A cryomodule for the RIA driver linac

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We present a cryomodule design for the superconducting linacs for the proposed Rare Isotope Accelerator Facility (RIA). This paper discusses the design of a cryomodule for all the drift-tube-loaded superconducting cavites required for the machine. The same basic design will be used for the low and medium velocity sections of the driver linac and also for sections of the radioactive ion beam (RIB) linac. Fundamental design choices such as separate vs. common beam and insulating vacuum spaces are driven by the clean fabrication techniques required for optimum cavity performance. The design can be adapted to a variety of cavity geometries.

INTRODUCTION

The US nuclear physics community proposes the construction of a Rare Isotope Accelerator (RIA) designed to accelerate a wide variety of ions from protons through uranium [1]. The machine consists of four main elements: a driver accelerator, a target station for isotope production, a post accelerator for isotopes produced at the target, and an experimental area (see Figure 1). The driver and post accelerators are linear machines using superconducting RF (SRF) accelerating cavities of various geometries, depending on the beam velocity. The low and medium velocity portions of the driver ($0.024<\beta<0.4$ where $\beta=v/c$) as well as the post accelerator use drift-tube-loaded (DTL) SRF structures operating at 4.6 K while the high velocity portion of the driver (β of 0.49, 0.61 and 0.81) uses elliptical structures. Figure 2 shows the various cavity geometries. The two highest velocity structures make use of existing Spallation Neutron Source (SNS) cavity geometry [2]. Cryomodule design for all elliptical cell cavities will closely follow the SNS model [3]. This paper addresses design concepts for cryomodules for the DTL structures.

DTL structures used in heavy ion linacs typically run at lower frequencies than elliptical cavities. Historically they have operated with common insulating and beam vacuum spaces. In the last decade substantial progress has been made in increasing the accelerating gradients for these structures, partly through application of techniques developed in the high velocity elliptical cell cavity community. Chief among these techniques is the removal of sub-micron particulate contamination on the cavity surface by high pressure water rinsing (HPWR) and development of clean handling techniques. To be effective, these techniques require that a clean environment for the cavity be rigorously maintained.

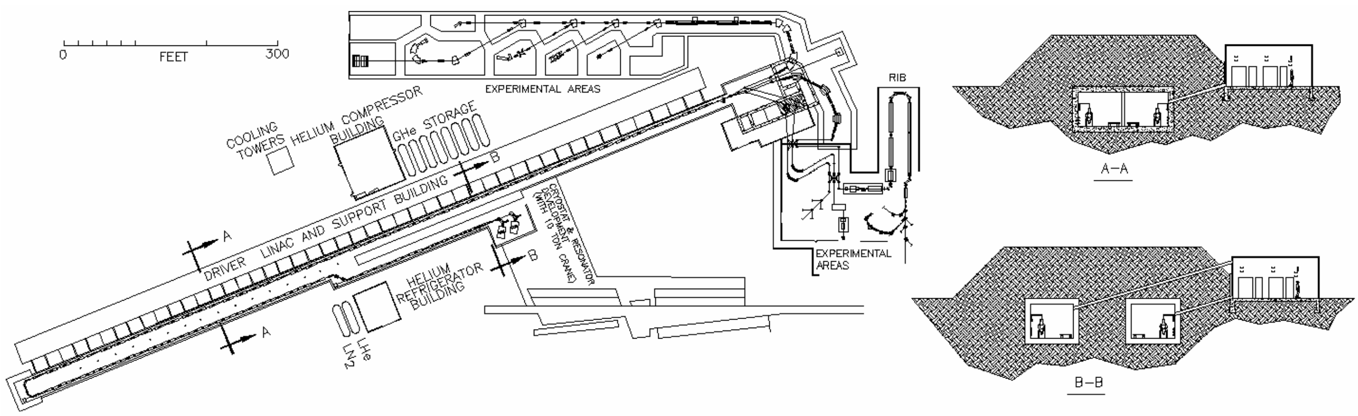

Figure 1 Layout of the Rare Isotope Accelerator (RIA) facility

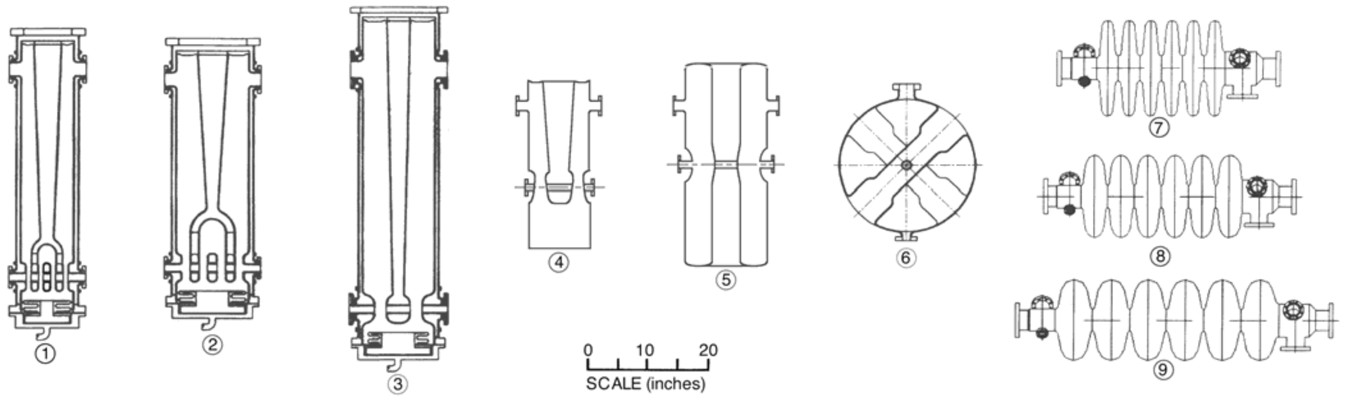

Figure 2 Cavity geometry for the RIA driver. Drift tube loaded structures 1-6 are suitable for the cryomodule described here while elliptical structures 7-9 will reside in SNS-style modules.

The cryomodule described here evolved from existing, successful designs at Argonne National Laboratory (ANL) with the addition of features that permit separate cryogenic and cavity vacuum systems while retaining the desirable elements of past designs.

CRYOMODULE DESCRIPTION

The top loading box-style cryomodule design concept is shown in Figure 3. Features include efficient use of interior space, ease of access and assembly, and ability to accommodate a variety of structure geometries in one basic design. A similar layout is used very successfully in an existing heavy ion linac at ANL, where resonators with geometries 1 and 2 in Figure 2 operate with a common beam and insulating vacuum.

Current SRF practice emphasizes cleanliness as a means of achieving the highest accelerating gradients. Separate beam and insulating vacuum spaces can be achieved in a top loading design via the angled vacuum vessel end walls shown in Figure 4. After the cavity string has been assembled in a clean room, gate valves at either end are closed. The assembly is suspended from the vacuum vessel top plate and lowered into the vessel where angled plates on the beam tube seal against the vacuum vessel end walls. A separate beamline vacuum allows the use of standard cryogenic techniques such as multilayer insulation (MLI), a forbidden practice where beam and insulating vacuums are common. Handling is greatly simplified as well since the size of the clean room compatible object is minimized.

Beam dynamics issues require module-to-module spacing to be minimized. The current design achieves about 0.5 m between active elements. Preliminary lattice calculations [4] indicate the spacing to be adequate in maintaining beam quality. Table 1 gives basic cryomodule parameters. The number of cavities required to achieve the required beam energy depends on the gradient achieved; therefore high

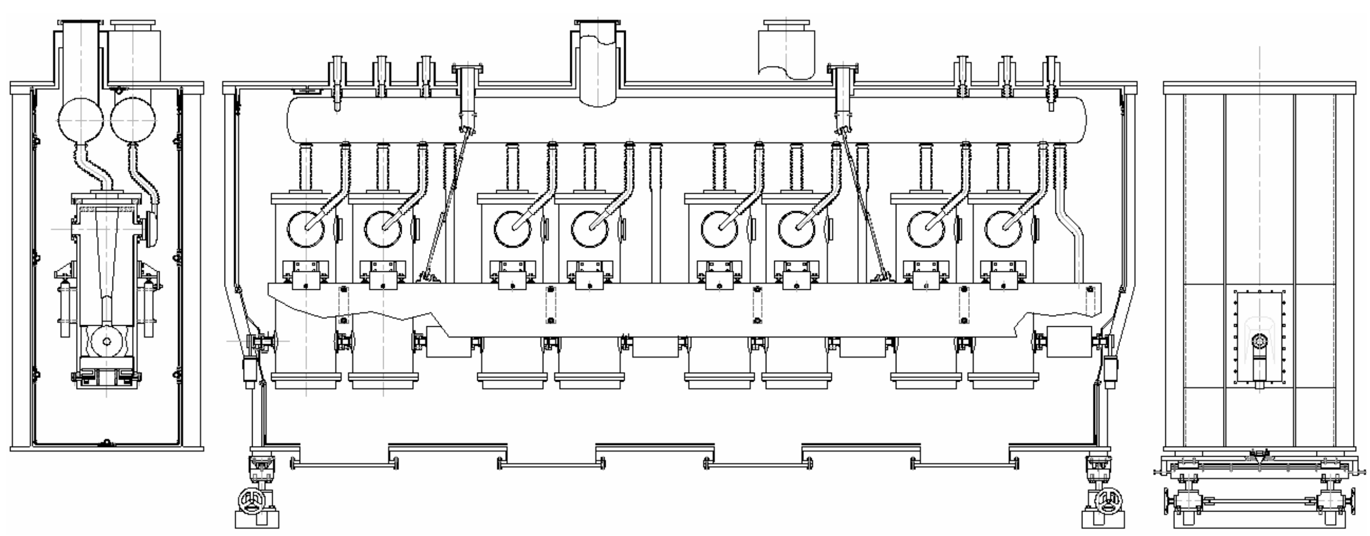

Figure 3 Top loaded box cryomodule concept showing separate beam and insulating vacuum spaces

Table 1 Driver linac parameters (DTL cavity sections)

Driver linac section	low velocity		medium velocity		total
Cavity frequency [MHz]	57.5	115	172.5	345	
Cavity geometry (see Figure 2)	1,2,3	4	5	6	
Cavities required (@20 MV/m E_{peak})	41	36	88	72	237
Cavities required (@22.5 MV/m E_{peak})	37	32	78	64	211
Cavities required (@27.5 MV/m E_{peak})	32	26	64	52	174

gradients are desirable to either reduce the overall length and cost of the driver or to provide operating margin. Original estimates of drift tube cavity performance were based on existing machines without separate beam and insulating vacuum spaces. Recent developments [5] using HPWR suggest that peak electric fields beyond the original 16 MV/m estimate are reliably achievable. Table 1 shows how the number of drift tube cavities falls as performance improves. There is an additional dynamic heat load imposed by higher gradient operation, with a potential factor of three increase in power dissipation per cavity, but the extra refrigeration cost is dwarfed by the savings associated with the need for fewer cavities (total system cost associated with DTL structures are estimated at roughly 400k$ per cavity).

Module length will be determined by the lattice and by handling issues. Current lattice configurations call for eight or nine cavities per cryomodule, with between two and eight focusing elements per module depending on lattice location. These elements are superconducting solenoids operating at 4.6 K with fields between 6 and 11 Tesla. This gives cryomodule lengths of around 4.5 to 5 meters, which is considered manageable for clean room handling and tunnel installation. Depending on gradient chosen, there will be between 20 and 30 of these cryomodules fabricated for the driver linac. The post accelerator contains approximately 100 additional DTL cavities (about 12 cryomodules).

SUPPORT SYSTEMS

The drift tube cavities operate at 4.6 K using a pool boiling/thermosiphon approach identical to that employed by the Positive Ion Injector (PII) cryomodules used in the ATLAS heavy ion linac at ANL [6]. The RIA cryogenic system concept is described in reference [7] and provides refrigeration totaling 5 kW at 4.6 K, 8.6 kW at 2.0 K, and 15.3 kW at 35 K in addition to 15 g/s liquefaction. These loads are based on the original 16 MV/m peak electric field gradient. An increase to 27.5 MV/m could mean a 30% reduction in cavity count, although the factor of three increase in dynamic heat load (assuming constant static load) translates to a 17% increase in required capacity at 4.6 K.

Input coupler development is underway. Drift tube structures can employ either fixed or variable coupling. Either form is suitable for this cryomodule. The adjustable coupler shown in Figure 5 couples magnetically to the cavity and is installed up through ports in the module bottom plate to minimize particulate contamination during coupler adjustment.

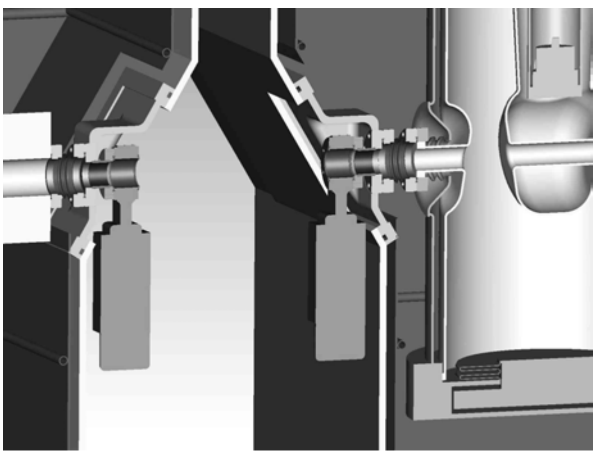

Figure 4 Detail of vessel end wall design showing isolated beamline in a top-loading design

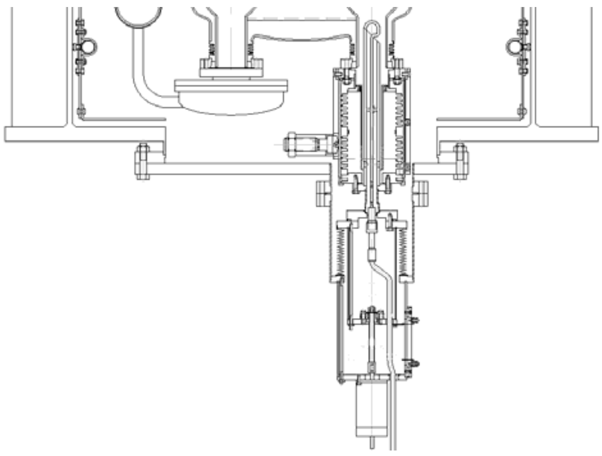

Figure 5 Adjustable input coupler concept for drift tube cavities

Cavity tuning may be accomplished using slow pneumatic tuners similar to those used in PII at ATLAS, consisting of a mechanical linkage actuated by a cold helium gas operated bellows which compresses or extends the cavity along the beam axis. Other mechanical tuners using cold stepper motors in vacuum or motors external to the cryostat are also compatible with this design. Such a tuner is effective in bringing the cavity on frequency after cool down and canceling the effects of slow pressure fluctuations caused by the cryogenic system during operation. For fast disturbances (e.g. microphonics) the cavities can either be overcoupled or employ PIN diode "fast tuners" similar to those used at ATLAS [8]. These devices each dissipate as much as several hundred watts at about 100K.

The cavities are mounted to a cross-braced frame assembly and aligned with respect to the beam line on this frame while in the clean room. After all clean components are assembled, the cavity string is isolated by gate valves on either end of the assembly. The string is removed from the clean room and suspended from the vacuum vessel top plate, after which the top plate assembly is lowered into the vacuum shell. Radiation shielding with multilayer insulation lines the walls and floor of the vacuum shell as well as the underside of the top plate. Large access ports are included to facilitate troubleshooting and maintenance in place, without requiring removal of the top plate assembly from the vacuum shell.

CONCLUSION

A box cryomodule geometry is well suited to the DTL SRF cavities which make up the low and medium velocity portions of the RIA driver linac as well as the post accelerator. Such a design builds on successful existing designs while incorporating new features such as separate insulating and beamline vacuum spaces, which can maintain ultra-clean cavities. Clean conditions enable the use of modern cavity fabricating and processing techniques which result in substantial gains in cavity performance. The rectangular cross section accommodates a variety of cavity geometries, permitting a single basic cryomodule design to cover a wide range in beam velocity. Assembly of a cavity string plus ancillary components is straightforward and permits a top-loading configuration consistent with close module-to-module spacing and separate vacuums.

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