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Fermilab Cryogenic Test Facilities

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Abstract. Fermi National Accelerator Laboratory (Fermilab) has multiple cryogenic test facilities, undertaking testing of superconducting magnets, Superconducting Radio Frequency (SRF) cavities, SRF cryomodules and other helium cryogenic components. The test areas within Fermilab include: Meson Cryogenic Test facility (Meson), Industrial Building 1 (IB-1), Heavy Assembly Building/Illinois Accelerator Research Center (HAB/IARC), New Muon Lab, (NML) and the Cryomodule Test Facility (CMTF). Meson and HAB/IARC utilize repurposed Tevatron era reciprocating engine based cryogenic refrigerator systems, whereas CMTF and IB-1 utilize gas bearing turbine based coldboxes. Each of these test areas support the various Fermilab projects and collaborations including the Linear Coherent Light Source II (LCLS-II), Proton Improvement Plan II (PIP-II), High Luminosity Large Hadron Collider (HL-LHC), and Mu2e. This paper outlines the diverse and extensive cryogenic test capabilities within Fermilab.

1. Introduction

Fermi National Accelerator Lab has several cryogenic test facilities located throughout its campus: Meson Detector Building (Meson), Industrial Building-1 (IB-1), Heavy Assembly Building/Illinois Accelerator Research Center (HAB/IARC), Cryomodule Test Facility (CMTF), and New Muon Lab (NML). Each of these test facilities support accelerator research & development, quality testing, or scientific research. In order to produce liquid helium, the gas is compressed via industrial oil injected compressors and expanded either through turbines or expander engines. Every facility has different needs of refrigeration power in order to perform the tasks each was designed to do. Some areas require the capability to bring systems to 4K while some testing area require 2K achieved by pulling vacuum on the liquid helium bath. This paper will give an overview the equipment used to achieve our refrigeration for each area as well as the purposes of each test area.

2. Compression

The liquefaction process starts with compressing helium. Cryogenic facilities at Fermilab predominately use Tevatron-era, refurbished Mycom compressors which have a maximum mass flow rate of 60 g/s when fully loaded in order to facilitate the needs of the various cryogenic systems. The number of compressors at each location is dependent on the needs of each test area. Each Mycom compressor consists of a Mycom 2016C screw compressor with a 400 hp electric motor, an oil pump, an oil reservoir, three oil coalescers, a charcoal adsorber, a molecular sieve, and a final filter. These filters are to ensure oil and water do not make their way into the cryogenic systems as effectively as possible so helium entering the refrigeration system is a pure as possible. Test facilities that provide 2K operations for their experiments will also have a separate "purifying" compressor whose sole purpose is to pull helium discharged from a warm vacuum compressor system at roughly 1 bar and send compressed gas at a minimum 10 bar through a liquid nitrogen cooled charcoal adsorber. When lines go sub-atmospheric there is always a risk of pulling air into the closed cryogenic system should a small leak occur, either through rotating machine vibration or thermal expansion/contraction for example. The purifying compressor is to remove any oxygen and nitrogen that may have been pulled in from a leak in from the sub atmospheric lines.

Figure 1: Typical Mycom compressor with Oil removal

Discharge and suction pressures are controlled via inventory control valves. There a PLC controlled pneumatic valves that are used to redirect flows based on a pressure setting. For example, should suction pressure be lower than 1 bara, a valve will open from either compressor discharge or helium storage to make up pressure in the suction line. Alternatively, if discharge pressure is above the typical setpoint of 19 bar then a different valve will redirect a portion of this flow back to helium storage. Note that these setpoints can and do change depending on the needs of the cryogenic system.

3. Refrigeration

There are two different strategies helium is liquefied for the test areas. NML, Muon Campus, HAB, and Meson Cryo Central use refurbished Tevatron-era expander engine satellite refrigerators to supply experimental halls with the necessary cryogens. CMTF and IB-1 however use cold box turbine expansion for a more efficient helium liquefaction for their test area.

3.1. Tevatron Satellite refrigeration

These satellite refrigeration systems consists of two expander engines, Dry and Wet, and a minimum of four shell and tube heat exchangers, see figure below. Some satellite refrigerators are "Star heat exchangers" meaning there is an additional heat exchanger utilizing the nitrogen boil off from the liquid nitrogen pot. The dry expander engine takes helium that has been precooled from returned refrigeration and helium passed through a shell and tube heat exchanger where liquid nitrogen exists within the shell and expands it. Afterward the cooled helium is sent through a third heat exchanger to precool helium flowing toward the Wet expander engine. Helium passed through a 4th heat exchanger being precooled by returned liquid helium boil off to ideally precool to 7 K at the inlet of the Wet engine. Helium is then liquefied after expanding through the Wet engine and sent to a supply dewar or through a liquid nitrogen shielded transfer line. Test Areas are supplied from here.

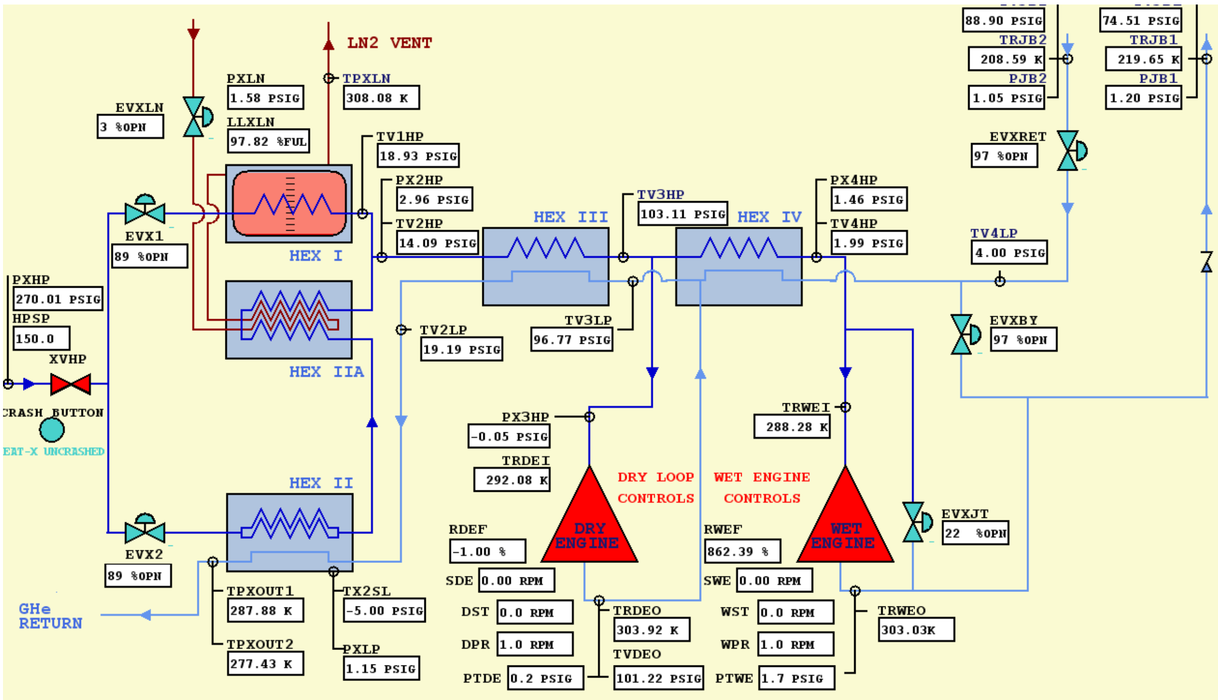

Figure 2: Example of a Star heat exchanger. Note that a standard satellite refrigerator would be missing HEXIIA.

3.2. **Tevatron Satellite refrigeration Turbine Expansion Refrigeration**

The Superfluid Cryogenic Plant (SCP) was delivered to Fermi National Accelerator Lab in June 2013 from Linde Kryotechnik, LLC and utilized at CMTF. Three primary mode can be used with the SCP Mode 1: 1.8 K, Mode 2: 2K , and Mode 3: 5K. Modes 1 & 2 utilize cold subatmospheric gas returned through the plant in order to maintain a high capacity. Mode 3 is a pure liquefier mode where the helium boil off from the cryomodule goes directly to Mycom suction via a warm vacuum compressor without passing back through the SCP. In recent activities, CMTF has predominately used Mode 3 during cryomodule testing due to several failure of the cold compressors. 2K capabilities will be discussed later in the next section. IB-1 utilites a CTI-1500 plant that generates 300L Liquid helium per hour.

Figure 3: Superfluid Cryogenic Plant

4. 2K Operations

Meson, NML, CMTF, IB-1 all require 2K operations for their various tests in order bring the SRF cavities to superfluid helium temperatures. The common technique to bring helium baths to 2K is to bring the testing chamber down to 23 Torr, typically accomplished by a Kinney Vacuum pump system. Two types of these Kinney vacuum systems exist throughout Fermilab. The two stage Liquid ring vacuum system KMDB-10000/Pompe ring pump is used at Meson, CMTF, and NML order to achieve superfluidity. KMDB-10000/Pompe ring pump consists of a 100 hp, 1780rpm rotor on the belt driven booster and a 200 hp, 1770rpm motor on the belt driven ring pump. These warm vacuum compressor systems have a 12 g/s capacity. Another two-stage liquid ring pump is KMDB-3200/KLRC951 combination which has a 6 g/s capacity. This system consists of a belt driven Booster pump with a 40 hp motor at 2400 rpm, a direct driven 1750 rpm liquid ring pump, oil pump, oil-water shell & tube heat exchangers, and oil reservoir. Both systems are oil injected for two reasons. First is to ensure a good seal exists between the two interlobes of the Kinney pump. The second reasons is to remove heat generated by the compression of helium.

Figure 4: 12 g/s KMDB10000/Pompe ring pump combination

Figure 5: KMDB3200/KLRC950 Kinney system

5. Test Areas

5.1. Meson Detector Building

Meson Detector Build (MDB) consists of three test caves: Horizontal Test Stand (HTS), Spoke Test Cryostat (STC), and Rapid Cycling Magnet Test Stand. HTS performs integrated cavity tests with fundamental power couplers and tuners. Currently the main focus of HTS it to test 1.3 GHz and 3.9 GHz cavities for the LCLS-II project. STC is supporting the PIP-II project by testing 325 MHz and soon 650 MHz cavities that will be installed together for PIP-II cryomodules which will be tested as a whole system at CMTF.

Liquid Helium is supplied by Meson Cryo Central (MCC) which houses four Tevatron-era expander engine refrigerators with a dedicated Mycom compressor per refrigerator and a purifying compressor, 5 compressors in total. Three of the expander engine packages run at a time providing 1000W of refrigeration at 4.5K. One KMDB10000/Pompe Ring pump is capable of providing 2 K operations for both caves simultaneously.

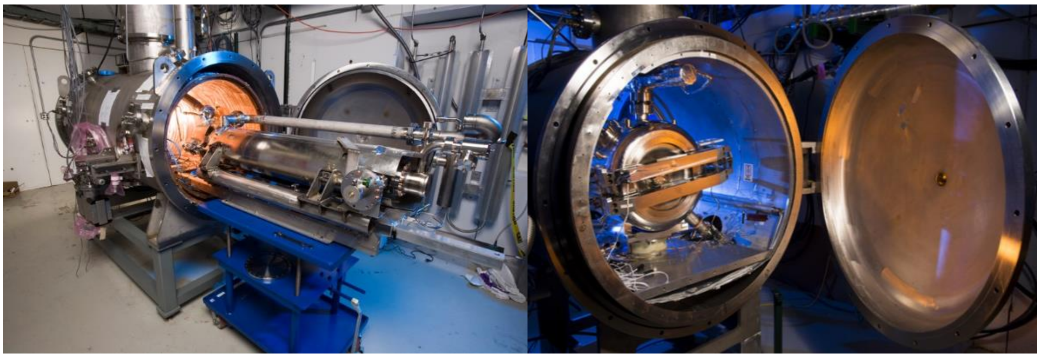

Figure 6: Horizontal Test Stand (Left) & Spoke Test Cryostat (Right)

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5.2. Industrial Building-1

The industrial Building-1 (IB-1) is a test area with multiple test stand responsible for testing and qualifying individual cavities and superconducting magnets to support multiple projects throughout the lab. Test Stand 3 test superconducting magnet for multiple projects including LCLS-II SPQA, Mu2e HTS lead & splice, and RTD calibration. Vertical Test Stands (VTS) is composed of three different stands as pictured below for SRF cavity R&D and qualification tests for LCLS-II and other projects. Vertical Magnet Test Facility (VMTF) supports magnet R&D and tests.

IB-1 is supported by a turbine cold box CTI 1500 Cold Box. This cryogenic plant provides up to 300 Liters per hour of liquid helium. The system has 4 KLRC3200/KLRC920 two-stage liquid ring vacuum pumps to enable 2 K operation

Figure 7: Vertical Test Stand

5.3. Heavy Assembly Building

The Heavy Assembly Building (HAB) test area is tasked with the testing of superconducting transport solenoids (14 in total) for the future Mu2e experiment at Muon Campus. The test stand in the CDF pit consists of a cryostat with two removable top heads where solenoids are mounted and then inserted into the cryostat. HAB is cryogenically supported by two Tevatron-era expander engine refrigerators each with a corresponding Mycom compressor providing 600 Watts of refrigeration at 4.5 K. Unlike the other test facilities, currently HAB only supports normal helium operations and not superfluid helium operations.

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Figure 8: Heavy Assembly Building Cryostat

5.4. Cryomodule Test Facility

The Cryomodule Test Faculty (CMTF) was designed to test and validate the quality and performance of assembled Superconducting Radio Frequency cryomodules. CMTF houses two testing caves: Cryomodule Test Stand (CMTS) and Proton Improvement Plan II Injection Test cave (PIPII-IT). The Linear Coherent Light Source II (LCLS-II) project has tested nineteen 1.3 GHZ cryomodules in CMTS with three 3.9 GHz cryomodules planned in the near future. PIPII-IT will test cryomodules that will be installed within the PIPII project at Fermilab.

The Superfluid Cryogenic Plant (SCP) is a state-of-the-art cryogenic plant designed and developed by Linde to serve the refrigeration needs of CMTF. Purchased in 2013 this plant provides 2K, 5K, and 50K flows to the two test caves with a capacity of 500 W at 2K refrigeration. CMTF utilizes three 60 g/s fully loaded Mycom compressors for helium supply with one purifying compressor and a spare compressor should one compressor fail. In order to reach 2K operation, SCP has a string of cold compressors that will bring test stands to 2K. Alternatively a special made vacuum pump utilizing a KMBD-10000 Tuthill Kinney booster and a Pompe ring pump can be used in order to achieve 2 K operations. In the future to support PIPII_-IT, two KMDB3200/KLRC950 two-stage liquid ring pump system will be installed in order to allow 2K operations for the two cave independently.

Figure 9: Cryomodule Test Stand

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5.5. New Muon Lab

One test facility was converted from use after the Tevatron was decommissioned. The New Muon Lab (NML) formerly supported experiments with an external beam source but now has been converted into a research and development center for the next generation of particle accelerators. An electron injector is located within NML to provide a pulsed electron source for the Integrated Optics Test Accelerator (IOTA) ring. NML utilizes two capture cavities and an 8 cavity cryomodule for experiments up to 150 MeV electrons. Funding has been obtained for a 2.5 MeV proton injector to be installed for future experiments. The installation is currently on going.

The cryogenic system that supports the experimental operations is composed of two refurbished Tevatron satellite expander engine liquefiers capable of 125 L/hr liquid helium. Each liquefier has a dedicated 60 g/s Mycom screw compressor (2 total), a “dry” expander engine and a “wet” expander engine working with a series of heat exchangers to ensure efficient cooldown is possible. 2K operations are obtained via a KMBD10000/Pompe ring pump for the two capture cavities and cryomodule simultaneously.

Figure 10: New Muon Lab cryomodule

6. Conclusion

Fermi National accelerator Lab is diverse in both its helium cryogenic capacity and the work that is being performed on its campus. Fermilab is charging its way to the forefront of technology in both its capabilities and research looking to lead the world in cryomodule assembly and testing.

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