

# SUPERCONDUCTING $\beta=0.15$ QUARTER-WAVE CAVITY FOR RIA

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## Abstract

A 109 MHz niobium quarter-wave cavity, fully configured with an integral stainless steel helium jacket, has been built and tested as part of the R&D for the Rare Isotope Accelerator (RIA) driver linac. The two-gap cavity is designed to accelerate ions over the velocity range  $0.14 < \beta < 0.24$ . Final processing of the cavity RF surfaces, including high-pressure rinsing and assembly of the cavity with a high-power, variable rf coupler, were all performed under clean-room conditions. Cold test results including high-field cw operation, microphonics, and helium pressure sensitivity are discussed.

## INTRODUCTION

A superconducting (SC) linac for the Rare Isotope Accelerator (RIA) ion driver requires several hundred SC cavities of several different types spanning the velocity range  $0.02 < \beta < 0.8$  [1]. We report here on the first cold tests of a prototype for one of these types, a  $\beta=0.15$  niobium quarter-wave resonator (QWR). Although the QWR cavity discussed here will initially be used in an energy upgrade of the existing ATLAS accelerator, it has been developed specifically for the RIA driver linac as one of a set of three SC cavities spanning the intermediate velocity range  $0.12 < \beta < 0.5$ . The other two cavities are a half-wave cavity, reported elsewhere at this conference [2], and a two-cell spoke-loaded cavity which has been reported previously [3]. The cold-test results for the

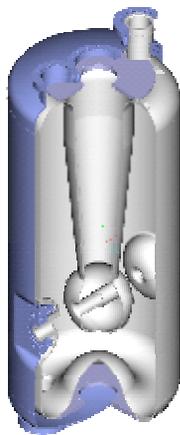


Figure 1: A partially cut away view of the RIA quarter-wave cavity generated in Pro/Engineer. The active length along the beam axis is 25 cm.

QWR cavity discussed below represent the completion of development of the entire set of three cavities, in all of which the performance substantially exceeds the requirements of RIA.

## DESIGN AND CONSTRUCTION

The design of the  $\beta=0.15$  QWR is shown in Figure 1. The inner niobium shell is shown in gray while the stainless-steel helium vessel is shown in blue. Electromagnetic parameters are listed in Table I. The cavity design was developed using numerical finite-element models in full 3D, using Pro/Engineer for the mechanical properties and CST Microwave Studio for the electromagnetic properties.

The useful accelerating range spans the velocity region  $0.10 < \beta < 0.30$ , a velocity somewhat higher than for most existing quarter-wave structures. A correction for beam steering, inherent in quarter-wave structures due to the rf magnetic field in the beam region, has been incorporated

<b>Frequency</b>	109.13	MHz
<b>Geometric Beta</b>	0.144	v/c
<b>Active Length</b>	25	cm
<b>QRs</b>	40	ohm
<b>R/Q</b>	548	
<i>below for <math>E_{acc} = 1</math> MV/m</i>		
<b>E<sub>peak</sub></b>	3.2	MV/m
<b>B<sub>peak</sub></b>	58.3	Gauss
<b>RF Energy</b>	0.17	Joule

Table I: Electromagnetic properties of the QWR cavity

by tilting the drift-tube faces by approximately  $9^\circ$  [4]. The top and bottom of the QWR cavity are terminated in a large-radius toroid to avoid sharp corners and facilitate both chemical processing and rinsing, and also high-pressure water rinsing.

The cavity was formed of high-purity, RRR > 250, 3mm niobium sheet. The center conductor, toroids, and drift-tube faces were hydroformed, while the outer housing was rolled from flat niobium sheet. The niobium cavity-shell is enclosed in an integral stainless-steel helium vessel, as is the case for all of the ANL-developed RIA cavities. The stainless jacket is joined to the niobium at the cavity ports by a vacuum braze with pure copper. All nb-nb joints are electron-beam welded.

## SURFACE PROCESSING

### Chemical processing

It is well established that electropolishing of a niobium surface gives a substantially smoother and brighter rf surface than a heavy buffered chemical polish (BCP) and experimental data indicate that rf losses are reduced



Figure 2: The electropolished rf surface of the QWR just prior to the final closure weld.

particularly at real operational surface fields of  $>20$  MV/m [5].

The following technique has been used at Argonne for electropolishing drift-tube cavities with small aperture ports, where electropolishing of the closed cavity is impractical. As applied to the QWR cavity, prior to completion of the closed cavity, each of four major niobium sub-assemblies was given a heavy electropolish (100~150 microns), as can be seen in Figure 2. The sub-assemblies were then electron-beam welded together, following which a very light BCP (8 $\mu$ m) was used to remove any residual oxide, etc. resulting from the weld.

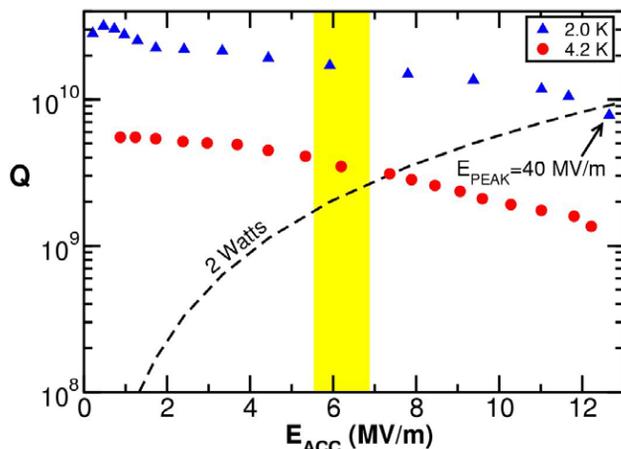


Figure 3: Initial test results for the RIA quarter-wave resonator. The value of  $Q$  at 4.2 K exceeds  $10^9$  even at peak surface fields as high as 40 MV/m.

### High-pressure rinse and assembly

After BCP, the cavity was cleaned with a high-pressure water rinse (HPR) for 90 minutes and dried in the clean-

room. It was then transported to a clean assembly area where a variable coupler and the cavity vacuum system, also cleaned by HPR, were connected, completing the cavity vacuum system. The sealed system was then removed from the clean area and installed in the test cryostat.

## COLD TESTS

The oil-free cavity vacuum system was allowed to

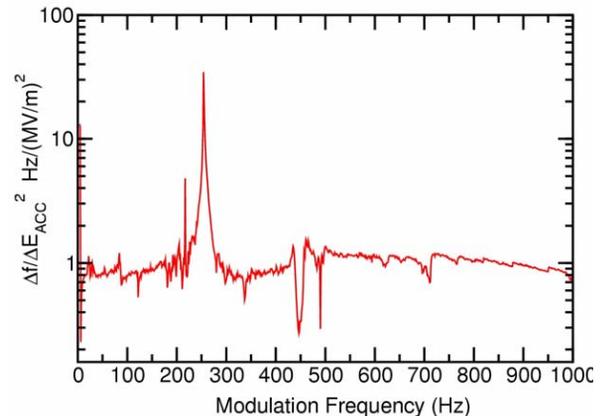


Figure 4. The amplitude of the Lorentz force transfer function. There are no low lying modes below 200 Hz.

pump to a few  $10^{-7}$  torr for 24 hours prior to cooldown. The cavity was cooled to 4.2 K with particular care to limit the time between 80 and 150K to about 30 minutes in order to avoid hydride formation.

### Superconducting performance

The cavity was cooled to 4.2 K, cooling rapidly ( $\sim 1/2$  hour) from 150 K to 80K to avoid hydride formation. Following a brief period of conditioning with up to 200 watts of power, primarily to 'burn through' low-level MP barriers, the performance detailed in Figure 3 was observed.

No significant electron-loading was observed. We note that the nominal residual resistivity is 3 n $\Omega$  at 4.2 K and less than 2 n $\Omega$  at 2 K. Very little 'Q-slope' is observed at either 2 K or 4.2 K, and the  $Q$  remains high even at the highest gradients. The gradients were finally limited by a thermal-magnetic quench at an accelerating field above 12 MV/m, corresponding to a peak surface electric field of more than 40 MV/m.

The cavity performs sufficiently well at 4 K that no refrigeration advantage would be gained by operation at 2 K.

### Microphonics

Microphonics is an important issue for all RIA cavities, since beam loading will be relatively small and any additional RF bandwidth required for microphonics could impact the cost of RF power.

The relevant acoustic properties of the QWR cavity are characterized by the Lorentz-force transfer function, which identifies mechanical modes which couple to the rf

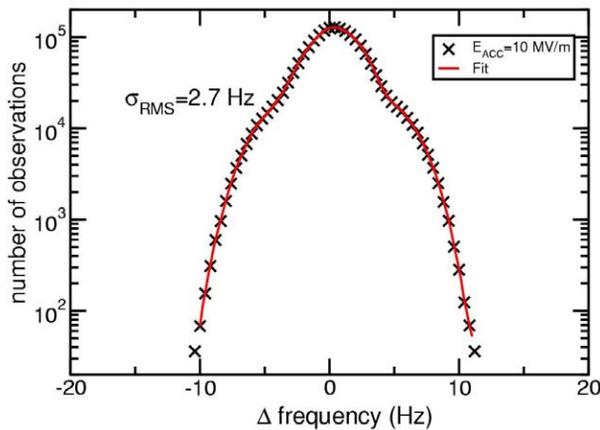


Figure 5: Probability density for quarter-wave eigenfrequency deviations for cw operation at  $E_{ACC}=10$  MV/m.

eigenfrequency. The transfer function, shown in Fig 4, was measured by modulating the rf drive power and observing the resulting cavity rf frequency response. No significant acoustic modes were observed below a frequency of 200 Hz.

The measured probability density of rf eigenfrequency shifts in stable cw operation is shown in Figure 5. for operation at  $T=4.2$  K and  $E_{ACC}=10$  MV/m. Data was collected for a total of 300 seconds in three separate measurements and then summed. Measurements were performed using a very low noise reference (HP 8665B) and a cavity resonance monitor (CRM) device. The

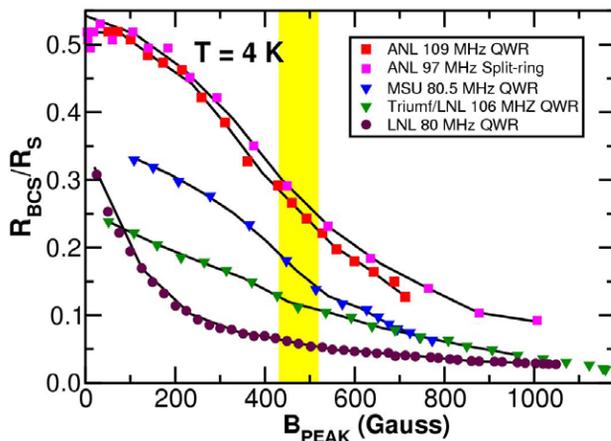


Figure 6: A comparison of recent experimental results to the BCS limit for surface resistance. ANL cavities received a heavy electropolishing.

spectral shape is well described as a pair of Gaussians. The rms frequency jitter is only 2.7 Hz even though we have not yet incorporated a planned mechanical damper.

## DISCUSSION AND CONCLUSIONS

A measure of the cavity surface quality for the RIA QWR along with five other quarter-wave cavities at similar frequencies is shown in Figure 6. The curves comes from published electromagnetic parameters and Q-curve data, shown here in the form of the reciprocal of the effective surface resistance  $1/R_s$ , as a function of the (peak) surface rf magnetic field. This quantity is normalized to the calculated BCS surface resistance [6] for each cavity, a value of  $1/R_s$  equal to one represents the theoretical maximum.

Results in figure 6. are all for cavities tested recently and assembled with some manner of clean handling. We note the cavity surfaces were prepared by BCP, except for the those cavities processed at ANL, where we use electropolishing and generally observe smoother surfaces than for BCP. All of the cavities shown operated at rf magnetic fields as high as 1000 Gauss or more. The two electropolished cavities, however, show substantially higher values of  $Q_0$  ( $R_{RES} \sim 3-4$  n $\Omega$ ) and, more importantly for actual use, reduced Q-slope and lower surface resistance ( $R_{TOTAL} \sim 15$  n $\Omega$ ) at operationally useful field levels.

We have designed a QWR cavity suitable for production and tested the prototype in a realistic accelerator environment. The results substantially exceed the RIA design goals in all respects, and demonstrate that it is possible to produce drift-tube cavities capable of operating at 4.3K at peak surface electric fields well above 20 MV/m while maintaining a high-field Q well above  $10^9$ .

## ACKNOWLEDGMENTS

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