FERMILAB-PUB-24-0401-STUDENT

2024 URA-Fermilab Undergraduate Women in STEM
July 29, 2024

Research Report

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MONITORING HELIUM CRYOGEN USAGE WITH IFIX SOFTWARE AT IB1 TEST FACILITY

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ABSTRACT

At the IB1 facility of the Applied Physics and Superconducting Technology Directorate within the Cryogenic Division at Fermilab, Liquid Helium is essential to the testing activities. The test stands require large amounts of Helium to test the thermal and superconducting cavities and magnets. The Liquid Helium that enters the test stand is monitored through a series of valves and controls to determine the start and stop for monitoring time. There are 3 phases of cryogen usage that must be considered for each stand, cooldown, warming and overnight mode. With a new system in place, cold hour tracking will be more objective and precise within each test stand ensuring better calculations for User's fees which are charged to various groups that employ the facility and aid replenishment of Helium and continual operation at IB1.

INTRODUCTION

Fermilab has long been a pioneer in studying and furthering research for particle physics. Having been the site of the discovery of neutrinos and quarks, Fermilab prides itself on continuing to build upon that legacy and be at the forefront of scientific innovation and discovery. Projects like the Proton Improvement Plan (PIP-II), and the LCLS-HE-II assist scientists to collect data for further research and development as well as supporting the US mission of winning the science race. These projects have superconducting cavities or magnets that are used for accelerating particles to that collide into a target which produce various subatomic particles. To keep these superconducting materials functional, and safe through cooling, cryogenic liquids are introduced. These liquids include Helium, Nitrogen and in some other cases liquid Argon. At the division of cryogenics, engineers, scientists, technicians, and operators work to produce cryogen and test superconducting materials at their facilities before they are installed to create these massive projects for accelerators.

As Helium becomes more expensive and lower in supply, keeping track of the amount of Helium we supply is essential. Keeping a consistent helium supply is a major financial burden that the lab has incurred. With the cost of helium continuing to grow it is imperative to create a better system to track cryogen usage. At the IB1 test facility for cavities and magnets, the system for tracking these cold hours, is very subjective and dependent on the time stamp recorded when an update is made in the system about a test stand. Sometimes their update of the IB1 Weblog can happen a few hours after the actual task was performed and the cryogen was present.

Many Users employ the testing facility for their cavities and magnets from various projects such as SLAC, LCLS-II-HE and PIP-II. Giving Users a more objective and precise system for tracking cold hours would avoid confusion and make a fairer system for everyone involved.

The monitoring of cold hours is done from the series of Weblogs through a website. Operators use remote controls for the valves that give historical records of temperatures, flow, and pressures when opened. Using this system that is already in place we can find a specific point withing the piping and instrumentation that can be marked for Start/Stop of the Cold

Hour clock and therefore create a more specific, and clear record of cold hours, creating more accuracy.

ABBREVIATIONS

IB1	*Industrial Building 1*
LHE	*Liquid Helium*
GHE	*Gas Helium*
LN2	*Liquid Nitrogen*
LLCS-II-HE	*Linac Coherent Light Source II*
PIP-II	*Proton Improvement Plan II*
SLAC	*Stanford Linear Accelerator Center*
VTS	*Vertical Test Stand*
TS4	*Test Stand 4*
VMTF	*Vertical Magnet Test Facility*
ΔT	*Delta T (Temperature Difference)*
BLM	*Bureau of Land Management*
FHR	*Federal Helium Reserve*

PROCEDURES

At the IB1 facility there are three vertical test stands, Vertical Test Stand 1(VTS1), Vertical Test Stand 2 (VTS2), and Vertical Test Stand 3 (VTS3), which test cavities. There is also Vertical Magnet Test Facility (VMTF) and Test Stand 4 (TS4), VMTF is a vertical magnet test stand with a remote-control system from the 1990s that is outdated. TS4 is a large horizontal magnet test stand that has recently been updated for the LCLS-HE magnet experiments. All these stands have a unique set of piping and instrumentation that must be analyzed and understood to determine when to start and stop the clock to count cold hours. To create more effective system all these individual test stands need to be understood and analyzed.

All the VTSs are setup with the same configuration but have a different location for valves that have the same functionality and therefore the valve numbers correlate with the stand. VTS1 has prefix 28, VTS2 has prefix 29, and VTS3 has prefix 30. For example, VTS1 might have valve YCV-2801 and VTS 2 would have valve YCV-2901 which has the same purpose but a different location and controls a specific test stands' operation.

Test Stand 4 is large and complicated that has been setup with a pre-cooling and pre-warming stage to ensure that the magnets do not exceed the ΔT. This ΔT is incredibly important since it prevents a magnet from cracking due to a large temperature distribution difference. This ΔT is measured across the magnet from end to end and therefore if one end is warmer than a different side of the magnet the operators know they need to slow down the cooling process to make sure both sides are similar in temperature. When running a cooldown and warm up on TS4 there is a greater number of controls and factors that must be monitored. TS4 has 4 separate phases of cooldown and warmup. First you have the precooling stage to bring the entire magnet from room temperature, 294K, to 80K. This process is slowed by using a mixture of cold and warm GHe. Once the magnet reaches about 80K then LHe is introduced to cool down the magnet to 4K and lower depending on the demands of the test. Once testing has been concluded, to initiate warming we enter a pre-warming stage. In this stage we turn on the heaters and slowing warm up the magnet. Once we reach the threshold of 80K or greater then LHe is no longer supplied, and a mixture of cold and warm helium takes over for the rest of the warmup process. Knowing these steps, we know that there are a few ways to monitor cryogen usage but also that we will need to keep track of pre-cooling and pre-warming separately to be able to monitor GHe usage. Overnight mode for TS4 will be counted without actively turning on the system at all during the duration of all the tests. Since the TS4 magnets are usually quite large, it is easier to simply keep counting cold hours which will, in the long run, cost less than warming and cooling multiple times between tests or days.

VMTF is an old system and therefore does not have a trackable user interface like the other 4 test stands. To get around this it will be necessary to implement a new control into the modern iFix control screens. VMTF follows the same cool down and warm up procedure as the VTSs and therefore using the same logic can track cold hours easily. In the case of VMTF we need to create a new control which will be placed on the VMTF Quench Page on iFix with a start and stop switch. This switch can then track the cold hours. Although this method does not create a totally objective count, we can limit error by adding the button operation into the Operating Procedure of VMTF in the corresponding location of the best times to engage the switch to the correct position. The operating procedure gives a clear description of how-to operate VTMF for cooling, warming and overnight modes, therefore will be the best way to incorporate a new button procedure for tracking.

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To create system that can track the cold hours it was easier to simply look at the existing system. Using the controls on iFix we can obtain historical records of when a valve is closed and how much it is being opened over time. With iFix we are also able to view all the sensors that are needed to run a successful test such as temperature, liquid level, and internal pressure of the test stand. Using all these controls we can not only understand when to start and stop the clock but also modify the scripting of these controls to better monitor cryogen usage and cold hours. Before we can designate controls that should be monitored for cold hours, we want to understand how a VTS stand is cooled and warmed. Anytime cryogen is present within the system we will count this time toward a cold hour. For the VTS an initial pump and backfill is done to clean and prepare the system for helium to enter. Once this is done the system introduces a LN2 shield to cool down and create an insulating barrier. Now the system is ready for the LHe which cools the cavity or magnet down to 4K or below. When it is time to warm up cryogen stops being supplied, and the stand is slowing warmed back to room temperature at about 294K. IB1 only operates during the day and therefore test stands are put into Overnight mode in which cryogen supply is shut off, but the system remains cold and prevents the temperature from changing too much within the test Dewar. Overnight procedures are done every single afternoon during the work week and on Friday the system is left in overnight mode the entire weekend until Monday morning.

RESULTS

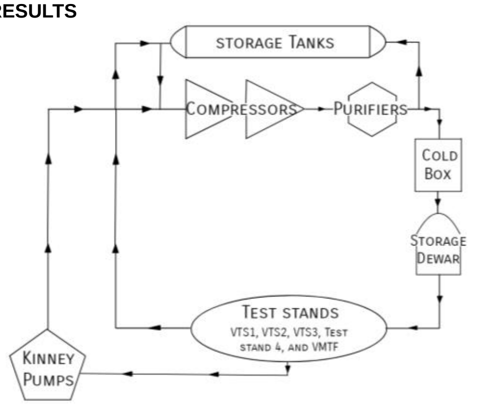

Figure 1. *Flow chart of the closed loop system followed within the IB1 facility.*

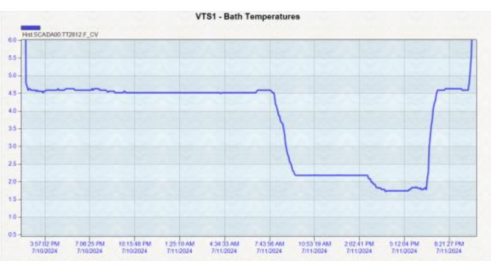

Figure 2. *VTS1 Temperature Sensor TI 2812 depicts change temperature change over time at the bottom of the VTS1 Dewar correlating to cryogen present within the system when temperature reads above 5K.*

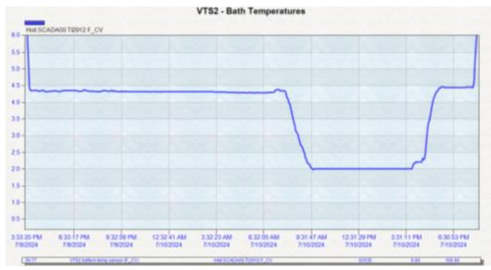

Figure 3. *VTS2 Temperature Sensor TI 2912 depicts change temperature change over time at the bottom of the VTS2 Dewar correlating to cryogen present within the system when temperature reads above 5K.*

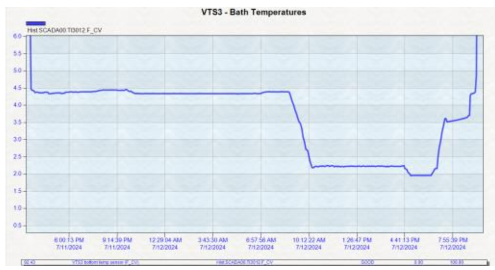

Figure 4. *VTS3 Temperature Sensor TI 3012 depicts change temperature change over time at the bottom of the VTS3 Dewar correlating to cryogen present within the system when temperature reads above 5K.*

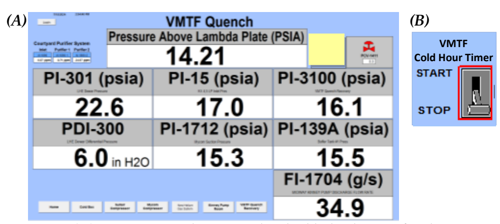

Figure 5. *(A) VMTF Quench page with a highlighted space for the proposed location of a new switch. (B) Proposed design of new switch added to the VMTF Quench Page.*

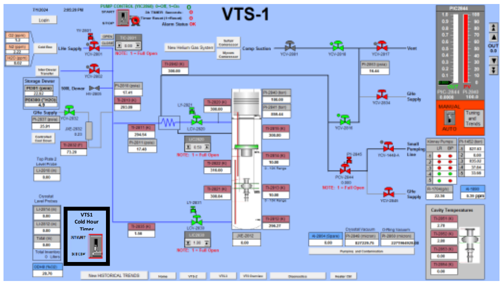

Figure 6. *VTS-1 controls page from iFix with proposed location for special circumstance cold hour timer outlined. This page has Cooldown and Warm Up controls and sensor readings panel. This panel is used cooldown, and warmup of VTS-1.*

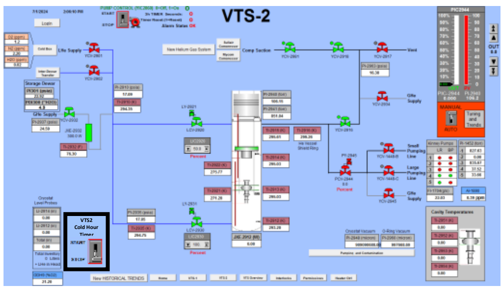

Figure 7. *VTS-2 controls page from iFix with proposed location for special circumstance cold hour timer outlined. This page has Cooldown and Warm Up controls and sensor readings panel. This panel is used cooldown, and warmup of VTS-2.*

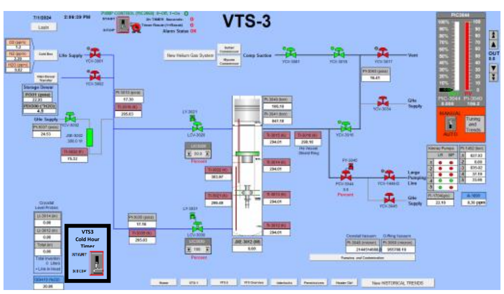

Figure 8. *VTS-3 controls page from iFix with proposed location for a special circumstance cold hour timer outlined. This page has Cooldown and Warm Up controls and sensor readings panel. This panel is used cooldown, and warmup of VTS-3.*

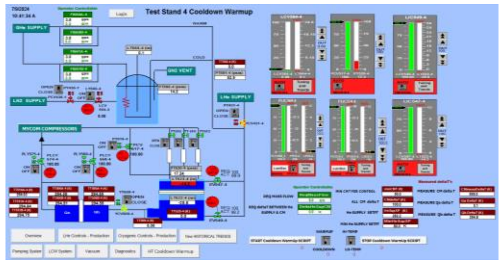

Figure 9. *Test Stand 4 Cooldown and Warm Up controls and sensor readings panel. This panel is used turning pre-cooldown, cooldown, pre-warmup, and warmup of TS4.*

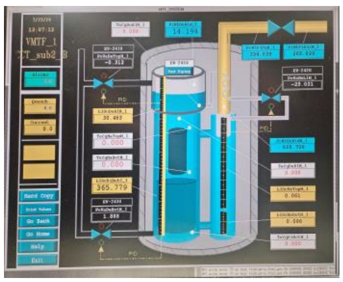

Figure 10. *VMTF old controls system located on a local computer next to the VMTF pit.*

ANALYSIS AND DISCUSSION

The complexity of the system that all the VTSs and TS4 and VMTF are connected to is a closed loop system which limits the wastage of helium and ensures that keeping track of LHE and GHe is manageable and trackable. In the flow diagram from Figure 1 we can see the different steps of the lifecycle of helium within IB1 as it travels from the Dewar, compressors, purifier, cold box, test Dewars and back through the system to ensure the purity and correct physical state.

When looking at the data presented by the Figures 2, 3, and 4 we can see that when cryogen was added to a system, we have a vertical drop in temperature and the moment that warming the system was initiated a vertical spike can be seen as well. Using this data, we can monitor TI 2812, TI 2912 and TI 3012 from Figures 6, 7, and 8 as a form of marking when to stop the clock by taking the timestamp of the moment that the system is at 5K therefore marking the end of cryogen presence within the Dewar. Since IB1 is a helium cryogenic plant and helium has a boiling point of about 4.2K at 1 atm and at 5K is in the gaseous state. When cryogen is no longer present a cold hour is no longer being counted. To begin the counter, we see that the vertical drop in the graph occurs when Helium Cryogen is introduced to the system, when the valves from Figures 6, 7, and 8, YCV2801, YCV2901, and YCV3001 are opened and let cryogen into the system begin to count the usage. One exception to the opening of the valves is when the operators use a method called inter-Dewar transfer in which they take some cryogen from other test stands and supply the new test with liquid, this process still supplies cryogen and therefore if either valve is opened on a test stand, we mark it as the start of a cold hour count. For this process we monitor the valves YCV2802 YCV 2902 and YCV3002. Additionally, when marking the end of the cold hour all supply valves must be closed ensuring no more cryogen is being supplied. Another special circumstance is the use of thermal cycles for testing a cavity or magnet. For this test the stand reach 5K multiple times and therefore we cannot depend on the 5K to mark the end. Instead, operators will be expected to press a button on each VTS page to engage a counter and will count the cold hours. It is standard practice to count the cold hours overnight during the week but stop the clock for the weekend. When counting cold hours for a weekend overnight test we will monitor the valves YCV 2801, YCV 2901, and YCV3001 (YCV 2802, YCV2902, and YCV 3002 for inter-Dewar transfers) closing to stop the clock and cold hour counting from Figures 6, 7, and 8. There are some tests such as Thermal cycles that cause the test stands to be warmed and cooled to various temperature and fully and partially multiple times. For these scenarios it is hard to keep track of the cold hours using the valve open and close therefore a special timer button as seen in Figures 6, 7, and 8 will be monitored to count the cold hours.

For TS4 we will employ a series of controls that have been introduced along with the new TS4 control system. For the tests being run we have two new buttons that run pre-coded scripts that help the operators manage pre-cooldown and pre-warmup. Both of these can be seen on Figure 9 in the bottom right. The switches labeled “COOLDOWN/WARMUP” and “HI-TEMP/LO-TEMP” contribute to the code and deal with making sure the magnet cools down and warms up slowly to prevent cracks within the magnet due to large temperature difference distribution across the magnet. The controls will be tracked to start counting the time of pre-cooldown. During pre-cooldown a mixture of cold and hot GHe is supplied and therefore no cryogen is introduced but due to the high volumes of GHe that are being supplied counting the cold hours on this gas is necessary. To start precooling we will look at when “START Cooldown WarmUp SCRIPT (COOLDOWN/HI-TEMP)” is hit to begin the count and stop counting precooling when “Cooldown WarmUp SCRIPT (COOLDOWN/LO-TEMP)” is hit, from there we will mark cooldown to be started as soon as the PCV 431-4 valve is on or open. For warm up we will look at the same steps as pre-cooldown however the steps are reversed, “START Cooldown Warmup SCRIPT (WARMUP/LO-TEMP)” will start the pre-warming stage, and “STOP Cooldown Warm Up SCRIPT (WARMUP/HI-TEMP)” will mark the end of this stage. When the PCV431-4 valve is off or closed we know that the test is done being supplied with cryogen. Since the process to cooldown TS4 is much longer and takes more time, it is expected that TS4 will be kept cold once it has been cooled down and run continuously until all the tests are finished being run, therefore an overnight mode does not need to be considered.

To start counting hours for VMTF since the control server is from the 1990s (Figure 10) we need to create a more modern solution to the problem and add a button to an iFix screen that can count the amount of time that a test is running. The button will be located on the VMTF Quench page from Figure 5a and will be a switch (figure 5b) therefore the operators will be able tell when the switch has been switched on and when it has been shut off. The moments when the button must be engaged and switched off will be detailed in an updated version of the VMTF Operating Procedure, TID-N-161. For cooldown we can begin counting after step 2.7.5 which reads, “For the initial cool down, set valve EV-2410 at 20% open EV-2430 100% open for bottom fill. EV2420 should be closed, but make sure that the backfill system maintains a positive pressure in the pumping line. Keep EV -2420 closed and use the backfill system to maintain positive pressure in the pumping line”. To stop counting we can turn off the counting switch after step 2.16.12, “When the test Dewar is empty of liquid, take as much flow as possible through FCV-2432 while maintaining the compressor suction no higher than 21 psia (estimated; operator’s discretion) as read on the refrigerator controls PC.” For overnight status we will follow steps 2.17.6 to stop the count for the weekend and step 2.8.6 to restart the counter. Each step respectively is regarding the EV-2410 valve which can be seen in Figure 10 to be closed and opened and turn off the supply of cryogen to the system.

CONCLUSIONS AND SUMMARY

Using the methods and signals detailed above it is expected that this new system will be more objective and systematic in calculating User fees and cryogen costs. With this new method we will be able to better know how cryogen is being utilized ensuring that the right amounts are being calculated and can create a standing record for future reference.

Next steps for managing cryogen use would be to look at a monitoring system for LN2 use. The system at IB1 for LN2 is currently fully manual. Before LN2 can be effectively monitored, a series of computer controls and sensors need to be installed into the facility that control flow. The need to create a system to monitor Nitrogen is not a top priority since the price of LN2 is drastically lower than helium, however taking a proactive approach to create a system can help with future budgeting issues and self-sustainability of IB1.

To test the functionality and effectiveness of this new system a control test needs to be run where over the course of a month the old Weblog entries method is used and the new valve dependence method is used to see the difference in accuracy of time tracking and how it affects the monitoring, usage, and time discrepancies between the two methods. The new method should promote more active measures for monitoring helium and create a better record of the helium usage within the system.

SCIENCE POLICY STATEMENT

Conducting research on the usage of helium and the creation of a better system for monitoring helium within a facility is imperative to remain competitive and within budget with growing prices for Helium. Helium has become more expensive over the course of the past year due to a shortage around the world of pure helium supplier. Qatar and the US supply about 75% of all helium that the world uses. Over the course of the past few years however, helium production has not been able to keep up with the demand for helium causing prices to rise more making it more imperative for facilities to try to maximize the helium they do use.

In 2013, the US established the Helium Stewardship act of 2013 which helped protect domestic companies from having to pay too much for their helium. Now that the US helium stockpile and Federal Helium Reserve (FHR) has been exhausted through foreign commerce and growing domestic demand, US helium dependent facilities are now facing growing costs for helium. The Land Management Bureau (BLM) although striving to fix the problem has not found a sustainable solution to meet demands for helium within the US. Without a new solution to the domestic problem on the horizon the responsibility of managing Helium usage falls to the individual companies that need Helium for Research and Development, Manufacturing, and other helium dependent industries.

ACKNOWLEDGEMENTS

Special thanks to my supervisor Maria Barba-Higueras for assisting and guiding me through this research project.

Special thanks to all the operators at IB1 who helped answer all my questions on operations, piping, and test stand specifications. Thanks Brett Swanson, Daniel Marks, Daniel Banovz, George Kirschbaum and Randall Ward.

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