

# SUPERCONDUCTING INTERMEDIATE-VELOCITY DRIFT-TUBE CAVITIES FOR THE RIA DRIVER LINAC\*

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## Abstract

This paper reports the status of prototypes for two types of niobium superconducting drift-tube cavity. The structures are intended for use in the ion-linac driver-accelerator for the proposed rare-isotope accelerator (RIA) facility, and cover an intermediate range of particle velocities,  $0.18 < \beta < 0.5$ . Both structures fit within a cylindrical housing of roughly 18 inch diameter and 15 inch length, and incorporate two drift tubes to define the accelerating field. The cavity types are a 172.5 MHz lollipop-loaded cavity for (peak)  $\beta = v/c = 0.19$ , and a 345 MHz spoke-loaded cavity for  $\beta = 0.4$ . The results of numerical electromagnetic and mechanical simulations will be presented and several evolving design features discussed. These include, for example, a design for an integral stainless-steel helium jacket which provides for very good frequency stability against changes in helium pressure. We also discuss the reduction of beam steering effects using small, asymmetric changes in the drift-tube geometry.

## 1 INTRODUCTION

Recent development at ANL of SC niobium cavities has focused on accelerating structures suitable for the proposed rare isotope accelerator (RIA)[1,2]. In several earlier papers we have presented preliminary designs for a full set of drift-tube cavities suitable for the RIA driver linac [3,4]. Here we update and discuss in more detail the design of two cavities which cover the relatively unexplored range of intermediate velocities,  $0.2 < \beta = v/c < 0.6$ .

The two cavities, shown in section in Fig. 1, are a 172.5 MHz lollipop-loaded structure and a 345 MHz spoke-loaded structure.

We note that several single-cell SC spoke cavities have already been built and tested [5,6,7]. Many cavities will be required for the 1.3 GeV RIA driver linac, so that multi-cell cavities will be much more efficient. For the accelerating structures discussed here, two cells have been settled on as providing the best balance between maximizing voltage gain and maximizing velocity acceptance [2].

It should also be noted that the cavities described here operate at multiples of (805/14) MHz, reflecting a recent shift in the bunch frequency of the RIA driver to permit using in the final sections of the RIA driver linac the same 805 MHz SC cavities and cryomodules being developed for the SNS project.

## 2 CAVITY PROPERTIES

### 2.1 Electromagnetic Properties

The electromagnetic properties of the cavities have been numerically modeled using the codes MAFIA and also CST Microwave Studio. Table 1 shows the principal parameters. An aluminum 86% scale model of the spoke cavity was built to check and correct frequency before cutting niobium. Perturbation measurements of the EM fields generally confirmed the numerical results to within a few percent.

Note that the OD of the housing of the lollipop cavity is

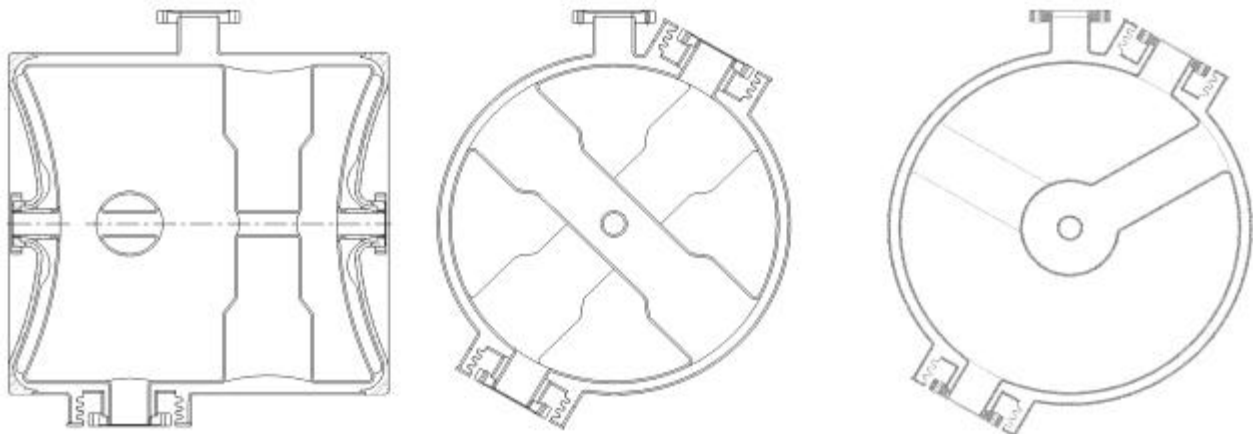


Figure 1: Side and end sectional view of the 345 MHz two-cell spoke cavity, and end section of the 172.5 MHz two-cell lollipop cavity. The housing OD is 48.6 cm for the spoke cavity and 51.6 cm for the lollipop.

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Table 1: Principal parameters of the cavities.

Parameter	Lollipop	Spoke
Frequency	172.5 MHz	345 MHz
Active Length	36 cm	38 cm
Diameter	47.8 cm	44.8 cm
Frequency	172.5 MHz	345 MHz
Rf Energy*	158 millijoule	152 millijoule
$E_{pk}$ *	3.8 MV/m	3.5 MV/m
$B_{pk}$ *	118 Gauss	86 Gauss
QRs	49	85
Voltage Gain at 5 MV/m, 30 phase	1.56 MV	1.65 MV

\*At an accelerating gradient of 1.0 MV/m

3 cm larger than for the spoke cavity. Initially, we had hoped to keep the diameter of the lollipop cavity the same as that of the spoke cavity, in order to benefit from using the same tooling for both structures. This constraint on diameter produced an unacceptably high peak magnetic field for the lollipop cavity,  $B_{pk} = 161$  gauss/(MV/m) [4]. In the present design, the diameter of the inductive stem was increased, which decreased  $B_{pk}$  to 118 gauss, but required an increase in diameter of 3 cm to keep the frequency at 172.5 MHz. This diameter increase is sufficiently small, however, that a single cryostat design will still be adequate for both cavities.

## 2.2 Mechanical Properties

A primary mechanical requirement is that the cavities be sufficiently stiff that fluctuations of pressure in the helium cooling bath do not induce excessive RF frequency shift and phase noise.

In this regard, the end-faces of the cavity are particularly critical and have been dished-in, with a spherical radius of 51.3 cm. They have also been reinforced with 12 radial gussets formed of 1/4 inch niobium welded to the exterior side of the niobium dished ends.

Another technique for reducing pressure-induced deformation is to join the cavity to an integral jacket to contain the liquid helium. By attaching the jacket to the cavity at the beam ports, the inward pressure on the niobium cavity ends can be balanced by the outward pressure on the helium jacket. With the cavity end face thus effectively supported at both the OD and the center beam port, the resultant strain on the niobium end face in effect forms a toroidal bulge with maximum inward displacement at roughly half the cavity diameter.

Note that the electromagnetic fields on the interior surface of the end flange are predominately electric near the beam axis and predominately magnetic near the outer diameter. An inward deflection in a region of magnetic surface field raises the RF frequency and in a region of electric field lowers it. By properly shaping the support gussets, the profile of the inward bulge can be controlled in such a way as to balance the two terms, and substantially reduce the net frequency shift. The 345 MHz spoke cavity design shown in Figure 1 has been

tailored in this manner using numerical FEL modeling of the mechanical properties. The estimated maximum deflection caused by application of 21 PSI helium pressure is .005 inch. The effect on RF eigenfrequency from this deformation on both end-faces is estimated to be 6 KHz. Such a result compares favorably with the observed shift of approximately 100 KHz in the single cell prototype spoke cavity under similar circumstances [4].

The integral helium jacket is essentially the same in both the spoke and lollipop cavities and is formed of 1/8 inch stainless-steel (SS) sheet for the cylindrical portion, and 1/4 inch SS on the ends, with the corner reinforced by flanging as shown. At the beam ports the transition from niobium to SS will be made either by brazing, or by beam-welding with a vanadium transition section.

## 3 INTERACTION WITH BEAM

Figure 2 shows the voltage gain as a function of particle velocity for the two cavities. The two cavity types can accelerate with 85% or more of peak efficiency over a velocity range from 15 to 53% the velocity of light. This covers an energy range from 10 to 170 MeV/nucleon.

### 3.1 Beam Steering

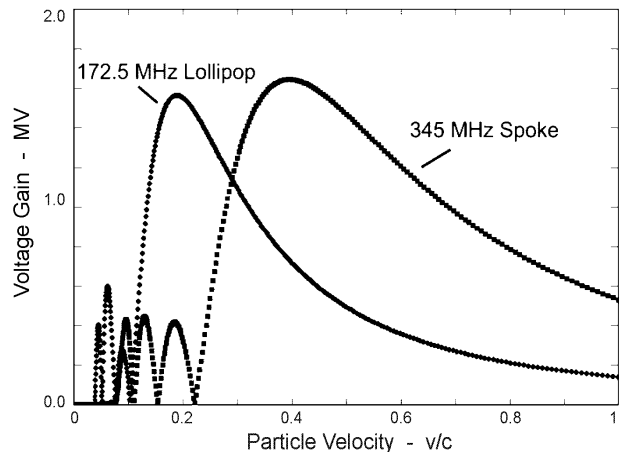


Figure 2: Voltage gain per unit charge as a function of particle velocity for the two cavities, each operating at a gradient of 5 MV/m and a phase of -30°.

The lollipop cavity can under some circumstances cause objectionably large beam steering. This problem surfaced when we increased the diameter of the inductive post to minimize the magnetic field. The post, however, introduces a substantial transverse electric field, particularly in the central accelerating gap. The horizontal component of the transverse field is shown in Figure 3 in the curve labeled 'no correction'.

The transverse electric field causes the beam to be steered an amount dependent on particle velocity and operating phase, as is shown in Figure 4 the curve labeled uncorrected.

Such transverse steering is particularly objectionable in the RIA driver linac, which must accelerate multiple

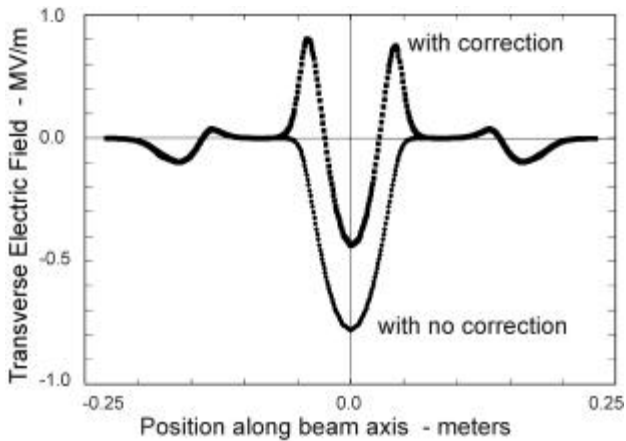


Figure 3: Transverse horizontal electric field along the beam axis of the 172.5 MHz lollipop-loaded accelerating structure, shown for two different drift-tube designs.

charge state beams [8,9]: for multi-Q beams, steering, particularly at the lower velocities, can cause unacceptable emittance growth.

The steering can be greatly reduced by tilting the interior faces of each of the two drift-tubes by a rotation of 4 degrees about a horizontal axis perpendicular to the beam axis. As shown in Figure 3, this does not actually eliminate the transverse field, but rather introduces a counter-steering, so that the integrated effect, as shown in Figure 4 in the curve marked 'corrected', is to greatly reduce steering over the entire useful velocity range, from 0.15c upwards.

#### 4 CONCLUSIONS AND FUTURE PLANS

We have completed designs for two superconducting niobium cavities suitable for use in the RIA multi-beam driver linac for the velocity range from 0.15 to 0.55c. The

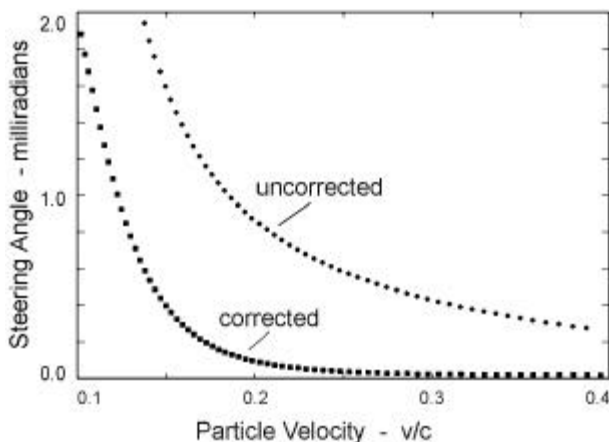


Figure 4: Steering deflection angle for a particle of unit charge to mass ratio accelerated through a single 172.5 MHz lollipop-loaded cavity operating at 5 MV/m and a phase of  $-30^\circ$ .

designs for both cavities exhibit good electromagnetic and mechanical properties, and are consistent with extrapolating from single-cell cavity performance to operation at gradients of 5 MV/m or higher [6,7].

Work is proceeding to complete and test prototype cavities. Tooling is currently under construction for forming elements of the two cavities from 1/8 inch sheet niobium. Development of a niobium - vanadium - stainless-steel weld transition which will enable electron-beam (EB) welding of the cavity into the housing is well advanced. Both cavity prototypes are expected to be complete in early 2002.

#### 5 ACKNOWLEDGEMENTS

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