

FERMILAB CRYOMODULE TEST STAND DESIGN AND PLANS*

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Abstract

A facility dedicated to SRF cryomodule testing is under construction at Fermilab. The test stand has been designed to be flexible enough to cool down and power test full length TESLA-style 8-cavity cryomodules as well as cryomodules for low- β acceleration. We describe the design considerations, status, and near future plans for utilization of the test stand.

INTRODUCTION

The Cryomodule Test Facility (CMTF) at Fermilab is a research and development facility for accelerator science and technology, in particular, the testing and validating of Superconducting Radio Frequency (SRF) components. CMTF provides the necessary test bed to measure and characterize the performance of SRF cavities in a cryomodule. CMTF was designed to be a flexible test facility, configurable in different ways to meet the needs of current as well as future projects at Fermilab and abroad.

CMTF consists of two new adjoined buildings (as pictured in Fig. 1) located adjacent to the existing NML building, and together with NML comprises a world-class facility for testing SRF components with and without beam [1]. The smaller (4000 square foot/371.6 m²) Compressor Building houses the warm compressors, vacuum pumps, water cooling system and utilities for the entire facility. The larger building depicted in Fig. 5 consists of a (15,000 square foot/1,394 m²) high-bay with a 20-ton overhead crane and contains two liquid helium refrigerators, two Cryomodule Test Stands, a test area for RF components and electrical systems, a cleanroom area for particle-free preparation of SRF components, and a control room/office area.

The facility houses a large state of the art cryogenic plant capable of providing a total of 500W of cooling capacity at 2 Kelvin that can provide simultaneous operation of the two independent test stands.

The goal of the first test stand, CMTS-1, is to test cryomodules of various frequencies in pulsed or continuous wave mode. It is currently being prepared to support the testing of cryomodules for the LCLS-II project being built at Stanford Linear Accelerator (SLAC). It will test both 1.3 and 3.9 GHz cryomodules in Continuous Wave (CW) mode for LCLS-II.

The second test stand currently houses PXIE, the R&D program to test the front-end of the proposed PIP-II

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Figure 1: CMTF building adjacent to NML.

accelerator.

The beginning portions of the PIP-II accelerator are being installed and commissioned at PXIE and will eventually contain two different types of cryomodules [2].

TEST CAVE

The CMTS-1 test cave is a shielded enclosure sized to house cryomodules as large as TESLA-style 8 cavity 1.3 GHz ones. Inner dimensions are 64' 9" (19.74 m) long by 15 feet (4.57 m) wide with a height of 10-1/2 feet (3.2 m) as shown in Fig. 2. The walls are composed of shielding blocks and are 3 feet (0.914 m) thick with integrated penetrations for RF waveguide, cabling, etc. The roof is removable in order to move cryomodules in and out of the cave and is similarly composed of blocks with a total thickness of 3 feet (0.914 m).

Interlocked radiation detectors will be situated both within the cave and on the roof of the cave to ensure that safe levels are maintained during cryomodule testing. The cave will be considered an Oxygen Deficient Hazard (ODH) area thus monitoring and ventilation schemes are being implemented based on experience at similar test areas at Fermilab.

Cryomodule Support Girders

The fundamental design of the cryomodule support girders is based on that by INFN, Milan and used at DESY for FLASH. This design was later modified slightly to accommodate using available English structure steel shapes and standard AISC sections [3] while maintaining important metric standard features such as feed/end cap interface hole placement as was applied at Fermilab for CM-1 and currently CM-2 [4] at the NML/FAST facility.

The recent emphasis on reducing stray magnetic fields to maintain high Q_0 in SRF cavities has led to an appreciation of the need to maintain good 'magnetic hygiene' [5]. Given their bulk, composition and proximity to the cryomodules under test, the design and fabrication of the support girders has been given special scrutiny.

There are two ways to approach the stray field issue and minimize its effect: provide magnetic shielding or eliminate the source(s) and the latter has been applied. Girders previously fabricated for this purpose consisted of common structural steel found either in Europe or within the United States. The chosen approach involved changing the original girder material specification from A36 structural steel to 316L stainless steel. This change also applies to any hardware used within the design, especially near the cryomodule.



Figure 2: CMTS-1 feed and end girders staged in the CMTS-1 cave.

The basic structure consists of two pseudo W-beams (24" in height) welded together. Roughly 122" from the feed cap end there is a vacuum vessel support with a hole-pattern to receive the Base Assembly Support and bears one half of the cryomodule weight, 8,130 lbf. At the other end, the two top and bottom W-beam flanges are coped to accept two top and bottom plates which are welded to the webs of the two horizontal beams. Between these two top and bottom plates, there are two vertical gusset plates used to compensate for the moment produced by the vacuum load, a 25,080 lbf reaction. Then, at the same end, on top, the top plate the triangle gussets are welded directly above the two plates. Two pseudo W16 beams (possessing 1.5" thick web and flanges) support the cryomodule end plate and is attached to the end assembly described above.

The Feedcap and Endcap girders are essentially identical in terms of the structural integrity. While the Feedcap girder floor position is fixed by a rigid cryogenic transfer line, the endcap girder will need to be moveable such as for the case of testing shorter 3.9 GHz cryomodules. In this case the endcap girder will have to be moved closer to the feedcap. In Fig. 2 one can see the completed girders staged in the CMTS-1 enclosure. Final placement and alignment has yet to be completed.

Structural steel hardware (such as critical girder and anchor bolt connections) used with the original design has been retained in the CMTS-1 girder design. These components are far enough from the cavity string to prevent stray field exposure.

RF LAYOUT

Per LCLS-II design, each cavity will have its own RF source. Figure 3 depicts the planned RF distribution layout and power feed to each cavity. Solid state amplifiers (SSA's) will be located outside and immediately adjacent to the test cave. Circulators to minimize reflected power back to amplifiers are mounted above each SSA. Individual waveguide runs will enter the cave near the cave ceiling height and then drop vertically above the respective coupler port. Directional couplers to measure both forward and reflected power are located both before the circulator and immediately prior to the input coupler of each cavity. The vertical sections are designed for easy and rapid removal to allow sufficient clearance in order to crane cryomodules in and out between tests.

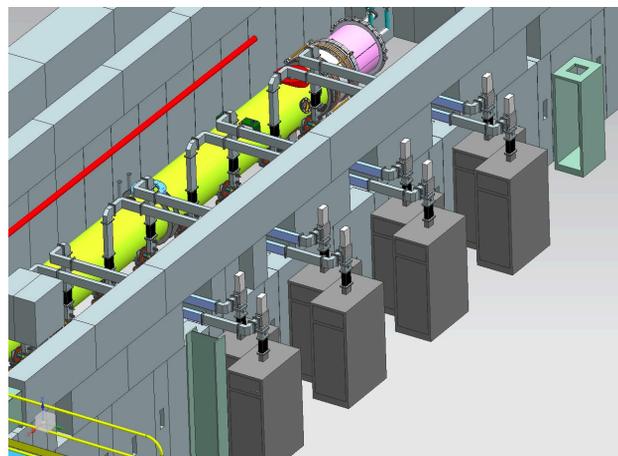


Figure 3: RF layout for testing LCLS-II 1.3 GHz cryomodules.

CRYOGENIC SYSTEM

The cryoplant for CMTS-1 has been described extensively [6,7,8]. The major components in support of CMTS-1, include the cryoplant, distribution box, transfer line and valve box, and feed and endcaps. The first three of these are visible in Fig. 4.

Cryogenics Plant

Two cryogenic plants are installed at CMTF. The Superfluid Cryogenic Plant (SCP) was purchased from industry and designed to maintain loads at the nominal temperatures of 2 K, 4.5 K, and 40 K while operating in a pure refrigeration mode. The SCP includes 3 cold compressors in series, which allows the plant to recover refrigeration from 2 Kelvin return flow. The other plant is a refurbished CTI-4000, which was previously used at the

Table 1: The specified (Spec) and experimentally tested (Test) refrigeration capacity of the Superfluid Cryogenic Plant for CMTF

Nominal Temp	Unit	Mode 1		Mode 2		Mode 3	
		Spec	Test	Spec	Test	Spec	Test
1.8 K	W	250	257	N/A	N/A	N/A	N/A
2.0 K	W	N/A	N/A	500	527	N/A	N/A
5 K to 8 K	W	600	619	600	619	100	118
40 K to 80 K	W	5,000	6,136	5,000	6,136	700	720
Liquid He	g/s	N/A	N/A	N/A	N/A	16	25

SLAC National Accelerator Laboratory (SLAC). The helium refrigerators are installed in a pit so that control valves and instrumentation on the top plate are easy to access and so that the vacuum shell can be removed in case repairs or modifications are necessary on the internal piping.

There are three primary modes of operation for the plant, as shown in Table 1; this table also compares the specified and empirically determined capacity as measured during acceptance testing. Mode 1 and Mode 2 have 1.8 K and 2.0 K liquid helium leaving the SCP, respectively, while having the cold sub atmospheric vapor from the cavity bath returning to the plant. The temperature difference of 0.2 K between the two modes is quite significant, since the SCP will have twice the capacity at 2.0 K that it does at 1.8 K. One of the functions of CMTF is to search for the optimal tradeoff between plant efficiency and cavity temperature. Mode 3 is running the plant with a liquefier load, as would be the case during cool down.

Distribution Box

The SCP helium output is sent to a distribution box which was designed at Fermilab and fabricated by PHPK Technologies®. Control valves and instrumentation within the distribution box control flow to the cryogenic loads including CMTS-1.

There is a cooldown supply circuit from the SCP that supplies helium between 40 K and 300 K to each supply line leaving the distribution box, which allows any load to be cooled down at a precise rate independent of the status of the other two loads. A 3000 liter liquid helium dewar connected to the distribution box via U-tubes acts as a buffer for operational upsets and is also used to provide temporary additional cooling capacity during cryomodule cool downs. Parasitic heat loads in the distribution box are intercepted with a liquid nitrogen cooled radiation shield, but the liquid nitrogen is not distributed to any of the loads from the distribution box. No liquid nitrogen is used in the CMTS-1 test cave.

Transfer Line & Valve Box

Immediately after the transfer line exits the distribution box, the transfer line bends upwards and runs up into the bottom of an expansion can. This increases the transfer line elevation by 3.3 m, which allows the transfer line to pass over all the RF equipment for the two test areas at CMTF. After exiting the expansion can the transfer line runs horizontally for 21 m, then into a valve box on the roof of the CMTS-1 cave. The opposite side of the valve box has a short horizontal run of transfer line, then drops down in the CMTS-1 cave. The valve box on the cave roof serves a number of functions. The most important function of the valve box is the isolation of cryogens from personnel during cryomodule installation and removal. Valves separating cryogens from personnel will be locked out and tagged for the time period between cryomodule tests. The distribution box contains most of the control valves required for cryomodule testing. However, control valves often fail to maintain a leak tight seal after extended use. A second set of manual valves are located in the CMTS-1 valve box. The volume

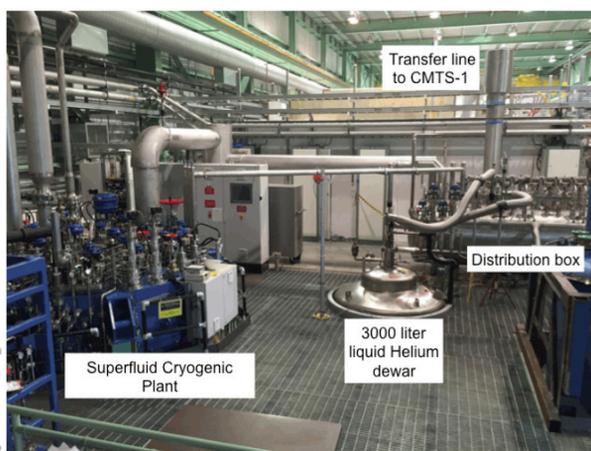


Figure 4: Cryogenic plant for CMTS-1.

Valves internal to the SCP allow refrigeration to be recovered once the return helium temperature drops below 80 K. The SCP acts almost as a pure liquefier at the start of a cryomodule cool down, moves into a mixed refrigeration/liquefier mode once the return temperature(s) drop below 80 K, and operates in a pure refrigeration mode (Mode 1 or Mode 2) during normal cryomodule operation.

between the two valves can be actively pumped to ensure that no cryogenics can be released into the cave. There is a vacuum break on either side of the valve box so that the vacuum space can be filled with dry nitrogen. Dry nitrogen can be injected into the valve box vacuum space to help the valves warm up and stay warm, which increases the probability the valves will seal leak tight. All pumping and backfilling of the cryomodule helium circuits will be done using ports on the valve box.

Feed & End Caps

The Feedcap and Endcap designs are similar to those already used at the Fermilab Accelerator Science and Technology (FAST) facility at Fermilab. The FAST Feedcap and Endcap designs in turn are based on the Cryomodule Test Bench at DESY. The detailed design and fabrication of the CMTS Feedcap and Endcap was done by Bhabha Atomic Research Centre (BARC).

There are a few significant changes from the FAST Feedcap and Endcap. The tunnel for LCLS-II has a 0.5% slope, so cavity circuit liquid level control cannot be managed in the same way as previous 1.3 GHz cryomodule designs. Each cryomodule must have its own separate pipe for two phase flow to the cavities to avoid having all the liquid collect at lower elevations and all the vapour collect at higher elevations. In turn, this means that each cryomodule requires its own Joule-Thomson valve and cool down valve. The control valves and riser pipe are placed in the middle of the cryomodule, which means that only half the length of the 300 mm sub atmospheric pipe will see flow from the cryomodule JT or cool down valves. A control valve was added to the Endcap so that flow can be circulated through the entire length of the 300 mm pipe during cool downs and warm ups.

The other major change is to the interconnects that connect cryomodule piping the Feedcap and Endcap. Rather than using welded linear bellows as is the case for FAST, U-shaped assemblies with three flexhoses using conflat flanges will be employed at CMTS-1. These flexhose interconnect assemblies can be installed quickly and can handle significant misalignment of the pipes while still providing for the thermal contraction of the cryomodule piping. The 300 mm sub atmospheric return pipe does not have sufficient clearance for a conflat flange, so an indium sealing flange will be used instead.

OTHER SUBSYSTEMS

The testing infrastructure including controls, interlocks, Low Level RF, etc. is largely identical to what has already been employed at other Fermilab SRF test stands. In part this was done to be able to bring CMTS-1 into operation as rapidly as possible.

Controls

The controls platform - hardware and software, timing, device interfaces, etc. - will be based on the

Fermilab ACNET protocol. Capabilities afforded by ACNET include an extensive suite of existing user applications including a growing number of GUI's and development tools for same, real time plotting of devices, data archiving, alarm capability for devices out of tolerance, remote operation, and schemes for automation of tasks. Much of this capability has already been developed for SRF testing and will be exploited and expanded as needed. ACNET does have capability for interface to alternate controls protocols, thus alternate systems can be interfaced as needed. This will likely prove to be useful for evaluating controls components developed at SLAC for use in LCLS-II.

RF Interlocks

The goal of the RF Interlocks system is to provide system protection by treating each of the eight RF feeds (SSA, circulator, waveguide, and coupler) as stand-alone units. To measure the state of each power unit, the interlocks system uses inputs from photo-multiplier tubes monitoring the waveguide, field emission probes at three discrete points in the couplers, temperature sensors on the coupler ceramic windows, and power measured by the directional couplers. Capability also exists to digitize the input analogue signals and make them available for viewing and archiving via ACNET. The RF interlocks system enables/disables the LLRF signal by enabling a GaAs fast switch as well as removing a permit from the solid state power amplifier when a fault condition from an input is sensed. Depending on the severity of the fault, either automatic or manual resets will be supported.

Since the testing scheme is planned to include both individual cavity tests and unit tests with all cavities operated together, the interlocks logic will support both standalone and integrated monitoring of each RF feed.

STATUS

The first use of CMTS-1 will be for the seventeen 1.3 GHz and two 3.9 GHz cryomodules being assembled at Fermilab for the LCLS-II project. Prior to transport to SLAC, all of them will be cooled down and verified to meet specification. A test plan is in the process of being developed which draws on previous cryomodule experiences and will allow consistent evaluation among the LCLS-II partner labs. LCLS-II cryomodule testing is planned from early 2016 through 2018.

The test cave has been installed and the bulk of the major components received including the girders, feed and end caps and other cryogenic components. Integration of the cryogenic feed from the SCP into the cave is in progress.

Commissioning of the test area is expected in late 2015. The completed cryogenic system will be commissioned in parallel with the RF and interlock systems.

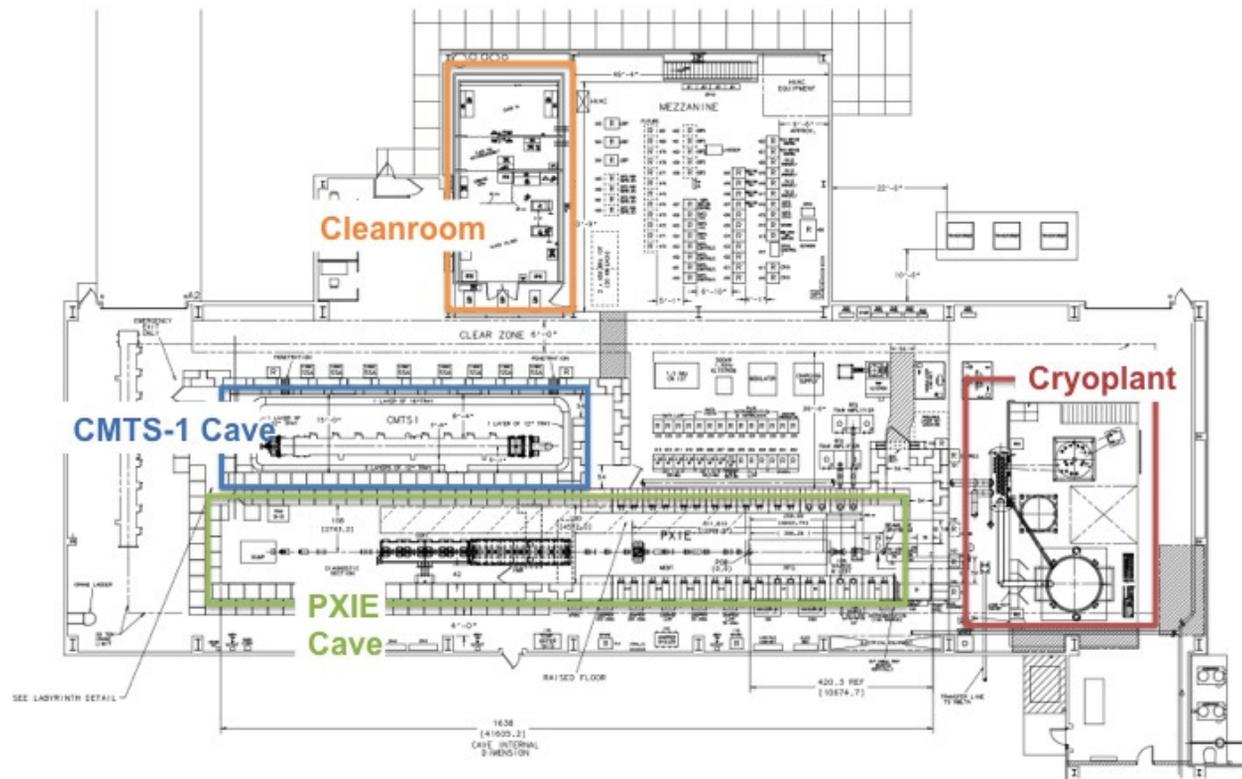


Figure 5: Layout of CMTF. The Cryomodule Test stand is outlined in blue, Cryoplant area in red, PXIE enclosure in green, and Cleanroom in orange.

The first LCLS-II cryomodule is destined to arrive in early 2016. The duration of testing for this prototype cryomodule is planned for three months in order to fully commission CMTS-1, refine testing protocols, and gain the necessary experience. Subsequent cryomodules will be tested at faster rates ultimately intended to achieve a 28-day cycle for production cryomodules.

SUMMARY

Fermilab is constructing a facility dedicated to testing SRF cryomodules. CMTS-1 is now being assembled to qualify both 1.3 and 3.9 GHz cryomodules for LCLS-II. Commissioning is expected to commence in late 2015 with testing of the first cryomodule expected in the first half of 2016.

ACKNOWLEDGMENTS

The authors recognize the diverse and capable expertise of many people both at Fermilab as well as its partners elsewhere in the United States and around the world. The realization of CMTS-1 is based on the construction and operation of similar test stands. We acknowledge the advice freely shared by those operating these facilities.

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