

# Fermilab CMTF Multi-Level Cryogenic Distribution Control System

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**Abstract.** The Cryomodule Test Facility (CMTF) is a research and development facility, it houses a large state of the art cryogenic plant capable of providing a total of 500W of cooling capacity at 2 Kelvin. Its first test Cryomodule Test Stand (CMTS), 1.5m diameter and 9m long, is to test both 1.3 and 3.9 GHz cryomodules in Continuous Wave (CW) mode for the LCLS-II project. The cryogenic control system includes three subsystems, they are MyCom compressors, Linde super cryogenic plant and CMTS cryomodule cavity. Each subsystem control should be independently design, but operate integrated together. Therefore, the CMTF multi-level distribution control system consist of two redundancy SIMATIC manager central controls, three Siemens PCS7-400 controllers as subsystem and seven DL205 PLCs as field control. Those authorized remote control centers are to be operate by synoptic HMI through Fermilab ACNET.

This paper presents a method which has been successfully used by many Fermilab distribution cryogenic control systems.

**Keywords:** Cryomodule test facility, Multi-level distribution system, real-time remote control.

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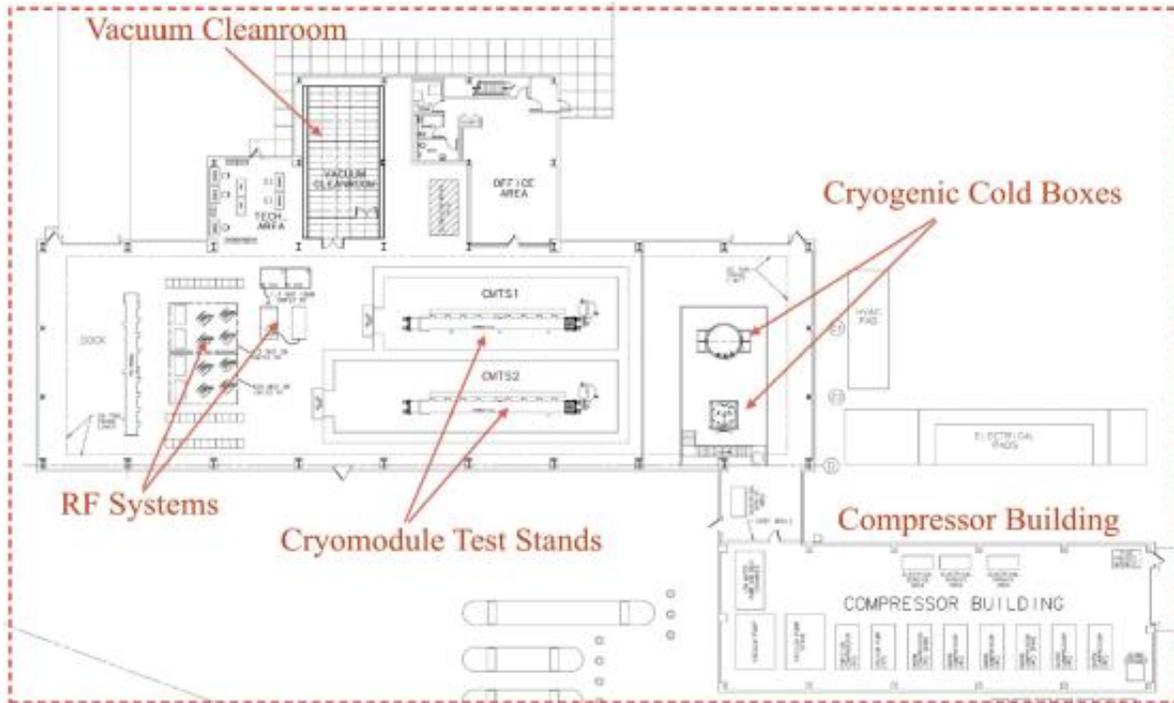
## INTRODUCTION

Fermilab Cryomodule Test Facility (CMTF) will house the new cryogenics plant as well as multiple stand-alone SRF cryomodule test stands. One of the buildings will house the noisy vibrating equipment (seven compressors, two vacuum pumps, etc.) needed to operate the cryoplant. The other building will contain: the Linde cryogenic plant, cold box, cryomodule test stands, RF systems, a vacuum clean room, and an office area.

The CMTF is for the test facility to house two test caves that are capable of testing various styles of cryomodules at 325 MHz, 650 MHz and 1.3 GHz, in pulsed and continuous wave (CW) modes of operation. The test stands will be used to assess the cryomodule performance prior to their commissioning. A layout of the entire Cryogenic Module Test Facility complex is shown in FIGURE 1.

## TEST FACILITY DESCRIPTION

The CMTF is composed of compressor room and helium refrigeration, which is provided by an onsite cryoplant. The warm compressors are the MyCom brand 300KW compressors #1 through #6, plus compressor #7 serving as a purifier compressor as shown on the FIGURE 2. The goal of the seven compressors is to demonstrate stability of operations up to four compressors in parallel between typical suction @ 15.5 Pisa +/- 0.1 psi and discharge @ 290 Pisa +/- 3 psi.



**FIGURE 1.** Layout of CryoModule Test Facility



**FIGURE 2.** CMTF Warm Compressor building

The Superfluid cryogenic helium plant (SCP) of Linde is shown on the FIGURE 3, SCP has 2K @ 250W capacity, it supplies liquid helium to various styles of cryomodules. The CMTF is to house two test stands. One is LCLS-II (Light coherent light source) main linac 1.3GHz Cryomodule, another one is Half-Wave (HW) cryomodule for the Project X Injector Experiment (PXIE). The LCLS-II 1.3 GHz CM contains TESLA style superconducting accelerating eight 9-cell cavities as shown on the FIGURE 4, FIGURE 5 and FIGURE 6.

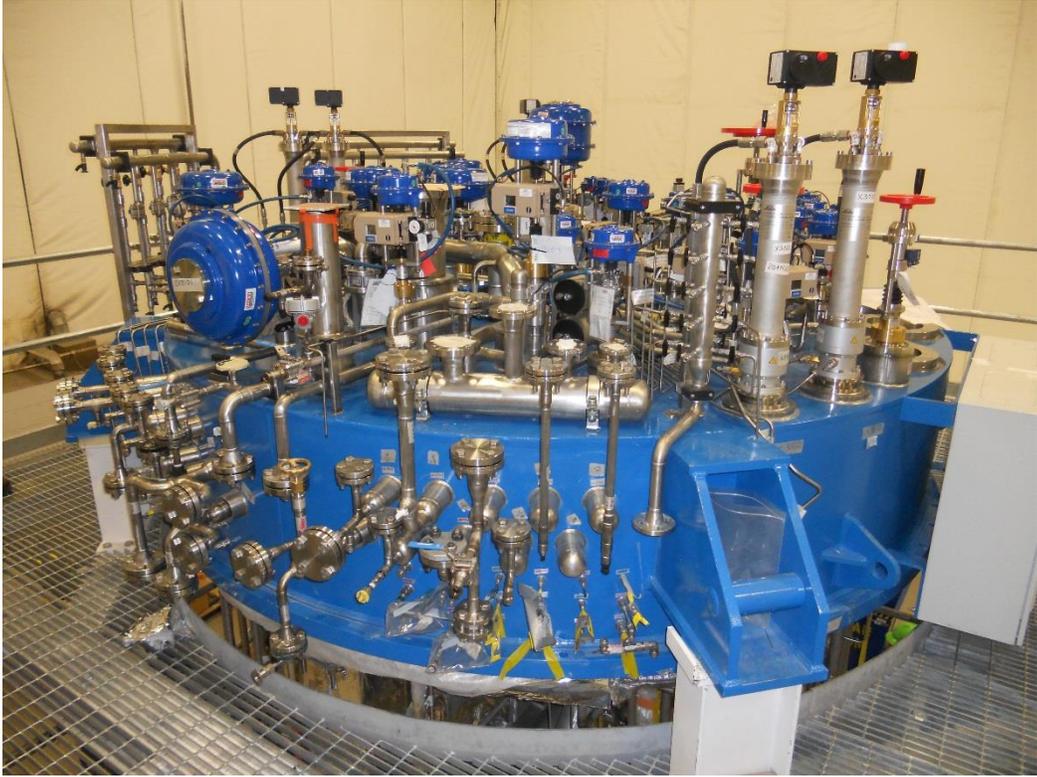


FIGURE 3. CMTF Linde SCP Cryogenic plant

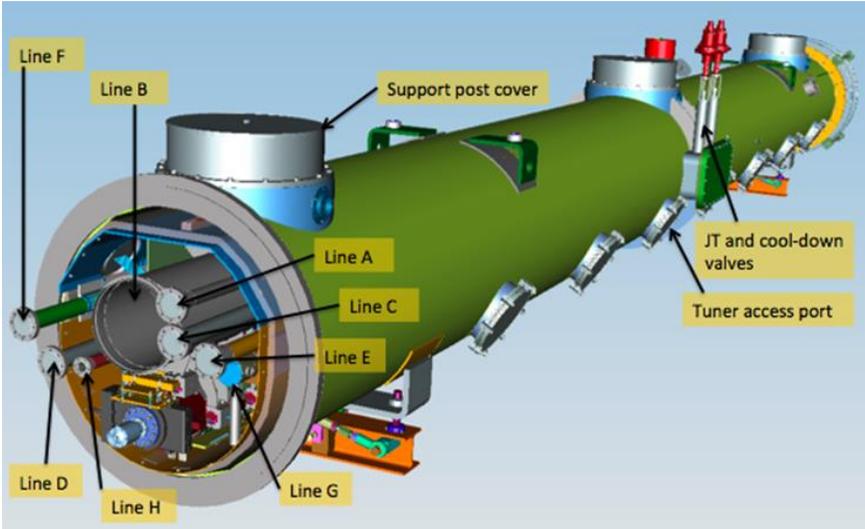


FIGURE 4. CAD model image showing the positions of lines and valves within the cryomodule



**Figure 5:** A cavity string (8 cavities) for LCLS-II (Fermilab)



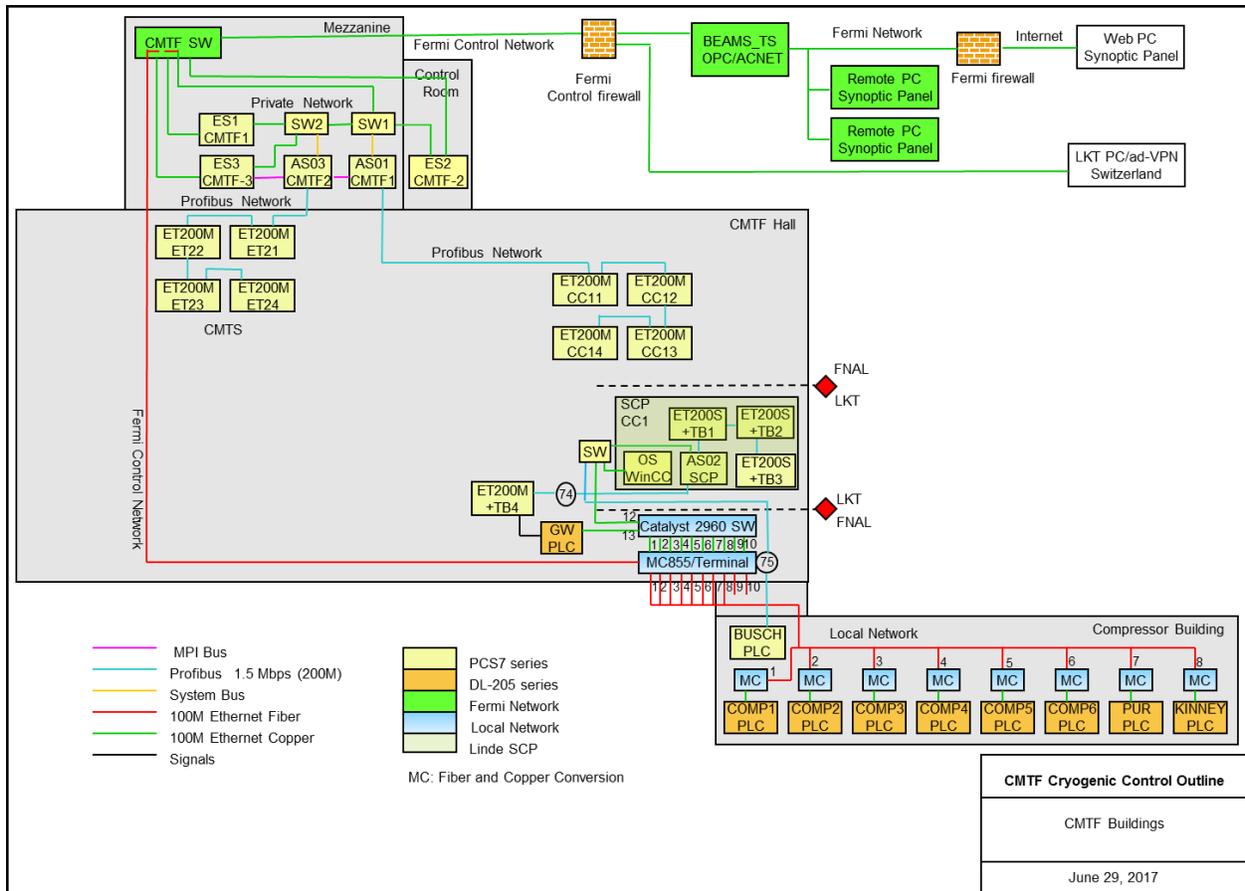
**Figure 6:** The image showing the RF 9 cell cavities

## CRYOGENIC CONTROL SYSTEM

The main control system at CMTF consists of the Siemens Process Control System SIMATIC PCS7. Simplified schematics for the CMTF controls system is shown on FIGURE 7.

The multi-level distribution control system uses Siemens Engineering Station (ES) as its operation level; SIMATIC NET IE as its OPC (Object Linking and Embedding(OLE) for Process Control) server; Fermilab Synoptic HMI system as its Web operation and monitor level; Fermilab ACNET (Accelerator Control Network) as its archive, monitor and alarm level; S7-400 as its central control level; ten ET200Ms with 74 I/O Modules as its remote data acquisition and I/O control field level; eight DL205 PLCs as its remote independent sub-control field system and one gateway GWPLC as its media communication between S7-400 and field sub-control systems. S7-400 central control system handles all PID LOOP control, signal conversion and logic control as well as communication between Fermilab ACNET and PCS7-400and DL205s.

The control of the localized equipment such as the main 300 KW MyCom compressors, expansion engines and purifier compressor are done using localized, self-contained, and PLC based sub-controls system, (Automation Direct DL-205 PLCs by KOYO®) which communicate directly with the PCS7 system using a fiber optic line. The localized PLCs interface with the equipment motor controller and manage the machine local interlocks. The start/stop/reset features, the remote/local control as well as a limited amount of input and output channels are also managed by this PLC Locally, a local touch panel display allows for manipulation and control of these systems and parameters.



**FIGURE 7. CMTF Cryogenic Control System Outline**

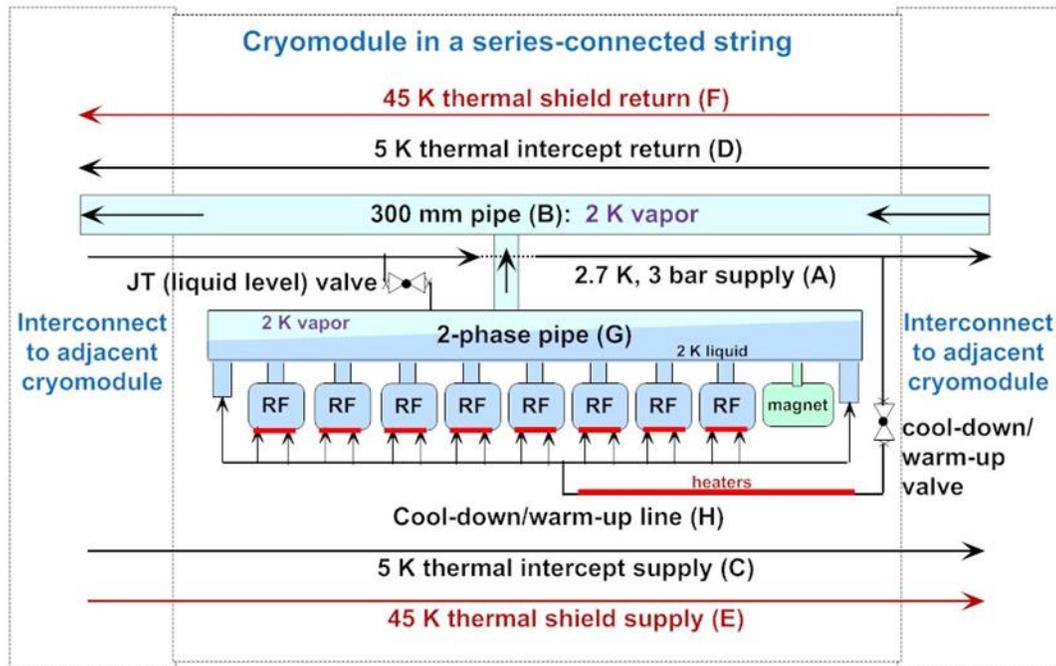
The top layer human machine interface used for the CMTF Cryogenic system is Synoptic graphic user interface from Sun-Microsystem JAVA. The Synoptic system is a graphical interface between the PCS 7 system and the end user which uses graphical tools to display the cryogenic process. Control of the system can also be done using those tools by simply clicking on graphical components and manipulating the output. The displays are created using the Synoptic graphical builder. Synoptic also supports alarm handling and plotting packages.

Many of the I/O devices are also sent to the Fermilab ACNET control system from PCS 7 using a SIMATIC NET IE OPC server. This flexibility gives experimenters access to data from various systems in one platform for ease of plotting and data management.

## LCLS-II CRYOMODULE TEST

Over the last half year three LCLS-II Cryomodules (CM) have been successfully tested in the CMTS. The LCLS-II CM has 8 cavities; each cavity has 9 RF cells and a 50W heater. The CM is 12.2-meter-long and contains 230 liter liquid helium (185L in 8 cavities, 45L in others). The CMTF 4KW@2.0K cryogenic plant fills up the CM and its two end dewars with two phase helium. The larger volume CM, high volumetric flow rate and high helium vapor velocity of Joule-Thomson (JT) valve contributed to some PID operational difficulties in controlling liquid level in the cryomodule's pipe and end dewar.

Figure 8 illustrates the cryomodule piping arrangement and shows that Line A provides the approximately 3 bar pressure and 2.7K helium to the cryomodules. The JT valve PID control provides helium from Line A to the RF cavity helium vessels by maintaining a liquid level in the 2-phase pipe and dewar. The JT valve PID control provides helium from Line A to the RF cavity helium vessels by maintaining a liquid level in the 2-phase pipe and dewar.



**Figure 8:** Cryomodule helium flow schematic

Higher temperature liquid into the JT expansion valve results in a significant fraction of the helium flow through the valve flashing immediately to vapor at the low pressure (31 mbar), 2 Kelvin, valve exit. Above 5 K results in more than 50% of the flow just passing through the 2-phase pipe and out to the 300mm gas return pipe as vapor.

The Synoptic HMI view for CMTS cryogenic controls system is shown on Figure 9. Due to the CM dewar level responds very slow to PVJT position change and its cavity heater power also changes frequently, the Common PID control will result cryogenic system oscillation, therefore, we developed a special optimal dynamic PID logic for it. The optimal dynamic PID control logic is consisted of three type of control logics, they are: error subzone PID control, pre-estimate logic control and dynamic weight control.

The optimal dynamic PID cryogenic control system has been successfully operated at LCLS II pCM, CM1 and CM2 testing. the PVJT valve operation for stabilize liquid level (LL) is shown on Figure 10. The PVJT maximum position was set at 64%, Minimum position was set at 40%, PID set point was 90.5% at liquid level LL301. The optimal dynamic PID logic active range was set at +/- 1% of SP.

When LL301 raised to 89.5%, PVJT position was low to its first 55% estimated optimal position from Maximum 64%. After LL301 was over 91.5%, PVJT control was switched to its PID gains control. And after more than half hour LL301 was downed to 91.5%, then PVJT was put to its second time 51% estimated optimal position. Due to optimal dynamic PID control logic has learned automatically from LL and position changed within the past three hours, it has kept LL301 from oscillation and kept it at ~90.5% set point by stabilized PVJT valve control.

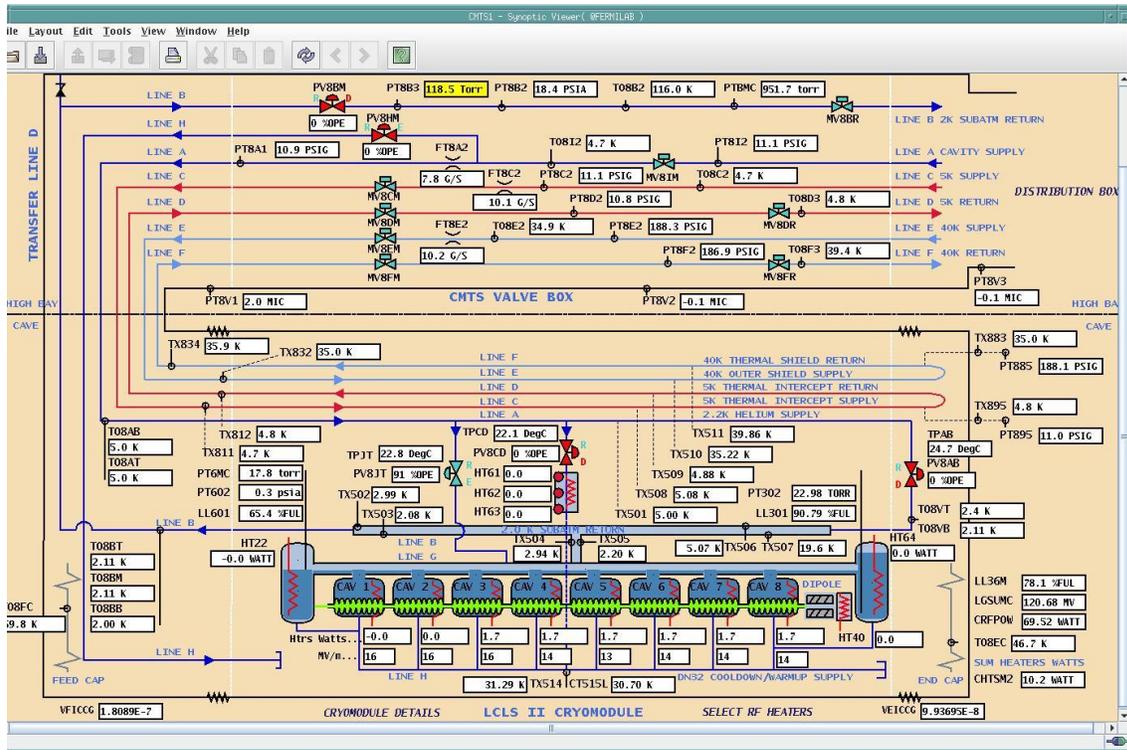


Figure 9: CM Test stand control view for LCLS-II

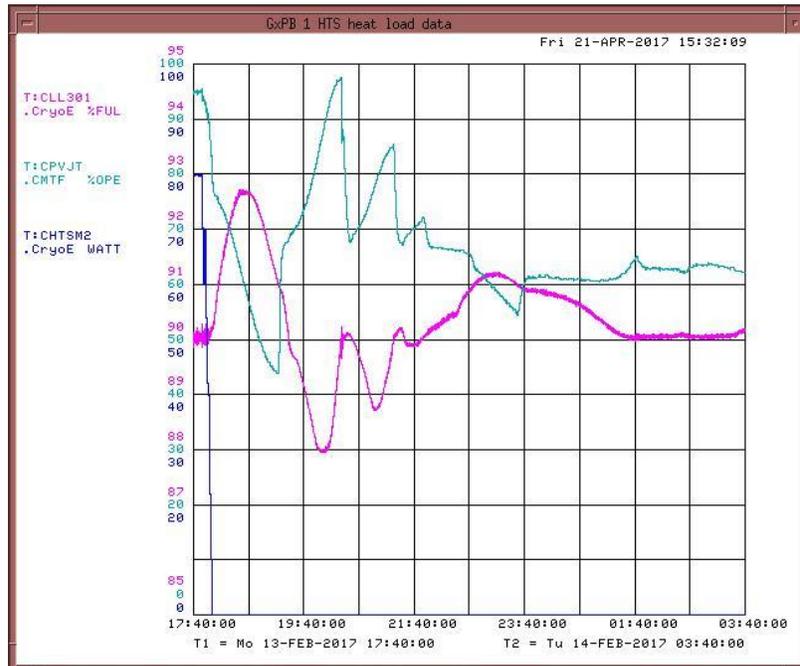


Figure 10: CM RF power down from 80W to 0 W

## **CONCLUSION**

The CMTF cryogenic system is working on its schedule with the predictive operation of several LCLS-II CMs, including the pCM, CM1 and CM2. The optimal dynamic PID control logic has worked very well to protect LL and pressure from oscillation at 2K mode, it has worked good on the difficulty longer time postpone cryogenic system.

## **ACKNOWLEDGMENTS**

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