Cavity Development for RIA

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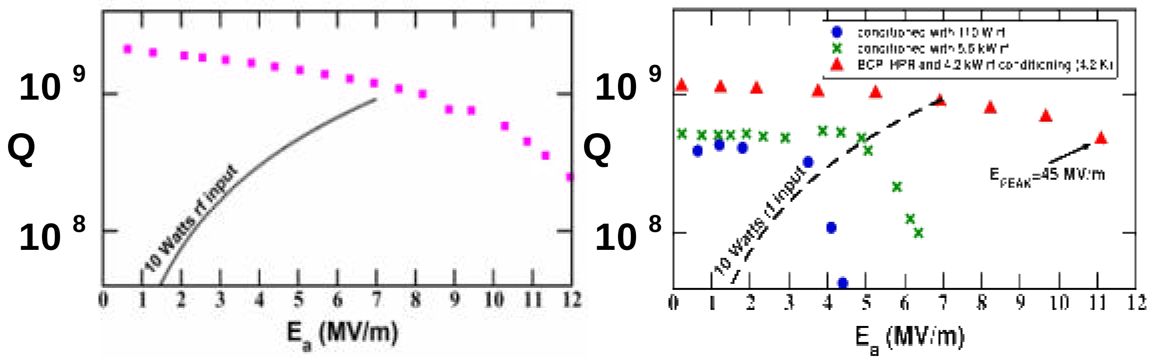
R&D Topic: Main Linac

Abstract

The SCRF group at Argonne is developing five types of superconducting niobium cavities to cover the velocity range required by the RIA driver linac. Earlier RIA cavity R&D at ANL produced two prototype 350 MHz single-cell niobium spoke cavities which achieved excellent performance in long-term cold tests. This work clearly established the effectiveness of clean processing and handling techniques to achieve high fields and low RF losses in TEM-class (drift-tube) cavities. In the course of this work we have expanded cavity processing facilities for ultrapure high-pressure water rinsing and clean room assembly of cavities and cryostats. We have designed and are at varying stages of prototype construction of full production models of a 115 MHz quarter-wave, a 172 MHz half-wave, a 345 MHz two-cell spoke, and two types of 345 MHz three-cell spoke cavities for the RIA driver linac. All of the cavities are housed in an integral stainless-steel helium vessel. The two-cell spoke prototype has been completed and tested in a new cryostat which maintains the cavity cleanliness by employing separate cavity and cryogenic vacuum spaces and a clean variable power coupler. Experimental tests of the prototype cavity show low RF losses (5-10 nΩ surface resistance), low levels of microphonics (Δf~5 Hz rms at E_{ACC}=7 MV/m) and high field (E_{PEAK}>40 MV/m) practically field-emission-free performance. Measured fields in the two-spoke (E_{PEAK}=32 MV/m at P_{IN}=20 Watts at T=4.2 K) substantially exceed the design goal (E_{PEAK}=21 MV/m) for this cavity and clearly demonstrate that we have developed the construction and processing techniques to successfully build multi-cell spoke cavities.
*Speaker

Introduction

We continue to invest in RIA cavity R&D which has the potential for major cost savings and long-term performance benefits for the RIA driver linac. In the mid-1990's the SCRF group at Argonne began a program to develop the cavities for the intermediate velocity range required for heavy-ion acceleration in the RIA driver linac. Low-beta ($0.04<\beta<0.15$) TEM-cavities for ion linacs and high-beta (β~1) elliptical cell cavities for electron linacs have operated for years, however, the intermediate velocity region ($0.2<\beta<0.8$) was relatively little developed [1]. The first RIA prototype cavities were a pair of 350 MHz single-cell bare niobium spoke cavities, one for β=0.3 and the other for β=0.4, constructed from ANL discretionary funds. Two years later, following the implementation of high-pressure water rinsing and clean assembly, both at Los Alamos for the β=0.3 cavity and separately at Argonne for the β=0.4 cavity, these cavities were operated at high fields (E_{PEAK}>40 MV/m) with relatively low rf losses and minimal field



Figures 1. and 2. Measured Q-curve data for the ANL β=0.3 (left) spoke cavity processed and tested by LANL and β=0.4 (right) single-cell prototype spoke cavity processed and tested at ANL.

emission [2]. The field performance exceeded the initial RIA specification of E_{ACC}=5 MV/m (E_{PEAK}~20 MV/m). Test data are shown in Figures 1. and 2.

Production Model Prototype Cavities

The success of these early niobium-shell prototypes led to the present designs for five full production quality prototypes, shown in Figure 3. The goal of this effort is to establish the engineering and performance properties for realistic cavities. Important issues such as microphonics levels can only be meaningfully studied in cavities with integral helium vessels, operating in a realistic accelerator environment. In addition, the use of clean processing and handling including electropolish, high-pressure water rinse, clean room assembly and separate cavity and cryogenic vacuum systems is establishing the techniques necessary to consistently produce high performance TEM-class cavities.

RIA cavities shown in Figure 3. span the velocity range 0.15<β<0.8 as discussed by Shepard [3] in these proceedings. Niobium components are being formed from 3 mm RRR=250 niobium sheet and all of the cavities are housed in an integral stainless-steel helium jacket. Details of cavity fabrication, which have been established by Argonne and its partners in industry, are described elsewhere in these proceedings [4]. A series of recent tests on a fully jacketed two-cell spoke cavity including field performance and microphonics tests are reported here.

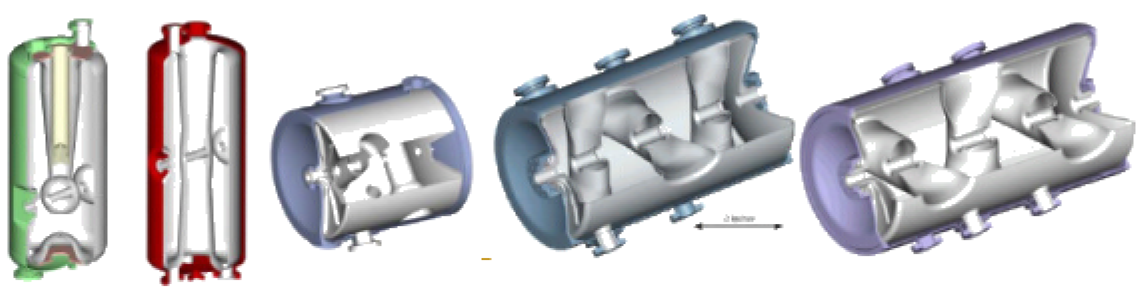
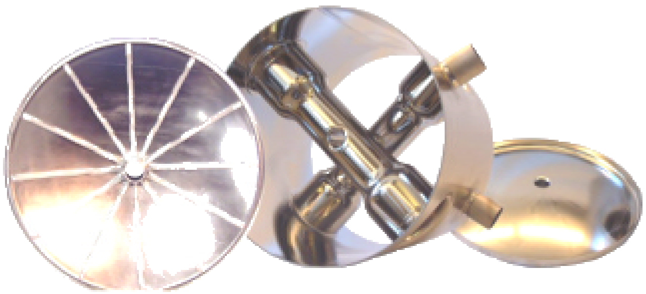


Figure 3. Cavities currently under development at Argonne for the RIA driver linac from left to right: A 115 MHz β=0.15 quarter-wave, a 172 MHz β=0.26 half-wave, a 345 MHz β=0.4 two-cell spoke and a pair of 345 MHz three-cell spoke cavities for β=0.5 and β=0.62.



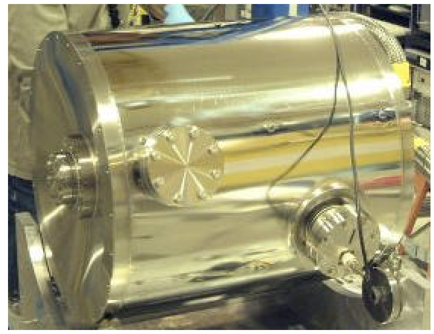


Figure 4. Niobium components of the two-cell spoke cavity follow electropolishing (left) and the completed resonator (right) showing the outer stainless-steel helium jacket.

Cold Tests of the Two-cell Spoke Cavity

The first of the RIA production quality prototypes, the two-cell spoke, is complete and a series of cold tests have been performed. Processing of the critical cavity RF surfaces included a heavy ~100 micron electropolish just prior to the final closure weld. Electropolished niobium components are shown in Figure 4. The components were then welded together and a light ~10 micron chemical polish in a solution of 1:1:2 BCP was used to remove weld residue. Finally, the cavity was then rinsed and filled with clean deionized water in preparation for high-pressure rinsing.

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

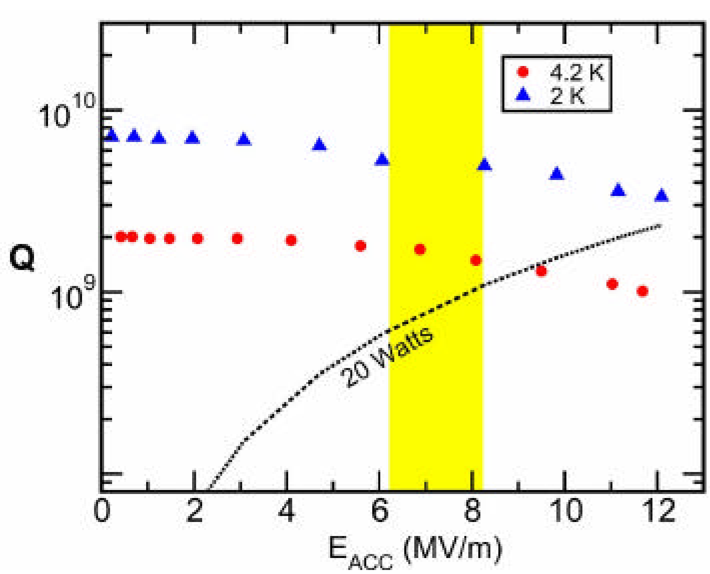


Figure 5. Measured Q-curve performance of the two-cell spoke cavity. The yellow band represents the proposed range of operation for RIA cavities

For the two-cell spoke high-pressure rinse was performed for 80 minutes using 320 gallons of ultra-pure water and the cavity was dried in the clean room for 72 hours. After clean room assembly of vacuum system and coupler, the cavity was sealed and evacuated and the entire cryostat was transferred to the experimental test cave.

Q-curve results from the latest series of cold tests are shown in Figure 5. RF losses for this cavity are small with a Q_0 corresponding to a residual surface resistance $R_S < 10$ nΩ.

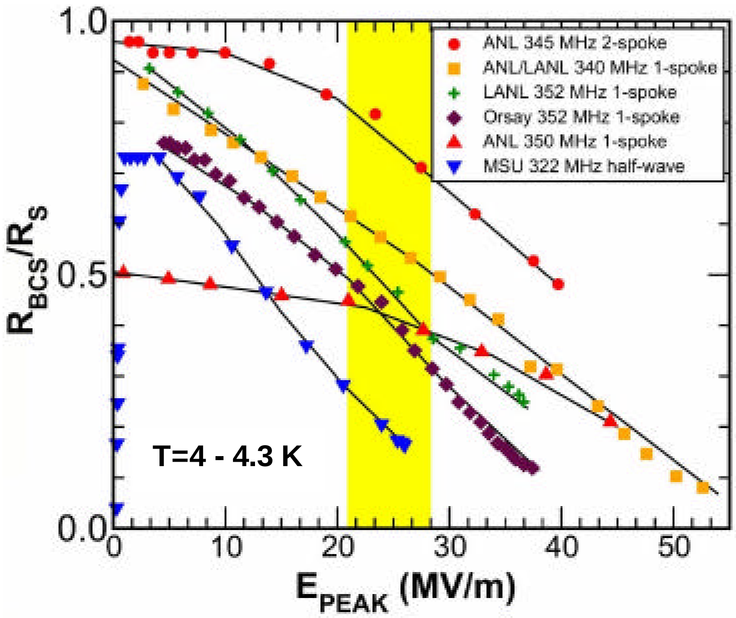


Figure 6. A measure of surface quality for recently constructed λ/2 (half-wave and spoke) cavities.

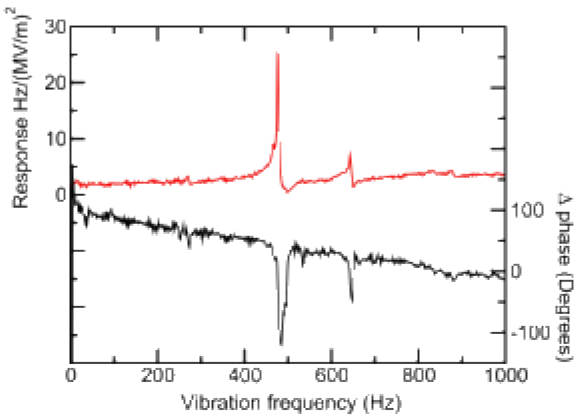
No measurable field emission is observed even at the highest accelerating fields and, with this electropolished surface, we see minimal "Q-slope" in both 2 K and 4 K operation. The two-cell spoke cavity establishes a new high-field performance record for λ/2 (spoke and co-axial half-wave) cavities, operating 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 all of the benefits of 4 K operation.

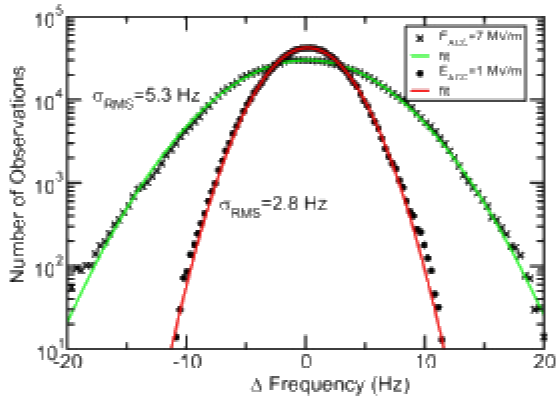
Recently, considerable development effort has been devoted to λ/2 cavities with frequencies near 345 MHz both for RIA and other projects. Cavity surface quality for six of these cavities is shown in Figure 6. in a geometry independent format. The data comes from published Q-curve data which has been 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 [5] for each cavity. A value along the y-axis equal to one thus represents the theoretical maximum. Results are generally very good with the total RF surface resistance roughly equal to twice the BCS value at operational fields. This performance is entirely suitable for RIA operations. Notably the two-cell spoke cavity, which exhibits a substantially 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.

Microphonics and RIA Cavities

Microphonics will be a key issue for all medium and high-beta RIA cavities. Since beam loading will be relatively small the microphonics bandwidth will drive the considerable cost of RF power for RIA. This issue is being meaningfully addressed here through tests of the production model two-spoke in a realistic accelerator environment.

Tests on the two-cell spoke cavity indicate that it performs particularly well with respect to microphonics. Figure 7. shows the transfer function for the RF field to the cavity mechanical modes measured with a cavity resonance monitor [6]. Measurements are performed by modulating the RF input power and scanning through the modulation frequency. The cavity response shows two peaks at several hundred Hertz but, most importantly, shows no low lying mechanical modes typically seen in many quarter-wave and elliptical-cell geometries, for example.





Figures 7. and 8. Measured transfer function (left) for the two-cell spoke cavity and the measured probability density for RF eigenfrequency excursions (right).

The probability density for RF eigenfrequency shifts has also been measured both at low fields and at realistic operational accelerating fields as shown in Figure 8. Performance in both cases is good (Δf~3-5 Hz rms). The modest additional jitter observed for E_{ACC}=7 MV/m is due to bubbling in the liquid helium bath. Piezoelectric and magnetostrictive actuators, both of which are under development for the two-cell spoke cavity by Argonne and its collaborators [7], should be well suited for tuning these low frequency pressure induced fluctuations due to bubbling. In addition, relatively simple design modifications to decrease the cavity helium pressure sensitivity and to decrease the source of pressure fluctuations themselves are also being implemented.

Summary

The SCRF group at Argonne is leading a collaboration with industry and other institutions to develop the techniques needed to produce high performance TEM-cavities for RIA. Early RIA R&D on single-cell spoke cavities 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 very low RF losses and good behavior with respect to microphonics. We plan to continue this R&D effort on TEM cavities, which we believe, has the strong potential to realize major cost and performance benefits for RIA.

References

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