SUPERCONDUCTING DRIFT-TUBE CAVITY DEVELOPMENT FOR THE RIA DRIVER

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Abstract

This paper reports the design and development of two intermediate-velocity superconducting cavities and design of an associated cryomodule for the RIA driver linac. The two cavity types are a 115 MHz, β_{GEOM}= 0.15 quarter-wave resonant (QWR) cavity, and a 173 MHz, β_{GEOM}= 0.26 half-wave loaded cavity. Both cavities are well-corrected for dipole and quadrupole asymmetries in the accelerating field. The cryomodule is being designed to incorporate a separate vacuum system for cavity vacuum to provide a particulate-free environment for the super-conducting cavities.

1 INTRODUCTION

The driver linac for the U.S. rare-isotope accelerator (RIA) facility [1,2] is capable of accelerating stable ions ranging in mass from hydrogen up to uranium with output energies from 400 MeV/nucleon for uranium and up to 900 MeV for protons. The linac is based on a set of superconducting resonators spanning the velocity region, $0.02<\beta<0.9$.

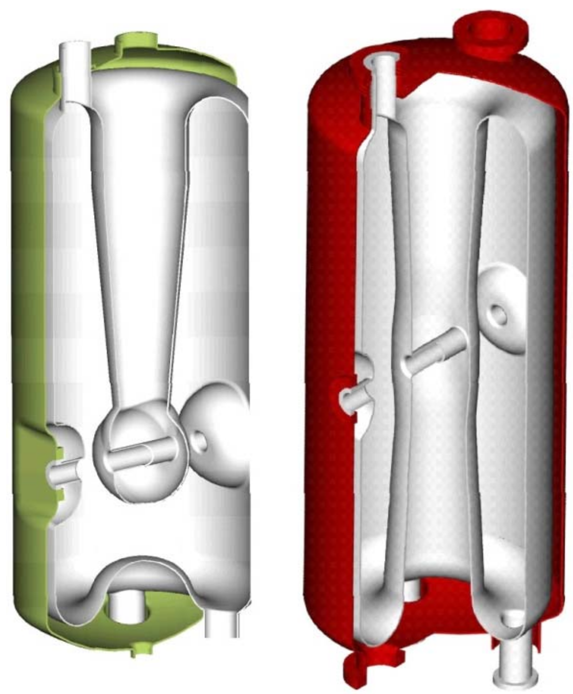

Figure 1. Cut-away views of the niobium cavity and helium jacket for the 115 MHz quarter-wave and 173 MHz half-wave resonant cavities

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The low velocity linac section, for v/c = $\beta \leq 0.1$, is formed of quarter-wave resonant cavities similar to those operated for years in existing superconducting (SC) heavy-ion linacs. The high-velocity section, $\beta \geq 0.5$, will employ the two elliptical-cell cavities developed [3] at Jefferson National Laboratory (JLAB) for the spallation neutron source (SNS) driver linac.

This paper discusses the two SC cavities required for the lower half of the intermediate-velocity region, $0.15 < \beta < 0.55$, a region for which, until recently, relatively little development work has been performed.

One recent development is the operation at several laboratories of SC drift-tube cavities at peak surface electric fields at and above 30 MV/m Reliable operation at these gradients could significantly reduce the cost of the RIA driver linac, but will require the development of ultra-clean processing and handling techniques similar to those developed for TESLA-type cavities. Such techniques have not heretofore been commonly applied to SC drift tube structures.

This paper also discusses a preliminary design for a drift-tube cavity cryomodule incorporating separate cavity and cryomodule vacuum systems, a departure from current practice, but required to maintain a particulate free environment for the SC cavities.

2 CAVITY DESIGN

2.1 Design and Numerical Modeling

Fig. 1. shows cut-away views of the niobium cavity and integral stainless-steel liquid helium jacket for the two cavities. Both cavities are formed of 1/8 inch niobium sheet, with an integral stainless steel helium jacket, also formed of 1/8 inch sheet, joined using brazed stainless-niobium weld transitions. In the RIA driver linac configuration, the 115 MHz QWR cavity covers a velocity range of $0.13 \leq \beta \leq 0.19$, and the 173 MHz half-wave unit from $0.13 \leq \beta \leq 0.19$.

The niobium outer wall of both cavities is a 30 cm cylinder with a toroidal shape terminating both ends. The toroidal shape provides good mechanical stability while using a minimum of niobium and may be more amenable to high-pressure rinse cleaning than would be a right-angled corner. Mechanical properties have been modeled using full finite element analysis (FEA) with the Pro/Mechanica software package. The designs are adequately stiff against changes in ambient helium pressure. Design of the interface with a mechanical slow tuner assembly is in progress.

The electromagnetic (EM) fields within the cavities were numerically simulated using the CST Microwave

Table 1. Electromagnetic parameters for the two cavities

type	*QWR*	*HW*
f	115 MHz	172.5 MHz
Bgeom	0.15	0.26
Length	25 cm	30 cm
QRs	42	58
at an accelerating field of 1 MV/m		
Epeak	3.2 MV/m	2.9 MV/m
Bpeak	57 G	78 G
rf energy	170 mJ	345 mJ

Studio software package. Resulting EM parameters are listed in Table 1. Surface fields are for an accelerating gradient of 1 MV/m, where the accelerating gradient is defined as the voltage gain for a particle of unit charge traveling at the synchronous velocity along the beam axis averagedover the interior length of the cavity along the beam axis.

2.2 Beam-Steering Corrections

Beam steering induced by the dipole fields in QWR structures causes unacceptable emittance growth in the RIA driver linac. Beam steering effects have been largely eliminated in the 115 MHz QWR cavity by tilting the faces of the drift tube and outer wall, in alternate directions, some 9° from vertical. The tilt introduces an electric dipole field which cancels the rf-magnetic-field-induced steering. Figure 2 shows the beam deflection as a function of particle velocity for a proton beam traversing the cavity operating at an accelerating gradient of 5 MV/m and a synchronous phase angle of 30°. Both the magnetic field steering and the electric field corrective steering vary as the sine of the synchronous phase angle, so the steering is effective for all rf phases and over the entire useful velocity range of the cavity, as is shown in Figure 2.

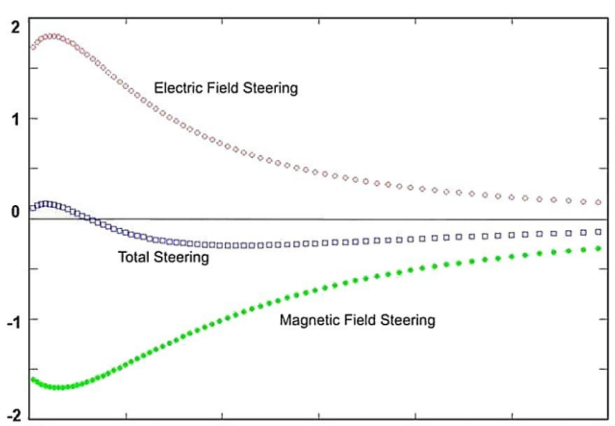
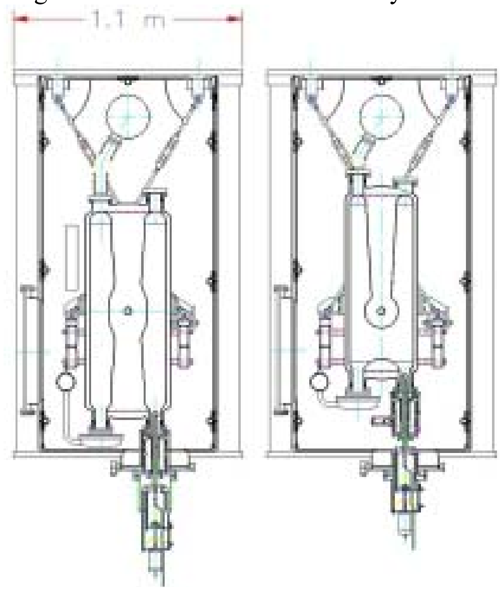


Figure 2. Beam deflection in mrad as a function of particle velocity β for a proton beam in the 115 MHz QWR cavity operating at 5 MV/m and synchronous phase of. 30°.

Figure 3.Section view of the box cryomodule



3 CRYOMODULE DESIGN

A preliminary design for a cryomodule for the SC drift-tube cavities is shown in Fig. 3. The box shape cryomodule readily accommodates and provides access to the variety of cavity types typical of SC heavy ion linacs, and has been used in several existing machines.

A new feature in the present design is the incorporation of separate vacuum systems for cryomodule and cavity. The separation will make it possible to assemble and seal a chain of cavities in an ultra-clean environment. This will minimize particulate contamination and provide the best opportunity for increasing cavity operating gradients to the level observed in off line tests.

The sections of the cryomodule shown in figure 4 show the paired support rails forming the 'strongback' for cavity and solenoid alignment. Figure 4 also indicates the location of lateral access ports for rf coupler installation and for possible on-line maintenance.

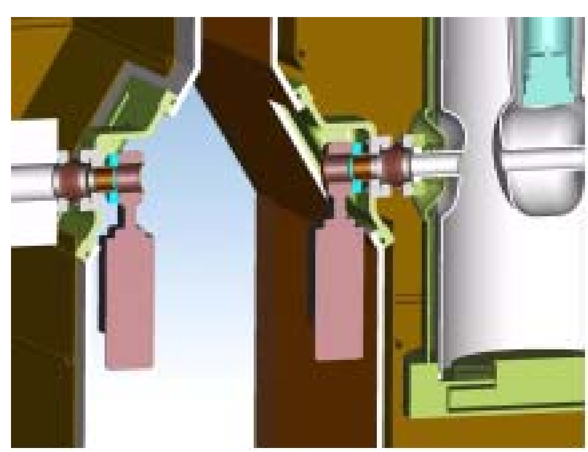


Figure 4. Section of the cryomodule interface region showing the room temperature beam-line valves.

By sloping the end faces of the cryomodule vacuum wall, as shown in Figure 4, a sealed cavity chain, including room-temperature beam-line valves, can be lowered intact into place for final assembly.

4 FUTURE PLANS AND ACKNOWLEDGEMENTS

Niobium prototypes of both the 115 MHz QWR cavity and the 173 MHz HW structure are presently being constructed with 1/8 inch niobium sheet of RRR ≥ 250. Design of the cryomodule is well-advanced, and construction of a prototype intended for on-line tests at the existing ATLAS SC heavy-ion linac will begin shortly.

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5 REFERENCES

[1] J. A. Nolen, paper MO302 in the proceedings of this conference (2002).

[2] C.W. Leemann, in Proceedings of the 2000 Linac Conference, Monterey, California, August 21-25, 2000, SLAC vR-561, p.331 (2000).

[3] M.M. White, paper M101 in the proceedings of this conference (2002).

[4] K.W. Shepard, in Proc. of the 10th Workshop on RF Superconductivity, Tsukuba, Japan Sept. 6-11, 2001.

[5] P.N. Ostroumov, K.W. Shepard, Physical Review Special Topics – Accelerators and Beams, vol. 4, 110101, 2001.

[6] M.P. Kelly, K.W. Shepard, M. Kedziein Proc 10th Workshop on RF Superconductivity, Tsukuba, Japan Sept. 6-11, 2001