HIGH GRADIENT TESTING OF A TWO-CELL C-BAND ACCELERATOR CAVITY WITH NICR HIGHER-ORDER MODE ABSORBERS*

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Abstract

This paper reports on the status of fabrication, tuning, and high gradient testing of a two-cell accelerator cavity with distributed coupling and higher-order-mode (HOM) damping slots covered with nickel-chromium (NiCr) absorbing material. The cavity is designed with a specific purpose to demonstrate applicability of NiCr material for damping HOMs in a C-band distributed-coupling accelerating structure, such as may be used in a C^3 linear collider. We are performing this simple high-power test to understand fabrication challenges for the cavity with NiCr HOM absorbers and examine behavior of the NiCr coating during high power conditioning. This paper provides details on electromagnetic and engineering design of the cavity, fabrication, cold testing, tuning, and reports the current status of high gradient testing at the CERF-NM C-band high gradient test facility at Los Alamos National Laboratory.

INTRODUCTION

At Los Alamos National Laboratory (LANL), we conduct high gradient C-band accelerator studies for multiple applications. In particular, LANL is a part of collaboration to develop cryo-cooled normal conducting radiofrequency (NCRF) C-band accelerating structures for the future Cool Copper Collider (C^3) and for compact high-repetition rates X-ray free electron lasers (FELs) [1-3].

The achieved luminosity for Higgs production in C^3 as well as the number of photons produced by the FEL source are highly dependent on the quality (low emittance and high brightness) of the electron beam. Among the sources of emittance growth in the long linac are the short and long-range higher-order-mode (HOM) wakefield effects in accelerating structures. Hence, wakefield damping by means of inserting damping materials into the accelerating structure is essential to decrease the quality and kick factors of excited wakefields. The accelerating structure that is proposed for construction of the cryo-cooled linac was designed with distributed-coupling to achieve high shunt impedance and reduce power requirements for high gradient acceleration [4]. Calculations of the long-range wakefields were performed numerically using the CST Studio Wakefield solver and ACE3P suite and was previously published in Ref. [5]. A new HOM damping design with longitudinal damping slots coated with nickel-chromium (NiCr) absorbing material was proposed for its compatibility with the proposed fabrication methods for distributed-coupling structures when the accelerating structure was fabricated in four quadrants which were then brazed together.

In order to test high-gradient performance of the distributed-coupling accelerator structure with a novel HOM damping configuration, LANL designed a simple two-cell standing-wave accelerator cavity for the high-power testing at LANL's C-band Engineering Research Facility in New Mexico (CERF-NM) [6]. This paper describes the design, fabrication, low-power testing, tuning, and the current status of the high-power tests for the two-cell C-band (5.712 GHz) accelerator cavity with NiCr absorbers.

DESIGN OF THE TWO-CELL TEST CAVITY

The CST Microwave Studio model of the two-cell C-band accelerator test cavity is shown in Fig. 1. The input power from a standard WR187 waveguide is divided equally into two cells. The four HOM damping slots were designed to be plated with NiCr and were supposed to be exposed to relatively low electromagnetic fields during the high gradient conditioning process apart from during the breakdown events when electromagnetic power coupled into the cavity would convert into HOMs.

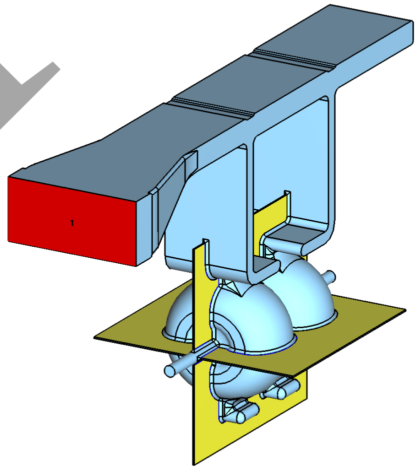

Figure 1: A CST Microwave Studio model for the test cavity with NiCr absorbers: blue color shows the vacuum volume, and yellow color highlights the surfaces of the HOM coupling slots covered with NiCr.

The details of the electromagnetic and engineering designs for the two-cell test cavity are presented in Ref. [7]. The design characteristics of the cavity are summarized in Table 1. During design, a particular attention was paid to minimizing the pulse heating temperature rise due to high surface magnetic fields at the location of the absorbing

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material which could have led to excessive material stress and peeling during repeated heat cycling in high-gradient conditioning. Figure 2 illustrates expected temperature increases on the surface of the cavity when conditioning with a 1 µs pulse length. A possible temperature rise of 22 K was found to be tolerable and is not expected to cause damage to the NiCr absorbing material.

Table 1: Design Characteristics of the Two-cell Test Cavity With Nicr Absorbers

Frequency	5.712 GHz
Iris radius	2.0 mm
Ohmic quality factor, Q_w	13573
Filling time, 2τ	756 ns
Power for 100 MV/m accelerating gradient	4.6 MW
Power for 100 MV/m accelerating gradient in 1 µs long pulse	5.5 MW
E_{max}/E_{cath}	2.70
$H_{max}*Z_0/E_{cath}$	1.10

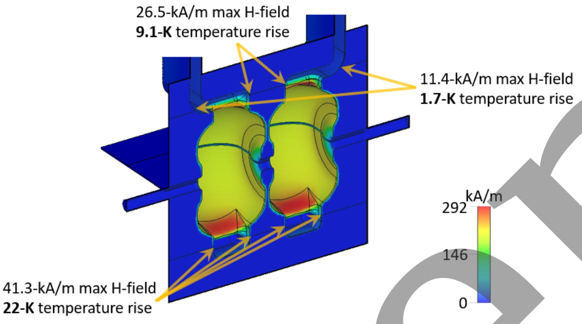

Figure 2: Calculated pulse heating temperature rise in the two-cell test cavity with NiCr absorbers for the accelerating gradient of 100 MV/m and the pulse length of 1 µs.

FABRICATION AND COLD TEST OF THE TWO-CELL TEST CAVITY

The test cavity was fabricated by Dymenso, LLC and delivered to LANL in March of 2025. Figure 3 shows parts of the cavity in various stages of fabrication and the photograph of the fabricated cavity on the bead pull test stand at LANL. First, the HOM damping manifolds were prefabricated into the quadrants of the cavity and alternating 700 nm layers of Ni and 200 nm layers of Cr material were deposited into these manifolds. Next, all cavity features were machined that removed the unwanted NiCr. The final brazing of the four quadrants also served as the heat treatment to diffuse and alloy Ni and Cr into NiCr. The cavity was cold-tested and tuned to achieve the correct coupling frequency and the uniform field profile. Tuning was performed with pushing and pulling on the stainless-steel tuning studs in both cells. The bead pull test was performed after each round of tuning until a balanced field profile was measured in the two cells. Final measured characteristics were in good agreement with the design and CST simulations and shown in Fig. 4.

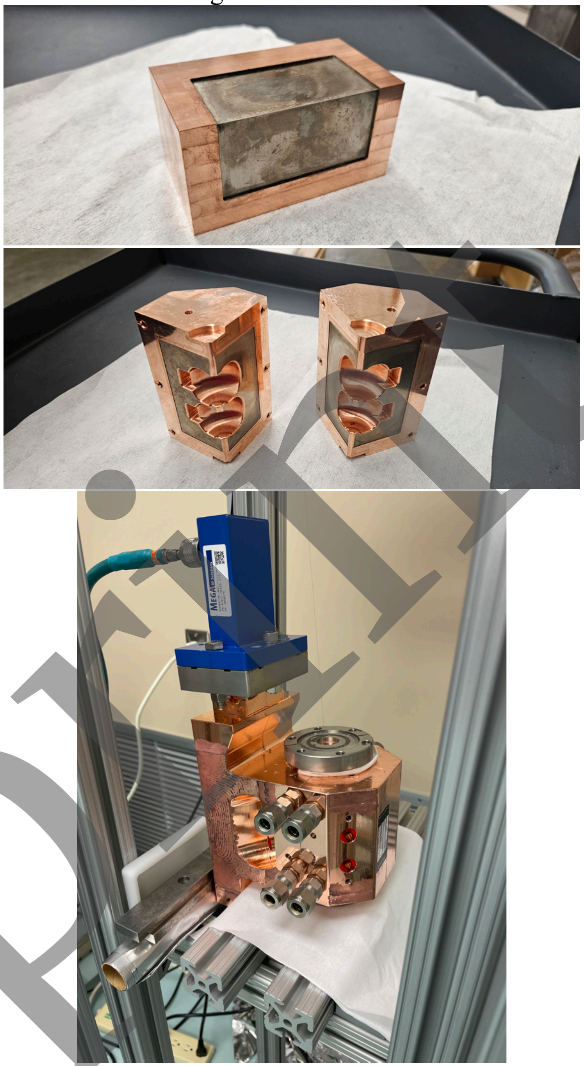

Figure 3: A photograph of the copper block with the machined HOM slot covered in layers of Ni and Cr (top); a photograph of two fabricated quadrants for the two-cell cavity with NiCr absorbers (middle); a photograph of the fabricated cavity under the cold test (bottom).

HIGH POWER TESTING OF THE TWO-CELL TEST CAVITY

The cavity was installed for the high-power testing at the CERF-NM C-band high gradient testing facility at LANL. A photograph of the test setup inside of the lead box that provides radiation protection is shown in Fig. 5. The power to the cavity is supplied by a 50 MW C-band klystron from Scandinova Systems. The diagnostics on the test stand includes the directional coupler installed right before the cavity and the two Faraday cups on both beam pipes of the cavity that detect dark current during conditioning and breakdown events. The conditioning started in mid-April at very low power, the pulse length of 700 ns, and repetition rate of 5 Hz. The input power and repetition rate were slowly increased and the breakdown rate was closely monitored. Figure 6 shows the input and output power traces recorded at the beginning of May and the corresponding computed gradient and the peak fields in the cavity computed with the MATLAB script based on the measured input and reflected power. Table 2 summarizes the measured conditions and peak fields. At the time of writing this paper, the cavity was conditioned up to the maximum coupled power of 2.63 MW with 700 ns pulse rate and 10 Hz repetition rate. The high-gradient testing will continue until the ultimate accelerating gradients limited by the RF breakdown are reached. The final breakdown rates will be measured and reported.

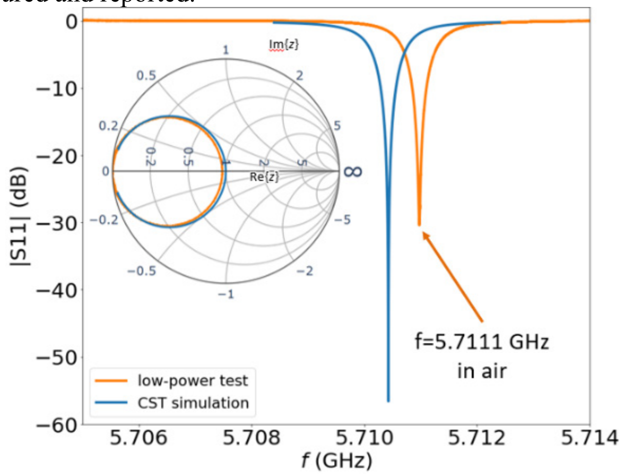

Figure 4: Coupling curve for the two-cell test cavity with NiCr absorbers measured at the completion of the cold testing compared to the computational prediction.

Table 2: Latest Measured Electromagnetic Conditioning Parameters for the Two-cell Cavity With Absorbers

Frequency	5.7119 GHz
Ohmic Q	14274
Pulse length	700 ns
Repetition rate	10 Hz
Maximum input power	2.63 MW
Achieved gradient	63.3 MV/m
Peak electric field	170.8 MV/m
Peak magnetic field	184.7 kA/m

CONCLUSION

In summary, this paper reported the status of the experiment that aimed to fabricate and test a 5.712 GHz two-cell distributed-coupling electron beam accelerating cavity with NiCr absorbers. In collaboration with SLAC National Accelerating Laboratory, this cavity was designed with a goal to study high-gradient performance limitations of this distributed-coupling geometry, and also the ability of NiCr absorbing material which is deposited in HOM coupling slots, to withstand the process of high-gradient conditioning and the associated HOM power generated by RF breakdowns and the pulse heating due to high electromagnetic fields. The cavity was designed, fabricated, cold-tested and tuned, and is currently installed at LANL's CERF-NM C-band high-gradient structure testing facility for high-power testing. Upon the completion of high-gradient testing the cavity will be inspected under the scanning electron microscope (SEM) to investigate possible damage to the NiCr absorbers due to exposure to high electromagnetic fields.

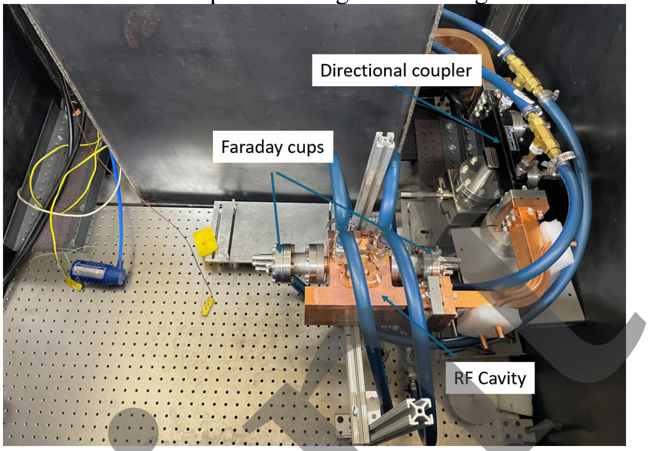

Figure 5: A photograph of the experimental setup inside of the lead box at CERF-NM.

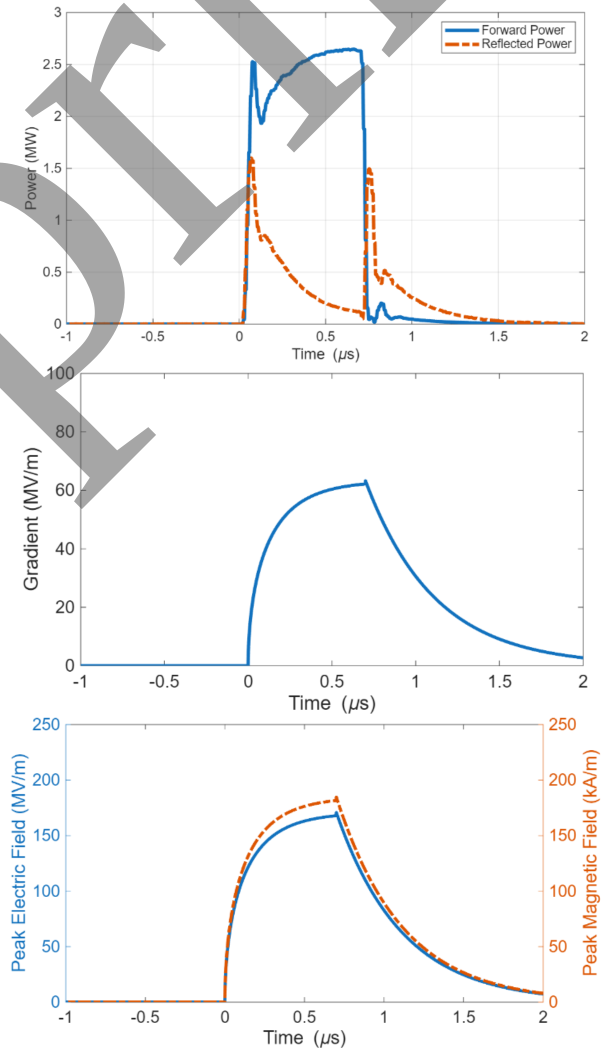

Figure 6: The latest recorded conditioning data: input and reflected RF power pulses (top); accelerating gradient in the cavity versus time (middle); peak surface electric and magnetic fields in the cavity versus time (bottom).

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