SUPERCONDUCTING ACCELERATING STRUCTURES FOR A MULTI-BEAM DRIVER LINAC FOR RIA[*]

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Abstract

A superconducting multi-ion-beam driver linac for an rare isotope facility (RIA) can accelerate all ions from protons to uranium to energies of 400 MeV/nucleon and above with a beam power of several hundred kW. This paper describes the design of a group of superconducting cavities for that portion of such a linac with particle velocities between 0.017 and 0.5 c. The structures are designed for niobium and operation at 4.3 K. They range in frequency from 57.5 to 345 MHz. The three lowest-velocity cavities are of the coaxial quarter-wave line geometry; two types of 4-gap interdigital cavities and one type of 2-gap cavity. The three higher-velocity cavities are all two-drift-tube structures, of differing frequencies, but designed to have the same size and shape of outer housing, in order to minimize construction and cryostat costs. Results of numeric simulation are presented.

1 INTRODUCTION

This paper discusses the design of a set of superconducting accelerating structures which can form the front-end of a multi-beam ion linac intended as a driver for a rare-isotope production facility (RIA) [1,2, 3]. More particularly, we describe a set of drift-tube loaded cavities at harmonics of 57.5 MHz, capable of accelerating particles over the velocity range $0.017 < v/c < 0.6$.

Low-velocity superconducting cavities have been developed and used in numerous heavy-ion linacs, primarily configured as energy boosters for electrostatic accelerators [4]. This application, however, has generally been limited to particle velocities less than 0.2 c and low beam currents , typically at most a particle microampere. A linac driver for RIA thus requires extension of the technology for SC ion linacs both to higher beam currents and also to higher particle velocities.

The beam currents required for a RIA driver, although higher than for booster linacs, are still quite modest, at most 0.5 mA. Space charge effects are negligible and beam loss should be small, particularly since for the set of cavity designs described here, it was possible to maintain a clear aperture of 30 mm over the entire velocity range. The large aperture and short length which can be achieved with SC cavities allow the linac to be configured for very large transverse and longitudinal acceptance, providing not only for high transmission but also for great operational flexibility [5].

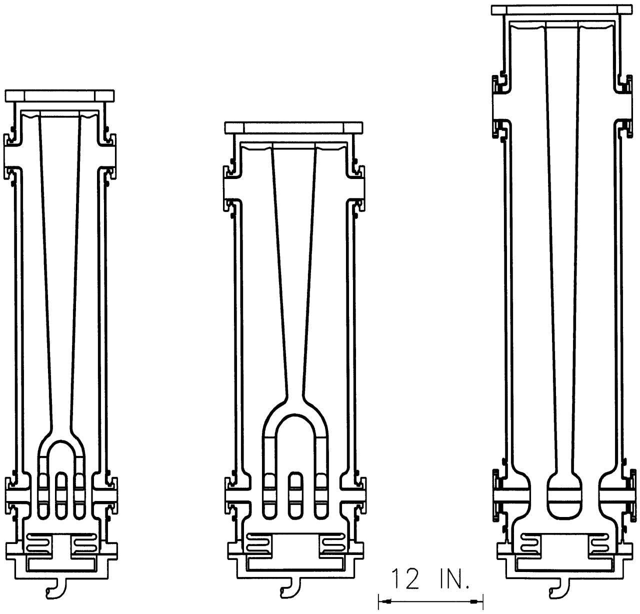

Figure 1 – Cross section view for the three lowest beta cavities for RIA, all operating at 57.5 MHz. From left to right they are: beta .021 fork cavity, beta .03 fork cavity, and beta .06 QWR. See text for details.

The extension of SC RF technology to higher velocities is also proving straightforward. Several prototype superconducting cavities for particle velocities $0.2 < \beta = v/c < 0.6$ have demonstrated good performance [6,7]. Recently, a single-cell version of the two-cell spoke loaded cavity described below has been successfully tested [7].

The cavities discussed in this paper fall into two distinct categories. The first category is closely related to existing designs presently used in various booster linacs. The a second category, for somewhat higher-velocities, is more recently developed and, as discussed below, will require somewhat different supporting systems.

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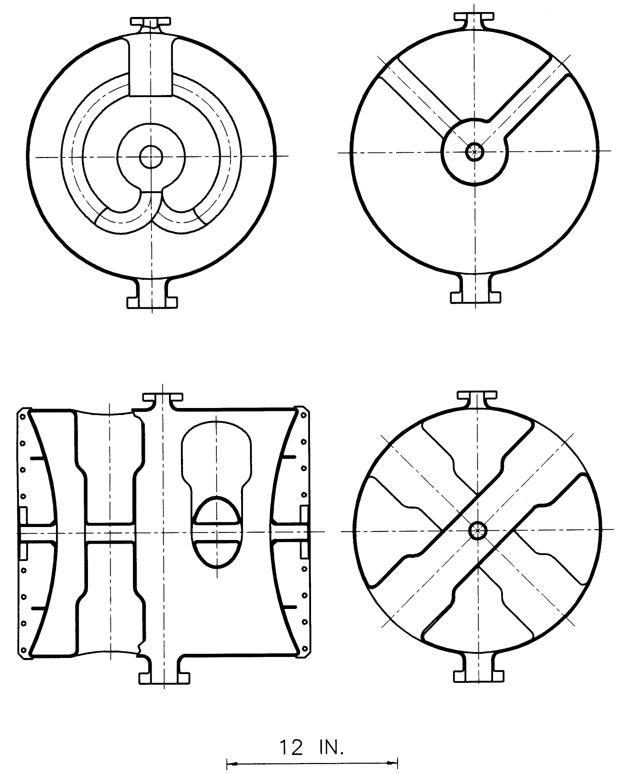

Figure 2 – Cross section view of three intermediate beta cavities for RIA. At the bottom of the figure are end and side views of a 345 MHz, beta = .4 spoke cavity. At the top of the figure are end views of both a 115 MHz beta .13 split-ring cavity, and also a 172.5 MHz beta .19 'lollipop' cavity. See text for details.

2 CAVITY DESIGN

2.1 Coaxial-line Cavities

The velocity range from the RFQ injector, .017 c up to roughly 0.1 c can be efficiently covered with the three types of coaxial-line structure shown in Fig. 1. All three of these cavity types are housed within individual stainless-steel jackets which provide an annular region for liquid helium. This design enables the cavities to be mounted in cryostats in which the beam vacuum and cryogenic vacuum are common, as has generally been the practice with SC ion linacs.

At the bottom of each cavity a niobium-bellows based slow-tuning mechanism is shown somewhat schematically. For the two 'fork' type four-gap cavities, the central 'drift-tube' extends across the housing and connects with the annular helium volume.

Visible in Fig. 1, near the top of the cavities, are two of three 2-inch diameter coupling ports on each cavity used to couple both the RF power into the cavity and also a VCX fast-tuning system. The fast tuning system is required to maintain phase control in the presence of microphonic fluctuations in the cavity eigenfrequency, since the beam loading will not be sufficient to produce adequate bandwidth to counteract microphonics.

2.2 Cavities with 44 cm Outer Shell

Figure 2 shows three cavity types, all with the same 44 cm diameter outer niobium shell, which span a frequency range from 115 to 345 MHz and a useful velocity range from 0.1 to more than 0.5 c. These three different types all use the same design cryostat, in which eight cavities mount together in a common liquid-helium vessel, and the beam and cavity-internal vacuum system is separate from the cryostat insulating vacuum.

By designing all three types with the same outer shell, all elements of the cryostat design will be the same for all three types of resonator. Since the combined number of cavities of these three types, more than two-hundred, is nearly half the total required for the entire driver linac, the savings in resonator and cryostat tooling and construction could be substantial. As shown below, constraining all three types to the same shell has entailed little or no compromise in cavity parameters.

Table 1: Geometric Parameters for the six drift-tube cavity types required for the RIA driver linac

Peak Beta -	Cavity Class -	Frequency (MHz)	Active Length (cm)	Housing Dimensions (cm)		Drift-tube Dimensions (cm)			
				Length	Diameter	No. of DT	Diameter	Length	Aperture
0.02	Fork	57.5	18	112	22	3	12.0	3	3
0.03	Fork	57.5	26	110	30	3	12.4	4	3
0.06	QWR	57.5	20	135	30	1	12.0	10	3
0.13	Split-ring	115	36	46	44	2	12.0	9	3
0.19	Lollipop	172.5	36	46	44	2	12.0	8	3
0.40	Spoke	345	38	48	44	2	*	9	3

Table 2 – Electromagnetic properties of the six drift tube cavities for the RIA driver linac. The peak fields and rf energy are referenced to an accelerating gradient of 1 MV/m.

Peak Beta -	**Cavity Type** -	**Frequency (MHz)**	**RF Energy (mJ)**	**E peak (MV/m)**	**B peak (G)**	**QRs** -	**Gradient (MV/m)**	**Voltage (MV)**	**Number Req'd.**
0.02	Fork	57.5	77	4.1	68	12.6	4	0.72	2
0.03	Fork	57.5	120	4.0	91	18.2	4	1.04	5
0.06	QWR	57.5	148	3.3	60	19.2	5	1.0	32
0.13	Split-ring	115	165	3.9	190	21.9	4	1.44	40
0.19	Lollipop	172.5	127	3.5	144	46.5	5	1.8	72
0.40	Spoke	345	142	3.2	80	78.1	5	1.9	96

2.3 Cavity Geometric Parameters

Table 1 shows the principle geometric parameters for the cavities. A clear aperture of 3 cm diameter has been maintained for all cavities in order to maximize the transmission and acceptance and to minimize the interception of beam halo [5]. For the three types of coaxial-line cavity, the axis of the housing is perpendicular to the beam axis. For the remaining three types, the axis of the housing is coincident with the beam axis.

In Table I, no drift-tube diameter is shown for the spoke-loaded cavity since for this cavity, the 'drift-tube' is formed by the spoke itself.

2.4 Cavity Electromagnetic Parameters

Table 2 shows the principle electromagnetic parameters for the various cavities, modelled numerically using MAFIA. The peak surface fields are comparable to those achieved in previously developed cavities of the same type and frequency [4]. In all cases, the electromagnetic parameters are at least as favourable as has been assumed in earlier discussions of possible designs for a RIA driver linac [3].

The 115 MHz split-ring cavity is expected to be limited to 4 MV/m gradients because of its relatively high surface magnetic field. The high magnetic field is the price paid for folding a 115 MHz quarter-wave line into the 44 cm diameter shell. Another possibility for this structure would be a two-gap single drift tube QWR Such a structure would probably provide less voltage, but would be cheaper to fabricate, would have broader velocity acceptance, and would not require forced-flow helium cooling. A detailed cost-performance comparison will be required to make a final choice.

2.3 Spoke-loaded Cavity

The spoke cavity design presented here has a spoke with a central section of reduced diameter. The step in diameter provides two benefits. By varying the length of the central section, the cavity frequency can be tuned without changing the housing diameter, which has been helpful in frequency matching. Also, the increased diameter at the outer ends of the spoke provides a modest reduction in the peak surface magnetic field.

3 CONCLUSIONS AND FUTURE PLANS

A set of SC drift-tube cavities have been designed which have large aperture and cover the velocity range required of this class of structure for a multi-beam driver linac for RIA. Warm models of the structures are being constructed to permit fine-tuning of the geometric parameters to match the frequencies of the cavity types.

Tooling and fabrication procedures are being developed for prototyping the 2-cell spoke and lollipop cavities with an eye both to performance and for economical quantity production.

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