together with gradient requirements, makes high Q_0 performance of the cavities very important.
   a. CEBAF 12 GeV Project requirements call for an *average* operating gradient of 19.2 MV/m in the new modules.
   b. RF power needs call for $Q_l = 2.0\times10^7$ to enable optimum use of 13 kW klystrons

with the anticipated microphonics and 460 µA design beamloading. See Figure 2.

c. Project requirements stipulate that capable cavities must be operable to at least 21 MV/m.

d. Exceptional cavities with low microphonics and high Q_0 may be useable to as high as 25 MV/m.

e. The 2.1 K dynamic heat budget is 31 W per cavity. High Q_0 LL cavities may live within this budget up to 25 MV/m. See Figure 3.

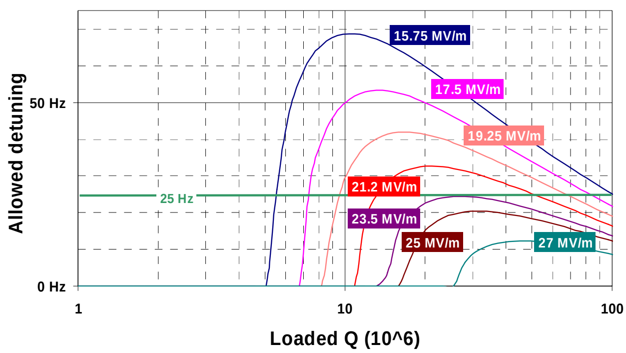


Figure 2: Detuning allowance for the LL-shaped 7-cell cavity with loaded-Q and anticipated 13 kW klystrons at several accelerating gradients and 460 µA beamloading.

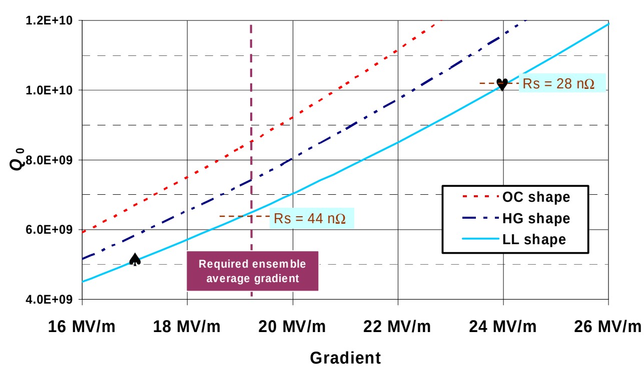


Figure 3: Required Q_0 vs. gradient producing 31 W for the HG and LL cell shapes, as well as the original Cornell/CEBAF (OC) shape.

6. The HOM couplers were moved closer to the end cells to compensate for the weaker cell-to-cell coupling of the new cavity shapes relative to the original CEBAF shape.

7. To be confident that all polarizations of HOMs are damped, two HOM couplers with a 115º angular separation between them are located on each end group.

   a. Measurements on copper models yielded $Q_{lHOM} < 2\times10^6$ for all modes as required.[7]

   b. BBU simulations with the HG and LL cavities placed in CEBAF and the JLab FEL indicate that either is acceptable for 12 GeV CEBAF schemes and the HG version is viable for use in the JLab FEL to 30 mA operation.[8]

8. The HOM coupler pick-up probe material has been changed from copper to niobium to avoid heating by the resonant fundamental rf field.

   a. To assure that this probe remains superconducting, the temperature of the feedthrough flange and center conductor will be stabilized.

9. Stiffening rings were added to both dumbbells and between end half-cells and helium vessel ends to assure rigidity and allow the option of a 1250º C bake.

10. The cavity fabrication sequence was changed to allow e-beam welding of the last cut-to-length beamtube section after final tuning, reducing the risk to alignment control and need for inter-cavity bellows in the 8-cavity string assembly.

11. As something of a style change, more scripted production cavity fabrication procedures have been developed and implemented for use in-house at JLab. These procedures and the data acquired with them are built using our *Pansophy* system.[9]

Tuner System

12. Moving the HOM couplers closer to the end cells required us to design a new tuner system. A simplified system incorporating components used in SNS cryomodules has been prototyped.

   a. Cavities are tuned in tension only.

   b. Greater than 2 mm travel is required to produce frequency range of > 500 kHz.

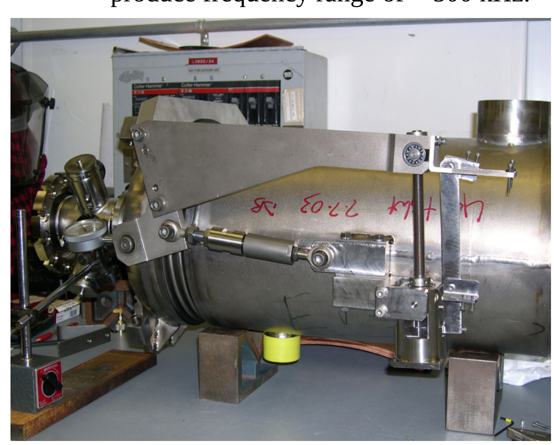
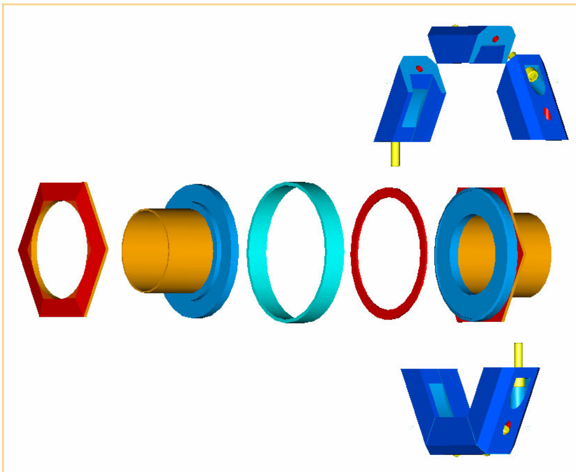


Figure 4: New “nutcracker-style” tuner actuated by cold stepper motor with harmonic drive and piezoelectric element.

Flanging Improvements

13. A new "Radial-Wedge" clamp has been adopted for use on all beamline flanges in order to provide high sealing forces and easy assembly with minimal access clearance requirements.[10]



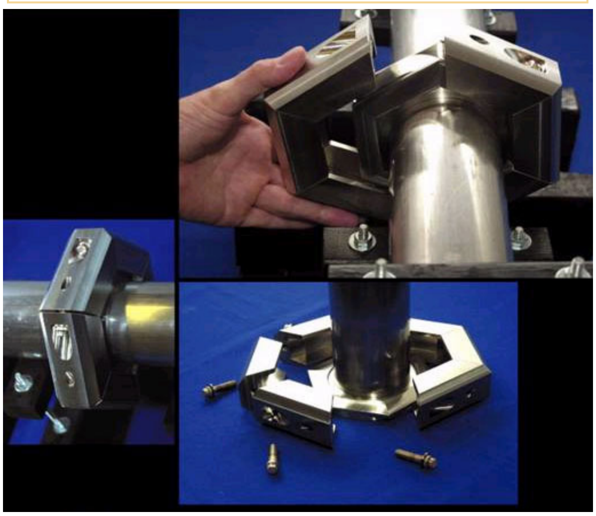


Figure 5: Radial Wedge Clamp for use on beamline flanges.

14. A new $Al_{55}Mg$ gasket design suitable for use on the fundamental power coupler waveguide flange has been developed.
    a. This gasket is an alternative to the use of indium, which presents a particulate contamination risk upon disassembly of the FPC flange joint.
    b. The selected "serpentine" shaped gasket is self-stabilizing against roll-over leaks that can occur due to flange compliance on the long sides of the rectangular waveguide flange.
    c. The cross-section of the gasket is identical to that used successfully on other NbTi flanges on DESY and SNS cryomodules.

Figure 6: FPC flange $Al_{55}Mg$ "serpentine" gasket.

Cryogenic Engineering

15. Improved heat stationing on the input waveguide increases the rf power handling capacity from 8 to 13 kW cw. Conducted heat from the copper-plated waveguide must not raise the temperature of the FPC flange above 8 K. Thermal modeling predicts 15 W load to the shield and 2.5 W load to 2 K via the cavity flange, during 13 kW cw operation.

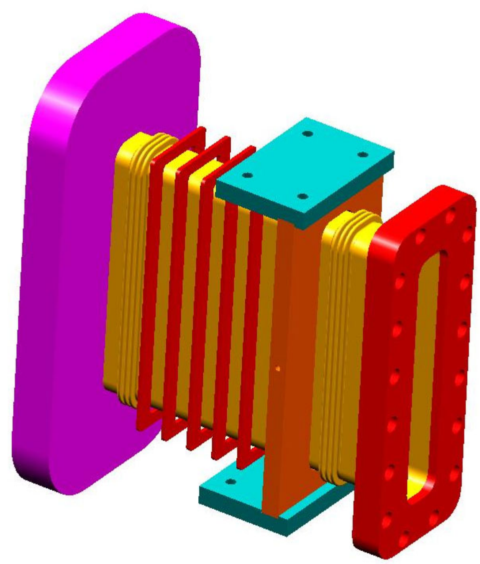


Figure 7: Redesigned transition input waveguide suitable for 13 kW operation.

16. The size of the helium vessel-to-supply header interface pipe was increased from 1-1/2" IPS (42.7 mm ID) to 3.5" IPS (95.5 mm ID) to avoid the potential for choked heat flow by exceeding the allowable critical heat flux in superfluid He.
    a. The first "70 MV" prototype cryomodule was found to have inadequate heat

conduction capacity for the current CEBAF operating temperature of 2.09 K.

b. The larger diameter riser used in *Renascence* will provide greater than 60 W per cavity conduction at 2.1 K.

17. The cryostat design was simplified by reducing the number of penetrations through thermal and magnetic shielding and the vacuum vessel.
18. Existing helium vessel designs have been adapted to interface with the new cavity and tuner schemes.
19. The design of the heat shield has been revised to handle 400 W at the nominal 50 K operating temperature.
    a. Assembly procedures have been updated based on experience with the first upgrade design.
    b. Increase thermal strapping of the 13 kW waveguides has been added in order to handle 20 W per waveguide.

STATUS

- The construction of *Renascence* is being funded as a reliability improvement to CEBAF. It will be installed in place of the weakest present cryomodule. No new rf systems will be available to exploit the full capability for several years.
- All major procurements have been placed.
- Cavity and tuner prototypes are under test.
    - The new cell shapes have been qualified against multipacting conditions up to relevant fields.
    - Initial tests on the first Nb HG cavity showed even lower Q_{lHOM} than expected.[11]
    - A program is underway to evaluate the benefits to be derived from various baking options (600º, 1250º, 120º C) and to refine the processing and handling procedures.
- Cavity fabrication is underway at JLab.
    - We are employing a mixture of job shop parts machining, in-house e-beam welding, and key late-stage in-house machining steps.
    - All cavity end groups are complete, as are all cell dumbbells.
    - The cavities will be completed in January 2004.
- String assembly is scheduled for late spring 2004.
- Cryomodule testing is scheduled for September 2004.
- This project is proceeding in parallel with completion of the first-generation upgrade cryomodule being built for the CEBAF FEL, the production of cryomodules for the SNS project, and recovery of the CEBAF accelerator from an unplanned warmup due to a hurricane-induced extended loss of power.

ACKNOWLEDGEMENTS

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