COLD TESTS OF A SUPERCONDUCTING CO-AXIAL HALF-WAVE CAVITY FOR RIA

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Abstract

This paper reports cold tests of a superconducting niobium half-wave cavity with integral helium vessel, the design of which is suitable for production for the Rare Isotope Accelerator (RIA) driver linac. The cavity operates at 172 MHz and can provide more than 2 MV of accelerating voltage per cavity for ions with $0.24<\beta<0.37$. Cavity rf surfaces were prepared using electropolishing, high-pressure rinsing and clean assembly. Measurements of Q_0 show a residual rf surface resistance R_S = 5 nΩs in both 2 K and 4 K operations. The cavity can be operated at 4.5 K with E_{Acc} >10 MV/m (E_{Peak} >30 MV/m). Performance exceeds RIA specifications of an input power of 12 Watts at 4.5 K and E_{Acc} = 6.9 MV/m. RMS frequency jitter is only 1.6 Hz at E_{Acc} = 8 MV/m and T = 4.5 K as determined from microphonics measurements in a realistic accelerator environment connected to the ATLAS refrigerator.

INTRODUCTION

The Rare Isotope Accelerator (RIA) superconducting (SC) multi-ion driver requires ~390 SC cavities of several different types spanning the velocity range $0.02<\beta<0.8$ [1]. We report here on the cold tests of a prototype for one of these types, a β=0.26 niobium half-wave resonator (HWR). The HWR cavity discussed here will initially be used in an energy upgrade of the existing ATLAS accelerator, however, 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 quarter-wave cavity, reported elsewhere at this conference [2], and a two-cell spoke-loaded cavity which has been reported previously [3]. The complete set of three cavities all substantially exceed the performance requirements of RIA.

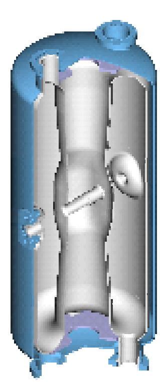

Figure 1: A partially cut away view of the RIA half-wave cavity generated in Pro/Engineer. The active length along the beam axis is 30 cm.

FABRICATION

The design of the β=0.25 half-wave resonator (HWR) is shown in Figure 1. with electromagnetic parameters in Table I. The inner niobium shell is shown in gray while the stainless-steel helium vessel is shown in blue. 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.

Table 1: Electromagnetic properties of the HWR cavity

Frequency	170	MHz
Geometric Beta	0.26	v/c
Active Length	30	cm
QRs	57	ohm
R/Q	241	
below for Eacc = 1 MV/m		
Epeak	2.9	MV/m
Bpeak	78	Gauss
RF Energy	0.338	Joule

The useful accelerating range spans the velocity region $0.24<\beta<0.40$. The top and bottom of the HWR 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, 3 mm 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.

PROCESSING AND ASSEMBLY

Electropolishing

Electropolished surfaces like those shown in Figure 4. are known to be substantially smoother than those achieved using standard buffered chemical polish (BCP). Electropolishing has been used here to remove between 100 and 150 microns of niobium from all of the critical rf surfaces. Results shown here together with other recent results for ANL cavities indicate that electropolishing

Figure 2: Electropolished niobium components of the RIA half-wave cavity.

reduces Q-slope in drift-tube cavities operating at 4 K as had been previously observed for elliptical cell cavities running at 2 K.

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 HWR 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 (8µm) was used to remove any residual oxide, etc. resulting from the weld.

Clean room assembly

Clean processing and assembly techniques have been systematically applied for the first time to drift-tube cavities at ANL and our results show that clean techniques may be used to repeatably achieve high gradients in drift-tube cavities.

Techniques and facilities currently in place at Argonne and used with the half-wave cavity include:

- A versatile electropolish apparatus which can accomodate various drift-tube parts
- An ultra-pure water high-pressure rinsing apparatus which can be tilted for different cavity geometries
- A large curtained cleanroom area for the assembly of cavities and couplers (See Figure 3)
- A pair of test cryostats, one vertical and one horizontal which for a separate and clean cavity vacuum system

Figure 3: Clean room assembly of the HWR together with a variable coupler and pumping system.

COLD TESTS

After installation into the vertical test cryostat the oil-free cavity vacuum system was allowed to pump to the low 10-7 Torr range for 24 hours prior to cooldown. The cavity was cooled to 4.2 K while limiting the time between 80 and 150K to about 30 minutes in order to avoid hydride formation.

Performance

The cavity was conditioned through multipacting in a couple of hours using up to 200 Watts of available rf power. No significant electron-loading was observed. 'Q-slope' is minimal for both 2 K or 4.2 K operations, and the Q remains high even at the highest gradients. The gradients were finally limited by a thermal-magnetic

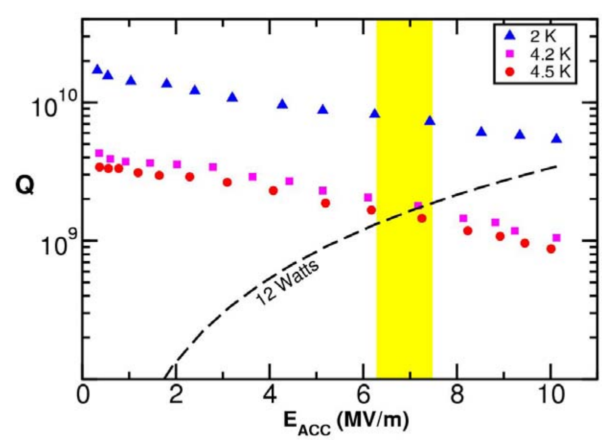

Figure 4: RIA half-wave resonator test results. The band indicates the RIA performance goal. The electropolished rf surface shows little Q-slope even in 4 K operation.

quench at an accelerating field above 10 MV/m, corresponding to a peak surface electric field of more than 30 MV/m. Cavity performance at 4.2 K is such that no refrigeration advantage would be gained by operation at 2 K.

MICROPHONICS

Microphonics levels in the RIA cavities will be key to determining both the cost of rf power for the driver linac and the fast tuning requirements. Microphonics measurements on the half-wave cavity have been performed here using an ultra-low noise rf signal generator and cavity resonance monitor (CRM) electronics capable of resolving eigenfrequency shifts as small as 0.1 Hz.

Measured eigenfrequency shifts for the half-wave cavity operating at both low and high fields are shown in Figure 5. The sample rate for each data set was 10 kHz with a sample time of 60 seconds each.

Observed frequency jitter is only 1.6 Hz rms, nearly independent of the rf power dissipated in the cavity. This observation is consistent with the very low helium pressure sensitivity measured to be –5 Hz/Torr and a measured Lorentz detuning coefficient of only -0.68 $Hz/(MV/m)^2$.

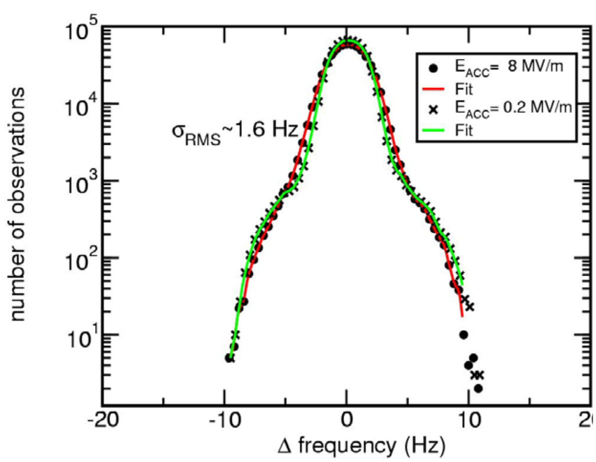

Figure 5: Microphonics measurements in the RIA half-wave cavity at low field level (crosses) and at E_{ACC}=8 MV/m (circles).

With the good mechanical stability of this half-wave geometry, the microphonics lie well within the expected beam loaded bandwith for RIA. An estimate of the beam loaded cavity bandwidth based on a voltage gain per half-wave cavity of 2 MV, a stored energy of 0.34 mJ and beam current of 0.5 mA for protons gives a value of 10 Hz or 6x the measured rms microphonics even with no additional fast tuner. However, additional fast tuning, such as with a VCX, piezoelectric device or overcoupling, will almost certainly be used to ensure phase stability.

CONCLUSION

We have designed and built a HWR 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 4.2 K at peak surface electric fields well above 20 MV/m while maintaining a high-field Q above 10^9.

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