LANSCE Activities in the Field of RF Superconductivity

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1. Current Laboratory Activities and Capabilities

The following is a brief summary of the results of our cavity-development activities in the last 3 years. Detailed information and publications can be found at http://laacg1.lanl.gov/scrflab/.

1.1 Tests of six β=0.64, 700-MHz, 5-cell elliptical cavities for the APT projects.

Six prototype cavities were built at LANL and in industry for the Accelerator Production of Tritium Project (APT). They were tested at LANL and JLAB. Figure 1 shows the tests results of all the cavities. Most of them showed X-rays at high gradients, which may be related to multipacting and/or field emission. All the cavities exceeded the design goal of the APT project with ample margin [1].

1.2 High-power couplers and cryomodule development for APT.

The APT design goal for the coupler was 210 kW CW per coupler and feed the power into one cavity with two couplers. The prototype coupler was tested up to 1 MW CW, which made the double coupler scheme to single 420 kW CW, enabling a significant cost reduction.

Inner and outer helium vessels were fabricated for assembling into a cryomodule, but we were unable to proceed the assembly further due to the stoppage of the project.

1.3 Design, procurement and tests of two β=0.175, 2-gap spoke cavities for Advanced Accelerator Applications (AAA) project.

We designed a spoke cavity for the first lower-energy section after RFQ for the accelerator-driven nuclear waste transmutation system in the AAA project. Two cavities were fabricated at Zanon, a manufacturer in Italy in collaboration with INFN/Milano. Figure 1 shows a cut-away illustration of the inside and the fabricated cavity.

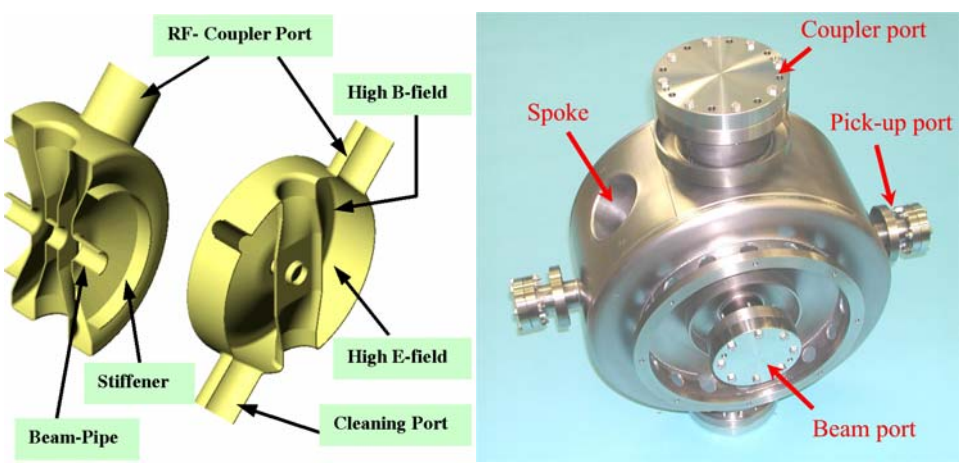

Figure 1: LANL-designed 350-MHz, β=0.175 spoke cavity. The E_p/E_a and B_p/E_a ratios are 2.82 and 7.38 mT/MV/m, respectively.

Figure 2 shows vertical test results of the two cavities named EZ01 and EZ02. EZ01 and EZ02 achieved 13.5 and 13.0 MV/m in accelerating gradient, respectively, which exceeded the AAA goal of 7.5 MV/m with ample margin that is important for required reliable long-term operations for a transmutation system.

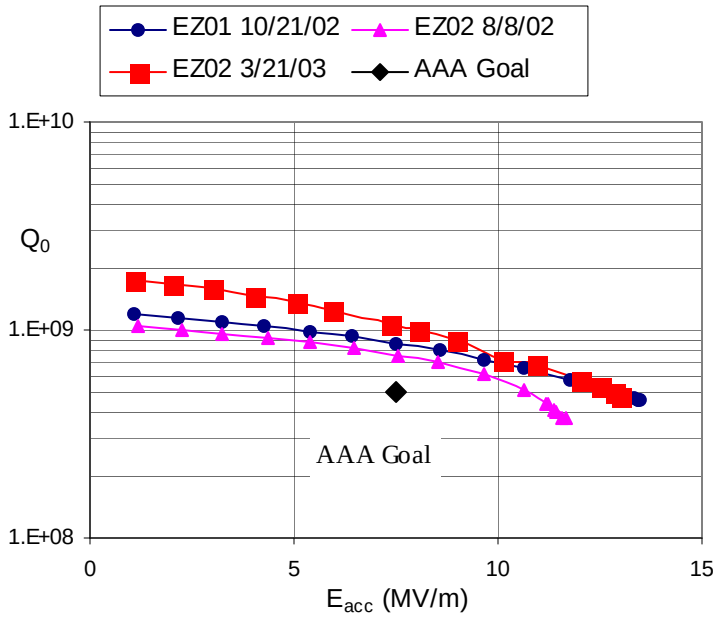

Figure 2: Vertical test results of two spoke cavities. The result of EZ02 tested on March 21, 2003 was that after disassembly, high-pressure rinse and reassembly.

1.4 Other cavity R&D activities

Nb_3Sn cavity development: We are seeking internal Laboratory funding to develop this material for low-loss operation at 4 K and at higher gradients.

MgB_2 and other higher-T_c material for SRF application: Measurement of RF surface resistance of MgB_2 was carried out at the superconducting technology center (STC) at LANL [2]. Funding is being sought for this effort.

1.5 RF activities

RF activities are currently involved with the SNS project. In particular, a pulsed high-power modulator-converter has been developed and is being produced. The modulator eliminates the need for a capacitor room, uses IGBTs for switching and self-clearing capacitors at low voltage for high storage efficiency. Up to140 kV is produced with high efficiency through a dc to dc nanocrystalline-core transformer. The unit can handle up to 1.1-MW average power.

Other work involves the difficult problem of RF control. Sophisticated in-phase and quadrature and feed-forward control models have been built up with experience over several projects and in collaboration with DESY. Full implementation of the control to high specification requires further work but nominal regulation (1% amplitude and 1° phase) are readily achieved. Devices that can effect fast cavity tuning and hence can be used for control are also of interest to the RF team

1.6 Capabilities

The RF cavity development team has a well equipped laboratory including a large (2600 sq. ft and class 100) clean room with high-pressure rinse facilities. The laboratory contains two RF-shielded vertical cryostats with liter He capacity and 2 K operation capability. It is also well equipped with tuning and RF measurement equipment. Proven engineering, cavity-fabrication, and processing facilities are also available in the Division and Laboratory. Experienced cavity

designers are equipped with sophisticated engineering and electromagnetic 3-D codes. Thus a complete capability from design to testing is in place.

RF development is well staffed with control and high-power expertise. A large laboratory for development and testing exists along with fabrication facilities.

Although testing with beam is currently not done, high-power beam sources are available at Los Alamos at the LANSCE and LEDA linacs. Conversion to beam testing may be possible, depending on projects nature and funding.

2. International Collaborations

We have collaborations with CEA/Saclay and CNRS/Orsay, France, for Accelerator Transmutation of Nuclear Waste projects, including SC-accelerator development.

We collaborated with Prof. Pagani and his group in INFN/Milano, Italy, during the fabrication of spoke cavities at Zanon, an Italian company.

We are planning to collaborate with University of Wuppertal, Germany, and INFN/Legnaro, Italy on the higher-T_c cavity development in addition to some US labs. These institutions have experience in this development.

We are collaborating with the JLAB, the University of West Virginia, and Reference Metals in a program to improve the mechanical properties of high RRR niobium.

3. Critical Technical Issues

3.1 APT elliptical cavities

The design goal of E_{acc} = 5 MV/m, i.e., B_p = 35 mT or ~ 17.5 % of the theoretical limit, set in mid 1990s seems low with the present technologies. TESLA project is trying to achieve 50 – 70 % of the theoretical limit for B_p. To achieve the TESLA-level gradients, i.e., E_{acc} = 14 – 20 MV/m for APT cavities, it is necessary to identify the cause of Q_0 drops at high field.

3.2 Spoke cavities for high power proton accelerators

The nominal coaxial power coupler designed for up to 100 mA beams might have a chance of degrading the cavity performance since it is attached to the cavity cell.

Regarding the cavity gradients, the both two cavities reached similar gradients but limited by quench. It is crucial to identify the cause of these quenches to increase the gradient. Although it is not necessary for the present design since the design accelerating gradient is limited by allowable phase advance per period and it is ~ 8 MV/m. This, however, will be a problem at higher β cavities and/or with RF-focusing mechanism where you can increase the design gradient.

3.3 Higher-T_c cavity development

Nb_3Sn cavities: It is crucial to establish the method of making a uniform Nb_3Sn layer. Also, the Q_0 drop at relatively low field as compared to high-quality bulk Nb cavities need to be solved, although there are not much data on the cavity performance so far. In addition, it is scientifically important to know the critical field of this material since predicted superheating critical field has not been confirmed experimentally.

MgB_2 and other materials: It is critical to demonstrate that the RF surface resistance of the material can be as low as or lower than Nb at higher operating temperatures to apply these materials to RF cavities for further cost reduction. The second important issue is the power dependence of the RF surface losses. Discovering/developing the material that will show little power dependence with higher gradients will be the key to the success of this research.

3.4 RF control level and cost reduction

Controlling linac rf stability to 0.1% and 1° phase is important for many applications, including synchrotron or accumulator ring injection. Current techniques provide an order of magnitude less control. The approaches include fast feed forward techniques and fast-tuning devices.

System cost is strongly affected by the number of klystrons needed. Techniques and devices need to be developed for controlling multiple cavities with a single power source.

4. Plans for Evolution of the program for the next 3 to 5 years

The following plans are conditional on funding:

4.1 Low-β elliptical cavities

- Identify the source of gradient limitation
- Develop/learn methodology to improve the gradient to reach ~ 80 % of theoretical limit.
- Prototyping of cavities for practical use, e.g., XADS, LANSCE upgrade, etc.

4.2 Spoke cavities for high power proton accelerators

- Procure power couplers for the spoke cavity and test them at room temperature
- Design, procure a cryostat and prepare for beam tests at LEDA
- Assemble a cavity with a power coupler in the cryostat, install it at the LEDA output and perform beam tests up to 100 mA.

4.3 Higher-T_c cavity development

Nb_3Sn:

- Re-establish the technique developed until 1996 and form a uniform layer on a small (~3 GHz) single-cell cavity and measure Q-E curves.
- Develop techniques to make a uniform layer on large-size and multi-cell cavities and spoke cavities
- Assemble a practical-size Nb3Sn cavity in a cryostat and beam test it somewhere

MgB_2 and other materials:

- Make small bulk samples with HIP or coated on Cu by pulsed-laser deposition, and measure RF surface resistance (Rs) and its power dependence.
- Improve Rs such that it shows lower Rs than Nb at higher temperatures.
- Develop methods to fabricate a real cavity in a cost competitive way

4.4 RF power and control development

- Continue Pulsed-Converter-Modulator development.
- Increase accuracy of Rf-field control levels by fast feed-forward and fast-tuning schemes.
- Develop microphonic- and Lorentz-detuning- correction techniques
- Develop system control with a high-power source controlling several cavities.

5. References

[1] T. Tajima et al., Proc. 10th Workshop on RF Superconductivity, Tsukuba, Japan, Sept. 6-11, 2001. http://laacg1.lanl.gov/scrflab/pubs/APT/LA-UR-01-5049.pdf

[2] A. T. Findikoglu et al., in this workshop and Appl. Phys. Lett. 83 1 (2003).