

## STATUS OF THE LANL ACTIVITIES IN THE FIELD OF RF SUPERCONDUCTIVITY\*

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### Abstract

Since the last workshop we have tested six  $\beta=0.64$ , 700 MHz, 5-cell elliptical superconducting cavities in collaboration with JLAB in vertical cryostats. All the cavities exceeded the requirements for Accelerator Production of Tritium (APT) ( $Q_0 = 5 \times 10^9$  at  $E_{\text{acc}} = 5$  MV/m) with ample margin. The low-field  $Q_0$  at 2 K was  $2\text{-}3 \times 10^{10}$  and the maximum accelerating field reached 12 MV/m, which corresponds to peak electric and magnetic fields of 41 MV/m and 835 Oe, respectively. Power couplers have also been tested in a test bench up to over 1 MW. Since the APT project has transitioned to Advanced Accelerator Applications (AAA) project, a new type of superconducting accelerating structure called spoke cavity emerged as an excellent candidate for the low energy sections between the RFQ and the elliptical cavities. We tested a  $\beta=0.29$ , 340 MHz, 2-gap spoke cavity on loan from Argonne National Laboratory. The results showed  $Q_0 = 2 \times 10^9$  at low fields and a maximum accelerating field  $E_{\text{acc}} = 12.5$  MV/m at 4 K. At 5 MV/m, the  $Q_0$  was  $1.5 \times 10^9$ . Encouraged by these results, we started fabricating some spoke cavities and are planning to test one of them in the beamline of LEDA (Low Energy Demonstration Accelerator) in the future.

## 1 INTRODUCTION

Facilities for preparation and testing of superconducting cavities at LANL were upgraded by the time of last workshop to test the  $\beta = 0.64$ , 700 MHz, 5-cell cavities prototyped for APT project [1].

Using these new facilities at LANL and the facilities used for CEBAF at JLAB, six 5-cell cavities have been tested [2-4]. The APT couplers also continued to be tested after we reported the achievement of 1 MW CW traveling wave in the last workshop [5-7].

In addition, we started studies on spoke cavities for low-energy sections of the accelerator being planned for the new AAA project (see next section) [8-11]. Since details of each work have been reported elsewhere, we summarize our activities briefly in this report.

## 2 AAA PROGRAM

Advanced Accelerator Applications (AAA) is a new

LANL-led multi-laboratory project that started in FY01 [12, 13].

The Accelerator Production of Tritium (APT) project has transitioned to this new project since it was decided that an accelerator would be a back up to light water reactors for tritium production.

The main objective of this new project is to demonstrate the practicality of accelerator transmutation of nuclear waste. The centerpiece of this program is Accelerator-Driven Test Facility (ADTF), which will be a high-power CW proton linac of  $>20$  MW [14].

Although not decided yet, its energy and current will be  $\sim 600$  MeV and  $\sim 33$  mA, respectively. If it will be expanded for APT capability, the current will be 100 mA.

## 3 SUPERCONDUCTING RF ACTIVITIES

### 3.1 Elliptical Cavities for High-Energy Sections

We started testing the  $\beta = 0.64$ , 5-cell APT cavities in early 2000 at both LANL and JLAB. Figure 1 shows one of the six cavities set on the cryostat insert before testing at liquid helium temperature.



Figure 1: APT 5-cell cavity set on the cryostat insert. Details of the tests are described in [2-4].

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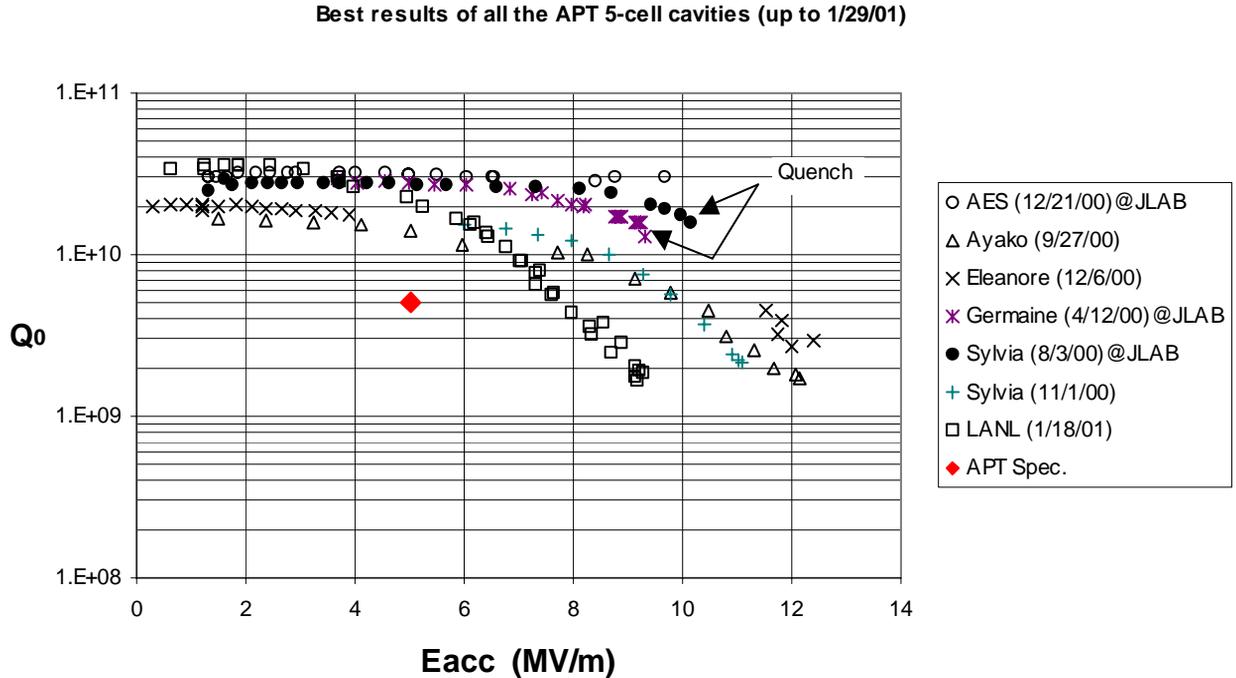


Figure 2: Test results of all six 5-cell cavities developed for APT. All the tests were performed in vertical cryostats at 2 K. In this figure only the best results are shown. The factors that contributed to these results are described in [4]. The results obtained at JLAB are depicted as @JLAB in the legend.

The length, cell diameter and beam aperture are 116 cm, 40 cm and 13 cm, respectively.

$E_{pk}/E_{acc}$  and  $H_{pk}/E_{acc}$  are 3.38 and 69.6 Oe/MV/m, respectively.

We have tested all six cavities, one built in house at LANL and five in industry. Figure 2 is a summary of achieved  $Q_0$  -  $E_{acc}$  curves of all the cavities. As shown in Fig. 2, all the cavities exceeded the APT requirements of  $E_{acc}$  and  $Q_0$  with ample margins. The LANL cavity was found to have a defect on the equator region of the middle cell and showed the worst result in terms of achieved gradient due to its heating.

Similar types of elliptical cavities of different  $\beta$ 's will be used for high-energy sections of the ADF with more challenging requirements for accelerating gradients and  $Q_0$  to reduce construction cost as much as possible, possibly  $Q_0 = 1 \times 10^{10}$  at  $E_{acc} = 10$  MV/m.

Taking into account some of the results in Fig. 2 and recent results of TESLA and SNS, it looks possible to achieve these values with more refined efforts to eliminate field emission and defects.

### 3.2 Spoke Cavities for Low-Energy Sections

Spoke cavities have been studied at Argonne National Laboratory (ANL) since early '90s to accelerate high-current ion beams and rare isotopes [15-18].

A spoke cavity is a rather simple structure with a spoke having a hole in the center housed in a cylinder. The

gaps between the spoke and the end walls are the accelerating gaps.

Some advantages of this cavity over elliptical cavities are smaller size for the same frequency, i.e., about half the diameter of the elliptical cavity, and mechanical stiffness, i.e., mechanical resonant frequencies are much higher than those of elliptical cavities.

We were able to evaluate one of the cavities made at ANL [9, 19, 20]. Figure 3 shows the ANL cavity set on the insert before low temperature tests.

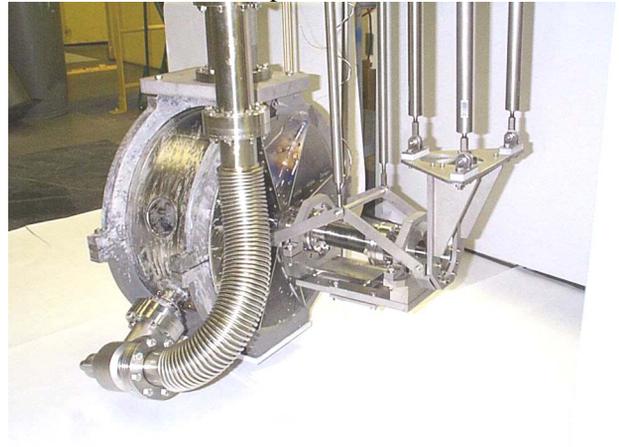


Figure 3: An ANL cavity ( $\beta=0.29$ , 340 MHz, 2-gap) set on the vertical cryostat insert.

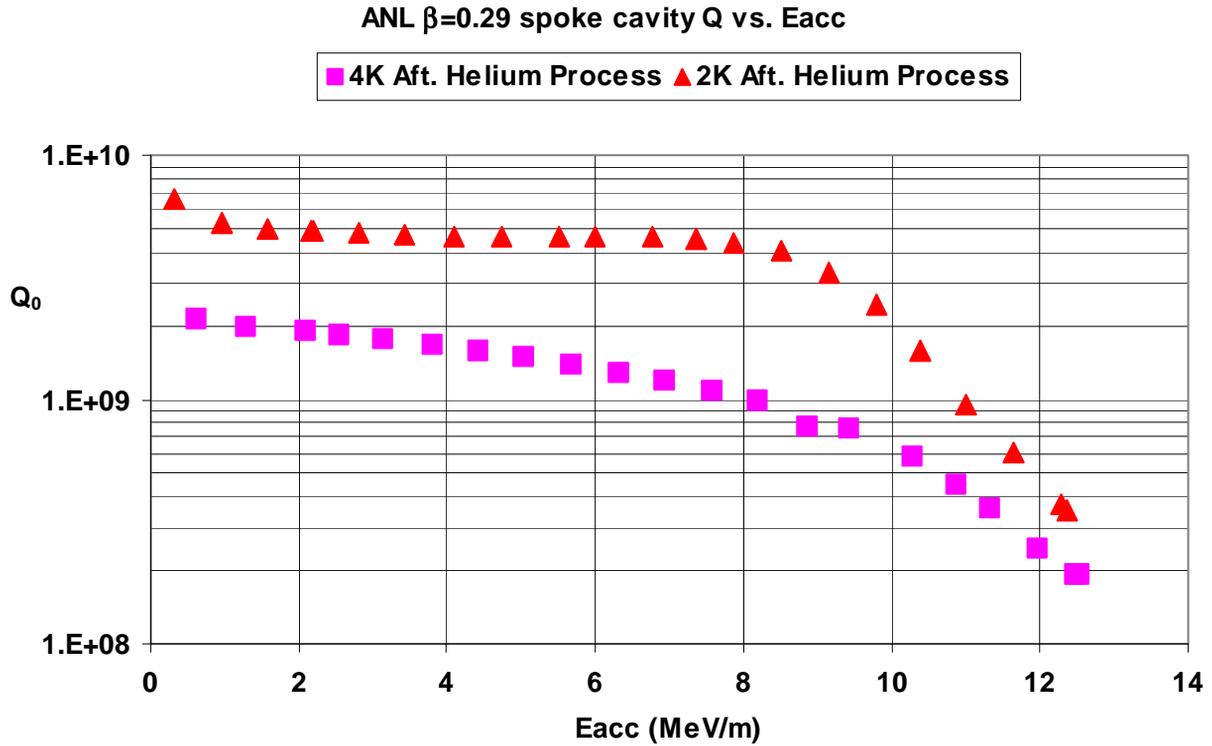


Figure 4:  $Q_0$ - $E_{acc}$  curves of ANL  $\beta=0.29$ , 340 MHz 2-gap spoke cavity tested at both 4 K and 2 K at LANL

This cavity had a history of field emission and was limited to around 5 MV/m during ANL tests [20].

At LANL, we chemically polished the cavity by 100  $\mu\text{m}$  with a 1:1:2 BCP solution and high-pressure rinsed with de-ionized water at 1000 psi in a class-100 clean room.

Figure 4 shows the test results at 4 K and 2 K. It shows only final data, i.e., after helium processing for  $\sim 5$  min. The maximum field was limited by heating with field-emitted electrons and subsequent quench. A complete description of the tests can be seen in [9, 20].

$E_{pk}/E_{acc}$  and  $H_{pk}/E_{acc}$  are 3.18 and 85 Oe/MV/m, respectively. As shown in Fig. 4, the  $E_{acc}$  reached 12.5 MV/m at 4 K, which corresponds to  $E_{pk} = 40$  MV/m and  $H_{pk} = 1063$  Oe.

Though we tested at 2 K because we had the capability of moving the input coupler and have pumping system to get lower temperatures, we intend to use this type of cavity at 4 K due to lower cost and simplicity of cryogenic system. Another reason for testing at 2 K was to check to see if the maximum achievable gradients are different between at 4 K and 2 K. As shown in Fig. 4, it was the same at 4 K and 2 K, although we sometimes observe a significant difference with elliptical cavities.

This was our first experience with a spoke cavity. We felt that this type of cavity was promising since we could

treat the cavity in the same way as elliptical cavities and there was no difficulty during testing.

Figure 5 shows a rendering of the  $\beta = 0.175$ , 350-MHz 2-gap spoke cavity designed at LANL and in the process of procurement now [8, 10, 21]. It has a cavity diameter of 39.2 cm, a beam aperture of 5 cm and an overall length of 20 cm [21]. The geometrical factor,  $E_{pk}/E_{acc}$  and  $H_{pk}/E_{acc}$  are 120  $\Omega$ , 2.84 and 69 Oe/MV/m [21].

We are planning to procure two cavities and test them in FY02.

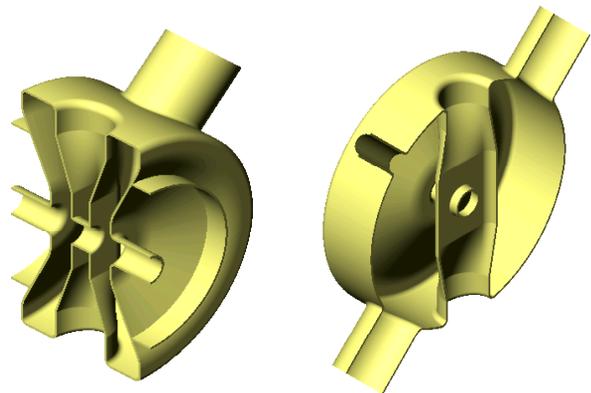


Figure 5: Cut-away view of the LANL-designed 2-gap spoke cavity.

### 3.3 The APT Input Coupler

Since the last workshop, that showed an achieved transmitted power of 1 MW [5], we continued testing of the APT couplers focusing on (1) tests with adjustable-tip inner conductor, i.e., it is designed to move  $\pm 5$  mm using bellows, (2) condensed-gas effects, and (3) longer-term steady power transmission at the new requirement of 420 kW.

The coupler with the adjustable tip reached 1 MW CW traveling wave and 850 kW for a sliding-short position corresponding to full current operation [7].

The condensed-gas effect was tested by cooling part of outer conductor with liquid nitrogen. The result showed some enhancement of electron activities, but none of them were hard barriers. According to the theory of multipacting bands in a coaxial line, we tested 5<sup>th</sup> order and above bands of one-point multipacting [22].

As for longer-term steady operation test, the coupler has been tested up to a total of 95 hours at 420 kW without a problem.

### 3.4 The Spoke Cavity Input Coupler

The present design of spoke cavities for AAA project requires up to 212 kW due to adding a capability of APT, i.e., 100 mA beam.

The design of the couplers for spoke cavities started early 2001. Our design is based on the TRISTAN normal conducting coupler for the APS cavity, which transmitted 300 kW to beam [24]. Compared to the APT coupler, this design is simpler, lighter and lower cost.

Figure 6 shows a schematic of the coupler being designed. It consists of a half-height WR2300 waveguide section merged with a shorted coaxial conductor. At the transition is a 4.8-mm thick cylindrical ceramic window. The outer conductor of the coax has an inner diameter of 103-mm and its impedance of 75  $\Omega$ . The center conductor is cantilevered off the shorting plate. This coupler has also a large pumping port to facilitate a good vacuum, which can shorten conditioning time. Thermal analyses of the window and center conductor for the testing up to 500 kW are underway.

### 3.5 Cryostat Assembly for APT Cavities

Activities on the APT cryostat decreased drastically due to the down select of the APT project and the following reduced budget. Nevertheless, we managed to put inner and outer helium vessels on two of the APT 5-cell cavities (Sylvia and Germaine) [25]. In FY02, we are planning to do a horizontal test using one of these cavities in CRYHOLAB in collaboration with Saclay.

## 4 SUMMARY AND FUTURE PLANS

The prototype cavities and couplers for APT project exceeded the design requirements with ample margin assuring reliable operation when it is built.

Since APT project transitioned to AAA, we started working on the superconducting spoke cavity that will allow us to save significant amount of annual operation cost compared to the case using CCL and CCDTL.

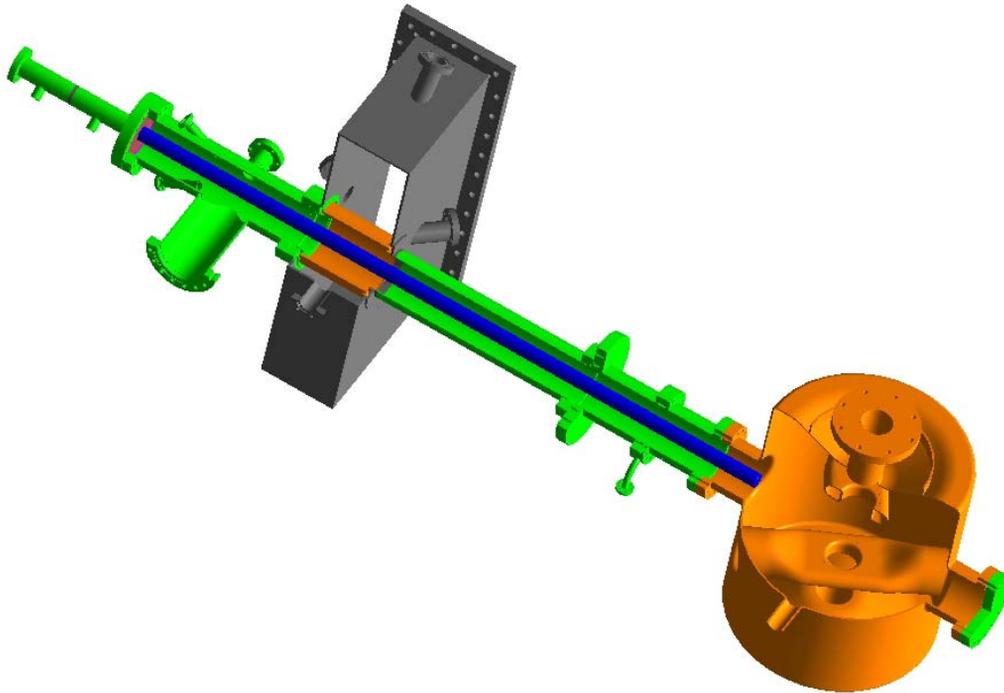


Figure 6: The power coupler being designed for spoke cavities.

We tested a spoke cavity on loan from ANL and obtained promising results. Encouraged by the result, we have designed a  $\beta=0.175$ , 350 MHz, 2-gap spoke cavity and two cavities have been ordered to a manufacturer in August 2001. We expect to receive these cavities by July 2002 and test them by the end of FY02.

Along with the cavity design, we designed a coupler for spoke cavities. Presently, we are refining our design and preparing for procurement. Hopefully, 3 or 4 couplers will be procured and tested in FY02.

Our final goal with this 2-gap spoke cavity is to demonstrate its feasibility with beam in the LEDA.

## 5 ACKNOWLEDGEMENTS

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