Operation Readiness Clearance (ORC)
of
SpinQuest (E1039) Polarized Target Magnet Cooldown

ORC - 2056

SpinQuest Polarized Target Group

Table of Contents

1 Introduction

This ORC is basically including the information for the superconducting magnet cooldown.

Figure 1: Left: view from the beam-upstream; Right: view from the in-cave

2 Superconducting magnet operation procedure

Restrictions

DO NOT exceed the rate limits listed below, the magnet can quench
DO NOT allow persons with medical implants near a magnet – death can occur
AVOID the need for fill during ramping, warm gas can cause quench
Ensure safety prerequisites for magnet ramping are met

Figure 2: Power supply for the superconducting magnet

Factory: Oxford Instruments
Model: MercuryIPS (Master and Slave)
Function: Energize the superconducting magnet
Power requirement: 100-240 VAC, 800 Watt.
At 208 VAC, max. current is 3.85 A for both master and slave
Cables and connections: The MercuryIPS power the superconducting magnet via twisted pair and heavy gauge superconducting magnet power cables. The positive and negative terminals of the master and slave are connected via metal busbar. The master and slave also connected by the provided DB-9 female to male cable, which goes from the DB-9 'out' port on the master to the DB-9 'in' port on the slave. The master should then be connected via the DB-27 RS323 to the RS232-Ethernet converter (PK70EX-232CR). Both master and slave are powered from the AC power strip Trip Lite PDU1230.

Before initial use, the following checks should be complete:

1.) A magnetic material sweep of the cave: Look for any loose bits of metal or tools that may be caught in the magnetic field. The cave should be cleaned of debris and a metal sweep should be conducted using small handheld magnets to check for and remove any material. The sweep should be performed at least up to 4 m away from the outside of the magnet can.

2.) A 30 Gauss boundary should be indicated on the floor near the cave to warn people that a strong magnetic field is nearby. Signage should be posted as per FNAL ES&H safety requirements.

3.) Check magnet leads and shim power leads are connected to the magnet. Check that the sensor leads, and heater leads are also connected.

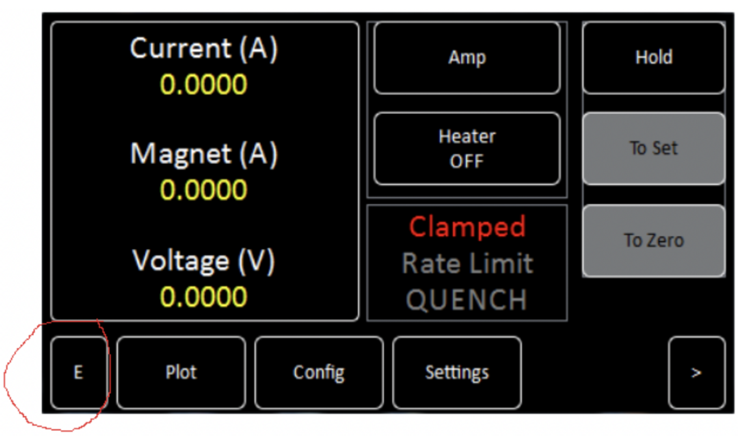
4.) Switch on MercryIPS, you should see on the LCD screen the options to run current to zero or to the setpoint. If the power supply and coils have successfully initialized, you will see the firmware version displayed.

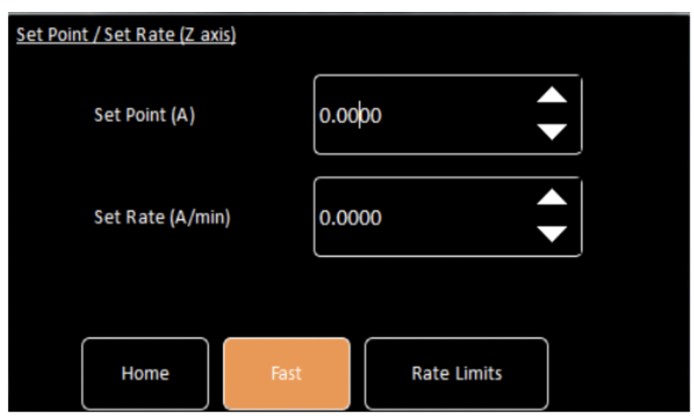
5.) Select the mode of display required, this can be in Amps or Tesla by pressing the button labeled CURRENT/FIELD on the LCD screen. Set this to Amps if not already done.

6.) Set this current to 0.5 A/min which is a safe current to start the magnet energizing procedure. This can be adjusted as needed later.

The magnet energizing can now be started by following these steps (Direct Manual Control):

A.) On the LCD screen push the bottom-left menu (Red circle labeled as "E") and change to "L". "L" means local control.





B.) Then push To Set to come to this display (to set the Set Point and Ramp Rate)

C.) Set the Set Point and Ramp Rate for the appropriate phase of the magnet energization accordingly,

Allowed Ramp Rate	Output Current
2 A/min	< 40 A
1 A/min	40-63 A
0.5 A/min	> 63 A

Remote Ramp-Up Procedure

Procedure: Instructions from Counting House which assumes: The magnet power supply is on and a sweep for magnetic objects from an area within 4m of the magnet has already been done

1. Put Magnet VI in "Monitor," if necessary, to allow updates from users

2. Press the "Unlock Magnet Controls" button in the Polarization Display Panel, VI

■ Verify that there is no current in the leads (Power supply icon, far left)

3. Press the "Hold" button

4. Hit the "Heater On" button and confirm this action in the dialog box that presents itself

■ Wait until the timer counts down to zero (maybe a little more)

5. The magnet must be ramped up in steps with the correct current rates, PDP should not allow you to exceed these rates, but be mindful. For 2.5T Set the Setpoint to 60.9135A and Set Rate to 3.0A/min. There is only one step in this case. For 5.0T there are four steps (seen below). At each step enter the Setpoint and corresponding Set Rate then press To SETPOINT

when the current has been reached press HOLD and changes the value to the Setpoint and Set Rate for the next step and press SETPOINT. After each change of Setpoint and Set, Rate check the Magnet Control display in PDP to make sure LabVIEW is reading incorrectly

■ A.) Setpoint: 80A Set Rate: 3.0A/min

■ B.) Setpoint: 100A Set Rate: 2.0A/min

■ C.) Setpoint: 115A Set Rate: 1.0A/min

■ D.) Setpoint: 121.825A Set Rate: 0.5A/min

2. Press "Hold"

■ If persistent mode is not desired, stop here

3. Wait for a few seconds

4. Press the "Heater Off" button

■ Wait until the timer counts down to zero (maybe a little more)

5. To ramp down leads, press the "To Zero" button

6. Press the "Lock Magnet Controls" button

Remote Ramp Down Procedure

1. Press the "Unlock Magnet Controls" button in the Polarization Display Panel, PDP

2. If necessary, Ramp the Power Supply to the Magnet Current

■ Type the value of the magnet current (this is in Amps) into the "Setpoint" box

■ Press "To Setpoint"

■ Wait for the PS current to reach the Magnet current

3. Press the "Heater On" button and confirm this action in the dialog box that presents itself

■ Wait until the timer counts down to zero (maybe a little more)

4. Set the first Setpoint and Set Rate values. PDP should not allow you to exceed these rates, but be mindful. With 2.5T you can just press TO ZERO. With 5.0T the magnet must be ramped down in steps. At each step enter the Setpoint and the corresponding Set Rate then press To SETPOINT when the current has been reached press HOLD and change the value to the Setpoint and Set Rate for the next step and press SETPOINT. After each change of Set Point and Set Rate check the Magnet Control display in PDP to make sure LabVIEW is reading incorrectly

■ A.) Setpoint: 115A Set Rate: 0.5A/min

■ B.) Setpoint: 100A Set Rate: 1.0A/min

■ C.) Setpoint: 80A Set Rate: 2.0A/min

■ D.) Setpoint: 0A Set Rate: 3.0A/min

5. Press the "Hold" button

6. Press the "Heater Off" button

7. Press the "Lock Magnet Controls" button

3 30-Gauss boundary of the magnetic field

To obtain the magnetic field inside and outside the magnet dewar, we use COMSOL to solve a set of Maxwell equation using finite element method.

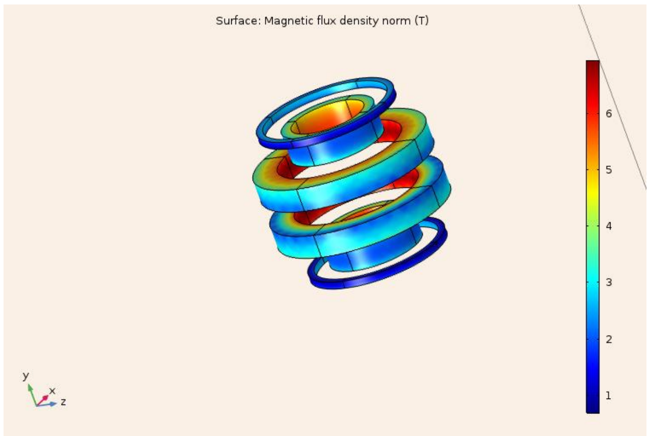
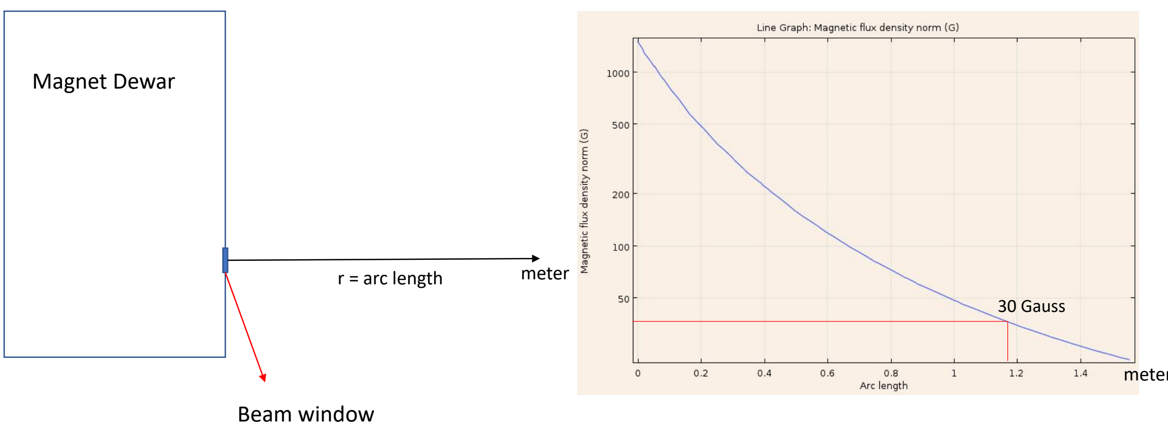


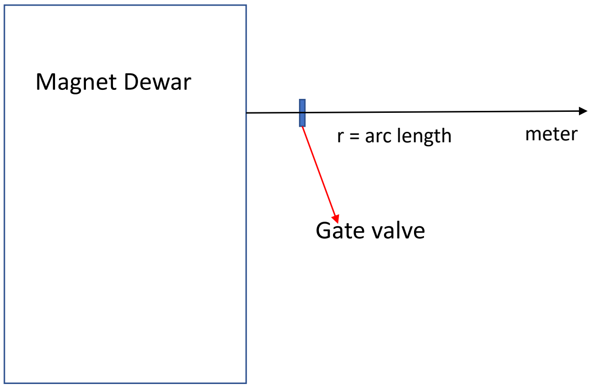
Figure 3: Magnetic field in the magnet obtained from COMSOL

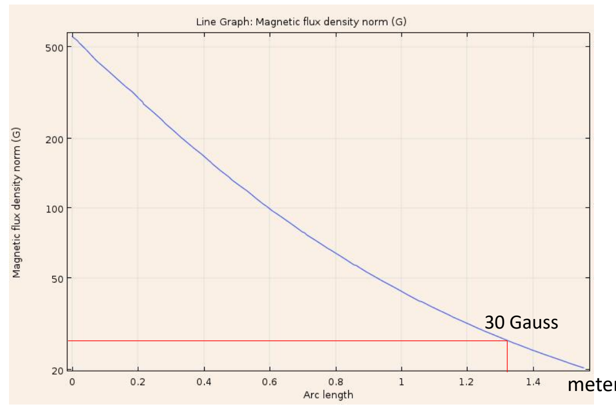
Magnetic field from the Dewar surface at the vertical position of the beam line.



The 30 Gauss boundary is at radius 1.18 meters from the Dewar surface at the vertical position of the beam line.

Magnetic field from the Dewar surface at the vertical position of the gate valve.





The 30 Gauss boundary is at radius 1.32 meters from the dewar surface at the vertical position of the gate valve.

Therefore, considering the calculations for 30-Gauss boundary, we can consider marking the bottom of the ladder to the target cave as the 5-Gauss boundary to ensure the safety.

4 Liquid Nitrogen Fill Procedure

4.1 Conditions for a Liquid Nitrogen Fill from the Outside Storage Dewar

The conditions for a liquid nitrogen fill from the outside storage Dewar to the QT purifier or Target Magnet nitrogen shield are as follows. The LN2 outside storage Dewar has liquid and is ready for transfer, which means sufficient liquid and pressure to make the transfer. The magnet nitrogen shield or QT purifier level probe indicates that there is space for a transfer. If delivery to the magnet, the magnet and fridge insulating vacuums are pumped out and operational. The main OVC on the magnet is less than 5 × 10−6 Torr. There is no ODH alarm and no indication that an alarm would occur for the next hour.

4.2 Liquid Nitrogen Fill for the QT purifier

1. The purifier liquid nitrogen level shows less than 60% full.
2. The pressure in the outside tanks indicates that there is liquid to transfer (over 15 psig).
3. The fill valve on the purifier VNFA should be closed while EV-200-N is open for pre-cooling of the line.
4. Open PV-100-N by controlling EV-100-N.
5. Open EV-200-N.
6. Open the HV valve on the nitrogen storage dewar gradually. CV-108-N will open to vent the boiloff of the cooling line. PRVLN2-2 may open if the pressure exceeds 15 psi. If this occurs backoff the HV valve on the tank.
7. Once the temperature at TE-104N drops below 100 K, the line is ready for liquid transfer.
8. Open VNVA to vent the purifier during the fill.
9. Open VNFA to start the liquid nitrogen fill into the purifier.
10. Continue to fill while monitoring the liquid nitrogen level.
11. Once fill is complete close outside HV.
12. Close VNFA.
13. After 20 minutes close PV-100-N.

4.3 Liquid Nitrogen Fill for the Target Magnet Shield

1. The magnet shield liquid nitrogen level shows less than 60% full.
2. The pressure in the outside tanks indicates that there is liquid to transfer (over 15 psig).
3. The fill valve on the purifier PV-105-N should be closed while EV-102-N is open for pre-cooling of the line.
4. Open the HV valve on the nitrogen storage Dewar gradually. CV-108-N will open to vent the boiloff of the cooling line. Monitor the pressure in the line, do not exceed 25 psi.
5. Once the temperature at TE-104N drops below 100 K, the line is ready for liquid transfer.
6. Open MV-106-N.
7. Open PV-105-N by controlling EV-105-N.
8. Continue to fill while monitoring the liquid nitrogen level in the shield.
9. Once fill is complete close outside HV.
10. Close MV-106-N.
11. Close PV-105-N.
12. After 20 minutes close PV-100-N.

5 Liquid Helium Fill Procedure

5.1 Conditions for a Liquid Helium transfer from QT Dewar to magnet

The conditions for a liquid helium transfer or fill from the QT storage Dewar to the Target Magnet are as follows. The QT storage Dewar has liquid and is ready for transfer, which means at least one of the 250 L Dewars has sufficient liquid to make a transfer (approximately 70 L to make a 50 L transfer). The superconducting magnet level probe indicates that there is space for a transfer. Also, the magnet, fridge, and QT transfer line insulating vacuums are pumped out and operational. The main OVC on the magnet is less than 5×10^{-6} Torr. There is no ODH alarm and no indication that an alarm would occur for the next hour.

5.2 Fill control options

The QT PLC system will automatically keep the Magnet Dewar between certain level setpoints when in the Auto setting. The Transfer line is used to transfer the liquid helium from the most full liquefier Dewar to the magnet Dewar. The transfers can be automated based on certain level setpoints or it can be triggered by the operator when set to manual mode.

5.3 Automatic fill (PLC Transfer Line Auto)

1. Magnet Dewar level below set point → Request transfer
2. Check liquid levels in liquefier Dewars and if it is sufficient see if this liquefier is able to transfer (If "Allow partial transfer" is enabled, if the sum of all liquefier Dewar levels is sufficient, they will all transfer in sequence).
3. Once it is determined which liquefier(s) will do the transfer, the liquefier(s) will pre-cool the liquid in its Dewar prior to transfer.
4. Once the liquid is considered pre-cooled, the system will start pre-cooling the transfer line by opening the respective liquefier transfer line valve (either VJVA or VJVB) and open the VPC valve to allow warm boil-off to exit the system through the vaporizer and recovery path.
5. Once the temperature at TX1 drops below its temperature setpoint (100 K), the system will start pre-cooling the stinger by opening VJVT but keeping VPC open for boil-off to exit the system.
6. After a set time (30 min.), the system will close the VPC valve and start the actual transfer.
7. The system will keep transferring until any of the following conditions has been met
   a) Operator presses "Abort transfer".
   b) Magnet Dewar Level exceeds a set point.
   c) Liquefier Dewar Level drops below a set point.

8. The Liquefier will then revert to its liquefaction state. The transfer line will stay active if it is expecting another transfer from another liquefier. Otherwise it will revert to a safe state by closing the Dewar delivery valves (either VJVA or VJVB) leaving VPC open, this valve will allow any left-over liquid to be boiled off safely and be captured by the recovery manifold.

5.4 Manual fill (PLC Transfer Line Manual)

1. User determines that a fill is required.
2. Check liquid levels in liquefier Dewars and if it is sufficient see if this liquefier is able to transfer (If "Allow partial transfer" is enabled, if the sum of all liquefier Dewar levels is sufficient, they will all transfer in sequence).
3. Pre-cool the liquid by closing SV03, restricting the flow of warm gas to the liquefier.
4. Once the liquid is considered pre-cooled, start pre-cooling the transfer line by opening the respective liquefier transfer line valve (either VJVA or VJVB) and open the VPC valve to allow warm boil-off to exit the system through the vaporizer and recovery path.
5. Once the temperature at TX1 drops below 100 K, start pre-cooling the stinger by opening VJVT but keeping VPC open for boil-off to exit the system.
6. Wait about 30 min., then close the VPC valve and start the actual transfer.
7. Continue to transfer while monitoring the level of the Magnet Dewar and the level in the QT storage Dewar.
8. Stop the transfer by closing the delivery valve (either VJVB or VJVA) leaving VPC open, this valve will allow any leftover liquid to be boiled off safely and be captured by the recovery manifold.
9. Close magnet delivery valve VJVT.

6 Magnet pre-cool procedure

For the initial cool-down or a cool-down that starts with the superconducting magnet coils at room temperature it will save considerable helium if the coils are pre-cooled with liquid nitrogen. This should be done prior to the helium fill procedure to reduce the need for excessive liquid helium to cool-down the large stainless-steel magnet former. This procedure requires filling the liquid helium space of the magnet with liquid nitrogen and leaving it cool overnight and then to boil off over the course of two days. After the nitrogen boils away there is a pumping and purging procedure done with helium gas so that the magnet is cleared of nitrogen gas. Filling with liquid helium can then commence.

Materials required: EVAC KF adaptor (40 to 16). Move liquid nitrogen fill line from nitrogen shield vessel to magnet helium space. The pump mentioned here is already in place and connected (Edward scroll pump, also called the magnet pump). For pre-cooling the steps are as follows:

1. Pump and purge helium magnet space by pressurizing from helium backfill supply up to 3 psi and then pumping down with magnet pump to 0.05 Torr. Do three cycle.
2. Connect KF adaptor from nitrogen fill line KF-16 to magnet helium riser KF-40 with EVAC chain clamps and aluminum KF seals.
3. Open parallel plate relief valve PSV 401He (propped open with screen around open air access).
4. Fill helium tank all the way with LN2 while monitoring the temperature sensors (thermocouples) in magnet helium space to determine liquid level.
5. Once top tank sensor is at 77K stop fill.
6. Remove nitrogen fill line and place back in nitrogen shield vessel. Connect helium riser to helium backfill supply in cave.
7. Let liquid nitrogen boil off over next two days while monitoring temperature sensors.
8. Once sensors indicate vessel is empty (higher than 77K again), close PSV401He and disconnect magnet pump from helium recovery manifold to vent pump and purge process into NM4 Hall.

9. Pump and purge about ten times or until sensor no longer reduce temperature while pumping. Do this by back-filling to 3 psig and then pumping down to 0.05 Torr.
10. Once pump and purge cycles are complete disconnect backfill supply from magnet riser and prepare system for helium fill.

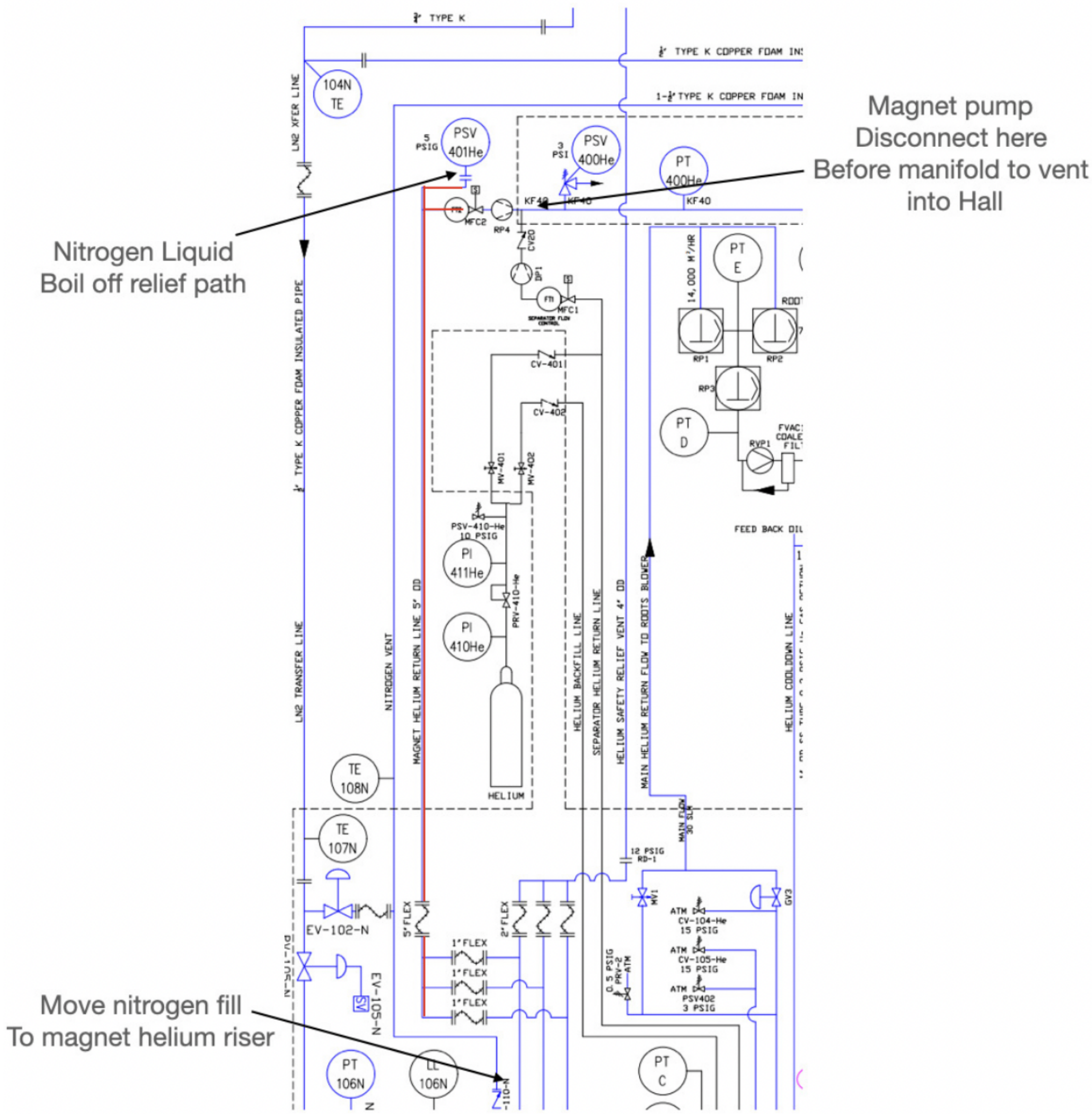


Figure 2: Helium-space nitrogen boil off relief path and pump-out path.

7 Magnet cool-down procedure

7.1 Introduction

This is the procedure for performing the initial cooldown of the UVA target magnet. There are two preferred phases of the cooldown one that brings the magnet close to 77 K, and then to bring the magnet the rest of the way down to 4K.

7.2 Superconducting magnet

The superconducting target magnet Dewar is a standard Oxford Instruments superconducting magnet vessel that contains a 5 T superconducting magnet coil wound around a stainless steel former. There are three risers that vent the liquid helium boil off as well as quench relief that vents through the magnet helium return line which route the vapor either back to the liquefier or out of the building if the pressure exceeds 5 psi. The magnet Dewar holds 145 liquid litters of helium cooled to 4 K simply for the sake of running the superconducting magnet. The lower section houses the magnet coils inside a cylindrical Dewar. The quench protection diodes and resistors sit in the top of the magnet tank. The top magnet tank is a cylindrical helium reservoir. These sections are connected by two 6.0 cm ID tubes with an indium seal on both. A vertical center bore through both the upper and lower sections allow for insertion of the 4He evaporation refrigerator and the target insert. There is also a rectangular open bore through the coils where the beam passes. The magnet Dewar has a large annular geometry that wraps around the refrigerator area separated by the insulating vacuum. This is the main holding tank for the cold helium before being pumped over to the refrigerator through the U-tube transfer-line.

The liquid helium fill port is the 3/8" female connector designed to seal to a transfer line bayonets. The bayonet fits into a sealed compression fitting to pass helium through the riser down to top of the tank. The liquid must cool the top of the tank before liquid will run down to the coil region to cool the magnet. If the magnet is pre-cooled with liquid nitrogen the initial fill will require about 350 liquid litters to fill the magnet Dewar. Without the liquid nitrogen pre-cooling the amount of liquid helium required more than triples.

7.3 Nitrogen shield

The liquid nitrogen shield Dewar is also part of the Oxford Instruments magnet. This Dewar has a volume of 115 L. The nitrogen Dewar surrounds the magnet Dewar tank on top of the magnet and creates a thermal barrier with vacuum on either side. The nitrogen Dewar operates at atmospheric pressure so this can operate as an open vessel. As nitrogen boils off and vents out of the cave and then out of the building. The liquid nitrogen tank connects to an aluminum radiation shield that surrounds the magnet Dewar. The liquid nitrogen tank should remain at least half full in order to protect the liquid helium components from heat radiation from the outside. It is not a pressurized unit and only to sits at 77K to provide thermal insulation between the outermost vacuum region and the liquid helium reservoirs.

7.4 Procedures

7.4.1 Evacuating the cryostat OVC

In order to maintain the thermal isolation of the liquid helium it is necessary that a high vacuum be maintained within the cryostat outer vacuum case (OVC). The nose reservoir should not be evacuated prior to evacuation of the OVC as the external pressure differential limit is 8 psia. The OVC is connected to the target beamline which connects to a large TMU-1000PC turbo capable of getting to a low 10^{-5} Torr with a single day of pumping. It is preferred that OVC is pumped down for multiple days prior to filling with any cryogenics. The turbo is backed up by a dry rotary pump of about 20 m^2/hr pumping speed. The turbo is operated using the DMU600 controller. The turbo can be cycled up after pumping down with the backup pump to mid 10^{-3} Torr. When bringing the OVC backup to atmosphere, the space should be pressurized with nitrogen gas, to prevent atmosphere and moisture from settling in the vacuum space. For long duration of in operation, store the OVC at atmosphere filled with nitrogen gas.

7.4.2 Pre-cooling the magnet

Before filling the magnet vessel with liquid helium, the vessel should be cooled to a temperature below 100K, this will save a considerable amount of liquid helium. To perform the pre-cool, fill the magnet vessel with liquid nitrogen completely. This can be done with two commercial 160 litter Dewars and a cooper foam insulated transfer line, or the file line used to supply the liquid nitrogen insulating shield. Once filled this should be left in for about 12 hours. The appropriate venting of the magnet should be in place to allow the liquid nitrogen to boil off as needed. The liquid nitrogen can be left in until it evaporated completely. There are Allen-Bradley Resistors on the top and bottom of the coils that can guide as level indicators. Liquid nitrogen temperature is approximately 7Ω. To ensure no liquid nitrogen is left connect a nitrogen backfill source and pressurize to just over atmosphere and then pump out with the magnet KNF pump. Repeat this process until the resistors indicate that the liquid is evaporator and no longer changes during the pumping and purging process. Do not stop the nitrogen evacuation prematurely as not removing the remaining nitrogen can cause serious problems. Monitor the background in the OVC with a leak detector connected to the OVC pumping line to check for low temperature leaks. The formal pre-cooling procedure is in SEAQUEST Document 10032-v2.

7.4.3 Nitrogen shield fill

In the interest of economy it is advisable to pre-cool the magnet before filling the nitrogen shield vessel the first time around. After the first pre-cool fill is done one can fill the shield. The shield has its own fill port and is filled directly from the outside liquid nitrogen storage tank. The nitrogen vessel also has it own vapor vent however the fill port is less than 10 mm in diameter so filling should be done gradually. It is expected to take about 1 hour to fill the shield. Follow the fill procedure described in SEAQUEST-doc-10053. The basic steps are listed here. The LN2 fill steps are:

1. pre-cool transfer line (flow liquid at reduced rate for 20 minutes, or temperature ready).

2. Start LN2 fill (flow liquid at recommended rate for 40 minutes).

3. Stop LN2 fill.

4. Measure and record LN2 level probe reading.

Be careful not to overfill the nitrogen shield this can lead to seal failure.

7.4.4 Initial fill of Liquid Helium

The fill will follow the FNAL ODH logic, so a request to fill signal is sent and if there is not ODH alarm the fill can commence. The delivery of the liquid helium is provided through the vacuum insulated QT transfer line. This vacuum should be monitored at all times with thermocouples before and during the transfer. The transfer line should already be in place and ready but the line must be pre-cooled and the cool-down line must be ready to receive the vapor from pre-cooling the line. Follow the fill procedure described in SEAQUEST-doc-9670. The basic steps are listed here. The LHe fill steps are:

1. Pre-cool transfer line (flow liquid at reduced rate for 20 minutes, or temperature ready).
2. Start transferring the liquid helium by pressurizing the QT storage Dewar. The transfer rate should be such that the transfer line is not more than about 1 meter covered with frost. The initial transfer rate should be equivalent to about 10 litters per hour. This rate can be increase as the magnet cools and the boil-off reduces.
3. When the liquid helium reservoir has been filled, stop the transfer by releasing the pressure of the storage vessel. Set the QT transfer status to standby.
4. Measure and record LHe level probe reading.
5. By monitoring the Allen-Bradley sensors, when the magnet temperature falls below 10 K, the transfer rate can be further increase in order to fill the liquid helium container more efficiently.

References

[1]https://seaquest-docdb.fnal.gov/cgi-bin/sso/ShowDocument?docid=10060

[2]https://seaquest-docdb.fnal.gov/cgi-bin/sso/ShowDocument?docid=10062

[3]https://seaquest-docdb.fnal.gov/cgi-bin/sso/ShowDocument?docid=10053

[4]https://seaquest-docdb.fnal.gov/cgi-bin/sso/ShowDocument?docid=9670

[6]https://seaquest-docdb.fnal.gov/cgi-bin/sso/ShowDocument?docid=10032

[7]https://seaquest-docdb.fnal.gov/cgi-bin/sso/ShowDocument?docid=9651