CRYOMODULE DESIGN FOR THE RARE ISOTOPE ACCELERATOR*

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Abstract

The Rare Isotope Accelerator (RIA) driver linac will produce >400 MeV/u proton through uranium beams using many types of superconducting accelerating cavities such as quarter wave, spoke, and elliptical cavities. A cryomodule design that can accommodate all of the superconducting cavity and magnet types is presented. Alignment of the cold mass uses a titanium rail system, which minimizes cryomodule size, and decreases both the tunnel cross-section and length. The titanium rail is supported from the top vacuum plate by an adjustable tri-link, which is similar to existing Michigan State University magnet technology. A prototype cryomodule is under construction for testing 805 MHz, v/c=0.47, six-cell niobium cavities in realistic operating conditions. Details of the design and progress to date are presented.

INTRODUCTION

The Rare Isotope Accelerator (RIA) driver linac is designed to accelerate heavy ions to 400 MeV/u (β=v/c=0.72) with a beam power up to 400 kW [1]. To obtain these intensities, partially stripped ions are accelerated in a 1400 MV superconducting linac. A design based on the 80.5 MHz harmonic requires six cavity types as shown in Table 1 [2]. The first and last cavity types were developed for other linacs and the remaining four are variants of these two.

A rectangular cryomodule design with cryogenic alignment rail that can accommodate all of the superconducting cavity and magnet types is proposed for RIA. This type of module has been used at Michigan State University (MSU), TESLA, INFN Legnaro and Argonne National Laboratory. In particular, a prototype cryomodule for the elliptical cavities with geometric β, β_{geo}, of 0.47 (optimum β, $\beta_{opt,}$ of 0.49) is presented and easily extends to the other cavity types. While the Spallation Neutron Source (SNS) has already developed a cryomodule that could be used for the elliptical cavities of RIA [8], it would be inappropriate for the drift tube cavities, and significant simplifications and cost savings are possible with the rectangular cryomodule due to RIA's continuous, relatively low power beam.

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Table 1. Overview of RIA Driver Linac Cavities (80.5 MHz harmonic).

β_{opt}	f(MHz)	Type	Status
0.041	80.5	$\lambda/4$	Developed for INFN Legnaro [3]
0.085	80.5	$\lambda/4$	Prototype in Fall 2003 [4]
0.160	161	$\lambda/4$	Prototype in Summer 2003 [4]
0.285	322	Spoke $\lambda/2$	Demonstrated in 2002
0.49	**805**	**6-cell Elliptical**	**Demonstrated in 2002 [5]**
0.63	805	6-cell Elliptical	Developed for SNS [6]

DESIGN

Beam dynamics simulations for efficient beam transport with minimal emittance growth have shown that four β=0.47 cavities per cryomodule with cavity alignment tolerances of ±1-2 mm are acceptable [9]. Figure 1 shows the rectangular cryomodule with four 805 MHz β=0.47 six-cell cavities, and Table 2 shows the main parameters.

The cavity with titanium helium vessel, power coupler and tuner are shown in Figure 2. The first transverse mechanical mode of the cavity is damped by attaching the center of the cavity to the helium vessel with titanium spokes. A titanium to stainless transition is used to attach the cavity to the helium manifold. No higher-order-mode dampers are required due to RIA's relatively low beam current [10]. An external room- temperature frequency tuner is used for improved reliability and maintainability. An external actuator can also be used to damp microphonics.

The input rf power is less than 10 kW for beam loading and microphonics control. The same ceramic window as SNS is used and transitioned to a smaller diameter vacuum coax for capacitive coupling to the cavity [11, 12]. The outer conductor does not require helium gas cooling which greatly simplifies the cryoplant. The thermal load from the power coupler to the helium system was calculated assuming 10 kW of rf power and a center conductor at room temperature. The outer conductor is 0.89 mm thick stainless steel with 8 microns of RRR=10 copper. Figure 3 shows the temperature

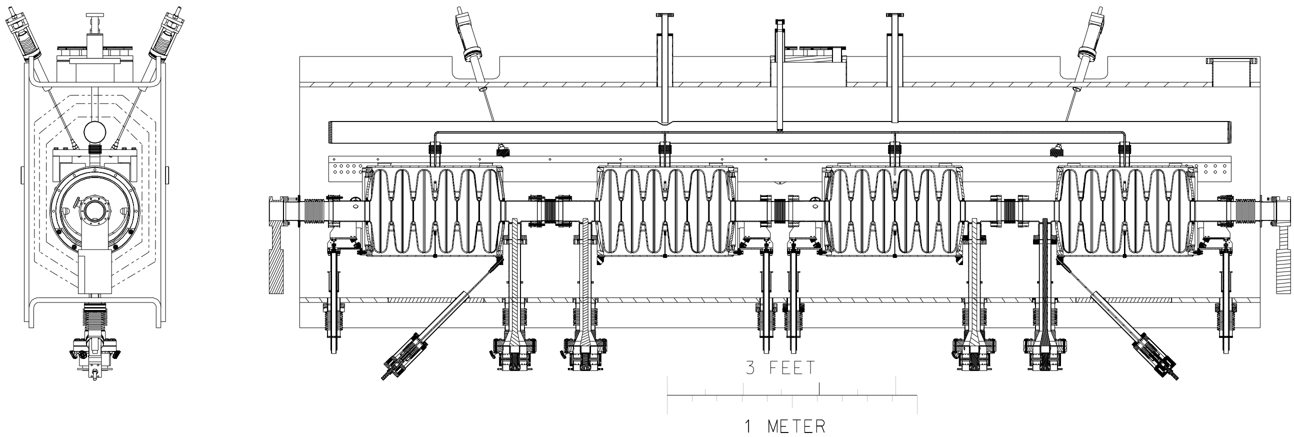

Figure 1. RIA Cryomodule with four β=0.47 elliptical cavities (side and end view).

profile along the outer conductor, which has a liquid nitrogen intercept. The helium and nitrogen load are 1.6 and 4 W per coupler respectively. Operation with 50 K helium gas in lieu of liquid nitrogen would further decrease the helium load.

Table 2. Design specifications of RIA cryomodule.

Cavity	
Frequency	805 MHz
v/c = β	0.47
He Vessel Diameter	0.362 m
Total Mass	71.6 kg
Beam Aperture	0.075 m
Design Q	5×10^9
V_{acc}	4.2 MV
RF loss	22 W
Input RF power	<10 kW
Cryogenic Module	
Length	4.0 m
2K Cold Mass	400 kg
Total Module Mass	3000 kg
# Bayonets	4
# Support Links	6
2K Heat Load	
Power Coupler	1.6 W/ea
Tuner	0.8 W/ea
Total / RF OFF	15 W
Total / RF ON	103 W
Shield Heat Load	<100 W
Pressure Rating	
2K System	3 bar
Thermal Shield	10 bar

All four cavities are rigidly aligned on a titanium rail with optical fiducials at the ends and center of the rail that can be viewed when cooled to 2 K to verify alignment. The 2 K cold mass is assembled in a Class 100 cleanroom as shown in Figure 4. The cavities are aligned using push-pull mechanisms and shims outside the cleanroom. The 2 K cold mass is supported with six nitronic links. The link forces are monitored using strain gauges. Two magnetic shields and a 77 K thermal shield are supported by the helium distribution and thus mechanically isolated from the 2 K cold mass. The vacuum vessel is made from low carbon steel plate. During transportation pins secure the cold mass to the vacuum vessel, and a stiffener is inserted into the power coupler. The most sensitive component to shock is the power coupler's inner conductor, which will plastically deform above 4.6g.

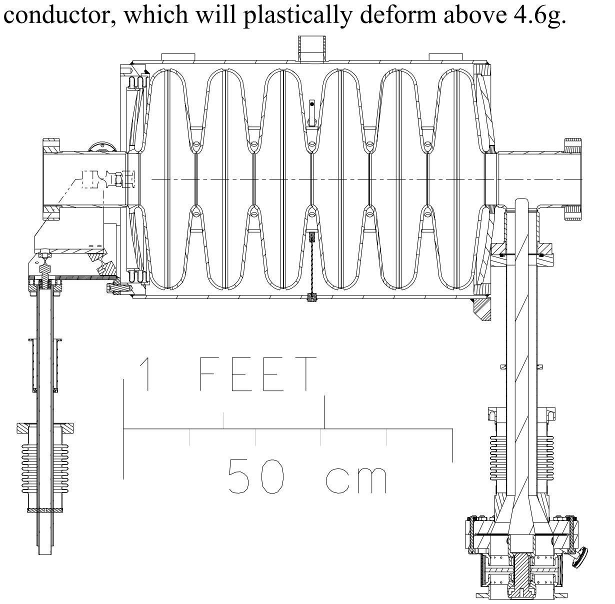

Figure 2. Cavity with helium vessel, power coupler and tuner.

The cryogenic distribution system houses the control valves and heat exchangers to simplify the cryomodule and allow commissioning of the cryogenics before installation of the cryomodule.

The rectangular cryomodule with titanium rails offers several advantages over that used for the SNS. The rectangular design concept can be used for all of the RIA superconducting cavities and superconducting magnets. The module will cost less than half that of SNS. The smaller helium vessel simplifies construction and processing of the cavities, and decreases the cryomodule width, thereby decreasing the tunnel width. Also, the titanium rail and small helium vessel simplify fixturing and alignment of the cavities. The lower power rf couplers do not require helium gas cooling which simplifies the coupler and cryoplant, thereby decreasing the module and tunnel length. With the cryogenic controls adjacent to the module, the room temperature slot length for diagnostics and focusing elements can be reduced, again decreasing the tunnel length. The cavity tuner is removed from the cold mass and operated at room temperature for improved reliability and maintainability.

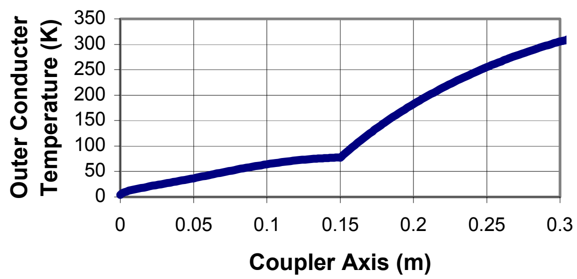

Figure 3. Temperature profile along outer conductor of the power coupler.

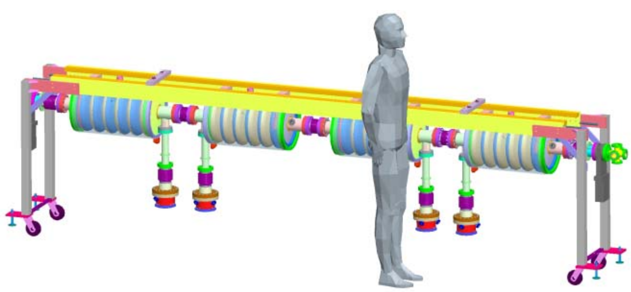

Figure 4. Clean room assembly of 2 K cold mass.

CONSTRUCTION AND TEST PLANS

A two cavity version of the rectangular cryomodule is under construction to demonstrate performance and costing. The cavities shown in Figure 2 are complete and will be tested in a vertical dunking Dewar in the summer of 2003. Next the 2 K cold mass will be assembled and then installed inside the cryomodule for testing by the end of 2003. Once the design has been demonstrated for elliptical cavities, a low beta version for the quarter-wave and half-wave cavities will be constructed.

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