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HIGH GRADIENT TESTING RESULTS OF THE BENCHMARK a/λ=0.105 CAVITY AT CERF-NM*

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Abstract

This paper will report initial status of high gradient testing of two C-band accelerating cavities fabricated at Los Alamos National Laboratory (LANL). At LANL, we commissioned a C-band Engineering Research Facility of New Mexico (CERF-NM) which has unique capability of conditioning and testing accelerating cavities for operation at surface electric fields at the excess of 300MV/m, powered by a 50 MW, 5.712 GHz Canon klystron. Recently, we fabricated and tested two benchmark copper cavities at CERF-NM. These cavities establish a benchmark for high gradient performance at C-band and the same geometry will be used to provide direct comparison between high gradient performance of cavities fabricated of different alloys and by different fabrication methods. The cavities consist of three cells with one high gradient central cell and two coupling cells on the sides. The ratio of the radius of the coupling iris to the wavelength is a/λ=0.105. This poster will report high gradient test results such as breakdown rates as function of peak surface electric and magnetic fields and pulse heating.

INTRODUCTION

In recent years, Los Alamos National Laboratory (LANL) has been conducting research on High gradient C-band (5.712 GHz) accelerator structure motivated by a number of LANL-specific mission needs. This includes potential high gradient C-band upgrade to Los Alamos Neutron Science Center (LANSCE) proton linac to increase the final energy of the proton beam to 3 GeV. In addition, material science research at LANL may benefit from a powerful directional high-repetition-rate X-ray source of 43 keV photons that may be produced by a 42 MeV electron beam through Inverse Compton Scattering (ICS). The goal of this research is to develop high gradient normal-conducting radio-frequency (NCRF) copper-based accelerator structures that withstand extreme electromagnetic field. In order to understand material's behavior under extreme fields, material science research along with experimental study of breakdown of copper alloys are very important to design, fabricate and test next-generation high gradient accelerator cavities. With a C-band high gradient test stand, LANL now has an appropriate tool to probe into material behavior and analyze them under extreme fields in C-band. [1].

We have recently commissioned the C-band Engineering Research Facility of New Mexico (CERF-NM) [2]. The CERF-NM is powered by a 50 MW 5.712 GHz Canon klystron that produces 50 MW pulses with the pulse length between 300 ns and 1 microsecond, repetition rate up to 200 Hz, and is tunable within the frequency band of 5.707 GHz to 5.717 GHz. The RF power from the klystron fed through a WR187 rectangular waveguide which is attached to a magic tee that splits the power into two halves. The power-split is necessary to protect the Klystron from excess reflected power that may come from the device-under-test. The other halve of power is then dumped into a water load. The waveguides were conditioned up to a maximum power of 30 MW, whereas the klystron was conditioned to full power 50 MW. During testing, the base pressure was 5×10^{-7} torr. Thermocouples were attached to the body of the cavity and RF windows to monitor temperature rise at the time of testing. There are two directional couplers and one Faraday cup for diagnostics purpose. The first directional coupler was placed immediately after the klystron and the other just before the cavity for measurements of incident and reflected powers. The Faraday cup was placed at the beam pipe after the structure to measure dark current which is indicative of vacuum breakdowns at the cavity being tested. All the data such as pulse count, breakdown pulse count, number of breakdowns, and real-time monitoring of signals are collected by a national instruments PXIE chassis that implemented in FPGA oscilloscope for real-time measurement. The control systems analysis code which is known as FEbreak was able to achieve a 95% pulse capture efficiency [3]. The details of the test stand, its capabilities are reported in Ref. [2].

Many cavities that we plan to test at CERF-NM are to be coupled on axis to reduce peak surface magnetic fields. Thus, the mode launchers were designed and fabricated for the test stand. The mode launchers convert the TE10 mode of the rectangular WR187 waveguide into the TM01 mode of the cylindrical waveguide for the on-axis coupling. Four mode launchers were fabricated and conditioned up to the maximum input power of 10 MW.

For more details on the mode-launcher design, fabrication, and testing, see Ref. [4].

We plan to test several cavities for high-gradient testing at CERM-NM. Right now, we are testing LANL-fabricated copper-based benchmark cavity which is intended to establish benchmark parameters for future high-gradient performance at C-band. This benchmark cavity is a three-cell test structure with the ratio of the iris radius, a, to the wavelength, λ, of a/λ=0.105. The structure was a direct scale of the similar test structures fabricated and tested by other institutions at the frequencies of X-band and S-band [5, 6]. This exact cavity shape is most commonly used to make comparison between high gradient performance of cavities

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fabricated of different alloys and by different fabrication methods. Testing the cavity of this most common shape at the frequency of 5.712 GHz allows us to eliminate the effects of specific cavity geometry on the high gradient performance and compare high gradient performance of C-band structures to that of the higher frequency structures (X-band) and lower frequency structures (S-band).

This paper highlights the design parameters and cold-testing results of the benchmark a/λ=0.105 test cavity, reports the initial results of the high gradient testing of the first cavity and predicted peak surface fields.

DESIGN, FABRICATION AND COLD-TEST RESULTS OF THE a/λ=0.105 BENCHMARK CAVITY

The three-cell benchmark a/λ=0.105 cavity support three different modes. From these modes, the highest resonant frequency (5.712GHz) corresponds to π-mode. The field distribution and resonant frequency all were simulated with CST Microwave Studio [7]. The results are shown in Fig. 1 As shown in field profile, it was found that the center cell supports two times higher peak electric field as compared to end cells. This is also a signature of resonant π-mode.

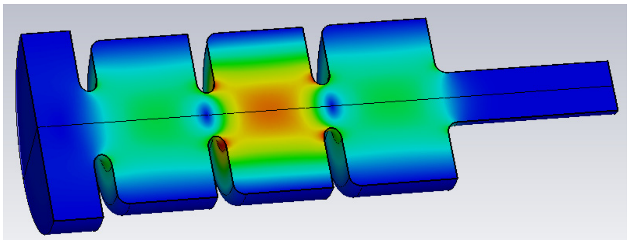

Figure 1: CST Microwave Studio design of the C-band a/λ=0.105 cavity: distribution of the electric field's magnitude.

The Q factors, simulated peak electric and magnetic field in the cavity is tabulated in Table 1.

Table 1: Design Parameters for the C-band Three-Cell Benchmark a/λ=0.105 Cavity

Frequency	5.712 GHz
Cell length	1.034 inches
Iris radius, a	0.217 inches
a/λ	0.105
Q	12682
E/√P[MW]	87.1 MV/m
H/√P[MW]	127 kA/m

LANL fabricated benchmark cavities are shown in Fig. 2. The cavities were fabricated commercially by Dymenso, LLC in San Francisco, CA [8]. The three-cells were fabricated with the high precision milling and brazed together in a hydrogen oven. A photograph of the two fabricated cavities is shown in Fig. 2.

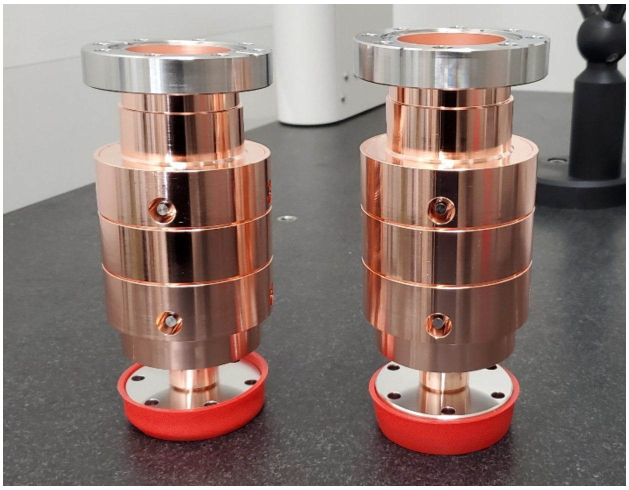

Figure 2: Photograph of the two fabricated C-band a/λ=0.105 cavities.

We conducted cold test of these cavities after we received them at LANL. First, we connected a mode launcher (which is already conditioned to 10MW) to the input flange of the cavity. The cold-test was performed by connecting a mode launcher to the input flange of the cavity and measuring the reflection coefficient (S_{11}). The on-axis electric field profile was measured with a beadpull to ensure the correct field distribution between the central cell and the two coupling cells.

For more details on cold-test results, see Ref. [9].

HIGH GRADEINT TESTING

The two cavities were delivered to LANL and the first cavity was installed at the CERF-NM for high gradient testing in May of 2022. The photograph of the high gradient test setup inside of the lead box is shown in Fig. 3. The diagnostics on the waveguide line included the directional coupler installed right before the mode launcher to measure forward and reflected power and the Faraday cup for dark current measurements. Ion pumps were installed before the mode launcher and right after the cavity to ensure good vacuum during conditioning.

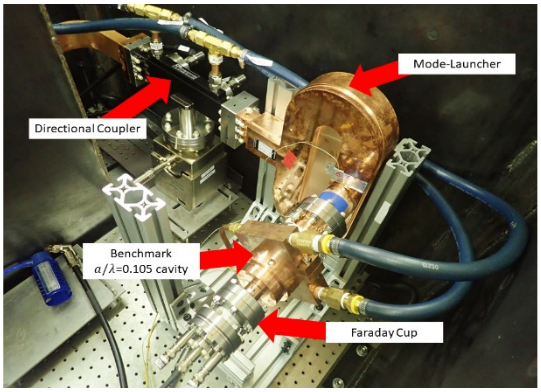

Figure 3: Photograph of the C-band a/λ=0.105 cavity installed for high gradient testing at CERF-NM.

The first cavity is currently being conditioned to the highest gradient. At this point, the conditioning is finished at the pulse lengths of 400 ns, 700ns and 1μs up to the highest input power of 13 MW. Now we are in the process of doing breakdown mapping of the a/λ=0.105 cavity. The mapping process is being done as follows. First, we start at the maximum operational power level (13MW) and count number of breakdowns for several hours in a row until we get consistent number of breakdowns for two contiguous hours. When we achieve consistent BDs for certain power level, we will record it and move to a lower power level by reducing input power by 0.5MW. A typical RF forward and reflected pulses from the cavity testing are shown in Fig. 4. Estimated achieved peak fields in the cavity are E_{surf}=246 MV/m, H_{surf}=359 kA/m (Fig. 5). Upon conclusion of the high gradient conditioning and testing, the probabilities of breakdown in the cavity will be mapped at different pulse lengths as functions of the peak surface fields and the pulse heating.

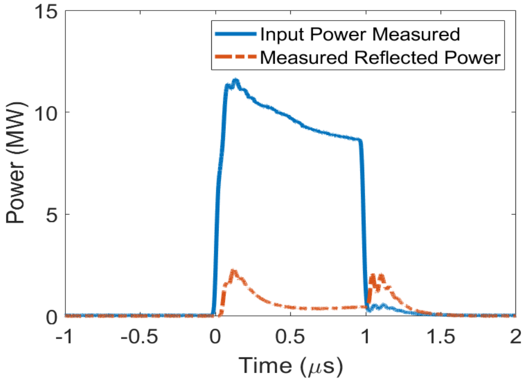

Figure 4: Typical measured 1μs pulse shape for high gradient testing of three-cell benchmark a/λ=0.105 cavity.

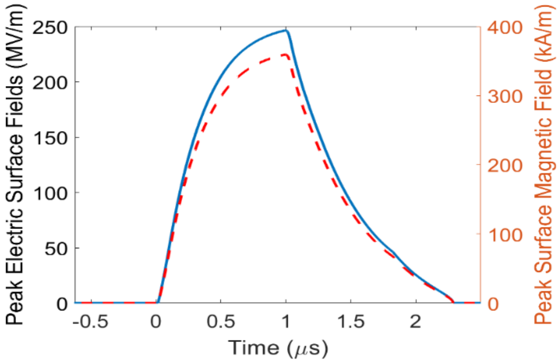

Figure 5: Estimated peak electric and magnetic surface fields of three-cell benchmark a/λ=0.105 cavity.

CONCLUSION AND PLANS

This paper summarizes the design, fabrication, testing the benchmark three-cell a/λ=0.105 copper cavities, and the initial results of high gradient conditioning of the first cavity. At LANL, we commissioned a new C-band high gradient test facility CERF-NM, and high gradient testing of accelerator cavities has commenced. The two proton Cu/Cu-Ag $\beta = 0.5$ accelerator cavities have already been tested at CERF-NM and the results of these tests are reported in [10]. For the test of benchmark cavities, we used mode launchers to the TE_{10} mode of the rectangular waveguide into the TM_{01} mode of the cylindrical waveguide for on-axis coupling into the test cavity. The mode launchers were successfully conditioned up to 10MW, and the first cavity with the on-axis coupling is now undergoing the high gradient testing. The maximum power of 13 MW was coupled into the cavity at the pulse lengths of 400 ns, 700 ns, 1μs. Later in 2022, we plan to test the benchmark cavity and collect breakdown data to map at different pulse lengths as a function of peak electric and magnetic fields and surface heating.

The newly established C-band high gradient test facility is open to collaborators. Beyond operating CERF-NM, LANL has plans for further development of its C-band accelerator capabilities.

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