CRYOMODULE DEVELOPMENT FOR THE CEBAF UPGRADE*

J.R. Delayen, L.R. Doolittle, E. Feldl, J. Hogan, J. Mammosser, V. Nguyen, H.L. Phillips,
J. Preble#, W.J. Schneider, D.X. Wang, and M. Wiseman
Thomas Jefferson National Accelerator Facility, Newport News Virginia 23606 USA

Abstract

Long term plans for CEBAF at Jefferson Lab call for achieving 12 GeV in the middle of the next decade and 24 GeV after 2010. In support of those plans, an Upgrade Cryomodule capable of providing more than three times the voltage of the original CEBAF cryomodule specification within the same length is under development. Development activities have been focused on critical areas thought to have maximum impact on the overall design. These have included the cavity structure, rf power coupling, cavity suspension, alignment, cavity tuning, and beamline interface. It has been found that all design and development areas are tightly coupled and can not be developed independently. Substantial progress has been made toward an integrated design for the Jefferson Lab Upgraded Cryomodule.

1 CRYOMODULE REQUIREMENTS

1.1 Tunnel Layout

The CEBAF energy upgrade to 12 and then 24 GeV will be accomplished within the existing accelerator tunnel. The 12 GeV upgrade will be accomplished using an additional pass through one of the two linacs for a total of five and one half passes or eleven transits of a linac [1]. Currently each of the linacs has five module positions that were left empty during CEBAF construction. These ten positions will be filled with upgrade cryomodules along with the replacement of six existing cryomodules in the linacs and the two injector cryomodules.

1.2 Cavity

In order for the CEBAF accelerator to reach 12 and 24 GeV the upgrade cryomodules will be required to supply an average energy gain of 68 MeV [2]. This will be accomplished with an increase in both the operating gradient and the active length of the cryomodule. An increase in active length from 4 to 5.6 meters must be accomplished within the same footprint as the existing CEBAF cryomodules. The increased active length and an average operating accelerating gradient of 12.5 MV/m provides the required energy gain from a cryomodule. In order to operate at these gradients without exceeding the planned 2 Kelvin refrigeration capacity the quality factor of the cavities must be maintained at 6.5×10^{9} at operating gradients.

1.3 Fundamental Power Coupling

The upgrade cryomodule will be operated with the existing 5 kW RF power sources. The fundamental power coupler (FPC) is designed to use a minimum of RF power for gradient and phase control [3]. The nominal fundamental power coupler Q_{ext} is 2.1×10^{7} [4][5]. An additional requirement for the coupler is an insensitivity to mechanical deformation of 0.0013 meters axially and 0.050 radians angularly. This is required to support cavity to cavity alignment in the cavity string.

1.3 Beamline Interface

The beamline between cavities became crowded as efforts to maximise the active length of the cryomodule progressed. The decision was made to remove all bellows between cavities allowing for an additional two cells or 0.20 meters active length per cavity. The beamline outside the helium vessel contains the Higher Order Mode (HOM) coupler ports, fundamental power coupler, field probe port, and frequency tuner attachment.

1.4 Helium Vessel

The helium vessel encloses the cavity cells only, minimising the liquid helium inventory in the cryomodule. This is a change from the existing CEBAF design that encloses the FPC and the HOM coupler ports. The vessel design uses titanium construction with two titanium bellows at the outer diameter.

1.4 Tuning

The new tuning system design includes a coarse and fine tuning actuator. This is a change from the existing CEBAF design that has a single tuning actuator. The requirement for the fine tuning results from the limited RF power available and resulting requirement to minimise the RF power used for gradient and phase control. A control resolution of 1 Hz with a range of 1 kHz is required for the fine tuner and a resolution of 200 Hz with a range of 400 kHz is required for the coarse tuner [6]. The range of the fine tuner is sufficient to handle the normal operating

* Work supported by the U.S. Department of Energy under contract DE-AC05-84-ER40150.
# Email: preble@jlab.org

0-7803-5573-3/99/$10.00@1999 IEEE.

requirements which are typically within 100 Hz while the coarse tuner is used to tune the cavities after cooldown when additional range is required.

1.5 Cavity Suspension and Alignment

The cavity alignment requirements are unchanged from the original CEBAF requirements [7][8]. This requires the cavities to be aligned relative to the nominal beam trajectory with a root mean-square angular precision of 0.002 radians. To accomplish this a space frame will be constructed around the completed cavity string that will allow individual cavities to be final aligned in the "as installed" support configuration.

1.6 Requirements Summary

Many of the requirements for the upgrade cryomodule are very similar to the original CEBAF cryomodule. This results from maintaining the existing cryomodule footprint. Differences in the cryomodule are primarily driven by the increased energy gain, improvements in fabrication techniques, and changes in beam requirements. Table 1 lists the major differences in the upgrade cryomodule.

Table 1: Cryomodule Comparison

Parameter	CEBAF	Upgrade
Voltage2	20 MV	68 MV
E_{acc} Average	5 MV/m	12.5 MV/m
Q_0 @ E_{acc}	2.4×10^9	6.5×10^9
RF Windows	2	1
FPC Coupling	λ/2 stub on stub	λ/4 stub
Q_{ext} FPC	6.6×10^6	2.2×10^7
HOM Coupling	Waveguide	Coaxial
B.L. Bellows	5	2
Vac. Valves	10	4
Freq. Tuner	Single	Dual-Coarse/Fine
Cryounits (CU)	4	1
Cavities/CU	2	8
2 K RF Heat	45 watts	140 watts
50 K RF Heat	40 Watts	120 watts

2 DESIGN STATUS

2.1 Cavity

The cavity assembly has seven cells using the CEBAF cell designs for interior and end cells. The cells are assembled with an end collar that provides the interface to the helium vessel, beamline, and tuner attachment. The cavity design is complete at this time. A major difference from the CEBAF design is the use of a single eight cavity hermetic sealed string replacing the four two cavity strings used in the original CEBAF design.

2.2 Fundamental Power Coupler

The fundamental power coupler is a waveguide design and has been designed and tested using a copper model. The coupler uses a λ/4 stub geometry providing two significant benefits, the first is the minimisation of steering kicks resulting from the coupler electric fields and the second is the insensitivity to minor mechanical deformations in the coupler. The first is important to reduce the effects on the beam quality in the accelerator while the second allows for using the coupler for small cavity alignment adjustments. The copper coupler model has been used to determine final dimensions and demonstrate the required tolerance to mechanical deformations. The waveguide section that provides the thermal transition between the cavity and vacuum vessel has a common vacuum with the cavity and is sealed with a warm ceramic window. The waveguide incorporates a S bend which allows for the grouping of waveguides in pairs prior to penetrating the vacuum vessel and removes the warm ceramic window from the line of sight of the beam line.

2.3 Beamline

The beamline is the area outside the helium vessel and includes the FPC, HOM coupler ports, field probe, beamline flanges, and tuner attachment points. Noticeably missing between the cavities are any bellows or vacuum valves. To allow for no bellows in the beamline the beamline flanges and FPC must provide the adjustment required to maintain cavity alignment. The beamline flanges allow for an angular deflection by utilising a design that thins the material interior to the sealing surface. Deformation of the membrane results in the required angular deflection. The FPC provides additional axial and angular deflection where the beamline tube intersects the waveguide box. The combination of these allows for a dogleg displacement in the beamline.

2.4 Helium Vessel

The helium vessel is one of the major changes from the CEBAF design. The vessel has been reduced from a 0.61 to a 0.25 meter diameter. This is made possible by moving the RF couplers outside of the helium vessel. The vessel material is titanium to match the thermal properties of the cavities and eliminate differential thermal contraction difficulties. Two titanium bellows are incorporated into the vessel which allow for the remaining differential thermal contraction and tuning requirements.

2.5 Cavity Frequency Tuning

The tuner design is complete and being fabricated at this time. The design incorporates a single mechanism acted on by two actuators, one providing coarse and the other fine tuning adjustments. The coarse adjustment is accomplished using the same stepper motor used in the CEBAF design while the fine tuning is done using three piezo-electric actuators acting in parallel. Both actuators are mounted outside the insulating vacuum providing easy access to them at all times. The cold portion of the tuner is made of titanium matching the thermal properties of the cavities and eliminating differential contraction issues. The cold assembly has no friction generating parts and uses all flex joints to accomplish the required movement.

2.6 Support and Alignment

A warm space frame using support rods configured in a double paired cross pattern at each end supports each cavity in the cavity string. The space frame is supported inside the vacuum vessel at the quarter points, each being between the second and third cavity from the end. The frame is made up of a series of hoop rings installed perpendicular to the beam axis down the length of the cavity string and connected by axial support members. The frame is assembled around the string along with the tuner assemblies starting from one end and progressing to the other. When the space frame is completed magnetic shielding, thermal shielding, and associated components will be added to the structure. When complete the space frame will be wheeled into the vacuum vessel and locked into position.

2.7 Vacuum Vessel

The vacuum vessel is designed as a single pipe running the length of the cavity string. Four horizontal penetrations allow for bringing the waveguides and instrumentation out of the vacuum vessel. Eight smaller penetrations on the top of the cryostat allow for the tuner interface.

2.8 Testing

The upgrade cryomodule includes new design concepts for several components. A testing program has been designed to validate these concepts early on, providing confidence for the continuing design effort. A facility is under construction to provide a means to test various components. An important feature of this facility is the ability to quickly install, test, and remove components allowing for multiple tests in a short period of time. This facility, the Horizontal Test Bed (HTB), is being fabricated by modifying an early CEBAF prototype cryounit and will allow for the testing of two cavities with prototype components attached. Its commissioning is planned for May and the first test with prototype components is scheduled for June of this year.

2.9 Design Integration

The design of the cryomodule includes many closely interacting components. An attempt has been made to optimise critical high impact systems as a whole with regard to these interactions. This has necessitated a number of iterations in design as one component design evolves and impact on others is evaluated and considered. The beamline area has been the focus of considerable effort to date. This area includes all the rf coupling, the tuner attachment, and cavity support and alignment. The important issues include space, performance, fabrication, and processing considerations.

3 SUMMARY

The design of a upgrade cryomodule to support the energy upgrade of the CEBAF accelerator is underway. The design effort has focused on the least understood components of the cryomodule. These areas include the cavity and beamline, cavity string design, fundamental power coupling, cavity frequency tuning, and cavity string support and alignment. These efforts are not independent and require a series of iterations in order to look for a system optimisation. A test program is planned to allow for early and easy testing of prototype components allowing for effective development. The higher risk designs are scheduled to be tested in an integrated test by October of this year.

4 ACKNOWLEDGEMENTS

The work reported here has been accomplished by the Jefferson Lab Accelerator Development Department and Mechanical Engineering group.

[1] D.R. Douglas, R.C. York, and J. Kewisch, "Optical Design of the CEBAF Beam Transport System" Proc. 1989 IEEE Part. Accel. Conf., Chicago, IL, March, 1989.
[2] J.R. Delayen “Upgrade of the CEBAF Acceleration System”, these proceedings
[3] Lawrence R. Doolittle, D.X. Wang, “RF Control Studies For Moderate Beamline Coupling Between SRF Cavities”, Proceedings of the LINAC Conference 1998
[4] Lawrence R. Doolittle, “Strategies for Waveguide Coupling For SRF Cavities”, Proceedings of the LINAC Conference 1998
[5] J.R Delayen et al., “An RF Input Coupler System for the CEBAF Upgrade”, these proceedings
[6] J.R. Delayen et al., “Frequency Tuning of the CEBAF Upgrade Cavities”, these proceedings
[7] J.J. Bisognano, D.R. Douglas, and B.C. Yunn “Alignment Tolerances for CEBAF Accelerating Cavities”, CEBAF-TN-91-081, 15 October 1991
[8] D.R. Douglas and J. Preble, ”Alignment Tolerance for 7-Cell SRF Cavity”, JLAB-TN-98-022, 22 May 1998