LOW AND MEDIUM VELOCITY CAVITY DEVELOPMENT FOR THE RIA DRIVER LINAC*

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Abstract

This paper reports the design and development of three niobium superconducting drift-tube cavities intended for the ion-linac driver-accelerator for the proposed rare-isotope accelerator facility. The cavities discussed cover a range of particle velocities $0.12 < \beta < 0.5$. The results of numerical simulation of mechanical and electromagnetic properties are presented and several evolving design features are discussed. This includes a method of reducing beam steering by shaping the drift tubes in single-drift tube QWR cavities.

1 INTRODUCTION

The principal element of the U.S. rare-isotope accelerator (RIA) facility [1,2] will be a superconducting, 1.4 GeV ion linac capable of accelerating ions of any stable isotope from hydrogen to uranium and delivering several hundred kilowatts of beam at energies of 400 MeV/nucleon for uranium and more than 900 MeV for protons [3]. The highly-flexible linac is configured as an array of more than 400 short, independently-phased superconducting (SC) cavities of nine different types. which span a range in frequency from 57.5 to 805 MHz, and a range in velocity from $0.02 < \beta = v/c < 0.9$.

The cavity array can be tuned to provide a variable velocity profile, which allows the linac to operate efficiently over the full mass range of ions. The array of short cavities permits a lattice incorporating frequent transverse focusing elements, which provides very large longitudinal and transverse acceptance. This enables a novel mode of operation, accelerating beams of multiple-charge states [4]. Using multiple-charge-state beams substantially increases current for ion-source-performance limited beams, and also enables the use of multiple strippers without substantial loss of beam, which reduces the size and cost of the driver linac.

Of the required nine different types of SC cavities, most of the types are very similar, or even identical, with cavity types that have already been developed for other linacs. In sequence of increasing velocity, the first three cavity types closely resemble existing cavities which were developed for, and have been operating for years in several existing SC heavy ion linacs [5]. The last two cavity types, the 805 MHz $\beta = 0.61$ and $\beta = 0.81$ six-cell cavities, are both presently being developed at JLAB for the U. S. spallation neutron source (SNS) project [6].

The remaining four cavity types, covering the relatively unexplored [7] velocity range $0.15 < \beta = v/c < 0.55$, are

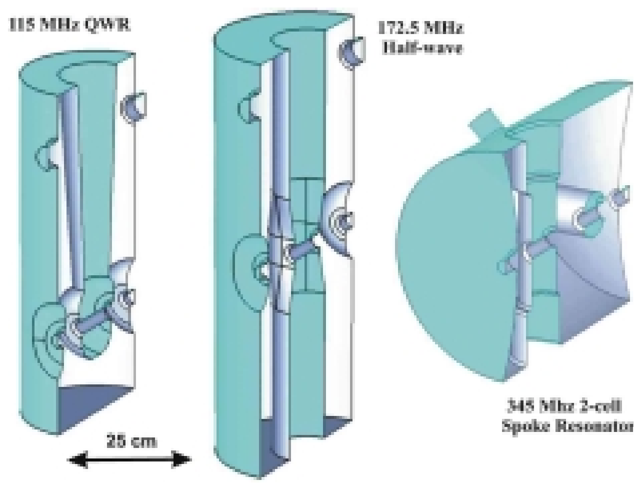

Figure 1: Sections of the niobium shell for three SC cavities covering a velocity range of $0.11 < \beta < 0.6$

the highest SRF development priority for the presently ongoing, funding-limited R&D specifically directed toward RIA [8,9,10]. This paper discusses the design and development of the three drift-tube loaded cavities of this intermediate-velocity class. Section views of these three cavities are shown, scaled to size, in Figure 1.

2 CAVITY DESIGN

The cavities were numerically modeled using the CST Microwave Studio software package. Electromagnetic parameters for the three cavity types are shown in Table 1. Peak surface fields and the RF energy are scaled to an accelerating gradient of 1 MV/m: the gradient is defined to be the energy gain per unit charge for a synchronous particle, averaged over the interior length of the cavity.

Table 1: Electromagnetic parameters for the three intermediate-velocity SC drift-tube cavities

Type	QWR	Half-wave	Spoke
Frequency	115 MHz	172.5 MHz	345 MHz
β_0	0.15	0.25	0.39
Active Length	25 cm	30 cm	38 cm
QRs	76	88	101
Epeak*	3.7 MV/m	3.1 MV/m	3.5 MV/m
Bpeak*	76 G	88 G	101 G
RF Energy*	201 mJ	361 mJ	153 mJ
*at an accelerating gradient Eacc = 1 MV/m			

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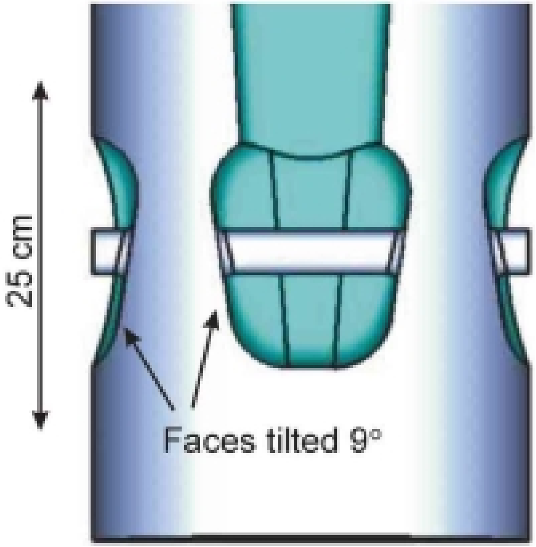
Figure 2: Detail of the beam-interaction region of the 115 MHz QWR cavity



The interior (active) length is defined to be the distance between the beam entrance face of the cavity and the beam exit face of the cavity.

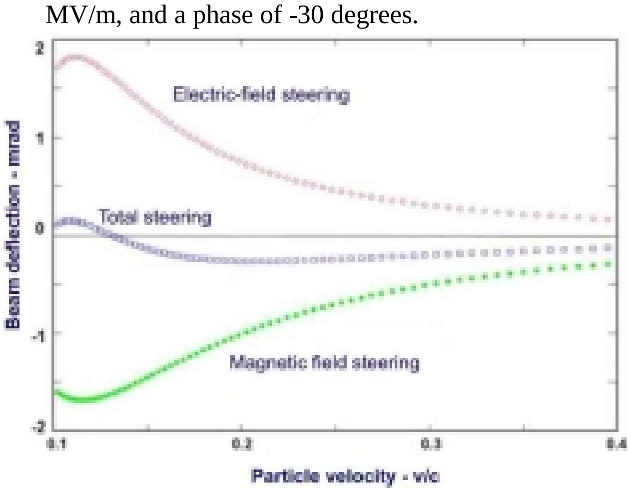
2.1 The 115 MHz Quarter-wave (QWR) cavity

The 115 MHz, $\beta = 0.15$ QWR cavity is of straightforward design, with parameters similar to earlier designs of this class [5]. A new feature is the introduction of corrective transverse electric fields to compensate beam steering effects.

Beam steering due to RF magnetic field has emerged as a problem in some superconducting drift-tube cavities [11]. In the quarter-wave class of cavity, RF magnetic fields on the beam-axis are sufficiently large in some cases to cause objectionable amounts of steering. For single-drift-tube QWR cavities, appropriate shaping of the drift tube faces can reduce the steering to acceptable levels [12].

By tilting the faces of the drift-tubes and also of the entrance and exit faces of the cavity housing, it is possible to introduce transverse electric fields which deflect the beam by an amount which has an RF phase-dependence proportional to the sine of the phase angle, the same phase dependence as for the magnetic field deflection. Adjusting the direction of the electric field to oppose the magnetic-field-induced steering provides a corrective technique. As is shown in Figure 3, it is possible to reduce the magnetic field induced steering by roughly a factor of ten over most of the useful velocity range and for all RF phases.

Figure 3: Steering of a proton beam for a single 115 MHz QWR cavity operating at Eacc = 5 MV/m, and a phase of -30 degrees.



It should be noted that a similar corrective effect can be obtained by simply offsetting the beam vertically with respect to the center of the resonator beam aperture [12]. In the case of the 115 MHz QWR cavity, however, an offset of approximately 1/2 cm would be required. Such a large vertical offset would appreciably reduce the available aperture, and would complicate the alignment process, so that in this case tailoring the drift-tube geometry is the preferred corrective method.

2.2 The 172.5 MHz Half-wave Cavity

The 172.5 MHz half-wave cavity has been chosen to replace the two-drift-tube lollipop cavity previously specified for the RIA driver linac for two reasons:

1. Detailed numerical ray tracing has shown that beam deflection by rf magnetic fields is particularly problematic in the lollipop cavity. While, as was discussed above, steering can be fairly well corrected in single drift-tube QWR cavities, in two-drift-tube QWR structures such as the lollipop and split ring no adequate method of correction is known. In the half-wave type (and spoke type) of cavity, the RF magnetic field on the beam axis is zero, to first order, and steering effects are small.

2. Maintaining a reasonable outer diameter for the originally proposed lollipop cavity yielded peak surface RF magnetic fields in excess of 750 gauss at the assumed 5 MV/m gradient. Such high magnetic fields could become performance limiting if the allowable peak surface electric field is increased, as recent development tests of drift-tube cavities using high-pressure water rinse cleaning techniques indicate feasible [13,14,15].

2.3 The 345 MHz Double-spoke Cavity

Two prototype single-spoke cavities at 340 and 350 MHz and $\beta = 0.3$ and 0.4 have already been constructed and tested. This work is being extended to develop a two-spoke cavity in order to increase the voltage per cavity and reduce the cavity count, and cost, for the RIA driver.

Design work for the double-spoke cavity has included finite-element mechanical analysis of the cavity, including both the 1/8 inch niobium shell and the integral stainless-steel jacket. The jacket and cavity design has been integrated to minimize the change in RF eigenfrequency caused by changes in pressure of the ambient helium bath [16].

3 STATUS OF PROTOTYPE CAVITIES AND FUTURE PLANS

Niobium for prototypes of all three cavities has been obtained, and a number of the required dies for forming elements of the cavities have been completed.

All of the dies for the double-spoke cavity are complete, and development of methods and parameters for electron-beam welding to join together the 49 separate niobium pieces of the prototype cavity is in progress. The completion of fabrication and initial tests are expected in the first half of 2002.

In recent tests at ANL and LANL, two 340-350 MHz single-cell spoke-loaded cavities have shown excellent performance, achieving accelerating gradients substantially above the 5 MV/m projected for RIA [14,15]. To follow up these results, tests of the double-spoke cavity will include evaluation of assembly techniques and the operating environment for this cavity.

Design of the 115 MHz QWR and the 172.5 MHz half-wave cavities is complete, and some of the dies have been fabricated. Completion of the both prototypes is scheduled for late 2002.

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