

# EVALUATION AND TESTING OF A LOW- $\beta$ SPOKE RESONATOR\*

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## Abstract

Within the framework of the Advanced Accelerator Applications (AAA) project we are interested in building and testing low- $\beta$  spoke resonators (cavities). To familiarize us with the specifics of these structures Argonne National Laboratory (ANL) kindly loaned us one of their spoke cavities for evaluation. This is a  $\beta=0.291$  2-gap resonator at 340 MHz. We benchmarked our computer codes by comparing room temperature measurements of frequency, tuning sensitivity, tuning forces, etc. with our 3D simulation results. The cavity was tested at both 4 K and 2 K. The results showed maximum accelerating gradients of 12.5 MV/m (4 K) and 12.3 MV/m (2 K), which correspond to a peak electric field of 40 MV/m and a peak magnetic field of 1063 Oe.  $Q_0$  values at 5 MV/m also exceeded by more than a factor 2 of present AAA specification. These results encouraged us toward development of spoke cavities for the low energy section (6.7 MeV to 109 MeV) of ADTF (Accelerator-Driven Test Facility) of AAA project.

## 1 INTRODUCTION

At LANL, the APT (Accelerator Production of Tritium) project transitioned to AAA (Advanced Accelerator Applications) project in October 2000. The main goal of this project is to demonstrate transmutation of nuclear waste [1]. The first goal of this project is to construct ADTF (Accelerator-Driven Test Facility), which will be a machine to show proof of practicality of ATW (Accelerator Transmutation of Waste) technology. The accelerator for ADTF is a 13.3 mA, 600 MeV CW proton linac. For high-energy sections, the 700-MHz 5-cell elliptical cavities developed for APT will be used, i.e.,  $\beta=0.64$  cavities for 211-600 MeV. Recently, however, it was decided to change the low-energy sections from a CCDTL (Coupled-Cavity Drift Tube Linac) to spoke cavities (6.7 – 109 MeV), and from a CCL (Coupled-Cavity Linac) to  $\beta=0.48$ , 700-MHz 5-cell elliptical cavities (109 - 211 MeV). With this change some \$20 M of annual operational costs will be saved. Since we did not have any experience with spoke cavities, and ANL (Argonne National Lab) has been developing them for many years [2-8], ANL kindly loaned us one of their cavities in November 2000. Since then, we have tried the following: (1) familiarize ourselves with the cavity, (2)

benchmark computer codes for designing spoke cavities for LANL and (3) estimate achievable performance with our present technologies at LANL. This paper summarizes the results of our tests. The details of the room temperature tests for benchmarking the computer codes, and the low-temperature tests for evaluation of the performance are described in [9] and [10], respectively.

## 2 ROOM-TEMPERATURE TESTS [9]

At room temperature, we measured tuning sensitivity, i.e., frequency shifts against axial displacements, axial displacements against forces, and axial electric field profile. Then, these were compared with the results computed with MICAV(COSMOS/M) and MAFIA.

Figure 1 shows a side view of the measurement set-up. We re-used our pre-tuning bench for 700-MHz APT elliptical cavities.

Table 1 summarizes the results. The calculated results with MICAV(COSMOS/M) agreed within 30 %. The errors appear to come from inaccuracy of load measurements and slight differences between the real cavity and the model input in the computer codes.

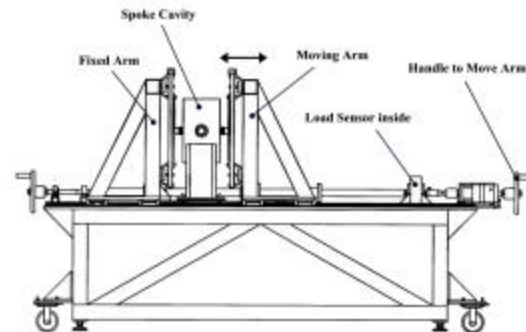


Figure 1: Room Temperature Test Set-Up.

Table 1: Summary of Room Temperature Tests  
(Benchmarking of computer codes)

	Calculation (MICAV)	Measured	Error (%)
Acc. mode Frequency (MHz)	338.821495	339.699401	-0.26
Tuning sensitivity (MHz/in)	11.32	9.356	+21.03
Structural stiffness (lb/mil)	44.4	34.36	+29.22
Tuning sensitivity for load (kHz/lb)	0.255	0.272	-6.35

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### 3 LOW-TEMPERATURE TESTS [10]

#### 3.1 Cavity Parameters

Table 2 shows the cavity parameters calculated with MAFIA.

Table 2: Cavity Parameters

Effective cavity length	0.1765 m
$ZT^2/Q$	295.4 $\Omega$
Geometrical factor, G	70.7 $\Omega$
$E_p/E_{acc}$	3.18
$H_p/E_{acc}$	85 Oe/MV/m

#### 3.2 Surface Treatment and Preparation

We chemically etched the cavity 100  $\mu\text{m}$  with a standard mixture for BCP (Buffered Chemical Polish), i.e.,  $\text{HNO}_3:\text{HF}:\text{H}_3\text{PO}_4=1:1:2$ . Then, it was high-pressure rinsed with Deionized (DI) water at 1000 psi and assembled with a driving coupler, pick-up coupler and a vacuum valve in a class-100 clean room. The details of all these processes are described in [10].

Figure 2 shows the cavity suspended on the cryostat insert. The diameter of the cavity is 17.42 inches (44.25 cm). The driving coupler moves about 2 inches (5 cm) with a scissor-hand-type mechanism so that we can measure at both 4 K\* and 2 K.

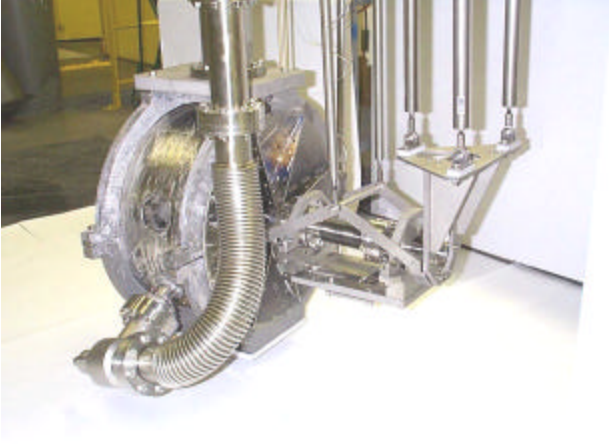


Figure 2: ANL cavity set on the vertical cryostat insert.

#### 3.3 Test Results

According to the previous results obtained at ANL [11], this cavity showed field emissions starting at  $\sim 4$  MV/m and a maximum field of  $\sim 5$  MV/m at both 4.2 K and 2.1 K. Low-field  $Q_0$  were  $\sim 5 \times 10^8$  (4.2 K) and  $\sim 1.2 \times 10^9$

(2.1 K). The 100  $\mu\text{m}$  BCP was intended to eliminate these source(s) of the field emission. Figure 3 shows  $Q_0$  as a function of accelerating gradients ( $E_{acc}$ ) in various conditions in our tests. The legends are shown in chronological order.

In the first 4 K measurement (solid triangles), the cavity showed field emission starting around 5 MeV/m and limited at 7.3 MeV/m with heavy electron loading and available RF power. The next day, we pumped down the cryostat and performed the measurement at 2 K as well as taking low-field  $Q_0$  data ( $\sim 1$  MV/m) at various temperatures to calculate residual resistance. At 2 K, as shown by the open circles in Fig. 3, low-field  $Q_0$  increased to  $8.5 \times 10^9$ , but field emission started around the same field 5 MV/m, and  $Q_0$  degraded reaching the same point as the 4 K measurement. We kept the power at the maximum level for about one hour (RF processing). The maximum field gradually improved to 8.3 MV/m as shown by x's in Fig. 3.

- Helium processing

Solid diamonds in Fig. 3 show the results after  $\sim 5$  minutes of helium processing at 2 K. The maximum field increased to 12.3 MeV/m. Low-field  $Q_0$ , however, degraded by  $3.2 \times 10^9$ , which corresponds to an increase of surface resistance by 5 n $\Omega$ .

Solid squares show the result after warming up to 4 K. This was done to see if the effect of helium processing remains at 4 K. As one can see, the maximum field reached 12.5 MeV/m, which is almost the same as that at 2 K. Both at 2 K and 4 K, the field limitations were quenching. Low-field  $Q_0$  degraded slightly by  $0.1 \times 10^9$ , which corresponds to an increase of the surface resistance by 2 n $\Omega$ .

Open diamonds show the results obtained after pumping down again to check the reproducibility of the results at 2 K. As one can see, the data overlapped with the previous 2 K data (solid diamonds) after helium processing, showing a good reproducibility.

- Warm up to 30-70 K

Since thermal breakdowns occur during helium processing due to the bombardment of helium ions on the cavity surfaces, the degradation of  $Q_0$  after helium processing might have been caused by trapped magnetic field [12]. To confirm this, we warmed up the cavity to 30-70 K and slowly cooled down. The stars of Fig. 3 show the results at 2 K after this heat cycle. As one can see, low-field  $Q_0$  did not recover, indicating that some different mechanism is responsible for this phenomenon. In addition, the maximum field degraded back to the value close to the one after RF processing and before helium processing. We tried helium processing for about 10 minutes and confirmed that it can improve the field again as shown by crosses in Fig. 3, although we could not continue processing due to a shortage of liquid helium.

\* At LANL, the atmospheric pressure is about 600 Torr, which corresponds to 4 K.

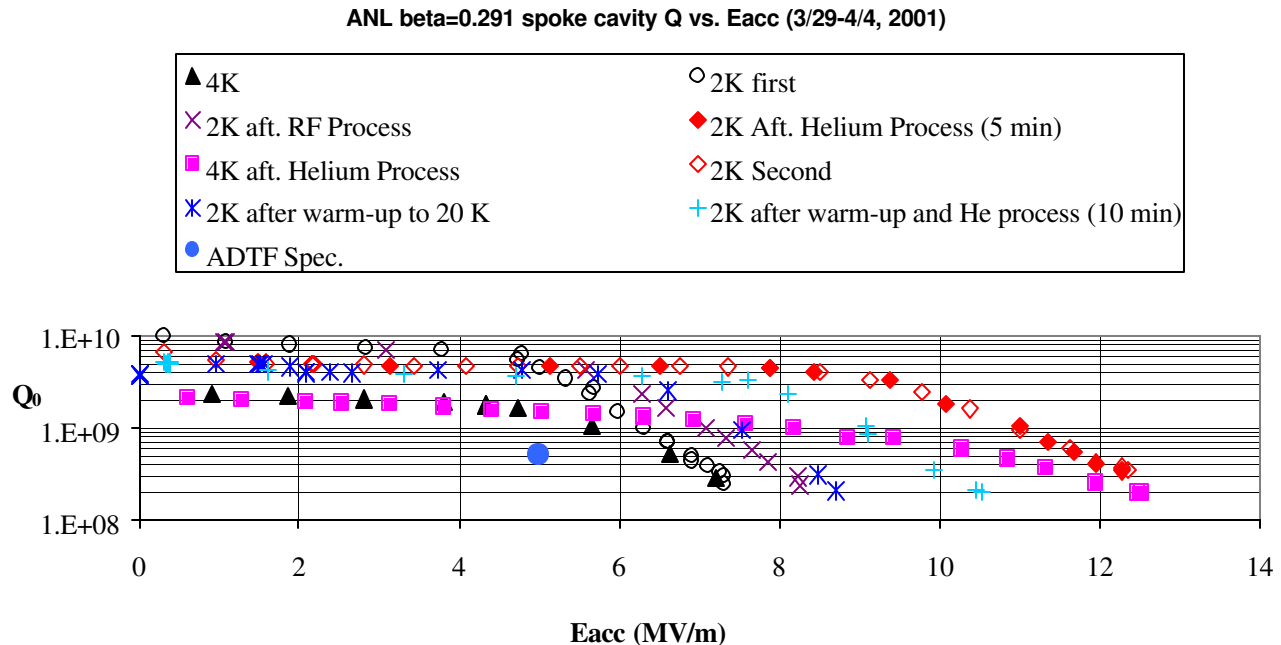


Figure 3: Q-E Curves in Various Conditions. Legends are written in chronological order.

## 4 SUMMARY

We present the test results of a spoke cavity on loan from ANL. Our computer codes for RF and structural analyses showed good agreement with measurement. The results at 4 K and 2 K were very encouraging and gave us a good hope to adopt spoke cavities for the low-energy section of the ADF of AAA project.

## 5 ACKNOWLEDGEMENTS

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## 6 REFERENCES

- [1] <http://aaa.lanl.gov/aboutaaa.html>
- [2] K. W. Shepard, et al., "Prototype 350 MHz Niobium Spoke-Loaded Cavities," Proc. PAC'99, New York, USA, March 29 - April 2, 1999. p. 955. <http://accelconf.web.cern.ch/accelconf/p99/PROCS.H.TM>
- [3] K. W. Shepard, et al., "Accelerator Development for a Radioactive Beam Facility Based of ATLAS," Proc. 8<sup>th</sup> Workshop on RF Superconductivity, Abano Terme, Italy, October 1997. p. 27.
- [4] J. R. Delaysen, et al., "Design Consideration for High-Current Superconducting Ion Linacs," Proc. PAC'95, Dallas, Texas, USA, May 1995. p. 1715. <http://accelconf.web.cern.ch/accelconf/p95/contents.html>
- [5] J. R. Delaysen, et al., "Development of High-Current Superconducting Accelerators at Argonne National Laboratory," Proc. 6<sup>th</sup> Workshop on RF Superconductivity, CEBAF, Newport News, Virginia, USA, October 1993, p. 11.
- [6] J. R. Delaysen, et al., "Design and test of a superconducting structure for high-velocity ions," Proc. LINAC'92, Ottawa, Ontario, Canada, August 1992. p. 695.
- [7] J. R. Delaysen, et al., "Recent developments in the application of t RF superconductivity to high-brightness and high-gradient ion beam accelerators," Proc. 5th Workshop on RF Superconductivity, DESY, Hamburg, Germany, August 1991, p. 376.
- [8] J. R. Delaysen, "Application of RF Superconductors to Linacs for High-Brightness Proton Beams," Nucl. Inst. Meth. in Phys. Res. **B40/41** (1989), p. 892.
- [9] T. Tajima, "Results of Room Temperature Tests on ANL Spoke Cavity (340 MHz, beta=0.291)," LANL Report, LA -UR-01-3162. <http://laacg1.lanl.gov/scrflab/pubs/ANL/LA-UR-01-3162.pdf>
- [10] T. Tajima, "Results of Low Temperature Tests on ANL Spoke Cavity (340 MHz, beta=0.291)," LANL Report, LA -UR-01-3161. <http://laacg1.lanl.gov/scrflab/pubs/ANL/LA-UR-01-3161.pdf>
- [11] K. W. Shepard, private communication.
- [12] J. Knobloch and H. Padamsee, "Flux trapping in niobium cavities during breakdown events" Proc. 8th Workshop on RF Superconductivity, Abano Terme, Italy, October 1997, p. 337.