DESIGN OF A FRIB HALF-WAVE PRE-PRODUCTION CRYOMODULE*

S. Miller#, H. Ao, B. Bird, G. Bryant, B. Bullock, N. Bultman, F. Casagrande, C. Compton, A. Facco[1], W. Hartung, J. Hulbert, D. Morris, P. Ostroumov, J. Popielarski, L. Popielarski, M. Reaume, K. Saito, M. Shuptar, J. Simon, S. Stark, B. Tousignant, J. Wei, J. Wenstrom, K. Witgen, T. Xu, Z. Zheng
Facility for Rare Isotope Beams, Michigan State University, East Lansing, MI 48824 USA
M. Kelly
ANL- Argonne National Laboratory, Lemont, IL 60439 USA
[1] also at INFN - Laboratori Nazionali di Legnaro, Legnaro (Padova), Italy

Abstract

The driver linac for the Facility for Rare Isotope Beams (FRIB) will require the production of 48 cryomodules (CMs). In addition to the β=0.085 quarter-wave CM, FRIB has completed the design of a β=0.53 half-wave CM as a pre-production prototype. This CM will qualify the performance of the resonators, fundamental power couplers, tuners, and cryogenic systems of the β=0.53 half-wave design. In addition to the successful systems qualification; the β=0.53 CM build will also verify the FRIB bottom up assembly and alignment method on a half-wave CM type. The lessons learned from the β=0.085 pre-production CM build including valuable fabrication, sourcing, and assembly experience have been applied to the design of β=0.53 half-wave CM. This paper will report the design of the β=0.53 half-wave CM as well as the CM interfaces within the linac tunnel.

INTRODUCTION

FRIB is a high-power heavy ion accelerator facility now under construction at Michigan State University under a cooperative agreement with the US DOE [1]. Its driver linac operates in continuous wave mode and accelerates stable ions to energies above 200 MeV/u with the beam power on target up to 400 kW. The linac has a folded layout as shown in Figure 1, which consists of a front-end, three linac segments connected with two folding segments, and a beam delivery system to deliver the accelerated beam to target [2].

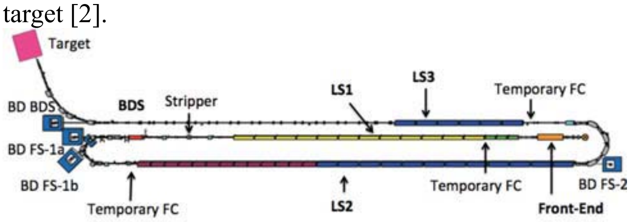

Figure 1: Schematic layout for FRIB driver linac.

The FRIB driver linac utilizes four different low-beta SRF resonator designs in CMs as described in Table 1. For high-beta applications, SRF has become an established technology with a history of industrial optimization efforts; however, for low-beta structures, FRIB will be the first facility utilizing industrially produced resonators on a larger scale [3].

Table 1: Required CM configurations for FRIB. Resonator and solenoid quantities per CM are shown in parenthesis. The β=0.041 CM will utilize a L_{eff}=0.25 m solenoid and all other CMs will utilize a L_{eff}=0.50 m solenoid.

Type	Cryomodule Qty.	Resonator Qty.	Solenoid Qty.
β=0.041	3	12 (4)	6 (2)
β=0.085	11	88 (8)	33 (3)
β=0.29	12	72 (6)	12 (1)
β=0.53	18	144 (8)	18 (1)
Matching Modules	3 (β=0.085) 1 (β=0.53)	12 (4) 4 (4)	N/A
Total	**48**	**332**	**69**

Each CM will be equipped with niobium resonators operating at 2 K with focusing solenoids, which include x-y steering, operating at 4.5 K. Due to the large number of CMs, the FRIB project lends itself to a manufacturing mind-set that incorporates large scale production into the design of individual module types. As a part of this manufacturing mind-set, FRIB has designed a pre-production CM that utilizes eight β=0.53 superconducting half-wave resonators (HWR) and one superconducting solenoid, as seen in Figure 2 [4].

CRYOMODULE DESIGN

The FRIB CMs are based on a modular bottom-supported design which is optimized for mass-production and efficient precision-assembly. Figure 3 displays the subsystem break down of the CM. Four types of superconducting resonators (β=0.041, β=0.085, β=0.29, β=0.53) and two solenoid lengths (Leff = 0.25 m and 0.50 m) are used in multiple configurations for the FRIB linac driver as described Table 1. FRIB CMs have been designed with a focus on

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# millers@frib.msu.edu

optimizing commonality between the CM types while incorporating robust manufacturing methods and minimizing material usage and assembly time. The following sections describe in detail the β=0.53 pre-production CM design.

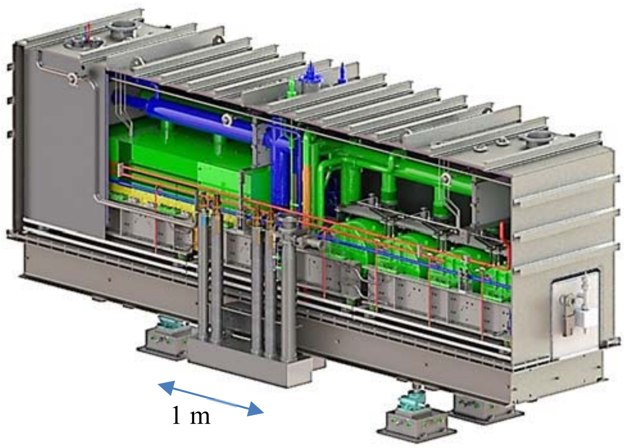

Figure 2: β=0.53 pre-production CM modular bottom-up design. This CM incorporates 8 β=0.53 HWRs and 1 solenoid.

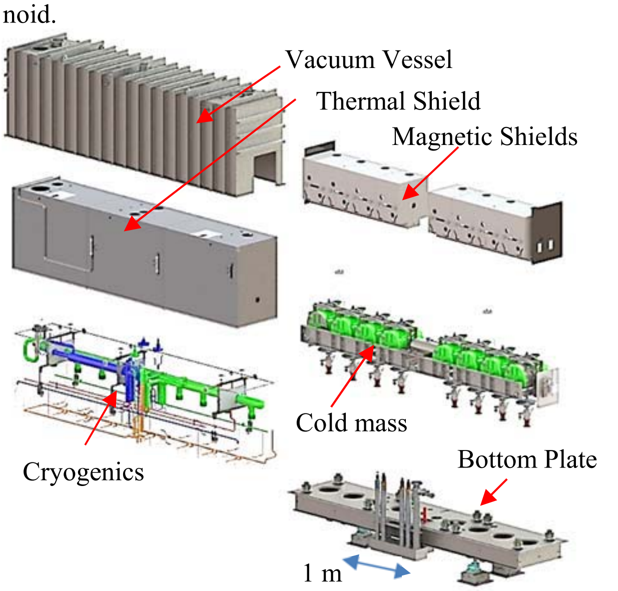

Figure 3: Sub-Systems of FRIB CM design. Supported off the bottom plate is the cold mass system, where the resonators are protected by local magnetic shielding (right). The cryogenic system attaches to the cold mass. All assemblies are encapsulated by the thermal shield and vacuum vessel (left).

Cold Mass

The support of the cold mass was designed of three 316L stainless steel (UNS S31603) welded alignment rail segments, which are annealed to relieve residual stress and restore magnetic permeability prior to precision machining. The structure is divided longitudinally into 3 pieces to minimize static deflections and shown in Figure 4. The cold string elements are fixed to the near side of alignment rail. A custom set of hardened copper bearings support the floating side of the cold string elements and allow for their differential thermal contraction. Installation of beamline bellows, fundamental power couplers (FPC), RF pickups, and a beamline end assembly rounded out the cleanroom portion of the design [5].

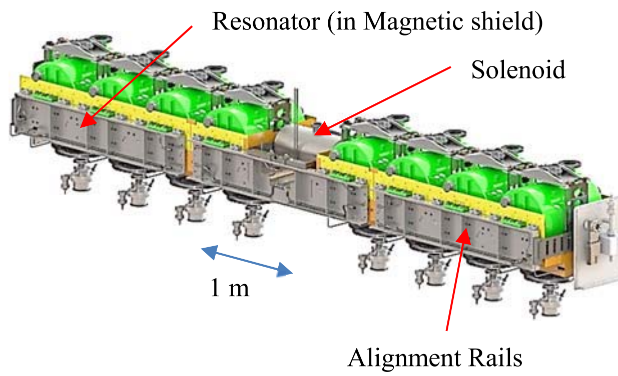

Figure 4: CM cold mass. Alignment rails support superconducting resonators and solenoid.

After removal from the cleanroom, the resonator tuners, which allow for the adjustment of the resonator operating frequency via a helium gas piston, are installed. RF power is delivered to all resonators by FPCs via coaxial RF lines. Shown in Figure 5 are the fundamental power coupler and resonator tuner assemblies for the design [6].

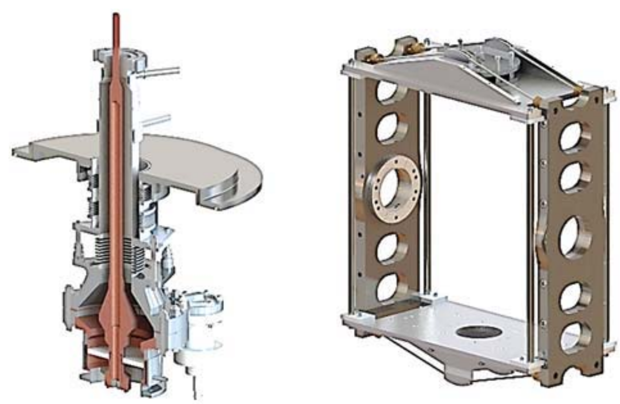

Figure 5: Half-wave power coupler assembly (left). Tuner mechanism by ANL (right).

On each end of the cold mass are the cold mass hoods. The hoods temporarily attach to the end alignment rail and have a beam line vacuum connection to the resonators on the end to the cold mass string. This connection is intercepted at 38 K. The hood allows for easy installation of gate valves, cold cathodes, and burst discs, all by conflat flange connections. When the cold mass is assembled with the vacuum vessel bottom plate, the hood is simply bolted and pinned into position and released from the end rail. Installation of the vacuum vessel cover makes an O-ring seal to the cold mass hoods which completes the seal for insulating vacuum.

Magnetic Shield

The magnetic field of earth and the surrounding environment is attenuated to meet the FRIB required permeability of μ=10,000 (at 500 mG). This is accomplished by using a 2 mm thick mu-metal local shield for the two sets of four resonators as seen in Figure 4. The vacuum vessel sub-system is primarily composed of steel and further attenuates the surrounding magnetic field.

Cryogenic System

To allow for efficient and repeatable CM installation, a FRIB standard cryogenic bayonet box is employed as seen in Figure 6. This design will benefit the FRIB production linac as it will allow for a single CM to be warmed and disconnected from the linac segment. The bayonet box is welded directly to the bottom plate of the vacuum vessel and connects to the internal cryogenic plumbing of the CM. This allows for the bayonet box to be fabricated separate from the vacuum vessel by vendors who specialize with cryogenic system construction. The interface between the cryogenic distribution line and the CM is a set of 5 U-tube bayonet connections.

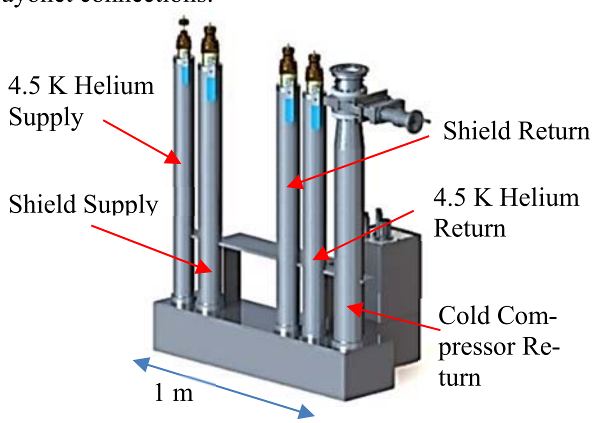

Figure 6: CM cryogenic bayonet box. The bayonet box connects to the distribution line by u-tube bayonets.

The cryogenic system has an independent helium circuit for the superconducting resonator (2 K) and solenoids (4.5 K). These independent circuits allow for magnetic degaussing cycles to take place using the superconducting solenoid to remove any residual magnetic fields while the resonators are warmed above the superconducting temperature of niobium. A gaseous helium thermal shield circuit, operating at 38 K, adds to the cryogenic efficiency by intercepting the heat conduction and radiation paths while minimizing the cryoplant plug in heat load [4].

Cryogenic design choices for the CM were made at a project wide level, approaching it as an all-encompassing system composed of the cryogenic plant, distribution system, and CMs. Collaboration with Thomas Jefferson National Accelerator Facility (J-Lab) on 2 K process improvements have yielded efficiency gains in the FRIB CM.

Thermal Radiation Shield

The thermal radiation shield is a segmented construction which simplifies assembly and allows for differential contraction between the three alignments rails as shown in Figure 3. The thermal shield is constructed from 1100-H14 Aluminium (UNS A911000) and cooled via a custom extrusion to distribute 38 K helium. A parallel 38 K helium line is also included which is dedicated for intercepting heat conduction from the FPC, warm beam line transitions, pressure reliefs, and composite support posts. The thermal shield is supported from the G-10 posts which attach to the vacuum vessel bottom plate.

Vacuum Vessel & Baseplate Assembly

The vacuum vessel is constructed primarily from A36 (UNS K02600). The main components are the bottom plate and vacuum vessel cover which interfaces with the hermetically sealed beamline cold mass hoods. Insulating vacuum space is sealed by an O-ring gasket which allows for simultaneous horizontal and vertical sealing. This O-ring gasket is constructed from ethylene propylene rubber more commonly known as EPDM (ASTM D1418) [7].

CONCLUSION

The β=0.53 pre-production CM design is complete. Procurement of components for this CM is complete and assembly is taking place at FRIB. Continuous vendor interaction is essential to ensure critical features for alignment, performance, and functionality are maintained. The testing of the CM is planned before the end of 2016 and will validate the HWR subsystems, alignment, and system level performance in the CM.

Design effort is now underway on design for the β=0.085 and β=0.53 matching CMs for the FRIB linac. The β=0.29 CM design is being developed in collaboration with JLAB and is expected to complete in early 2017.

REFERENCES

[1] J. Wei et al, "Progress towards the Facility for Rare Isotope Beams" Proc. of NA-PAC 2013, pp 1453-1457.
[2] M. Ikegami et al, "Commissioning Plan for the FRIB Driver Linac", Proc. of LINAC 2014, pp. 152-154.
[3] M. Leitner et al., "Status of the Linac SRF Acquisition for FRIB", Proc. of LINAC 2012, pp. 564–566.
[4] M. Shuptar et al., "Mechanical Design of the Cryogenic Sub-Systems for ReA6 Quarter Wave Resonator Cryomodule", Proc. of PAC 2013, pp. 1256–1258.
[5] L. Popielarski, et al., "Low-Beta SRF Cavity Processing and Testing Facility for the Facility for Rare Isotope Beams at Michigan State University", Proc. of SRF 2015, pp. 597-601.
[6] K. Saito, et al., "FRIB Project: Moving to Production Phase", Proc. of SRF 2015, pp. 1-13.
[7] S. Miller, et al., "Low-Beta Cryomodule Design Optimized For Large-Scale Linac Installations", Proc. of SRF 2013, pp. 819-823.

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