COLD TESTS OF THE RIA TWO-CELL SPOKE CAVITY

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Abstract

This paper reports recent cold tests of a two-cell 345 MHz spoke-loaded superconducting cavity built and tested for the U.S. RIA project driver linac. This cavity establishes a new performance record for λ/2 structures. RF surfaces were prepared using electropolish, high-pressure water rinsing and clean assembly techniques. At a realistic operating field of E_{ACC}=7 MV/m (E_{PEAK}=24 MV/m) the cavity has a residual surface resistance of R_{RES}=12 nΩ with minimal Q-slope even in 4 K operation. In addition the cavity operates field-emission-free up to E_{ACC}=12 MV/m (E_{PEAK}=41 MV/m). With a 3 cm aperture the cavity provides 3 MV of accelerating potential with 15 Watts of input power and useful acceleration over the velocity range 0.3c < v < 0.6c while operating at 4 K. A fully integrated stainless-steel housing with niobium-to-stainless steel braze transitions has been demonstrated and is suitable for production cavities.

1 INTRODUCTION

In the mid-1990's the SCRF group at Argonne began development of cavities for the intermediate velocity range required for heavy-ion acceleration in the Rare Isotope Accelerator (RIA) driver linac. Lower beta ($0.04<\beta<0.15$) TEM-cavities for heavy-ion linacs and high-beta ($\beta\sim1$) elliptical cell cavities for electron linacs have operated for years, however, the intermediate velocity region ($0.2<\beta<0.8$) had received relatively little development effort. The first cavities prototyped for RIA were a pair of 350 MHz single-cell bare niobium spoke cavities, one for β=0.3 and the other for β=0.4. Two years after the initial construction, high-pressure water rinsing and clean assembly, performed at Los Alamos for the β=0.3 cavity and separately at Argonne for the β=0.4 cavity, were applied and resulted in cavities running at high fields (E_{PEAK}>40 MV/m) with low RF losses and minimal field emission [1-3].

This early R&D established for the first time the use of clean techniques in achieving high performance in TEM (drift-tube) cavities. High-pressure water rinsing and clean room assembly led to a revolution in field performance for elliptical-cell cavities in the early and mid-1990's, however, it was speculated that because of their more complicated geometries the same techniques may not yield the same benefits for TEM-cavities. This has proven not to be the case and the results presented here along with recent results from other institutions demonstrate that TEM cavities may be operated with low RF losses and high peak surface fields comparable to those typically achieved for elliptical cell cavities.

2 SURFACE PROCESSING

2.1 Construction

The major niobium components of the two-cell spoke resonator were hydro-formed from 3 mm RRR=250 niobium sheet. The niobium housing diameter is 48 cm with an active length of 39 cm. The transverse spoke elements were formed in halves and then electron beam welded together. The niobium housing was rolled from flat 3 mm sheet. The spherical end walls were die-formed and then stiffened with 12 radial gussets cut from 6.25 mm niobium sheet. All dies are entirely suitable for a large-scale production for RIA. The three major niobium components of the two-cell cavity are shown prior to the final closure weld in Figure 1.

An integral stainless steel helium jacket surrounds the niobium housing and was rolled from 3mm sheet while the stainless steel end walls were machined from plate stock. Liquid helium is contained in the annular space, of about ½ inch, between the niobium cavity and the stainless steel jacket. A niobium to stainless steel transition, using a pure copper braze material, was used for the two axial beam ports, of 3 cm diameter, and the three radial coupling ports, of 5.08 cm diameter.

2.2 Electropolish

The cavity access ports are not sufficiently large to permit electropolishing of the completed cavity. To achieve the minimum surface roughness on the completed RF surface, the niobium elements of the cavity as shown in Figure 1 were initially electropolished removing between 100-150 microns of niobium from the inner surface only. The completed cavity was then finally processed using a short duration chemical polish in a

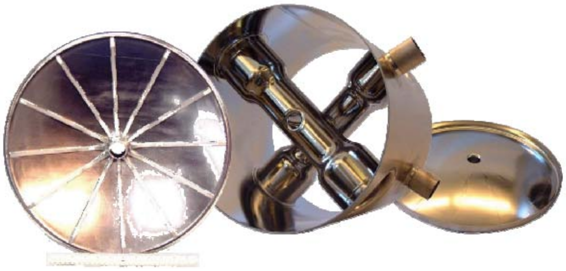

Figure 1. Three pieces of the RIA two-spoke cavity after receiving a heavy electropolish.

Figure 2. A horizontal test cryostat for the two-cell spoke cavity being moved into a clean assembly area.

solution of 1:1:2 BCP at T = 15 C to remove about 10 microns of material and any possible weld residue. This technique greatly reduces the surface roughness that would result from a heavy BCP alone. Following the BCP, the cavity was rinsed and filled with clean deionized water in preparation for high-pressure rinsing.

2.3 High-pressure Rinsing

The ANL high-pressure rinsing system, consisting of a high-pressure pump and an automated spray wand, was used to remove particulates from the interior cavity surface prior to final assembly into a test cryostat. The rinsing system supplies 15 liters per minute of ultrapure deionized water through eight 6.1 mm diameter jets at a nozzle pressure of 115 bar. The entire apparatus rests in a curtained clean area.

For the two-cell spoke high-pressure rinsing was performed for 80 minutes using 320 gallons of ultra-pure water and the cavity was dried in the clean room for 72 hours.

2.4 Clean Assembly

Final preparation of the two-cell spoke cavity was performed with the latest ANL clean processing facilities and hardware including:

- A clean room high-pressure rinse system using ultra-pure deionized water
- A large high ceiling clean room for assembly of the entire test cryostat
- A new test cryostat permitting a separate (clean) cavity vacuum system
- A particulate-free high-power variable RF power coupler

3 COLD TESTS

3.1 Two-cell Spoke Cavity Results

In a recent series of tests the two-cell spoke cavity has been cooled to liquid helium temperatures three separate times. Tests following the first cool down to 4.2 K were performed with up to 5.5 kW of RF power for pulse conditioning of surface emitters at the higher fields. The observed Q at low fields was $\approx 1.3\text{x}10^9$. During the initial cool down the cavity spent considerable time (~18 hours) in the temperature region (T=100 K to 150 K) where hydride precipitation is known to occur and which has been shown to lead to a decreased cavity quality factor Q. After performing the initial Q-curve measurements it was decided to warm the cavity to T=200 K and to cool down a second time. During the second cool down the cavity spent only 20 minutes in the hydride formation region and, in fact, the measured Q_0 was substantially higher with a value of $2.0\text{x}10^9$. The increase implies the presence of hydrogen Q-disease following the first cool down and also verifies that a fast cool down mitigates the effect.

Following each of the first two cool downs there was some electron loading observed first at accelerating fields around 5 MV/m as evidenced by a measured x-ray yield. This was caused by particle contamination from a cavity backfill procedure required to repair vacuum leaks during the first assembly of the cavity into the cryostat.

The cavity was cooled a third time, this time following an additional final high-pressure rinse and taking care to cool quickly through the hydride formation

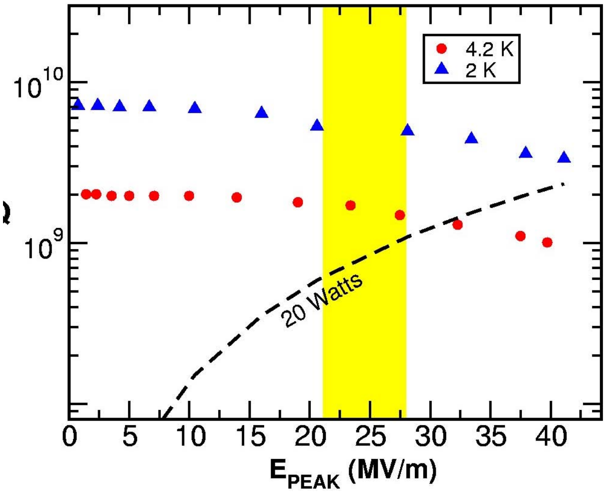

Figure 3. Measured Q-curve performance of the two-cell spoke cavity. The yellow band indicates the proposed range of operation for RIA cavities.

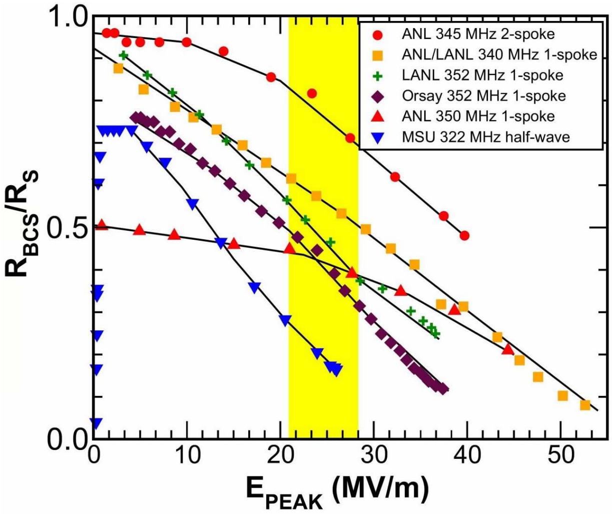

Figure 4. A measure of the surface quality of λ/2 (spoke and half-wave) cavities tested at T = 4 K - 4.3 K.

region. The two-cell spoke showed no field emission during these tests as indicated by the lack of any measurable x-ray emission even at the highest fields. Q-curve results from the latest series of cold tests are shown in Figure 3. RF losses are small with a Q_0 corresponding to a residual surface resistance R_S<10 nΩ. No measurable field emission is observed even at E_{PEAK}=41 MV/m and, with this electropolished surface, we see minimal "Q-slope" in both 2 K and 4 K operation. The two-cell spoke cavity establishes a new high-field performance record for λ/2 (spoke and co-axial half-wave) cavities, operating at E_{PEAK}=27.5 MV/m, the highest field called for in any of the RIA cavities, with an input power of P_{IN}=14 Watts and with 4 K operation.

3.2 Surface quality in λ/2 cavities

Recently, considerable development effort has been devoted to λ/2 cavities with frequencies near 345 MHz both for RIA and other projects [1,2,4-6]. Cavity surface quality for six of these cavities is shown in Figure 4. in a format which removes the effects of differing geometries. The data comes from published Q-curve data which has been divided by the published geometrical factor (G) to obtain the quantity $1/R_S$, the reciprocal of the RF surface resistance. This quantity is compared to the calculated BCS surface resistance [7] for each cavity. A value along the y-axis equal to one thus represents the theoretical maximum. Results generally show the total RF surface resistance roughly equal to twice the BCS value at operational fields. This constitutes excellent performance for TEM cavities and would be entirely suitable for RIA operations. Notably the two-cell spoke cavity, which exhibits an even lower surface resistance than for the other cavities, is the only cavity for which the surface-damaged layer (~100 microns of niobium) was removed using electropolishing rather than buffered chemical polish.

4 CONCLUSION

The SCRF group at Argonne has developed and tested a full production quality prototype two-cell spoke cavity which operates at f_o=345 MHz and has β_{opt}=0.4. This follows on earlier RIA R&D on single-cell spoke cavities. which demonstrated high-field performance in long-term cold tests and was the proof-of-principle for the use of clean techniques with TEM-class cavities. Recent test results in a fully jacketed multi-cell spoke cavity cold tested in a realistic operating environment show excellent high-field performance with E_{ACC} up to 12 MV/m (E_{PEAK}=41 MV/m) and with low RF losses (R_S=5-10 nΩ) and very little Q-slope even in 4 K operation. The cavity presently operates field-emission-free over the entire range of fields. The two-cell spoke cavity work constitutes a successful test of all of the construction and processing techniques needed to produce high performance multi-cell spoke cavities for the RIA driver linac.

5 ACKNOWLEDGEMENTS

The authors gratefully acknowledge the efforts of our undergraduate students Scott Gerbick, Chad Muir and Benjamin Mitchell who made important contributions to the experimental work presented here.

This work was supported by the U.S. Department of Energy, Nuclear Physics Division, under contract number W-31-109-ENG-38.

6 REFERENCES

[1] M.P. Kelly, K.W. Shepard, M. Kedzie, G. Zinkann, in Proc. 2001 Particle Accelerator Conf., June 18-22, 2001, Chicago, IL (2001).

[2] T. Tajima et al., Proc. Workshop on Spoke Cavities, http://lib-www.lanl.gov/documents/g/00796120.pdf

[3] K.W. Shepard, M.P. Kelly, M. Kedzie, T. Schultheiss, in Proc. 2001 Particle Accelerator Conf., June 18-22, 2001, Chicago, IL (2001).

[4] T. Grimm et al., in Proc. 2003 Particle Accelerator Conf., May 12-16, 2003, Portland, OR (2003).

[5] T. Tajima et al., in Proc. 2003 Particle Accelerator Conf., May 12-16, 2003, Portland, OR (2003).

[6] Guillaume Olry, in Proc. 2003 Particle Accelerator Conf., May 12-16, 2003, Portland, OR (2003).

[7] H. Padamsee et al., RF Superconductivity for Accelerators, p. 88.