Development and high power testing of C-band accelerator components

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International Workshop on Breakdown Science and High Gradient Technology HG2021



- EST.1943 -

20 April 2021



Managed by Triad National Security, LLC for the U.S. De

Outline of This Talk

- Project Overview
- Experimental activities
 - High gradient C-band test stand
 - C-band mode launchers
 - C-band test cavities
 - Collaborations
- Summary and near term plans

Overview: Why Los Alamos?

Achieving high-gradient performance (low breakdown rates, low field emission, etc.) is a *materials science* problem.

Los Alamos is, at core, a materials science laboratory with particular expertise and interest in metallurgy.

Los Alamos also considers itself the steward of accelerator science for the NNSA part of the DOE complex.

Thus, Los Alamos has both an institutional interest in and capability to address this problem.

Overview: High gradient C-band structures project at LANL

The goals for LANL's high gradient project are

- To establish the benchmark point for the rf breakdown probability at C-band (5.712 GHz).
- To conduct material studies.

Why C-band: see the talk by J. Lewellen on Monday.

<u>Material science of RF breakdown:</u> see the talk by D. Perez on Wednesday.

<u>Operations of the C-band klystron:</u> see the talk by M. Middendorf on Wednesday.

50 MW C-band klystron

- Conditioned to 50 MW
- Frequency 5.712 GHz
- $300 \text{ ns} 1 \mu \text{s pulse length}$
- Rep rate up to 200 Hz (typical 100 Hz)
- Nominal bandwidth 5.707-5.717 GHz





High gradient C-band test stand



High gradient C-band test stand (photos)





High gradient C-band test stand (more photos)





Mode launcher summary

- The mode launcher converts the TE₁₀ mode of the rectangular WR187 waveguide into the TM₀₁ mode of the cylindrical on-axis coupler.
- Three designs of the mode launcher were considered: original LANL design, INFN-like design (scaled from Xband), and UCLA-like design (scaled from S-band).
- LANL design was chosen for fabrication due to the compromise between the bandwidth, peak fields and pulse heating, and the simplicity of fabrication.
- 4 mode launchers were fabricated with an outside vendor (Dymensco).

LANL Mode Launcher



INFN Mode Launcher



UCLA Mode Launcher



Mode launcher comparison

	LANL	INFN	UCLA
Bandwidth @-20 dB	17 MHz (5.703 to 5.720 GHz)	35 MHz (5.691 to 5.726 GHz)	44 MHz (5.687 to 5.731 GHz)
Emax for 25 MW power	15.34 MV/m	11.4 MV/m	29.41 MV/m
Hmax for 25 MW power	46.9 kA/m	41.7 kA/m	57.39 kA/m
Pulse heating for 1 µs pulse	0.67 °C	0.53 °C	1.00 °C

Fabricated mode launcher – photographs

Fabrication of 4 mode launchers was performed at Dymenso, LLC. in collaboration with Philipp Borchard.



Fabricated mode launcher cold tests



MODE LAUNCHER S/N 1

f [GHz]

MODE LAUNCHER S/N 2

f [GHz]



Bench mark cavity: a/λ=0.105 structure







C-band benchmark test cavity

Frequency	5.712 GHz	
Phase shift per cell	π	
Cell length	1.034 in	
a/λ	0.105	
Iris radius	0.217 in	



Benchmark test cavity characteristics

Q (room temperature copper) with coupler cells: 12682

Peak power needed to achieve 200 MV/m peak surface field: 5.3 MW







Test cavity fabrication - brazing

- The total of 2 soft copper structures will be fabricated.
- Copper parts are fabricated at LANL's internal machine shop.
- One structure will be brazed in a vacuum furnace at LANL. The second structure will be brazed commercially in a hydrogen furnace (Altair?).



Test cavity fabrication – welding of the two clamshells

Electron beam welding is a core technology being developed at LANL. Lots of in-house expertise.

Welding two copper halves offers an alternative to bonding to produce a structure made of hard copper.



Bi-metal flanges for the hard copper structure

- We ordered bi-metal copper-stainless steel flanges for the hard copper structure.
- These flanges can be ebeam welded to the copper structure.
- Flanges ordered commercially from Atlas Technologies in WA.



Atlas combined different metals with bonding technology.

Tuners for the hard copper structure

- SS tuners cannot be brazed into the copper structure.
- Hard copper has much higher yield strength than soft copper – bigger forces required to cause deformations.



Mechanical design was conducted to ensure that the force applied to cause plastic deformation of the copper disc, *W*, is smaller than the force required to pull the threaded stud out of the copper.

Materials coupon tester concept

- An overmoded resonator for RT/Cryo material testing
- Concept under development: coaxially coupled structure
- Design criteria:
 - -Highest E, H surface fields on coupon surface
 - -Maximize $E_{coupon}/E_{cavity,}$ H_{coupon}/H_{cavity}
 - -Minimize fields at coupon/cavity joint





Materials coupon tester – design in progress



Plan for testing C-band cavities

- 1. Benchmark cavity
 - Fabricated by conventional machining.
 - Brazed in a hydrogen surface soft copper.
- 2. Welded cavity
 - Fabricated by conventional machining in two halves.
 - E-beam welded at LANL. LANL unique capability. Will result in a hard copper structure.
- 3. Same geometry with new materials
 - We plan to fabricate the same geometry of copper-silver with different contents of silver.
 - The structures will be welded.
 - The best content of silver will be evaluated in simulations.
- 4. Cryo-cooled cavity
 - The same geometries and materials will be tested at cryogenic temperatures.

Collaborations: SLAC C-band beta=0.5 cavities

- LANL's high gradient C-band test facility is the only high gradient C-band test facilities in the US and is open to collaborators.
- LANL provided us with Technology Evaluation and Development (TED) funding to test SLAC's C-band beta=0.5 cavities at high gradient.
- First cavity to go for testing next week.





Summary and near term test plans

- The high gradient test stand is finally coming online.
- FY21 outlook
 - Waveguide line is fully conditioned to 30 MW, 1 microsecond long pulses, 100 Hz repetition rate.
 - April May, 2021: testing of SLAC's beta = 0.5 cavities.
 - June-July, 2021: conditioning of the mode launchers.
 - August September, 2021: testing room-temperature cavities.
- FY22 outlook
 - -Hard copper and copper-silver alloy cavities testing.
 - -Cryogenic temperature testing.
 - -Materials coupons testing.