ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-MOPAB146

STATUS OF THE C-BAND ENGINEERING RESEARCH FACILITY (CERF-NM) TEST STAND DEVELOPMENT AT LANL*

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Abstract

C-Band structures research is of increasing interest to the accelerator community. The RF frequency range of 4-6 GHz gives the opportunity to achieve significant increase in the accelerating gradient, and having the wake fields at the manageable levels, while keeping the geometric dimensions of the structure technologically convenient.

Strong team of scientists, including theorists researching properties of metals under stressful thermal conditions and high electromagnetic fields, metallurgists working with copper as well as alloys of interest, and accelerator scientists developing new structure designs, is formed at LANL to develop a CERF-NM facility. A 50 MW, 5.712 GHz Canon klystron, was purchased in 2019, and laid the basis for this facility. As of Jan-21, the construction of the Test Stand has been finished and the high gradient processing of the waveguide components has been started. Future plans include high gradient testing of various accelerating structures, including benchmark C-band accelerating cavity, a proton β=0.5 cavity, and cavities made from different alloys. An upgrade to the facility is planned to allow for testing accelerator cavities at cryogenic temperatures.

INTRODUCTION

Recent development in the normal conducting accelerating RF structures research showed increasing interest in the C-band frequency range. This frequency choice has benefits of the elevated accelerating electric field gradients, when compared to the traditional lower frequency. And at the same time present mechanical dimensions that are less demanding in manufacturing, when compared to higher frequency cavities. The accelerating gradient of around 100 MV/m in the single-cell RF cavity at 5.712 GHz can be expected [1].

Using of the copper-silver alloys present promising results in reliable achievement of higher accelerating fields in the test cavities [1]. Also using cooled normal conducting cavity to temperature around 20-40 K allow increase of the electric and magnetic fields even more without electric breakdown rate increase [1].

Until recently the availability of the RF sources in the C-band frequency range was limited, but recent developments in this field makes the klystrons more affordable [2] and enables more active research in this field of study.

TEST STAND LAYOUT

The constructed Test Stand for the C-band project is situated in the former LEDA accelerator tunnel at LANL. This tunnel constrains exceed our requirement by a big margin. We share this tunnel with several other projects, and use only a small segment of the floor space (see Fig. 1).

At present the configuration of the test stand allows us to produce fields capable of accelerating of the electrons to 5 MeV with current not more than 1 mA. This essentially limits our capacity to testing of the single cell RF cavities.

However, we are planning to develop additional capabilities of this Test Stand to accommodate testing of the multicell cavities, producing up to 100 MeV electron beam current higher than 1 mA, depending on the funding available.

Figures 2 and 3 shows the photographs of the tunnel.

TEST STAND COMPONENTS

Klystron and Computer Controls

The C-band klystron, shown in Fig. 2, for frequency 5.707-5.717 GHz, maximum out power 50 MW, pulse length up to 1 us and repetition rate of up to 200 Hz was purchased, installed, and tested to the full power in year 2019. This Klystron is outputting RF power to the WR187 waveguide.

*Work supported by LANL LDRD program 20200057DR
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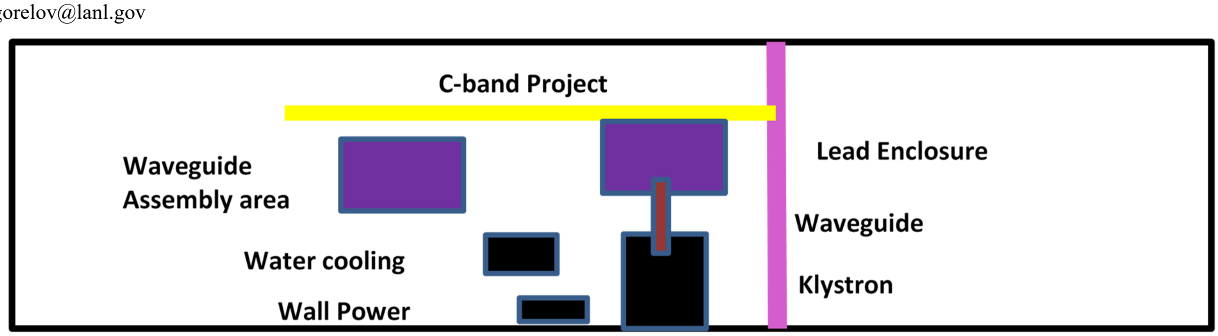

Figure 1: Schematic CERF-NM Test Stand layout in the LEDA tunnel at LANL.

12th Int. Particle Acc. Conf. IPAC2021, Campinas, SP, Brazil JACoW Publishing
ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-MOPAB146

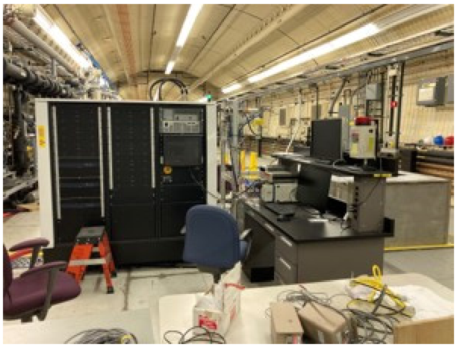

Figure 2: View of the tunnel. Foreground – computer control station. Left – C-band klystron. Right, background – lead enclosure.

Figure 3: View of the tunnel. Foreground – lead enclosure. Left – klystron. Background – waveguide assembly area.

For conditioning of the waveguide, and for the running of the breakdown rate measurements on the RF cavity we vary the pulse length between 0.3 and 1 us, and change the repetition rate between 1 and 100 Hz to achieve desired regime.

Lead Enclosure and Radiation Protection

The lead enclosure, shown in Fig. 3, was assembled in the tunnel in summer 2020. It has about 25 tons of lead bricks, that are encapsulated inside the steel jacket for elimination of lead contamination. In addition to the lead walls, we have built two lids about 3 tons each that go on top of this enclosure for running of the tests.

Thorough radiation analysis was performed to confirm the operational safety of this test stand. Figure 4 shows the results of this analysis.

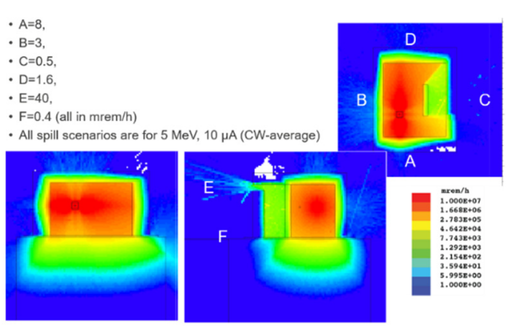

Figure 4: Results of the radiation safety analysis. Courtesy of Michael Mocco.

The estimated radiation level in the worst-case scenario is ~40 mrem/h in the vicinity of the opening in the lead shielding provided for the waveguide is acceptable for our use. In most practical situations the radiation level is minute and do not exceed the background levels of ~10-15 mrem/h.

Waveguide Assembly and Conditioning

Figures 5 and 6 show the mechanical design of the waveguide that connects the output port of the klystron with the equipment that is been tested inside the lead enclosure.

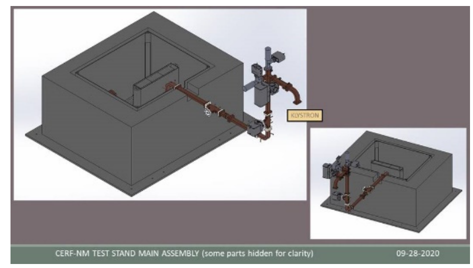

Figure 5: The 3D view of the waveguide assembly for the CERF-NM Test Stand. Courtesy of Harbhajan Khalsa.

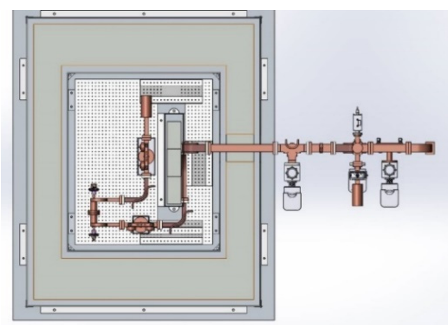

Figure 6: The top view of the waveguide assembly for the CERF-NM Test Stand. The assembly of two Mode Launchers (Mode Converters) at the end of the waveguide is shown on this figure. Courtesy of Harbhajan Khalsa.

The initial setup of the waveguide will have a two Mode Launchers (Converters) back-to-back for conditioning and confirming the conversion efficiency, as shown in the Fig. 7. The Mode Launchers are provided for conversion of the TE01 mode in the waveguide to TM10 coaxial mode, needed for coupling to the test RF cavity [3].

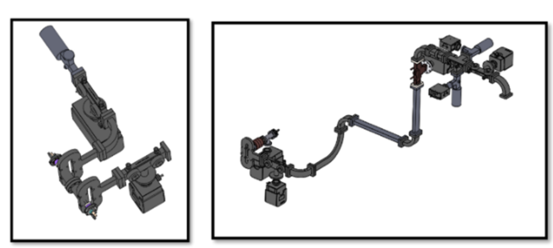

Figure 7: Left – two Mode Launchers back-to-back setup: for conditioning and conversion efficiency check. Right – test run setup with single Mode Launcher and RF cavity.

The test run setup has one Mode Launcher and the RF cavity attached to it. The estimated run time in this

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configuration for each of the test cavities is about 4 weeks. Currently the computer control code is been developed that would allow us to run 24/7, that will significantly reduce required run time [4].

Figures 8 and 9 show the two separate segments of the waveguide. The conditioning of the segments was done sequentially and allowed for relatively fast and painless process. Figure 10 shows a typical computer control screen during conditioning of the waveguide.

The assembly of the waveguide was started in January of 2021, and it was fully conditioned in March 2021.

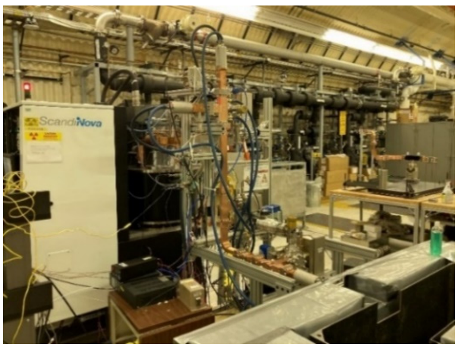

Figure 8: First segment of the waveguide in conditioning mode.

Figure 9: Second segment of the waveguide is installed inside the lead enclosure and later is connected to the first segment.

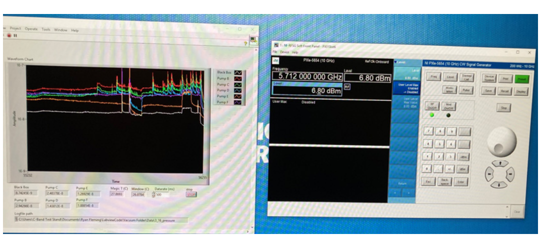

Figure 10: Typical computer control screen during waveguide conditioning. On the left is the window with the pressure measurements curves in different points along the waveguide line. On the right is the RF power control window.

FIRST CAVITY TESTING RUN

The first cavity testing started in May. Figure 11 shows the SLAC cavity, made of the OFHC Cu with geometry, that is suitable for acceleration of protons/ions with relative velocity β=0v/c=0.5. The details of running measurements on this cavity can be found in [5].

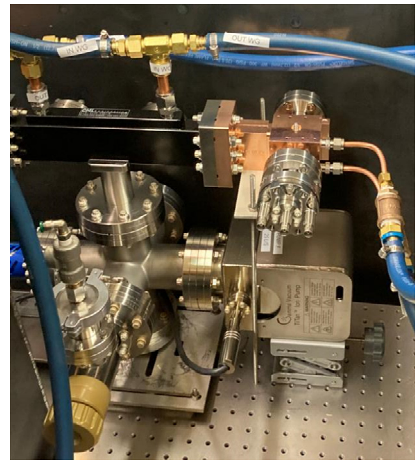

Figure 11: First cavity is been tested in the Test Stand. This is OFHC Cu cavity from our collaborators at SLAC, designed for acceleration of protons/ions at relative velocity of 0.5 of the speed of light.

The diagnostics on the Test Stand during production run includes pressure monitoring in multiple locations, directional couplers readings at the output if the klystron and at the input into the cavity, thermocouples readings on the cavity and the RF windows, separating the segments of the waveguide, Faraday Cup reading on the cavity, etc. The cooling water loops are engaged for the cavity, directional couplers, and RF window.

CONCLUSION AND FUTURE PLANS

The development of the C-band Test Stand is progressing successfully and the Test Stand is operational as of the mid-second year of the project. The schedule delays were insignificant, and did not impede the project. The Klystron was commissioned at the end of summer 2019; the lead enclosure was installed in summer 2020; and the waveguide assembly was started in January 2021. The waveguide was successfully commissioned in March 2021 and the first RF cavity from our collaborators at SLAC was installed and the testing was started in May 2021. The first results are expected by mid-summer 2021.

We are planning to continue testing our collaborator cavities, including the second cavity manufactured from the Cu-Ag alloy this summer. Later this summer, after conditioning of the Mode Launchers, we are planning to start testing of the baseline test cavity, which is being manufactured now. In the next FY22, which will be the final year of our LDRD project, we are planning to continue testing of the room-temperature cavities, and also install and test the cavities at the cryogenic temperatures. We also planning to finish design and manufacture the coupon testing cavity for material science studies [6].

We welcome all collaborators to study the rapidly growing field of C-band RF cavities and the High Gradient research in the RF cavities to our newly built CERF-NM Test Stand.

ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-MOPAB146

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