Cryogenic procedures for Torus, Solenoid, and Buffer Dewar

Updated 2021/04/14

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# UPDATED: TORUS Burp 8/22/2023 PID Group 11C pg 33 Parking the Torus at 80K (partial of this is just a Burp to 50K) and keeping the Solenoid and Buffer Dewar cold – August 22, 2023

– DK/DT/DI/CM

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Scope**:**

This document is the cooldown and operating procedure for the CLAS12 Torus, Distribution Can (DBX) and 500 Liter Buffer Dewar. It covers all steps necessary to safely take the Hall B Cryogenic Distribution System, The 500 Liter Dewar, and the CLAS12 Torus from room temperature to steady state cryogenic operation. Parts of this procedure may be used by experts to recover the magnet. Sections for Recovery from magnet quenches, refrigerator trips or power outages are titled. Future revisions will have these sections completed.

## Valve Control and PID Loops

A spread sheet that contains all control parameters (PID settings) for each active control device (Valves and Heaters) is attached as Appendix 1. In Appendix 1 there are different **PID Groups** used for different phases of the cooldown process. As the state of the systems pass from one mode of cooldown to another, PID parameters for control elements may change or the control element may go from Normal to Manual. The spread sheet contains two check-list columns which will be filled in after functionality of a Control Loop or control interlock has been tested and found to perform properly the check boxes will be filled out. Operators are warned that there may be some states of systems that the controls may not respond as intended, though rare, these can occur due to things as strange as blockages in piping, control read-back failure, or other portions of the system failing (refrigerator, compressor, air system….). The spread sheet also includes a section to allow warming the nitrogen shields above room temperature to improve the initial pump-down of the insulating vacuum.

## Nomenclature of the Torus and DBX valves and instrumentation

The nomenclature follows the CND (CEBAF Nomenclature Document) with details described here. Knowing the pattern will help the operator more quickly and correctly identify the hardware and should help to avoid errors in operation.

Typical signals are XXXABCDYYY

XXX is the type of hardware (LL = liquid level, SV = Solenoid Valve, PV = pneumatic valve, EV= electric valve, RV= relief valve, CV= Check Valve, HX=Heat Exchanger, HTR = heater, TD = Diode temperature sensor, TR = Cernox Temperature sensor, TP = Platinum Temperature sensor, PT=PI=Pressure transducer,…)

A is the system locator (8 is for Hall B, 6 is for ESR)

B is the system detail description (1 = Torus, 2 = Buffer Dewar and Targets, 5 = DBX, 6 = Solenoid)

C is the process circuit (1 = 4K supply, 2 = 4K return, 3 = 15K supply, 4 = 20K return, 5 = N2/LN2, 6 = Cooldown Helium

D is a counting number that usually increases in the direction of the flow

YYY is usually empty or a set of letters that help to identify function (S = Solenoid, T = Torus C = Cold, W = Warm, BY = Bypass, CD = Cooldown, TR = Torus Return……)

**Prior to use of this procedure the following documents must be read, understood and signed by all operators** ENP-16-59053-OSP Torus Magnet and Service Tower Cryogenic Operation

ENP-16-60975-OSP Hall B Distribution Can Operation Procedure

**Relevant documents:**

Hall B Warm Gas Piping B00000-09-00-0701

Hall B Torus Cryogenics P&I Diagram B00000-09-00-0100

Hall B Cryogenic Distribution Can P&I Diagram B00000-09-00-0500

Hall B Solenoid Cryogenics P&I Diagram B00000-09-00-0 600

Buffer Dewar 66850-E-02859

B000000402-S004 Hall B Magnet Cryogenic Instrument Description

B000000401-R015 Torus Hex Beam and Coil Strain Gages

B000000401-R016 Torus Main Supports and OOPS Strain gages and Load Cells

B000000401-R015 Torus Coils and Hex Beams Strain Gages Initial Conditions B000000401-R015

B000000401-R016 Torus Main Supports and OOPS Strain gages and Load Cells B000000401-R016

B000000901-P006 Hall B Check Lists for Cool Down of Cryogenic Systems

# Getting started

## Initial Conditions

* B000000901-P006 Hall B Check Lists for Cooldown of Cryogenic Systems.pdf is checked off for all items necessary for the start of cool-down.
* U-tubes between the DBX and TST and DBX and Buffer Dewar are installed
* System Purified and circulating helium at approximately 3ppm or less
* Set up the PID Control Loops In Appendix 1
* Setup and Test all Alarms for Cooldown

## PID/Interlock Initial Verification

Test the PID Control Loops with appropriate perturbations, initialing the “PID Verified” to Work Cells in the spread sheet (Appendix 1).

NOTES:

MOST PID Control Loops will need to be fine-tuned during the initial cooldown.

Some PID loops and may also need to be tuned differently depending on the phase of the operation.

Interlocks in general will not need to be changed. If interlocks need to be changed, D. Kashy or R. Fair must be contacted.

Upon successful verification of PID Loop/Interlock basic functionality, cooldown may begin. Basic functionality includes:

1. Controlled Device moves the full amount required in both manual and normal (“PID”) modes
2. Controlled Device moves in the correct direction to an offset in the set value vs actual value of the PID input
3. Controlled Device if it has any cascades is receiving its proper min/max from the cascaded PID
4. If Controlled Device has an interlock, the interlock has been dummy loaded and confirmed to act properly to shut the device if proper operating conditions do not exist, AND the actual trip value is reinstated into the PLC

At each phase of the cooldown verify the PID loops for that phase are working properly and fine tune as needed. D. Kashy (or his alternate) should be contacted if PID loops are not reacting properly or need fine tuning.

## Critical things to monitor or observe:

|  |  |
| --- | --- |
| System Parameter(s) | Operator Action |
| Monitor strain gauges and load cells for signs of unusual differential thermal contraction | Call Expert if values change into an alarm state (yellow or red) |
| Time rate of change of the cold mass should be kept below 3K/hr CCM\_DT\_Dt30 or DT120 or DT600 | Reduce control temperature DT (input of PV8563C.MAX) |
| Temperature differences between Hex Rings and Coils >35K | Reduce control temperature DT (input of PV8563C.MAX) |
| Ambient vaporizers getting iced past ½ of last series finned tube | Determine source(s) of flow and reduce flow as needed |
| Vacuum Jackets of Torus, TL, DBX, or U-tubes, sweating or icing | Call Expert, stop or slow cooldown, add pumping capacity or start pumping on static vacuum spaces |
| Temperature variation in a coil >35K METAL4K\_DT\_MAX | Reduce control temperature DT (input of PV8563C) |

## Contacting the Cryogenics Operators:

During normal working hours contact CHL control room at ext 7405 or the guard shack ext 5822

During off hours contact is through the guard shack ext 5822

Joe Wilson 269-7722 office 757-715-1167 cell

Chris Perry 269-6157 office 757-371-4926 cell

Johnathan Creel 869-8910

## Initiation of cooldown:

1. Make a Torus Log entry titled with the Time, Day, Month and Year of cool down. (Make entries for all steps, there cannot be too many entries) the electronic log book is at: <https://logbooks.jlab.org/book/hbtorus>
2. Confirm data logging is activated – including Fast DAQ- (Contact Wesley Moore or Ruben Fair)
3. Start plots of critical signals relevant to the stage of the cooldown, in general these will be flows, pressures, temperatures and valve or heater positions of active control parameters for that stage of cooldown/operation, these usually are the inputs/outputs of active PID loops and temperatures, pressures, and flow rates in the flow stream

# N2 cooling of the ESMTL and DBX

**PID Group 2**

***Discussion:***

The two main things to be aware of are:

* The Helium circuits need a positive gas source to keep them above atmospheric pressure.
* The TL N2 circuit can be cooled at any rate and is cooled directly with Liquid Nitrogen from the ESR valve Box.

One should also recognize that the TL slopes down as it enters Hall B so LN2 will run toward Hall B and hit warmer sections of the pipe, flash to gas and rapidly pressurize the line. The mass of the line is quite large as it is between the outside of a 5 inch sch 10 NPS pipe and the inside of a 6 inch NPS sch10 pipe with the 5” sitting on the bottom of the 6” creating an eccentric flow path. This will result in very unstable flow with continuous pressure spikes the size of which will be dependent on the pressure drop of the return path.

1. Close all valves in the N2 and Helium circuits on the Torus, Buffer Dewar and Distribution Box
2. Verify that all the ESR Valve box valves are closed EV67X1B are closed (X from 1-5)
3. Install the LN2 supply and the 4K supply and Return U-tubes at ESR from the valve box to the Hall B expansion can per procedure CRY-13-utubes-OSP\_rev6.
4. Setup the controls to keep the helium circuits at positive pressure (floating on CHL purifier suction pressure) with a slight warm circulation from the 4 atm helium line as follows:
   1. Verify with CHL staff that the warm helium supply valve MV6010B, the purifier return valve MV6031B and the quench to lead flow cross connect valve PV6030B are open.
   2. Open the Buffer Dewar Cold return valve EV8210BP fully
   3. Open the DBX warm and cold return valves for both the Torus and Solenoid PV8522TCD, PV8522SCD, PV8522TR and PV8522SR
   4. Open the following valves 20%
      1. 4K Helium supply the magnets: PV8512S, PV8512T,
      2. Variable temperature helium supply PV8566S, PV8566T
      3. Flow control valves in the Torus EV8115JT, EV8111BY, EV8111CD
   5. Open lead flow manual valves located on the vaporizer set by the TST, MV8121A and MV8121B flow controllers should then be opened to try to achieve their desired set value of the flow (from the PLC)
   6. Verify that the magnet cooldown mixing valves PV8563C and PV8563W are closed
   7. Verify MV8002, MV8561 and MV8562 are open and MV8561V is closed
   8. Check the return pressure and flow meter indication on local gages PI8525 and FI8525 located at the end of the catwalk on L2 of the Hall B spaceframe. PI8525 should read ~1psig and FI8525 should read 0.0
   9. Check the readback of PT8565. It should be ~1.0 to 1.1.
   10. **Start the Helium flow**
       1. Verify that PID for PV8563W has Min and Max positions of 0
       2. Verify the PID for PV8563W has PT8565 as an input and change the input value to be 1.3 or at minimum 0.1 at higher than the readback of PT8565 found in the previous step
       3. Slowly increase the max of PV8563W and tune the PID gains to get it stable
   11. Verify that the Nitrogen supply valves to the magnets are closed: EV8555T, PV8555S, PV8556T, and PV8556S
   12. Verify that PV8558 and EV8553 are in manual mode and fully open
   13. Verify that EV6751B has a max of 47.5%
   14. **Start the LN2 flow to the Hall/DBX (this is the LN2 cooldown of the transferline)**
       1. Have the ESR operator open CEV6751B and setup a PID loop to control on its outlet pressure PT8552 or a local gage at the ESR downstream of EV6751B if there is one. If this does not work then EV6751B could be set to control on flow rate CFI6751B, or put in manual mode
       2. During this phase check the pressure in the N2 Circuit looking at PT8552 and PT8554 if these pressures get up to pressure upstream of CEV6751B the flow will stop until the pressure downstream of the valve drops. This is not a problem and is very likely to happen.TP8552, TP8554 and TP8567. Note TP8555 will not drop much as not much cooling will get to this area as the leg is dead headed.
   15. Continue flowing down the transferline and monitor the temperatures in the DBX on the N2 circuit
   16. Any time after the cooldown begins but before any temperature in the DBX gets to 200K setup EV8553 to control on liquid level LL8554CP or LL8554DP put it in steady state N2 mode
   17. After the temperatures get down below 90K liquid should start to collect in the phase separator and the LN2 reservoir

# N2 steady state of ESMTL and DBX

**PID Group 3**

***Discussion:***

N2 that comes from the ESR through EV6751B is subcooled by a heat exchanger in the ESR Valve Box. This means it has the ability to absorb some heat before boiling and generating gas. But the LN2 does spend a significant amount of time in the Transferline from ESR to the Hall and the heat load will be such that gas is generated in the line. This will cause the liquid nitrogen flow to the Hall to be somewhat unstable. The expected period of the oscillation is 6-24 hrs. The DBX is designed to handle this instability. Even if the LN2 flow is not fully stabilized the shields the Torus will operate just fine. The LN2 fill valve (EV8553) for the liquid nitrogen reservoir, serves two purposes, the obvious one is to fill the reservoir, but the second function is to vent the gas from the transferline. There is also a feed from the bottom of the phase separator that takes liquid or gas from the reservoir to a heat exchanger that is sized as a condenser and subcooler to help stabilize the nitrogen supply for the Torus. With the helium system unchanged from the phase above, setup the system for steady state operations. This may take some time in tuning since the suspected oscillation will take a long time to stabilize and will also be a function of the use rate of LN2 and that will change depending on which mode of operation.

1. EV8553 will be controlling the level of the LN2 in the DBX
2. Have the operators at CHL/ESR put the LN2 supply valve EV6751B in manual mode at 47.5 percent and then remove and tag out the drive cable for EV6751B’s actuator located on the ESR valve box
3. Tune the PID’s for EV8553 if needed to control the Liquid Level of the LN2 reservoir and to vent the gas from TL burps EV8553.MIN. It will likely become evident that the level of N2 may not be fully stable and may overflow once in a while after the gas bubble from the transferline passes
4. The nitrogen back pressure regulator PV8558 (for N2 cooldown of the shields of the Torus) can now be setup. It too will not be fully stable as during passing of the gas bubble the system will oscillate.
5. With PV8558 in manual mode set the minimum position to 80% and maximum position to 100%.
6. Verify the input for PV8558 is PI8554 and set the set value to 2.0 atm. Adjust the gains, min/max changes to get stable operation while lowering the minimum position to 0
7. Also setup the PID loops for PID on HTR8554 to keep the reservoir from overflowing and pressure of the nitrogen gas backpressure regulator slightly open thus having enough gas flow to keep the PV8558 slighty open.

# Torus Shield Circuit Cooldown 300-100K

**PID Group 4**

***Discussion:***

***This process should start at a slow rate ~1K/hr, and once it is set up and running, the 300K-100K cooling of the Torus Cold Mass can start before or after this process. When both are running the operators should keep them within ~50K of each other.***

The shield will be cooled by running gas which is cooler than the shields through the Tubes that are welded to the shields. The temperature of the gas is controlled to limit the temperature difference between the gas and the temperatures of the shields plates themselves. The PLC scans all 8 shield outlet temperatures and uses the maximum of the 6 coil shields outlet temperatures and the 2 outlets of heat shields of the Downstream Hex Ring (TP815AR, BR, CR, DR, ER and TP815FR and TP815DSHRN and TP815DSHS) for a calculation. The calculation subtracts the maximum temperature (above) from the inlet temperature TP8151. The absolute value of this difference is given the signal name GN2\_METAL\_DT. This signal is used as the input value for the nitrogen heater HTR8559. To limit the cooldown stresses and cooldown rate, a temperature difference of 45K between the GN2 and the maximum metal temperature works well for the shields. This is not a hard number and it could be increased up to 50K if the cooldown rate is too slow (i.e. slower than the 4K cold mass). The variable temperature nitrogen gas is provided to the Torus by heating 80K gas with electric heater HTR8559. It is critical to feed the heater only gas as if it gets liquid it will not be able to keep up. The heater power is 3kW, and with 80K gas input it can warm up to ~15g/s of gas to 300K. As the required temperature drops (shield temperatures drop) even less power is required so the rate will not be limited by heater power. The 80K gas is generated by boiling LN2 in the nitrogen reservoir. Two heat sources are used to boil the LN2. The primary heat source is the heat exchanger coils of HX8565. This heat exchanger is used to cool a stream of helium to 80K. If additional gas is needed HTR8554 can be energized. The pressure of the cooldown gas is controlled by the N2 gas back pressure regulator in the DBX PV8558.

1. Check the Torus insulating vacuum to be sure that TC8103 is below 1e-3 torr.
2. Continue flowing the small amount of Helium to keep the helium system positive pressure, as setup in initial phase (N2 cooling of the ESMTL and DBX)
3. Confirm that EV8555T and PV8556T are closed.
4. At the beginning we will send a very small amount of flow through PV8556T the Torus shields to limit the amount of cooling power. This can be done easily by limiting the supply pressure available to drive the flow. Set PV8558 PID input to PI8554 with a control setpoint of 1.4 atm. Set HTR8554 minimum loop to keep PV8558 10% open. Tune these loops as much as possible. The tuning may need to be improved after flow has been increased through the Torus shields.
5. Set the input to nitrogen cooldown heater to GN2\_METAL\_DT with a set value of 30.
6. In small steps increase the maximum positon of the variable temperature supply valve PV8556T and increase the setpoint of PV8558 up to as much as 3.0 while watching to see that the heater HTR8559 is properly controlling the inlet temperature of the nitrogen to the magnet.
   1. A flow control can be setup to limit mass flow to the magnet based on the heater power at 75% of its maximum capacity or another number. One can look at the DT/Dt and adjust this heater power limit if desired.
   2. A secondary flow limit can be set by limiting the pressure in the torus shield supply circuit.
   3. Run in this mode for about one hour. If all is working well then: “Torus Cold Mass Cooling 300K-100K” should start
   4. If the cooling of the shields gets too far ahead (more than 50K below the cold mass temperatures) then the inlet temperature difference can be reduced or even set to 0 or a negative value until the temperatures of the shield and cold mass get closer to each other
7. When the shield temperatures in the Torus are all below 130K put the PID for HTR8559 in manual mode with 0 as the output and then administratively lock-out the plug to the heater. Thus providing 80K gas to the shields.
8. If it is desired one can change the input for HTR8559 as the inlet temperature TP8151 to hold the temperature at a fixed value and then step it down manually. PID settings for this are in the spread sheet. To do this put the heater manual set value to the current output value then change the mode to Manual.
9. If/when one wants to go back to cooling the process involves
   1. Pulling up a plot of the heater % output and the pressure at the last time it was running in cooling mode.
   2. Make sure the pressure is the same as it was during cooling if not put it back to that value. (setpoint of PV8558)
   3. Change the Setpoint of the heater to 10 then put the control in normal. Watch the output temperature and then increase the setpoint back to 45 or some other value.
10. Once the shield temperatures are all below 130K shut off the heater to provide 80K gas to the shields

# Torus Shield Operation 80K

**PID group: 5**

***Discussion:***

The 80K radiation shields are cooled by liquid nitrogen. The flow through the shields is “pumped” by a gravitational pump called a thermosiphon. LN2 flows down to the lowest point in each circuit through pipes/tubes with relatively low heat load thus very little gas is generated. After reaching the bottom of the circuit, the LN2 then passes through short length of thick wall tube that acts as a flow limiter. The LN2 then flows into a tube which is welded to the radiation heat shield. The heat that is absorbed by the LN2 creates some gas which bubbles that mixes with the liquid stream. This stream then has a lower density than in the supply stream and circulation develops.

A small continuous trickle flow of LN2 into the Torus is used to keep the reservoir at a constant liquid level. The Liquid Nitrogen is fed from the DBX through EV8555T. It comes from the ESMTL at ~3-4 atm through a phase separator and then to a heat exchanger (HX8555) which sub-cools the liquid. After traveling through the U-tube/N-tube (with heater HTR8559, which has been Administratively locked out) the liquid goes into the shield circuit plumbing below check valve CV8153 which forces it to flow through the shield circuits instead of directly into the reservoir. Using sub-cooled liquid as make-up vs saturated liquid/gas should make the thermosiphon more stable. After the Torus N2 shields are cooled below 130K and the coils of the magnet are below 130K, liquid can introduced into the shield circuit and back pressurization of the LN2 reservoir can be reduced by reducing the setpoint of PV8558

1. After the shield cooling has slowed to less than -0.5K/hr and the HTR 8559 has been off for 24 hrs LN2 cooling can proceed if the average cold mass temperature CCM\_T\_AVG is below 130K
2. Put the Nitrogen Gas heater HTR8559 in Manual mode with a setpoint of 0
3. Change the Interlock parameter for HTR8559 PT8151 from 1.2 to 1.02 atm
4. In 10% steps every 1-3 minutes open EV855T up to 70 %. When EV855T gets to 50% start closing PV8556T in 10% steps to 50%. Wait until TP8557T plumits from approximately 90K to 80K
5. Reduce the setpoint of PV8558 from 1.8 atm to 1.1 atm in 0.2atm steps
6. Increase the setpoint of EV8555T to 70% and wait until liquid starts to collect in the reservoir at LL8152DP and LL8152CP, while waiting one will see The DSHR sensors TP8151DSHRS/N first reach LN2 temperatures followed by the Coil Return temperatures TP815AR/…/FR. FR will be the last as it needs to get the supply line full to see a big change in cooling as compared to others which all get fed liquid earlier (see P&ID)
7. Coils A and F are delayed in filling. Coil A may take 1-2 hours after the first 4 and Coil F 8-10hrs.
8. Keep an eye on the icing of the ambient vaporizer HX8558M it should actually get less since the total flow is reduced because of the large heat of vaporization of LN2.
9. At this point the shield should be fully cooled, and the insulating vacuum in the Torus should be significantly better than when the cooldown began. The heat load on the 80K shield at this time will be at its highest level (it should get less as the vacuum improves with the 4K cryo-pumping effect after cooldown is complete). The Vacuum Jacket of the Torus should be inspected for any sign of sweat or icing. If there is ice or sweat check the temperatures on shield components in that area of the magnet for elevated temperatures. Also it may be necessary to add heat tape to keep water from dripping on the detectors.
10. Once liquid is collecting in the Reservoir tune the PID for EV8555T, thus far a “flatline” tune has not been achieved, and it is not likely to be so as the circuits in the shields seem to go through a kind of batch fill process
11. Once stable the LN2 portion of the cooldown is complete, move to the next phase of cooldown

# Torus Cold Mass cooling to 300K-100K

**PID Group 6**

***Discussion:***

***This process is to be done in parallel with 300-100K cooldown of the 80K shields and must be started before the shields get below 250K.***

The Torus 4K cold mass cooldown is done using variable temperature gas. This gas comes from the ESR at ~4atm (45 psig) and is split into two streams. One stream goes through a pair of heat exchangers (HX8564 and HX8565) that cool it to ~80K using LN2 from the nitrogen reservoir in the DBX. The other is at ~300K (room temperature). The gas is mixed to give any temperature between them. The mixed gas is then sent through PV8566T to the Torus. The Torus coils are cooled by heavy wall copper tube that is co-wound with the conductor. The downstream hex beams are cooled by tubing that is welded to the beams. After cooling the coils the same helium flow goes to the downstream beams and then to the JT valve EV8115JT where it enters the helium reservoir. Due to the length of this circuit (~700 ft) very little flow can go through it until it gets cold. We expect that 1g/s will be the maximum possible flow at 300K, this gas is called the primary supply. Cooling down using only this flow would take months so a second flow path was designed in the system to increase the cooling power. Additional helium from the mixing valves and heat exchangers in the DBX will enter the shell side of the Helium recoolers which are located in the upstream hex ring (one on each cold beam between coils) through the cooldown valve EV8111CD. This flow will extract the heat that was put into the primary supply gas from each coil allowing all 6 coils and the downstream hex beams to cool in parallel vs in series. The upstream hex beams are cooled by the gas in the shell side of the recoolers which has many copper pads and braids that are attached to both to transfer heat. To limit the cooldown stresses generated we will limit the temperature differentials in the magnet. Four temperature differences will be checked.

* CCM\_DT\_MAX = Maximum of all 6 coils of the (Maximum temperature on a coil/case – Minimum temperature on the same coil/case )
* CCM\_USHR\_DT = Average temperature of all coil temperatures – Average of all upstream beam temperatures
* CCM\_DSHR\_DT= Average temperature of all coil temperatures – Average of all downstream beam temperatures
* METAL4K\_DT\_MAX = Maximum of the three above ( CCM\_DT\_MAX, CCM\_USHR\_DT, CCM\_DSHR\_DT)
* HE\_METAL\_DT = Maximum cold mass metal temperature anywhere ABS [ (METAL\_T\_MAX) - helium inlet temperature (TD8111)]
* HE\_METAL\_DT2 = Maximum cold mass metal temperature anywhere ABS [METAL4K\_T\_MAX) - helium inlet temperature (TD8513T)]

The input temperature to the magnet TP8513T or TD8111 will then be controlled to keep the helium temperature of the inlet gas such that:

* METAL4K\_DT\_MAX is 25K (40K is Major Alarm Condition)
* HE\_METAL\_DT is 40K (60K is Major Alarm Condition)
* There are no alarms on the above signals once the magnet is below 110K

Interlocks will shut the warm and cold mixing valves PV8563W and PV8563C if the DT’s get above their Major Alarm Condition, and this will require expert intervention to reset the interlocks and resume the cooldown

1. Verify 4.5 K ESR supply valve EV6711B and EV6721 B cold return valves are closed.
2. Verify that the buffer dewar supply valve EV8210 is closed
3. Verify that the bayonet for the Solenoid 4K supply is closed and corked
4. Open PV8512T and PV8566S to 20% to keep the 4K helium circuit pressurized
5. Verify that both the Buffer Dewar return valves EV8210CD and EV8210BP are open 100%
6. Verify that both the Warm return valves PV8522TCD and PV8522SCD are open 100%
7. Verify that the magnet cold return valves PV8522TR and PV8522SR are both closed
8. Verify that Warm Helium Interface valve MV6031B at ESR to the Purifiers is open
9. The following exercise determines the amount of flow possible through each of the Torus Supply valves at Room temperature, be sure to monitor the following pressures and flows: PT8120, CPI603QB, CFI082. CPI084, FI8525, PI8525, FI8561, PT8513T, TD8513T, TD8111, PT8561. Contact the cryogenics group and tell them that a flow test to determine possible starting cooldown flow rates will be taking place and ask them to monitor their purifier system. NOTE: This process may have been done during the helium circuit purification process. If so find the data, it does not need to be repeated.
10. Open each of the following valves one at a time with 20% steps no more often than 2 changes per minute with the valves PID’s in Manual mode
    1. Open Torus 1.3 atm cool down valve EV8111CD to 100%
    2. Set the Torus primary circuit bypass valve EV8111BY to 100%.
    3. Open the Torus primary supply valve EV8115JT to 100%
    4. Open PV8566T 100%
    5. Slowly open PV8563W to see if we can achieve 10g/s on FI8561. Be in communication with ESR operators and go full open if we can go full open without overpowering the purifiers at CHL
    6. Log the max flow total flow.(Get readings from local warm gas supply flow meter FI8525 on the wall of Hall B Level 2 of spaceframe and FI8561, and CFI082- MUST coordinate with ESR operators to get change in flows)
    7. Close Manual valves on the current leads MV8121A and MV8121B
    8. Slowly close EV8111CD and EV8111BY and log the same data for flow just through EV8115JT
    9. Slowly close EV8115JT and Open EV8111BY and log the same data for flow just flowing through EV8111BY
    10. Slowly close EV8111BY and open EV8111CD and log the same data for flow just flowing through EV8111CD
    11. Test / Calibrate lead flow controllers
        1. Setup back pressure regulator PV8522TR to control the pressure (PI8120) in the helium reservoir in the magnet at 1.3 atm.
        2. Throttle EV8111CD in manual mode to get about 3g/s on FI8525.
        3. Open MV8121A see if additional flow is seen on FI8525 and if the flow controller EV8121A is controlling
        4. Close MV8121A and open MV8121B see if additional flow is seen on FI8525 and if the flow controller EV8121B is controlling
        5. Close MV8121B
        6. Put PV8522TR in Manual mode and 100% open
    12. The different flow rates are due to the differing pressure drops of these circuits.
11. Set Torus valves as follows
    1. EV8115JT 100% in manual
    2. EV8111BY 0% in manual
    3. EV8111CD 100% in manual
12. Put PV8566T in the DBX in manual at 100%
13. Setup PV8563W to control the delta P across the valve (DP\_CDHE\_8563W) at 0.3 atm
14. Setup PV8563C to control the supply temperature difference (see appendix 1)
    1. The input will be 45K for the helium temperature difference (HE\_METAL\_DT2 )
    2. The maximum will be 25K for the metal temperature difference (METAL4K\_DT\_MAX)
    3. NOTE: that if there are bad sensors or sensors that cause larger than expected DT’s they may need to be eliminated from the calculation data base (WE had a set of these, can we get those labels??)
15. Flow through EV8111CD will dominate the total flow during this stage of cooling. EV8115JT will remain open fully during this entire phase.
16. Return flow goes back to purification at CHL via the ambient vaporizer if pressure CPI084 goes above 1.15 atm we may need to reduce the position of EV8111CD and call cryo group
17. When the temperature of the helium return TD8120 is 200K, open the Vapor Cooled Lead manual valves (MV8121A and MV8121B) and verify that the heaters HT8121A and HT8121B are functioning (not getting cold or an ice ball is not forming).
18. Once the heaters are confirmed working MV8121A and MV8121B may remain open
19. Continue cool down procedure while maintaining the cool down criteria until all temperatures of the 4K mass components (as determined by TR811AR TR811BR, TR811CR, TR811DR, TR811ER, TR811FR and TR8114R) are under ~105K.
20. At any time the temperature may be held at a fixed value by changing the PID control of PV8563C to temperature control on TD8513T.
    1. To do this put the input Manual mode setpoint to the current value of the position and put the valve in manual mode
    2. Change the input of the PID control loop to PV8563C to TD8513T and change the setpoint to a desired temperature.
    3. Change the sign of the gains to the negative of the current signs (see the PID spread sheet)
    4. Put the PV8563C in PID mode
    5. The temperature can be stepped up or down manually from here or one can go back to automatic cooldown DT as described next.
21. To go back to automatic cooling ( also for RECOVERY from a Trip of the CD interlock)
    1. Put the input Manual mode setpoint to the current value of the position of the valve.
    2. Put the PID in Manual mode
    3. Look back at the time history of the control when the DT was being used and determine what the value of the position of PV8563C was when it was controlling on DT. Change the manual position to that value (if the temperature has not been stepped down).
    4. Change the sign of the PID gains for PV8563C and the input to the DT being used (HE\_METAL\_DT2)
    5. Put the PID in Normal mode.
22. When TD8111 gets below 125K start the ESMTL/DBX-Buffer dewar cooldown 300K-4K while continuing to flow helium between 120K and 80K through the Torus Helium circuit as above
23. When CCM\_T\_AVG, USHR\_T\_AVG, DSHR\_T\_AVG ARE ALL below 110K close PV8563W by putting it in manual mode with a position value of 0. The supply gas temperatures TD8513T and TD8511 should drop to between 80K and 90K.

**300K-4K Helium Cooldown of ESMTL/DBX and Buffer Dewar -VOID!!!**

**The Transferline should be cooled to 4K through the Torus prior to starting the dewar cooling.**

**PID Group 7**

***Discussion:***

The dewar is a low mass device and should cool quite quickly. The biggest issue with its cooling is that it is easy to overpressurize if 4K helium put in a warm dewar. On the first attempt to cool the dewar we blew the rupture disc because of this problem. When we got a second chance to cool it the RD blew again. This time the cause was not clear. On the 3rd try we found the U-tubes had poor insulating vacucum so one of the main things to keep an eye on is the insulating vacuum of the long flex transferlines.

1. If Starting this with 80K gas from the LN2 cooled 4 atm helium then PV8556T will be open to provide helium to the Torus. Open PV8512T to 30% to allow a feed to the buffer dewar. (solenoid is off line!)
2. Setup PID’s as per PID group 7B for EV8210, EV8210A, EV8210B and EV8210C. Note the A loop controls the min on EV8210 the C loop controls the Max of the B loop and the B loop controls/sets the max of the EV8210 loop.
3. Verify the EV8210CD is in manual and open
4. Put EV8210 in PID mode and watch it try to build the dewar pressure to 1200mbar. It may not be possible due to a low pressure drop in the CD line but this is OK as long as TE8210 starts to fall then the dewar is cooling. This can also be done with 4K coming down the TL
5. If cooling the Dewar and the Torus at the same time the CD line from the dewar and the Dewar 4K return can be cooled in parallel. Open EV8201BP fully and also PV8522TR fully. Watch TD8522DR it should at some point catch up with TD8211

Torus 4K Mass cooldown 100K to 4K

**PID Group 9**

***Discussion:***

***The 80K shields should now be put in steady state 80K operation mode. When all the major component average temps are below 110K this process can begin (CCM\_T\_AVG, USHR\_T\_AVG, DSHR\_T\_AVG)***

***If one is doing a 80K un park look to that section for more those details (in fact is should be more a similar situation as getting here was basically going into 80K park. Thus this section is redundant.)***

The End Station Magnet Transfer line has 4 helium circuits and the LN2 circuit.

The 4K supply to Hall B flows in a concentric space between a 2”OD Tube and a 1-1/4” sch5 NPS pipe. The 4K return flow returns to the ESR inside the 1-1/4” NPS pipe. The supply circuit must be the one to be cooled first assure that both pipes cool down at the same time to avoid tearing the line apart which would happen if the inner pipe (4K return) were cooled first while the outer tube remained warm. It is important in a later phase to understand that these pipes act as a heat exchanger when helium flows in both circuits.

The 4K supply line is cooled with 4 Kelvin 3 atmosphere helium (Super Critical Helium) or liquid helium from the End Station Refrigerator. This helium comes from the ESR valve box through CFI6711B and flow can be shut off or throttled using CEV6711B. The best place to take drop the pressure of this flow is CEV6711B. This assures that when the cold helium that is warmed by the warm pipes expands it will not reverse flow and thus get back into the ESR Valve box and upset the refrigerator or other Halls. For this portion of the cooldown only EV6711B will be running as an active PID controlled valve. Its setpoint may be changed depending on the stability of the line and cooldown rate. CEV6711B could also be set to a manual position but this will likely result in a longer duration for this portion of the cooldown and possibly more refrigerator instability.

CEV6711B has a CV of 3.0 and EV8111BY has a CV of 3.0 so to keep the system stable EV6711B should be throttled. Once the TL is cold (below 10K) then the flows can be diverted through the Torus supercritical circuit and also into the recoolers through EV8115JT and EV8111CD.

This phase of the cooldown is done with 4K helium. Again the flow will flow through two valves in the Torus. The primary supply valve EV8115JT will be fully open for most of this process and then throttled at the end of this phase. The cooldown valve EV8111CD will boost the cooldown power as before in the 300K-100K phase by recooling the helium in primary supply flow between coils. Flow will be limited to 10g/s or less depending on available capacity from the End Station Refrigerator. 4K helium flow from the ESR to the DBX will have already been established when cooling the ESMTL and the Buffer Dewar. 4K flow to the Buffer Dewar will be limited to allow maximum capacity for cooling the torus. The return path for the helium will be the same as the 300K-100K gas. Helium will flow through the helium return U-tube from the TST to the DBX. It will go into the return piping in the DBX and flow by TD8522TR that will allow the total flow return temperature to be monitored. With the cold return valve PV8522TR closed the flow will flow through PV8522TCD and out to the ambient vaporizer HX8524 and flow through warm flow meter FI8525. HX8524 will be more highly loaded during this phase as the gas going in will be colder so it should be checked to see if it is getting overpowered and if so the supply flow will need to be reduced. There are no restrictions to the temperature differences or time rate of change of the 4K mass during this process. The only limits on our flow are capacity of the ESR and the Purifier capacity. To assure that the no warm helium gas mixes into the 4K helium supply, the warm supply will be isolated from the cold supply and its pressure will be vented to 2 atm (below the nominal 3atm 4K helium pressure). When all temperatures are between 7 and 8K the process to switch to cold return and away from the ambient vaporizer can begin. Because all the piping in the Torus and most of the piping in the DBX is cold the switch to cold return can be done fairly easily if the ESR operators agree. The basic method is to first setup PV8522TCD to be a back pressure valve with a setpoint of 1.4atm. Then with EV6721B at ESR closed open PV8522TR fully. Then ESR can slowly open EV6721B while watching TD672 and other key refrigerator parameters. As they open their valve PV8522TCD will close to try to keep the Torus 1.2 atm tank at 1.4 atm. Once it is fully closed the torus is on cold return and ice on the vaporizer will begin to melt. Rope off the area below the vaporizer to assure people don’t get struck by falling ice blocks.

1. Change Alarm State for HE\_METAL\_DT and DT2 from Minor and Major to No Alarm for these signals.
2. Close the Warm Gas Supply Control Valve PV8563C and manual valves MV8562 and MV8561. The warm valve PV8563W should have already been closed at the end of the previous 300-100K cooldown phase
3. Slowly depressurize the volume between MV8562 and MV8561 using MV8561V to between 1.5 and 2 atm (7-15psig) while monitoring local pressure gage PI8561.
4. Depressureize PT8563 by cracking PV8566T then closing it while PT8513T is less than 1.5 atm. Watch to see that PT8563 stays lower than PT8513T and less than PT8651
5. Close PV8556T and Open PV8512T.
6. First cool the Transfer line to less than 10K by closing EV8115JT and EV8111CD and fully opening EV81111BY.
7. Contact ESR to have them slowly open and control the supply pressure to the hall from EV6711B at ~2.4 atm.
8. **Establish 4K supply flow to the Torus** slowly open PV8512T **Primary circuit** by: setting EV8115JT to 100% in manual
9. As the temperatures drop the helium gas density will increase and thus to maintain constant flow rate the valve positions will decrease. The CD valve EV8111CD will close first as its set point is lower than the primary supply valve EV8115JT
10. Temperatures in the 4K portion of the system will continue to fall
11. When all temperatures are less than 8K we will **begin the switch over to Cold Return**.
12. Start plots of TD8210, TD8513T and TD8111. Check the 4K return pressure in the DBX. There are no pressure sensors of this pressure directly in the DBX but it can be understood by looking at pressure sensors PT8120 (Liquid helium tank in the Torus), PI8210 (pressure in the buffer dewar), and even CPI8521 (return pressure in the transferline 4K return circuit) and the purifier suction pressure CPI084. All these should read about the same value, small differences can be attributed to pressure drops due to flow in the pipes. Contact ESR operations and ask what the pressure of the return stream of the valve box is (CPI672)
13. Put PV8522TCD in Normal mode controlling on PT8120 with a setpoint of 1.35 minimum or at least 0.1 atm above the ESR 4K return pressure from the cryo group.
14. Open Cold Return valve PV8522DR to 100% ( one time it did not open and we did not know it and wasted hours thinking we were cooling slowly. It turned out to be a bad connection in the actuator)
15. Once the pressure PT8120 is stable at its setpoint, call ESR and ask them to slowly open CEV6721B. PV8522TCD should slowly close.
16. The swap should take 30-40 minutes and as soon as the EV6721B moves even a little CTD672 should spike up…
17. When the EV6721B is fully open and PV8522TCD is fully closed put PV8522TCD in Manual at 0.0 set value
18. Make sure the flow limit on EV6711B is increased to 8 g/s by cryo.
19. Ice on HX8524 will slowly melt, so be sure that the drain is clear and that if it is large that it does not fall and hit persons below. (rope off area below the vaporizer)
20. Once the cold return flow has established, the primary supply flow to both the Dewar and the Torus should be increased slowly to beginning filling of the 500L dewar and the 4K LHe Reservoir in the Torus and the operations go into the final phase “Steady State Torus Operation 4K” PID Group 10 and “Steady state Buffer Dewar Operation” PID Group 8.

# Steady State Torus Operation at 4K

**PID Group 10**

***Discussion:***

The flow through primary circuit of the Torus passes through a heat exchanger HX8112 then one at a time through each coil starting with coil A and ending with Coil F. It flows through a recooler between each coil and through a recooler before cooling the downstream hex beams and finally flows through HX8115. It then passes into the Torus liquid reservoir through EV8115JT. This valve controls the flow through the coils it has a second purpose to create liquid helium for keeping the helium reservoir and recoolers full of liquid helium. The term JT refers to a process called Joule-Thompson expansion. This is constant enthalpy process (no heat added or extracted), if the properties of the inlet gas are within the correct temperature and pressure ranges, some of the inlet helium supercritical gas becomes a mix of saturated liquid and saturated gas. The gas then passes directly to the return line and past TD8120. The liquid fills the reservoir and the recoolers. Heat that enters the coils flows into the primary supply and this heat is then transferred into the liquid bath through 6 recoolers and HX8115 all of which boil off more liquid helium that also flows back to the ESR. The design of the system is to control the primary supply flow based on helium level in the helium reservoir. A small fraction (< 1g/s) of the 4K helium gas generated in the Torus is used to cool the Vapor Cooled Leads (VCL’s). Vapor cooled leads are designed to transmit the high current (3770A) from water cooled buss bars to the superconductor of the magnet. Helium “vapor” starts at 4K and warms as it flows up the leads and warms due to absorbing heat from the I2R loss of the conducting filaments in the lead. 400Watt heaters HTR8121A and HTR8121B will help to limit the ice ball size. After those heaters are ceramic breaks that have helium on the inside and air on the outside. There are male bayonets with Teflon flow dampers inside to minimize the cooling of the ceramics. The flow then proceeds through vacuum insulated lines that then connect to ambient vaporizers that are designed to ice up on the outside and warm the gas to room temperature. That warm gas then goes through the flow controllers, one for each lead. Flow is controlled based on mass flow and this mass flow is a pre-programed function of current in the magnet, 88slpm (0.24g/s) at no current and 112slpm (0.3G/S) at full 3770 amps. With the proper amount of flow, the heat load to the 4K system is minimized and the lead is protected from overheating.

1. Steady operations consist of keeping the helium level relatively constant. The superconducting level probe was raised in the reservoir during the summer SAD 2018, by 10 inches. Previously the magnet helium level was controlled based on LL8120DP because to get the level stable required filling past the top of the LL8120SC probe. This was due to needing to fill the recoolers from their exhaust port which is located high in the helium reservoir. The previous setting of the supply valve EV8111CD was 65% on LL8120DP and 72% on LL8120DP.
2. Another critical factor of operation of the Torus at 4K is to keep the pressure in the LHe Reservoir high enough to drive the lead flow. The lead flow returns through the warm return and its pressure can be seen read as PT8571 which is displayed on top of the Torus Helium screen near the center. To achieve full required lead flow we need to maintain the helium reservoir pressure PT8120 at minimum 0.1 atm above PT8571. This is done by the cold return valve PV8522TR based on its set value which should be about 1.35 atm or a bit higher (check PID sheet). Note that the higher PT8120 runs the warmer the coils will run because at higher pressure, helium has a higher boiling temperature.
3. There is a heater HTR8120 in the helium reservoir but it has not been needed. It is interlocked to not be allowed to turn on if the level in the tank is below 20% and this can be seen on the cool down interlocks page under cool down parameters button.
4. The lead flow control valves EV8121A and EV8121B should be enabled and their flow rate set point should be set by the PLC. Inlet valves will need to be opened and Fuse on SV8122 will need to be installed.
5. Heaters on the lead exhaust will need to be set up to control on a temperature on the lead. Enable and tune setpoints and PID loops for HTR8121A and HTR8121B.
6. Monitor Coil temperatures and check the system stability.
7. Look at Delta T’s from the CCM Cernox Temperatures displays. All should be less than or equal to 1K.

# Fast Dump Recovery – Liquid Helium in the TST and all Coils below 10K

**No specialized PID Group associated with this procedure**

After a fast dump we expect that one or more of the Super critical Helium relief valves has opened due to a pressure spike in that circuit. First, check to see which ones have opened. If they remain open, liquid air will be dripping off the metal surfaces and if they are not vented to the quench header there will be a plume of helium gas exiting from their exhaust port. Note: two of these reliefs, RV8112 and RV8114R are located on the top of the TST. Three more are come off the jumper pipes at coils B, D, F, RV811B, RV811D, and RV811F. Because the seals get very hard when exposed to Liquid helium the pressure of the circuit needs to be reduced to nearly one atmosphere to get them to reseat and seal. To do this one must limit the flow to the Torus. This will change the load on the ESR and so one should contact the cryogenics group or have the guard at ext 5822 contact their on call person. It is not necessary to wait for them to respond if they are not immediately available

The simplest way to reduce the pressure is to close PV8512T ( in the DBX), this should be done in 10% steps approximately 1 every 30 seconds

Once this is done one should put PV8522TR in manual mode and full open 100% (can be done in one step)

Then one can open EV8111BY fully to bleed off any gas leaking through PV8512T.

One should first start with hot air guns and attempt to warm the relief valves using them as there may be liquid Air (N2/O2) on the piping. IF: the person has proper training and after reading the Hot Work permit and with a fire extinguisher on hand and once the liquid air is gone one can switch to using propane torch to warm the leaking relief valves. Be careful not to burn any flammable wiring or materials.

Melt all ice covered surfaces on each leaking relief valve. It is not necessary to warm the inlet or exit lines more than a few inches from the relief.

Check to see if the flow has stopped by looking for recooling and listening for escaping gas. If there is no flow one can look to see if there is still liquid helium in the TST and look at coil temperatures

If there is liquid and or the coils are below 8K and with approval of ESR operators one can slowly repressurize the super critical helium circuit

Close EV8111BY

Leave EV8115JT in regulation mode

Start the recovery plot “2FastDumpRecovery1”

Watch PT8111 and PT8115 to see when the pressure starts to rise and watch TD8111 to see when it starts to change

Slowly open PV8512T 2% at a time. It may not move for the first few input changes then when the input get to ~10% it may jump open. If it does this then type in 8% and see if it stays slightly open by watching trends on the plots, continue to open slightly up to a maximum of 20% and watch PT8111 go up. TD8111 will go up quickly and may go over 40K but TD8111SC should stay below 10K as long as there is liquid on LL8120DP. Watch CTD672 to be sure that it stays below 8K.

Once TD8111 falls below 10K one can continue to open PV8512T in 5% steps to 40%. If all is good then open PV8512T in 10% steps to 100%

Finally put PV8522TR in Normal mode

# Quench Recovery– All coils below 100K and above 10K

**PID Group 11**

***Discussion:***

It is highly likely that if the magnet quenches some of the relief valves on the supercritical helium circuit will open. Priority should be given to re-seal those relief valves. Follow the procedure above but only to the point of warming the relief valves and assuring that there is no flow through them.

Cryogenic recovery from a quench should be done as soon as possible after sealing the relief valves and after checking the vacuum.

Repowering the magnet will not commence before understanding the cause of the quench and determining if additional controls or safety mechanisms need to be established.

The magnet will be in Cold return but will need to be switched to warm return. This will be rather simple since the flow to the magnet has been stopped to seal the relief valves. It is expected that PV8522TR will be closed or nearly so trying to keep the pressure up to its setpoint. If it is closed, then put in 0 for its Manual Mode request setpoint and put it in manual mode. Put PV8522TCD in Normal Mode controlling on pressure PT8120 (~1.4 atm).

Follow the procedure for 100-4K cooldown (PID Group 9) and then the procedure for Steady State 4K Operations (PID group 10)

If TD8111 is much warmer than the CCMA average temperature one can pre-cool the transfer line by opening EV8111BY to ~50% and closing EV8115JT to 20%. Note EV8111BY will pass much more flow than EV8115JT as it does not have ~700ft of ½” tube upstream of it so watch CFI6711B and keep this below 8 g/s. Once TD8111 drops below the CCMA average temperature flow should only go through the coils so as not to waste cooling power. Close EV8111BY and Open EV8115JT fully.

# Burping the Torus with the Solenoid (and Buffer Dewar) remaining at 4K (attempt;2 1 draft: 10/12/2020, tested 11/xx/2020)

**PID Group 11B**

***Discussion:***

**The Issue and a bit of History:** The CLAS 12 Torus has some sort of leak that causes a buildup of gas in the vacuum space. It could be an external air leak, but more likely is a small leak in the LN2 circuit within the vacuum space. The gas is cryo-pumped (freezes on 4 Kelvin surfaces of the magnet). Burping the Torus is a process of releasing frozen gas. If we do not burp the torus regularly the amount of frozen gas continues to increase and there is a concern that when the 4K portions magnet warm and release the frozen gas the vacuum could get so bad that the vacuum pumps can’t handle the load and possibly trip off and that the vacuum jacket would get cold and water vapor in the Hall would condense on the exterior surface of the Torus vacuum jacket. Cold water could then drip onto the detectors and might cause significant damage. This could happen during a planned burp or during an unplanned extended ESR outage. Since the initial cool down of the Torus, it has not remained at 4K for more than 6 months, except, for now (October 2020) as it has been 13 months since the last burp! To date we have not had such a large burp that the turbo pumps trip off. But this time the time has been more than double the previous durations, thus I expect a bigger pressure rise. Additional pumps should be installed at the upper turbo pump location just in case the main turbos can’t hold the outgassing load.

A burp of the Torus was attempted 1/2/2019 with the goal of keeping the Solenoid and Buffer Dewar cold and stable at 4K. When the Torus fully emptied the supply to the Hall Warmed and the solenoid then warmed. This could have been caused by two things.

1. The reduced flow to the Hall warmed more because the flow was less with constant transfer line heat load the temperature rose
2. The return gas from the Torus warmed and put its heat into the supply through the coaxial heat exchanger.

It probably was a combination of both of these. So the process will reduce the likelihood of either warming the supply or disturbing the Solenoid.

At the time of the previous attempt of this process the ESR was fully loaded and so we could not attempt to re-cool the full system so we shut off 4K to the full Hall. We found that the vacuum in both the supply and return U-tube to the solenoid were bad after we shut the flow to the Hall and this could have contributed or been the major cause of the failure to keep those cold during the burp. The other cause of the failure that I tried to fix real time was opening of the supply valve EV8611JT. I forced the EV8611JT\_Min and EV8611JT open to 85% but it was too late. I have updated the procedure below to try to maintain enough flow through the solenoid to keep the transfer line to the Hall stable and cold.

**Discussion:** If the Torus and Solenoid are not needed (~2 months or more) the Torus and Solenoid may be parked at 80K to reduce the load on the cryogenic system (use PID Group 13 procedure). If one wants to burp just the Torus, then this procedure may be followed. This procedure is written to allow the Torus to be burped quickly and then re-cooled back to 4K or to be burped and parked at 80K for some time. If we are just burping the Torus and cooling it right back down only the very first portion of this procedure will be used. Once the coils get above ~55K and burping has stopped cooling with 4K gas should commence. Using PID Group (?).

If parking at 80K is desired is critical to monitor the coil and hex beam temperatures so as not to create high stress levels due to differential thermal contraction. During cooling we used a variable METAL4K\_DT\_MAX as an interlock on the cooldown supply valves. In this case we will use it not as an interlock but as an alarm and an input parameter for the supply flow PID’s for keeping the magnet at a uniform temperature.

While “parked” at 80K, we flow clean helium from the 4 atm line from the ESR through the Torus. This keeps all portions of the Torus below 100K which is safe from a mechanical stress stand point. At this temperature frozen air gasses boil or sublimate and can be pumped out of the vacuum space and gas that leaks into the space does not freeze.

The clean helium comes from the ESR at 4 atm at room temperature so we must cool it and reduce the pressure. Cooling to 80K is done in the Hall B cryogenic distribution box, DBX, using two heat exchangers (HX8564 and HX8565) with liquid Nitrogen and its boil-off as the refrigerant. Besides keeping the magnet from warming above 100K this flow also keeps the primary (4K) circuits of the magnet at positive pressure to avoid contaminating them with air and allows keeping the U-tubes at ESR connected. BUT, to do so safely we must keep the pressure of the supply at a setpoint of 2.5 atm or lower. This then prevents back flow from the Hall into the ESR valve box or into the 500liter Buffer Dewar if the Torus 4K valve PV8512T were to leak. It also prevents 80K helium from entering the Solenoid 4K supply if PV8566S were to leak. The first part of the warm up must be done very slowly to keep the rate of vacuum rise and peak pressure minimized.

Burping and getting to 55K

1. Preparation
   1. Graph the following signals
      1. Torus Vacuums - CG8102, CG8103, TC8102, TC8103, CG8100, TB8100 and TB8101
      2. Torus and DBX Temperatures – CCM\_T\_AVG, METAL4K\_DT\_MAX, TD8111, TD8115, TD8120, TP8523, TD8512
      3. Torus and DBX Pressures – PT8565, PT8111, PT8115, PT8120, PT8512, PT8513S
      4. Torus Nitrogen – LL8152CP, SHLD\_T\_MAX, TP8152
      5. Other - HTR8120, PV8522TCD, PV8522TR, EV8115JT, EV8111CD, LL8120DP
      6. N2 Reservoir in the DBX – LL8554CP, LL8554DP, PT8554, TP8564, TP8567, EV8553, TP8555
      7. ESR signals – CEV6711B.ORBV, CEV6721B.ORBV, CTD672, CTD8521 CFI6711B
      8. Buffer Dewar – LL8210, TD8211, TD8210, PI8210, EV8210.ORBV
      9. Solenoid- TR8610, EV8611\_Min.ORBV, EV8611.ORBV, TD8522SR, PV8533SR
   2. Set up one main plot that has the most critical signals and will be the one that the operator must look at the most to see that all is well
      1. CCM\_T\_AVG, TD8522SR, TD8512, TB8100, PT8513S, PT8120, CFI6711B
2. Verify MB8561 and MV8561V are closed. Check the status on MV8002 and all other manual valves on the warm gas header (to target or purges), unless needed all flow paths should be closed. Verify that MV8561 and MV8562 and MV8561V (at the railing behind the DBX) are all closed and look at the pressure PT8561. It should be between 1.1 and 2 atm. IF below 1.1 do not proceed as the line may be contaminated with air, If above 2.0 contact an expert to review the system.
3. Verify that the cryogenic group operator has put the Hall B warm return flow to the purifiers so that any contamination stored in the piping gets adsorbed in the purifiers rather than being dumped back into the ESR cold box and have them open the 4 atm helium supply valve MV6010B
4. Verify PV8563C and PV8563W are closed.
5. Turn off EPICS Alarms on LL8120DP, LL8120SC, PT8115, and PT8111: change “MAJOR” to “NO\_ALARM”
6. Change the manual setpoint of PV8512S from 60 to 100. This may start a rattling noise in the DBX. Send someone down into the Hall to listen for it. The reason we did this is so as not to lose supply pressure when the solenoid starts to demand more flow. After everything is stable we may want to see if we can stop the rattle, if it is rattling one should try to see if the rattling can be stopped by somewhat throttling this valve without dropping PT8513S much below 2.6 atm.
   1. Note 2020/11/05: The expected rattle did not occur. DK was in-hall to listen, and as the value was stepped to 75, then 100, the rattle did not occur.
7. Change the Following on EV8611JT\_Min
   1. PV Setpoint 7.1 to 6.4
   2. Max Value from 67 to 100
   3. Sample Time 10 to 5 sec
   4. I- Gain -0.06 to -0.12
8. Change the following on the PID for EV8611JT
   1. Max Value from 75 to 100
   2. Sample time from 20 to 5 seconds
   3. I-Gain from 0.028 to 0.12
9. Wait for the Solenoid to get stable at the new parameters and for the Hall Flow to increase .The total flow to Hall CFI6711B it should increase about 5 g/s (From 11 to about 16g/s – note these numbers may not be accurate depending on the status of Hall A cryogenic system!)
10. Now is the time to start switching the Torus return flow from cold return (4.5k return) to the cooldown line.
11. First check that the control valve PV8522TCD has a setpoint of 1.5 atm. Set the maximum position of PV8522TR to ~5 % below its current position. The pressure in the Torus PI8120 should start to rise. When it stabilizes at a new value (higher than the setpoint of PV8522TR) then lower Maximum position again this time by 10%, the goal is to get PV8522TCD to open and get PV8522TR closed. When flow is going through PV8522TCD the pressure will be at the setpoint (1.5 atm) and temperature sensor TP8523 will start dropping. (Note this is a platinum thermometer so it will stop reading when it gets to approximately 30K it will jump to 0K this is not a problem.
12. Continue to step down PV8522TR now in 15% steps every minute or two until it is full closed.
13. Change set point to zero first, then put pv8522tr into manual mode.
    1. Once the PV8522TR valve is locked closed in manual mode, and if PV8522TCD is chattering with high frequency, the gains of PV8522TCD can be changed as follows: I-Gain = -30.000, P-Gain = -2.000
14. Reduce the setpoint of PV8522TCD from 1.5 to 1.2 atm in steps of 0.1 atm every 1minute or so.
15. Slowly close PV8512T to stop 4K supply flow to the Torus
    1. It is in manual mode, lower set-point in steps: 10% steps until PV8513T reaches 2.7atm, then continue to reduce in 5% steps
    2. Watch the pressure PT8513T down stream of this PV8512T
    3. Also watch that the supply and return of the solenoid remain somewhat constant in temperature TD8610 and TD8522SR
16. Watch the supply valve of the solenoid and Buffer and their liquid levels
17. The Torus helium level should start to drop

Warming:

1. Turn on HTR8120 to 100% in manual mode. When the level drops to 10% it will shut off automatically on its interlock, once it is off then put the heater in manual at 0%
2. Even before all the liquid boils off (LL8120SC) the Torus average coil temperature will start to rise CCM\_T\_AVG. About 7 hours later the vacuum should start to climb. It should recover but a second and bigger pressure rise should come approximately 22 hours after CCM\_T\_AVG started to rise. With a peak a 2-3 hours later.
3. Notes: During burp of 2020/11/05, CCM\_T\_AVG reached ~26K; Torus nitrogen temp of coil ccme (TP815ER) spiked when CCM\_T\_AVG reached ~20K (Peaked at ~160), Caused SHLDOUT\_T\_MAX to alarm. TP815ER remained elevated for ~75 minutes, then suddenly and quickly returned to ~80K.
4. This occurred in the 2019/05 attempt as well; two spikes spaced ~44 minutes apart, occurring when CCM\_T\_AVG reached ~26K.
5. Notes: During burp of 2020/11/05, CCM\_T\_AVG ~50K; degraded vacuum strained the system, and an additional pump was plumbed into the upper vacuum system. Recovery went \_\_\_\_ afterwards.
6. Re-cooling could commence ~36 hours after the CCM\_T\_AVG started to rise (CCM\_T\_AVG should get to at minimum 54K to assure full removal of the frozen gas)
7. It is critical that the pumps be monitored and alarms go to the ON Call if either or both Turbo pumps trip off.

NEXT Step is to recool the Torus to 4K

UNREVIEWED, UNTESTED DRAFT

1. Ideally one will wait until TC8103 has a vacuum level of .0013 Torr (or better) or CG8103 has a vacuum level of 1.8E10–5 Torr. (vacuum similar to prior to the start of the burp) This is approximately 3 days, without 80K gas warming the Torus.
2. If it is critical to get back online for physics, it is recommended to not proceed until TC8103 is below 5E10-3 Torr.
3. Now that we have achieved the appropriate vacuum level for this situation, we will add cold (4K) flow through the Torus.
4. At the time of the writing of this, we believe that all PID’s are set for nominal 4K operational mode.
5. Verify PV8566T is closed. Verify that PV8522TCD is open or controlling, and PV8522TR is closed, and in Manual Mode.
6. Put EV8111CD Manual Mode, at 0%; & EV8115JT Manual Mode, at 40%
7. Open EV8111BY to 100%
8. Manual Mode open PV8512T to 15%
9. Watch pressure in Torus lead reservoir PT8120. If above 1.5 atm, lower the position of PV8512T.
10. Manually open PV8512T in 5% steps, to a maximum of 25%, waiting several minutes in between steps. Watch inlet temp to Torus TD8111,
11. Once TD81111 is below 80K, slowly
12. Put EV8111CD & EV8115JT into Normal Mode, and close EV8111BY, in 5% steps to 0.
13. Once the Torus vacuum has recovered (~1E-3 on TC8103 ) then one can either continue warming to 80K following the procedure below or start cooling the magnet back to 4K
14. **To continue warming to 80K follow the steps below.**
15. Verify that 4K supply valve in the DBX PV8512T at 0% in manual mode
16. Verify that PV8563W is closed and shut off its air supply
17. Verify that PV8563C is closed and its air supply is on.
18. Enable Cooldown Alarms METAL4K\_T\_MAX at 100 Major and METAL4K\_DT\_MAX at 40 Major
19. Enable TD8111 Alarm at 90K Major
20. Put EV8111BY in manual at 60% to bypass flow through the coils and to allow supply temperature from the DBX through the LN2 Heat Exchangers to get the Helium temperature down.
21. Put EV8115JT in manual mode at 30%
22. PV8556T manual at 20%
23. Put EV8111CD in manual mode at 0%
24. Check PT8561 and PI8561 local to assure they are positive pressure. If they are then the system has been kept clean positive pressure helium since last used. Open the warm helium supply valves MV8002, MV8561 and MV8562
25. Reset CD interlock on PV8563C/W
26. Close the manual valves on lead flow lines MV8121A and MV8121B and disconnect the lead flow control cables and Pull fuse on SV8122.
27. Setup PV8563C\_Max PID with PT8565 is its control parameter and a set value of 2.5 atm set up gains as in the PID group. Setup PV8563 with its control parameter FI8561 at 5g/s. Make the Max position 10 and Min position 0 to start and put both in Normal mode
28. Open the variable temperature supply valve in the DBX PV8566T to 20% and watch the plots.
29. Increase the max of PV8563C to get the pressure up to 2.5 atm to 100%
30. Once the temperature TD8111 is below 90K then proceed
31. Open EV8115JT to 100% in steps while closing EV8111BY in steps at the same time.
32. Open EV8111CD to ~20%, Watch the pressure PT8111, if it drops below 2.3 atm then throttle EV8111CD.
33. Next step is to close down on the bypass valve EV8111BY in 10% steps watching PI8111 and PT8120. Continue till EV8111BY is closed.
34. Check the flow on the flow meter on the wall of the Hall FI8525 it should match FI8561
35. Open EV8115JT to 100%
36. One will know when the recoolers are empty when all the coil inlet and exit temperatures are climbing above 8K. After all the liquid has been boiled from the magnet one can slowly open PV8566T to increase the pressure at PT8111 to ~ 2.5 and then fully open PV8566T
37. Now the focus will be on EV8115JT and EV8111CD and getting the flows stable and the magnet warming. Setup the PID for EV8111CD per the PID sheet. 1.5 g/s should be fine as a setpoint.
38. Once the magnet is ~80-100K we will need to make sure that the hex beams and CCM’s are between 80 and 110K and the temperatures differences between them METAL4K\_DT\_MAX stays less than 30K. Adjust the flows through EV8115JT and EV8111CD to achieve this.
39. Set up on-call alarms on these parameters.
    1. Vacuum on magnet and Turbo speed
    2. CCM\_T\_AVG 120K, METAL4K\_T\_MAX at 100K and METAL4K\_DT\_MAX at 40K both major
    3. TD8111 at 110K HIHI Major

# Parking the Torus at 80K (partial of this is just a Burp to 50K) and keeping the Solenoid and Buffer Dewar cold – August 22, 2023

**PID Group 11C**

***Discussion:***

A burp of the Torus was done on Aug 22-24. The recovery was done on ????? This burp was done approximately 2.3 years after the last one and the effect on the Torus Vacuum and LN2 shields were worse than any that I, D. Kashy recall. But:

We successfully brought the magnet to 80K with the Solenoid and Buffer dewar remaining cold, full and stable through the entire warm up process. This is not to say that there were no challenges. Several things we done in advance to try to minimize upsets and issues.

1. A additional Blower system was attached where the primary blower was installed. This was very helpful because of the event below.
   1. The automatic valve for the primary blower (on level 3 PV8105B) did not open, when the turbo gate valves closed on rising pressure (~38K on CCM\_T\_AVG) the techs involved in the warm up opened up this blower to slow the pressure rise.
   2. We were able to manually open the PV8105 also
2. Prior to the start of the warm up we added a second backing pump to the lower turbo system and that kept the backing pressure on the lower turbo lower much lower than on the upper turbo. It is not clear what the peak pressures.
3. We should have added a second backing pump to the upper turbo before the warm up but did so later in the process (after both gate valves tripped) and this reduced the backing pressure from 1.6 torr to less than .2 Torr and let the turbo TB8100 quickly ramp to full speed!

There were two burps a small one started when CCM\_T\_AVG hit 22K and the vacuum peaked at 0.03 torr on TC8103 8 hours after the coils started to warm this quickly recovered and the coils continued to warm. The second started when the coils hit 38K (22 hrs after starting the warm up) and this peake at 24 hrs after the warm up start at 0.5 torr. This large vacuum rise cause the coils to quicly warm to 80K it also drove out all the LN2 from the shields and the shield LN2 reservoir in the Torus and LL8152CP went to 0 for 5.5 hrs. The shield outlet temperatures rose to 150K. They recoverd by midnight on August 23, 2023 or 11 hrs after the LN2 reservoir emptied.

In the early steps of the warm up we made some changes to the procedure and all were simplifications and worked very well and it is not expected that any changes or improvements are needed at the next burp.

Previous Burps

A burp of the Torus was attempted 1/2/2019 with the goal of keeping the Solenoid and Buffer Dewar still flowing. When the Torus fully emptied the supply to the Hall Warmed and the solenoid then warmed. We could not go to warm return because Cryo had to reduce load. The vacuum in both the supply and return U-tube to the solenoid were found to bad after we shut the flow to the Hall and this could have contributed or been the major cause of the failure to keep those cold during the burp. The other cause of the failure that I tried to fix real time was opening of the supply valve EV8611JT. I forced the EV8611JT\_Min and EV8611JT open to 85% but it was too late. I have put the changes into the procedure below.

Watch the vacuum in both magnets but especially the Torus. During previous Torus Burping we have seen two major burps, one at ~12 hrs after stopping flow and the second ~12 hours later. In the past we have seen vacuum burps peak at CCM\_T\_AVG at ~22 and 40K (May 10&11/2018 TC8104RP peaked at 0.26 and 0.46 torr, and TC8103 peaked at .009 and .018 torr, and on Jan 2&3/ 2019 TC8104RP peaked at 0.5 and 1 torr and TC8103 peaked at 0.02 and 0.04 torr (and TC8101 maxed at 0.93Torr)

**Other reasons to warm the Torus**

When long term operation is not needed (~2 months or more) the Torus may be parked at 80K to reduce the load on the cryogenic system. If one wants to burp the Torus, then this procedure may be followed. During this time it is critical to monitor the coil and hex beam temperatures so as not to create high stress levels. During cooling we used a variable METAL4K\_DT\_MAX as an interlock on the cooldown supply valves. In this case we will use it not as an interlock but as an alarm and an input parameter for the supply flow PID’s for keeping the magnet at a uniform temperature. Because we will be flowing clean helium from ESR through the primary circuits of the magnet we will keep the Torus at positive pressure and should be able to keep all U-tubes at ESR connected. We will keep the pressure of the supply at a setpoint of 2.5 atm to avoid having a higher pressure in the 4K Supercritical Circuit than at the ESR to avoid possibly back flowing into the ESR or Halls A and C or the Buffer Dewar or Solenoid. The first part of the warm up must be done very slowly to keep the vacuum rise to a minimum.

1. Verify that 3 additional pumps are installed and have good ultimate vacuums
   1. A second blower on a 4” line in parallel with roots pump 8105
   2. A small blower (ACP28) in parallel with both the upper turbo backing pump and the lower turbo backing pump. – ***NOTE: If the original backing pumps are replaced by the blower type roughing pumps maybe we don’t need to have both…***
   3. Put turbo pump(s) on the Solenoid helium supply and return lines and get them pumping to assure the vacuum stays good during this operation.
2. Set up graphs of the following signals
   1. Distribution Box Signals – TD8512, Pt8512, HTR8120, PV8522TR, PV8522TCD,
   2. N2 Reservoir in the DBX – LL8554CP, LL8554DP, PT8554, TP8564, TP8567, EV8553, TP8555
   3. Torus Vacuums and Coil avg temp –CCM\_T\_AVG, CG8102, CG8103, TC8102, TC8103, CG8100, TC8104RP, PV8100, PV8101, TC8101
   4. Torus Temperatures – CCM\_T\_AVG, METAL4K\_DT\_MAX, TD8111, TD8115, TD8120, TP8523
   5. Torus Helium Controls– PT8565, PT8111, PT8115, PT8120, LL8120SC, LL8120DP, EV8115JT, EV8111CD,
   6. Torus Nitrogen – LL8152CP, SHLD\_T\_MAX, TP8152
   7. ESR signals – CEV6711B.ORBV, CEV6721B.ORBV, CTD672, CTD8521 CFI6711B
   8. Buffer Dewar – LL8210, TD8211, TD8210, PI8210, EV8210.ORBV
   9. Solenoid- TR8610, EV8611\_Min.ORBV, EV8611.ORBV, LL8620SC, LL8670SC
3. Verify that the cryogenic group operator has put the Hall B warm return flow to the purifiers so that any contamination stored in the piping gets adsorbed in the purifiers rather than being dumped back into the ESR cold box and open the 4 atm helium supply valve MV6010B
4. Turn off EPICS Alarms on LL8120DP, LL8120SC and PT8115
5. Change the Max value of EV8611JT\_Min from 67 to 85
6. Change the Max value of EV8611JT from 75 to 85
7. Change the position of PV8512S from 60 to 100 in Manual mode
8. Slowly close PV8512T to stop 4K supply flow to the Torus (watch the pressure down stream of this valve PT8513Tand the total flow to Hall CFI6721B)
9. Change PV8522TR min from 2 to 0%
10. Change setpoint of PV8522TR from 1.35 to 1.45 atm
11. Change setpoint of PV8522TCD from 1.5 to 1.3atm
12. Wait until PV8522TR is fully closed then proceed
13. Slowly close the Supply valve to the torus in the DBX PV8512 from 100% to 0 in 20% steps and watch the pressure at PT8513T to see it slowly drop when it starts to drop at about 60% or 40% then make changes of 10% until you get to 30% and finish with 5% steps to 0%
14. Watch the supply valve of the solenoid and Buffer and their liquid levels
15. Turn on HTR8120 to 100%. When the level drops to 10% it will shut off automatically on its interlock, once it is off then put the heater in manual at 0%

*NOTE: the portion above worked well and neither the Solenoid or the Buffer Dewar had any significant bumps and remain cold and full to this point. 8/22/2023*

1. Torus will be warming slowly for ~24-48 hrs. When it reaches ~22, it will recover as the stuff that is vaporizing from the cold surfaces gets pumped out. When the magnet reaches ~38K on CCM\_T\_AVG the big outgassing event will strat. This happened this time 8/23/23 at about 22 hrs after warmup began. The vacuum peaked at 0.48 torr. This is much worse than all other burps and we should not wait more than 18 months between burps if at all possible and 24 months should be an absolute maximum.

It is critical that the pumps be monitored and alarms go to the ON Call if either or both Turbo pumps trip off. Watch the vacuum in both magnets but especially the Torus. During previous Torus Burping we have seen two major burps, one at ~12 hrs after stopping flow and the second ~12 hours later. In the past we have seen vacuum burps peak at CCM\_T\_AVG at ~22 and 40K (May 10&11/2018 TC8104RP peaked at 0.26 and 0.46 torr, and TC8103 peaked at .009 and .018 torr, and on Jan 2&3/ 2019 TC8104RP peaked at 0.5 and 1 torr and TC8103 peaked at 0.02 and 0.04 torr (and TC8101 maxed at 0.93Torr)

1. Once the Torus vacuum has recovered (~1E-3 on TC8103 ) then one can either continue warming to 80K following the procedure below or start cooling the magnet back to 4K
2. **To continue warming to 80K follow the steps below. (these are as written the past they should work but may be able to be optimized. This optimization takes years since we only burp the magnet very infrequently and they have not verified or updated yet during burp 8/22-24/2023 DHK)**
3. Verify that 4K supply valve in the DBX PV8512T at 0% in manual mode
4. Verify that PV8563W is closed and shut off its air supply
5. Verify that PV8563C is closed and its air supply is on.
6. Enable Cooldown Alarms METAL4K\_T\_MAX at 100 Major and METAL4K\_DT\_MAX at 40 Major
7. Enable TD8111 Alarm at 90K Major
8. Put EV8111BY in manual at 60% to bypass flow through the coils and to allow supply temperature from the DBX through the LN2 Heat Exchangers to get the Helium temperature down.
9. Put EV8115JT in manual mode at 30%
10. PV8556T manual at 20%
11. Put EV8111CD in manual mode at 0%
12. Check PT8561 and PI8561 local to assure they are positive pressure. If they are then the system has been kept clean positive pressure helium since last used. Open the warm helium supply valves MV8002, MV8561 and MV8562
13. Reset CD interlock on PV8563C/W
14. Close the manual valves on lead flow lines MV8121A and MV8121B and disconnect the lead flow control cables and Pull fuse on SV8122.
15. Setup PV8563C\_Max PID with PT8565 is its control parameter and a set value of 2.5 atm set up gains as in the PID group. Setup PV8563 with its control parameter FI8561 at 5g/s. Make the Max position 10 and Min position 0 to start and put both in Normal mode
16. Open the variable temperature supply valve in the DBX PV8566T to 20% and watch the plots.
17. Increase the max of PV8563C to get the pressure up to 2.5 atm to 100%
18. Once the temperature TD8111 is below 90K then proceed
19. Open EV8115JT to 100% in steps while closing EV8111BY in steps at the same time.
20. Open EV8111CD to ~20%, Watch the pressure PT8111, if it drops below 2.3 atm then throttle EV8111CD.
21. Next step is to close down on the bypass valve EV8111BY in 10% steps watching PI8111 and PT8120. Continue till EV8111BY is closed.
22. Check the flow on the flow meter on the wall of the Hall FI8525 it should match FI8561
23. Open EV8115JT to 100%
24. One will know when the recoolers are empty when all the coil inlet and exit temperatures are climbing above 8K. After all the liquid has been boiled from the magnet one can slowly open PV8566T to increase the pressure at PT8111 to ~ 2.5 and then fully open PV8566T
25. Now the focus will be on EV8115JT and EV8111CD and getting the flows stable and the magnet warming. Setup the PID for EV8111CD per the PID sheet. 1.5 g/s should be fine as a setpoint.
26. Once the magnet is ~80-100K we will need to make sure that the hex beams and CCM’s are between 80 and 110K and the temperatures differences between them METAL4K\_DT\_MAX stays less than 30K. Adjust the flows through EV8115JT and EV8111CD to achieve this.
27. Set up on-call alarms on these parameters.
    1. Vacuum on magnet and Turbo speed
    2. CCM\_T\_AVG 120K, METAL4K\_T\_MAX at 100K and METAL4K\_DT\_MAX at 40K both major
    3. TD8111 at 110K HIHI Major

# Un-Parking the Torus and Solenoid and Buffer Dewar – Cooling from 80K to 4.5K (Needs work and verification as of Jan 2/2019)

**PID Group 12**

***Discussion:***

This section was re-written for all 3 main loads parked at 80K in July 2018 for recovery after the Scheduled Accelerator Down (SAD) summer 2018. Depending on the capacity at ESR and Recovery system the cooling rate may be limited to different numbers by throttling the supply valve EV6711B by the cyro folks.

Possible Initial conditions: (updated to January 2019)

Torus and Solenoid are between 40K and 90K and The dewar must be emptied during the 80K park or the relief valves will blow during cooldown. All this depends on how long the 4K supply was off and if these items are receiving 80K LN2 (cooled Helium).

In the January 2019 case the Torus was being supplied with 80K helium while the Solenoid had only warmed to about 60K and the Dewar had liquid helium still in it.

For each possible set of conditions one must think ahead to avoid problems like warming or over pressurizing.

In general we don’t want to:

1. Warm Torus or Solenoid Coils
2. Warm Torus Hex Beams

At the beginning of this process we will cool down the Transfer line and DBX as well as the 4k supply U-tube at ESR (magnet buffer and dewar U-tubes).

To avoid warming coils significantly in the beginning, we start with Torus the EV8111BY taking most of the flow with just a tiny bit going through EV8115JT to allow TD8111 to see cold flow and thus be relevant until it reads below 30K.

To avoid warming the coils in the solenoid all flow will go through EV8611JT until the supply temperature at TR8610 is below 10K.

The Buffer dewar must be emptied in advance and will want to get a minimum flow through it farily early in the 4K cooldown to keep its U-tubes from warming much above 80K

The procedure below should address all the above concerns.

Prior to the start the system is “parked”. This should mean that the Dewar and the Torus have 80K flow and that their inlet and outlet are at or below 100K.

The helium supply path in the DBX is PV8563C to the LN2 heat exchangers to the cool down line in the DBX. If the Buffer Dewar has 80K flow, it is coming from both PV8512T and PV8566T which are open at the same time. Review the status of flow to each load and compare to the next few lines below.

In the Torus EV8111BY is closed and in manual mode. EV8115JT is 100% in manual and EV8111CD is in Normal mode with PID’s set up from Torus Group 11. The return valves for the Torus (PV8522TR and TCD) are both in manual at 100% to assure flow path for both the Torus and Buffer Dewar.

The Buffer Dewar has its EV8210 and EV8210BP controlling per PID group 13 in the Torus

IF the Solenoid is flowing, it has its supply valve PV8566S throttled in manual mode at 70%, the EV8611JT in Normal mode per PID group 11, and Cooldown valve EV8611CD closed per PID Group S5

NOTES:

1. During this phase the system insulating vacuums were pumped.
2. Cooldown rate below 100K is not limited by either mechanical stress (differential temperature) or time rate of change (DT/dt) but only by flow capacity of the recovery system or flow capacity of the cold box. The flow of the cold box should be limited by the ESR guys, but fast transients on our end could cause a problem for the refrigerator. So make small changes and watch the effect to see how your change ripples through the system.
3. Experience shows that throttling the flow at ESR (Via CEV6711B) makes the system most stable. Keeping PT8512 below 2.7atm during most of this process is a good way to go. To do this we must keep the supply valves open enough that the pressure drops. If PT8512 drops below 1.8 then it is likely one of the systems is taking too much flow.
4. Make log book entries in CLOG, and HBTORUS and HBSOLENOID logbooks and make distribution to [esr-users@jlab.org](mailto:esr-users@jlab.org) several times through the process
5. The transfer line (ESMTL- End Station Magnet Transfer Line) from ESR to Hall B should have LN2 flowing so most of the piping in it should be below 100K and once flow from the ESR valve box starts, temperatures in lines going into and out of the DBX on the supply circuit should quickly drop to near 80K. These will likely oscillate as bunches of hot gas get purged out of the system.
6. The goal for the Buffer Dewar will be a very slow cooldown so that it reaches 4K at about the same time as the magnets. This will allow all systems to build liquid at the same time and to put on cold return together. Since the mass of the Dewar is very small it will cool quickly so just a small trickle flow will be needed until the Torus magnet is below ~20K. *NOTE: If it has liquid in it then it probably will not get any flow until we get both magnets below 10-15K*.
7. The goal for the Solenoid will be to cool the cold mass and the lead reservoir with focus on the cold mass at first but as the Torus starts to collect liquid in its lead reservoir (LL8120SC) then the focus should switch to filling the Solenoid lead reservoir at LL8620SC at the same time, so that the both have liquid along with the buffer dewar having liquid, and all the return sensors in the DBX are below or well below 10K to allow going to cold return at ESR.
8. Check All PID’s for the current operating condition against the PID sheet and start a new one if there are differences.
9. THE New live plot function comes up in auto scale which continuously updates the scale to plot each signal full scale across the time region. This makes what might be small changes to the system and part of normal control look like things are going bad so make sure you look at the scales and you may want to make some scales manual, especially things that don’t change a lot like: valve positions, pressures, cooling rates, flow rates, the temperature may work too but may need to have ranges changed…

Things Highlighted in Yellow are updates from the August version of this document.

1. Contact Cryo 1-2 days before cooldown to verify capacity and an early in the daytime start.
2. Start Plots:
   1. **Torus:** CFI6711B, CPI8511, CEV6721B.ORBV, CEV6711B.ORBV, EV8111CD.ORBV TD8512, PT8512, PT8111, TD8111, TD8513T, PT8120, CCM\_T\_AVG (plot saved as “80Kto 4.5K un parking” under Torus/dinsley Note, verify that all signals are present
   2. **Solenoid:** CFI6711B, TD8513S, TR8610, EV8611JT.ORBV, EV8611CD.ORBV, PT8620, PT8670, TR8611, TR8670, COIL\_T\_AVG, COIL\_DT\_Dt30 (plot saved as “80Kto 4.5K unpark 3” in the Torus directory. Note, it may not have all the correct signals and you may need to add some)
   3. **DBX Cold Return Temps & liquid levels in the reservoirs**: TD8522DR, TD8522SR, TD8522TR, LL8210, LL8120SC, LL8120DP, LL8620SC, LL8620DP, LL8670SC, LL8670DP. (plot saved as “80Kto 4.5K unpark 4” in the Torus directory. Note, it may not have all the correct signals and you may need to add some)
   4. **Buffer Dewar:** CFI6711B, PT8512, TD8210, TD8211, PI8210, TD8522DR, EV8210.ORBV (plot saved as “80Kto 4.5K unpark 2” in the Torus directory. Note, it may not have all the correct signals and you may need to add some)

Verify “Comms” to ensure that all sensors are being read correctly by the controls.

1. Main-menu > Torus > Comms (red is bad. Try reset. Call Magnet group if additional help is needed)

**Hardware Preparation:**

1. Stop the pumping on the U-tubes and remove the CVI actuators. This will allow early detection of vacuums going bad due to poorly sealing CVI valves.
2. Prepare Solenoid vaporizer for additional flow (space-frame, level 3, beam left):
   1. All Fans are running on HX867
   2. All 3 flow meters FI8678A,B,C are valved in
   3. MV8678BY is also open to minimize pressure drop in the return line from the solenoid. these are all located on level 3 of the space frame beam left side.
3. Shut off 300k supply (space-frame, level 3, behind the DBX):
   1. Close MV8561 and watch PI8561 (a local gage) and PT8561 drop down to about 1.1-1.2 atm (1.5-3.0 psig).
   2. Once the pressures on PI/PT8561 get down below 1.3 atm close MV8562
   3. Then close PV8563C in manual mode. The pressures PT8563 and PT8565 should be or will drop to ~1.1 or 1.2 atm
4. Verify/inspect:
   1. Magnet gages are effective, & turbos are running
   2. U-tubes & ESR transfer line for sweat, especially those flowing 80k He
5. Verify the 4K supply and return U-tubes at ESR are installed
6. Verify EV6711B and EV6721B the cold supply and return valves are closed ( visible from the Buffer Dewar screen or the Accelerator Menu)
7. Set up PID’s of the following valves per PID Group 12a of the Torus (YES! This group now includes Torus, Solenoid and Buffer Dewar and make sure all cascades of these loops are also set up!)
   1. EV8115JT
   2. EV8111CD
   3. EV8111BY
   4. EV8611JT
   5. EV8611CD
   6. EV8210
   7. EV8210BP
8. PV8522TR:
   1. @10%, TCD@100%, SR @0% and SCD@100% should all be in Manual mode.
   2. Other PID parameters: Verify (Do not change) them from Torus PID Group 12.
   3. IF the Buffer dewar pressure builds and is not venting then PV8522TR manual set value should be increased to 15% or slightly higher.
   4. Having PV8522TR too open seems to allow an oscillation of many signals most importantly TD8512.

Return path established, now set up the supply path

1. Put HTR8120, HTR8620 and HTR8672 in Manual mode at 0.0
2. Close EV8210 in manual mode at -20%

Close 80k supply to the magnets:

1. Close PV8566T and PV8566S in manual mode at 0%
2. Set up 4k flow to the magnets:
   1. Open PV8512T to 60% in manual mode
   2. Open PV8512S to 80% in manual mode

Set up 4k path to both magnets:

Here, we focus flow path through the reservoirs, bypassing the coils.

Sending this initial flow through the coils would warm the magnets.

1. Close EV8111CD in manual mode at 0%
2. Close EV8611CD and EV8612 in manual mode at 0%
3. Open EV8111BY and in manual mode to 100%
4. Open EV8115JT to 85% in Manual mode
5. Put EV8611JT in PID mode. It should go full open and only start to throttle when the return in the DBX TR8522SR gets cold.
6. Change setpoints for PV8522TCD and PV8522SCD to 1.01 atm and then put them in Normal mode, which should keep them full open.
7. Change Min on PV8522TR and PV8522TCD to 20% (gives a path to vent the dewar and also to back flow the TL so it does not go subatmospheric while the outer pipe cools)

**First we cool the Transferline and U-tubes to the magnets by flowing 4.5k to both the Torus and Solenoid but not the Buffer Dewar**

1. Contact cryo:
   1. Verify that EV6711B is set to 2g/s on CFI6711B and that the PID is tuned for flow. ST=20sec, Gp=15, Gi=0.25, max 45 min -20. (Normal PID control of this valve is Input=CPI671, ST=5, Gp=-75, Gi=-1, Min and Max??)
   2. Have them slowly open the supply valve EV6711B.
   3. Tell them that we want a significant pressure drop across their valve EV6711B (0.3 to 1atm) so that warm parts of our piping does not cause a reverse flow into their cold box, they do not have a pressure signal to see this. We want to see PT8512 stay below 2.5 atm.
   4. We may or may not be able to take the full 2 g/s before TD8513T and TD8513S get cold so we may want to have cryo lower their setpoint to 1 or 1.5g/s. If we can then we could have them raise the flow setpoint to 3 or 4g/s.
   5. Notes 2021/04/15 11: ESR is stepping up EV6711B slowly. At 10% we started to see pressure increase in our system, indicating that there is actually flow to Hall B.
2. Watch:
   1. TD8512, TD8513T and TD8513S for a quick drop in temperature, followed by TR8610 and TD8111.
   2. These will oscillate up and down between 40 and 80K for about 20-30 minutes.
3. Condition Action:
   1. With the EV8111BY and EV8115JT full open &
   2. When TD8111 < 30K and PT8111 (should be) < 2.0 atm:
   3. Change the Manual setpoint of EV8115JT\_Max to 100.
   4. Put EV8115JT in PID mode. It should open to 100%. Later it will allow the valve to throttle when the reservoir LL8120SC gets full.

**Now we get the recoolers involved in cooling the Torus**

Max and other values may need to be adjusted to get a nice balance between Torus and Solenoid Cooing rates once Solenoid is in major cooldown mode.

1. Put EV8111CD in Normal mode
2. Wait for it to open to its min position
3. Close EV8111BY slowly (something like 100%, 90%, 75%, 50%, 30%, 0% every minute or two)
   1. As we are closing EV8111BY watch the pressure PT8111.
   2. EV8111CD should automatically start to open as the pressure PT8111 goes up and gets to or above 2.6atm.
   3. Continue to close EV8111BY making sure that EV8111CD is keeping PT8111 stable at 2.6. If the pressure is not rising then go to the next step.
4. Call cryo and ask them to slowly increase the flow setpoint to 6g/s if all is stable and they have the capacity.
5. Toward the end of the cooldown, when CCM\_T\_AVG is below 5K, increase the setpoint of EV8111CD\_Max to 2.3 atm, slowly lower EV8115JT\_Max to 65 % to build pressure at PT8115
6. Then compare PT8513T and PT8512 if they are nearly the same then open PV8512T in Manual to 100

**Next we focus more on the Solenoid.**

1. Once the Solenoid is stable in its flow controls get the dewar flowing.
2. Continue flowing through the Solenoid lead reservoir. This is done at first through EV8611JT but after TR8610 is below 20K most of the flow should go through PV8611CD to cool the cold mass. EV8611JT should automatically throttle to ~30% to get a trickle flow to the lead reservoir based on the return temp TD8522SR. We may want to limit the Max of EV8611JT but if the PID is working well that is probably not needed.
3. After TD8522SR gets below 60K, one should put EV8611JT in Manual mode at 40% (The PID settings of EV8611JT and JT\_Min to Standard operating values from Solenoid PID Group S3)
4. Put all EV8611CD in Normal mode. Use the starting values in the PID sheet for each loops settings. But over the course of the cooldown, the following settings should be adjusted to maintain stability of the system and to adjust the relative cooling rates These changes can and should be made every 2-6 hours as needed.
   1. Max of the EV8611\_Max\_Max loop (range 25-32)
   2. Setpoint DP8670VCLDP of EV8611CD\_Max (range 0.12 to 0.2)
   3. Setpoint COIL\_DT\_DT30 of EV8611CD (range -2 to -5)
5. PV8512S can now be put at its usual 4K operating position of 60%.
6. Note IF PT8571 is higher than 1.25 atm check with cryo to see what the recovery pressure is and that it is as low as they can run with.
7. If necessary one can ask for more flow up to 8g/s, but for overnight cooling 6 g/s should be enough to make good progress.

**Now we focus on the Buffer Dewar.**

Prerequisites:

* Buffer Dewar has no liquid
* Torus average coil temperature has cooled down to 40K

Notes:

* The Dewar pressure will likely track the lead reservoir pressures so think about this and how much flow is going to each load.
* The Dewar should only require 2-3 hours to go from 300K to filling. Buffer dewar cooling should be done while there are Hall B cryo expert operators manning the controls.
* Watching TD8210 is critical because it will drop very quickly when it is below 40K and the cold helium that flows through it will warm up a lot in the long u-tube thus making the likely hood of blowing the relief valve high. It also combines with flows from the magnets and all this flow goes through HX8524. This and its long lines make a high back pressure when flowing lots of gas.

1. Verify EV8210 primary loop is in Manual Mode at -20, leave it in Manual but change the rest of the PID settings of EV8210, and it’s A, B, C loops and EV8210BP PID’s to the values in Torus PID Group 12.
2. Change PID modes to the modes called out in Torus PID Group 12
3. Monitor PI8210, it should be 1300-1600 mbar. If PI8210 goes above 1600 mbar, throttle down on EV8210C.
4. Monitor TD8211 and LL8210. It should take 2-3 hours for TD8211 to drop to less than 10K, then the buffer dewar will start filling as indicated by LL8210.
5. When the buffer dewar starts filling, change the Buffer Dewar controls back to standard Buffer Dewar PID settings (Torus PID Group 8)
   1. Put PID settings of EV8210, and it’s A, B, C loops and EV8210BP in manual mode
   2. Change PID settings
   3. Put PID settings of EV8210, and it’s A, B, C loops and EV8210BP in the correct mode from Torus PID Group 8
6. Watch plots for TD8210, LL8210, TD8211 and PI8210. The buffer dewar should keep filling to it’s set point. PI8210 will remain above set point until the DBX return is transferred to cold return.

Notes:

* If things get out of control then manually close EV8210. If EV8210BP goes open but the pressure rises above the setpoint 1300 then the flow is being limited by PV8522TR and this valve must be opened more but we had an instability 1/11/2019 in the 4K supply with it further open so we must watch things. If all is going well we can slowly change the following
  1. Manual setpoint of EV8210C (range 0 to 50) (in 5% steps every 3-5 minutes)
  2. After some time when flow is obvious and the system is controlling pressure then the set value of EV8210 which is controlling onEV8210BP.ORBV may be changed from 10% to a higher value (range 10-50%)
* When the system is controlling there may be an oscillation on TD8512 and you may be able to reduce it and its temperature by opening PV8522TR from 50% to 100% and putting PV8522SR at 100% in Manual also. ( Worked nicely 1/11/19 when TD8522SR and TR were cold, may not be so good if they are warmer so maybe only one is partially open)
* Notice that the EV8210C loop has TD8210 is its input at 30K when it gets there the supply valve will throttle its max and this will stop a quick over pressurization of the dewar. At this point change the max allowed position of EV8210C to the average of its previous 15 minutes. If needed step that up a couple percent. (this only partially worked and after a while we put EV8210C in manual with max between 25 and 30)

**Continuing with Magnets**

1. Once helium starts to collect in any Magnet Lead Reservoir (LL8120SC or LL8620SC or LL8670SC) one should be able to go to standard PID settings for that part from the 4K operating PID’s (supply valves of that magnet only EV8115JT and EV8111CD for the Torus, and EV8611JT, EV8611CD, and EV8612 for the Solenoid ). To do this put each valve in Manual at its current position and then change the gains, then put in back in Normal mode. PID group S3 for the Solenoid and PID Group 8 for the Torus.
2. Also reset the lead flows setpoints FI8621A and B to 49 and FI8121A and B to 88 slm

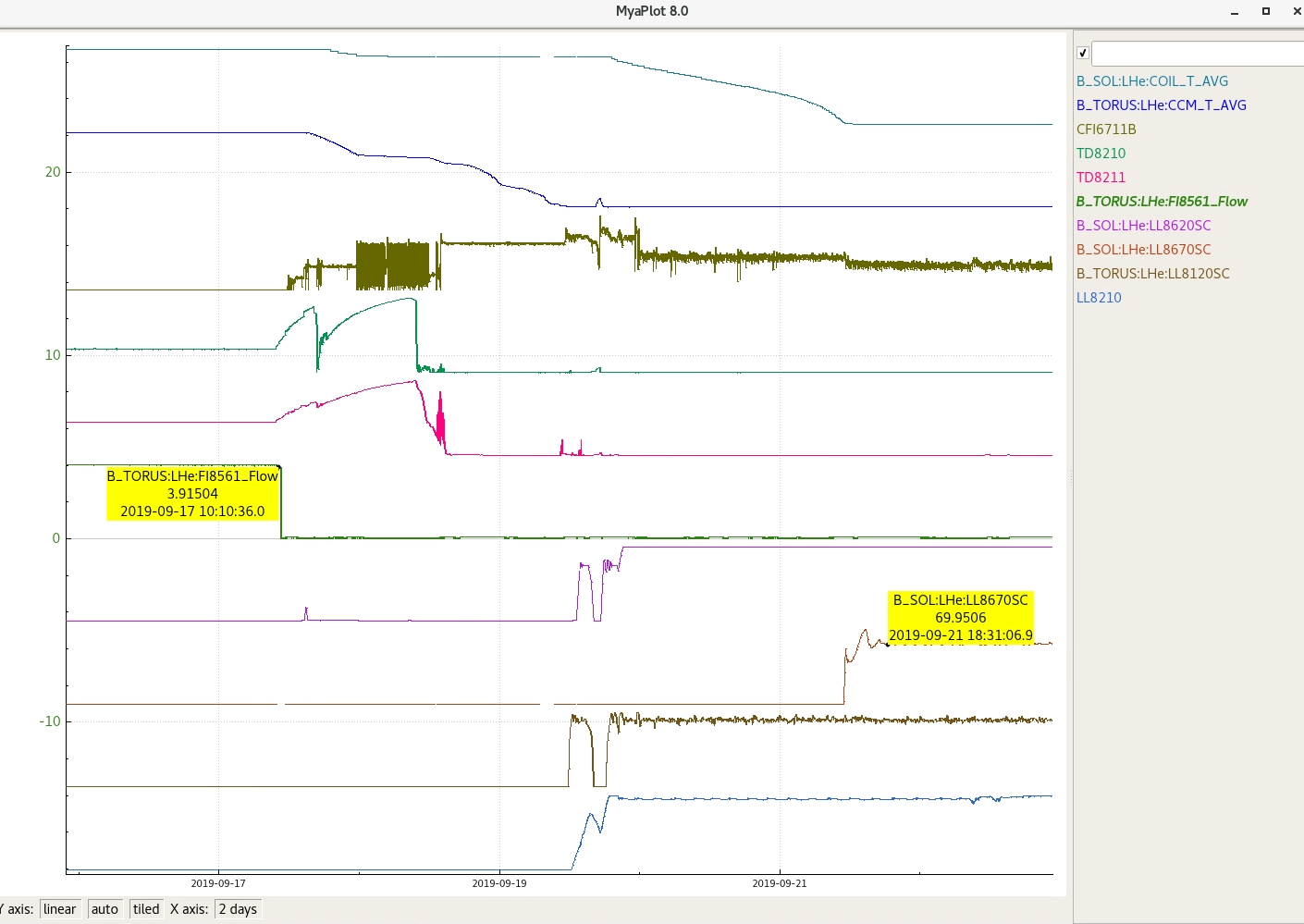
**When the Torus reservoir is filling, we can shift the cooling to the Solenoid lead Reservoir vs its coils. The goal is to get the system to cold return and then let the standard PID’s finish cooling the Solenoid coils.**

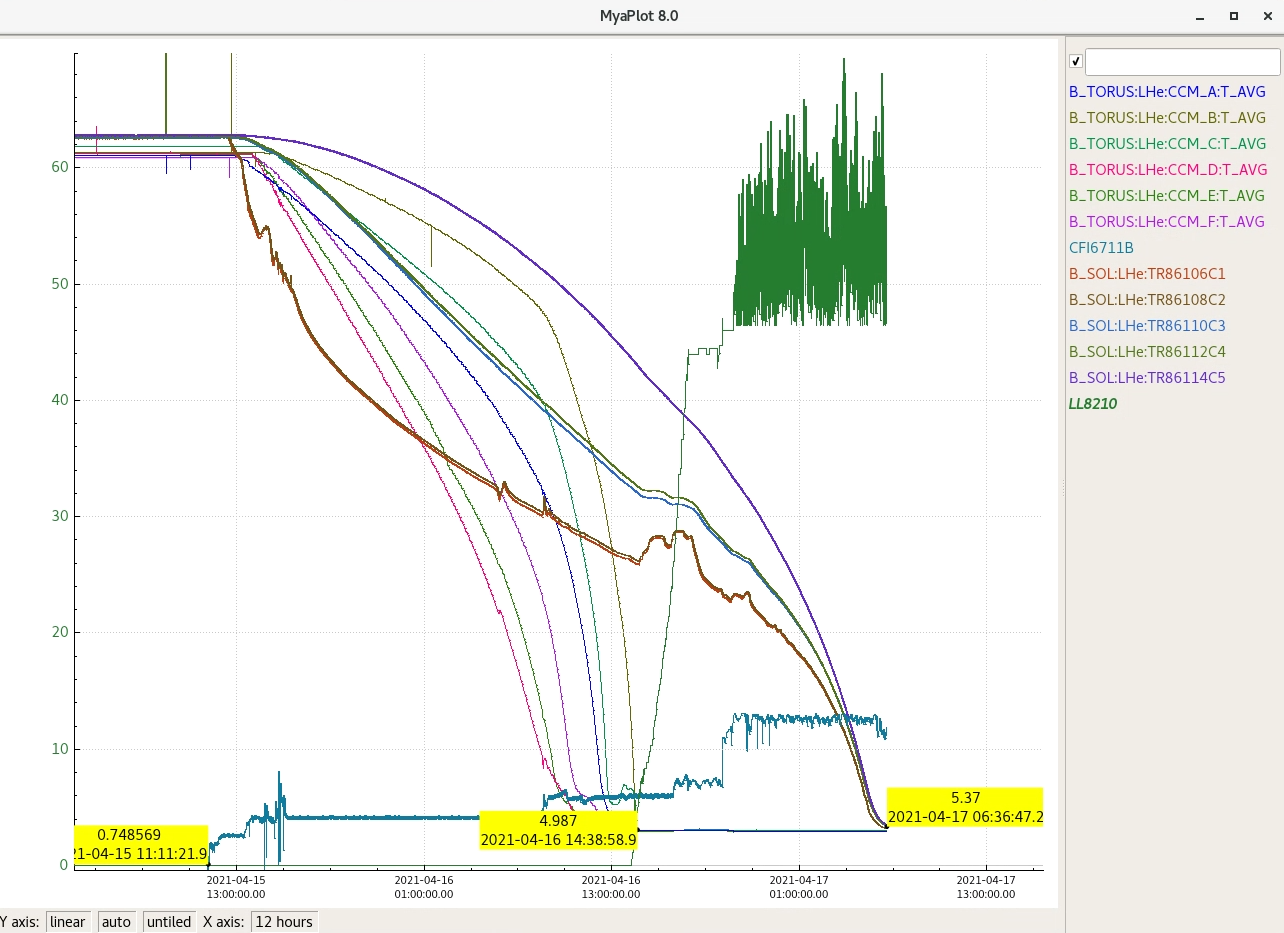
1. To shift the Solenoid cooling, look to see if the temperatures and flows (mostly solenoid) are stable. If so put the valves EV8611JT and EV8612 and EV8611CD in Manual at their current position. Then change the PID settings of these valves to their 4K operational PID settings S3 while leaving them in Manual. Change the setpoint of PV8522SCD to 1.35 atm and let it come to steady state. Then put EV8611JT, EV8612 and EV8611CD in PID Normal Mode.
2. You may want to limit the CD valves max values (both Torus and Solenoid) and keep EV8611JT\_Min in Manual mode at 40 % to keep from overfilling the LL8620SC reservoir, this just wastes flow and recovery compress and raises the return pressure.
3. When the Solenoid collects liquid in its lead reservoir, cooling will continue to the magnet and its reservoir per the standard PID’s
4. We will now prepare for switching to cold return. Setup a new plot with the following signals for transition from warm to cold return. CEV6721B.ORBV, CTD672, CTD671, TD8512, CFI6711B, CTD8513S, CTD8513T. This will allow you to see the important signals and track the cryo operator’s moves.
5. If:
   1. Both magnet lead reservoirs are full and about at steady state
   2. The dewar has liquid helium above 30%
   3. TR8522TR and 8522SR are below 8K
   4. TD8522DR is below 10K
6. Then:
   1. verify that the PID’s for PV8522TR, TCD, SR and SCD are all set to their 4K Mode settings PID Groups 10 for Torus and S3 for Solenoid) and in the normal mode and they working properly to keep the pressures of the reservoirs at set points.
   2. Call cryo and let them know that Hall B is ready to go to cold return.
   3. Also ask them to remove the limit on 4K supply flow rate by changing to pressure control on CEV6711B vs flow control.
   4. Cryo will very slowly open CEV6721B and we should quickly see CTD672 jump up. Once it jumps up it will continue to climb possibly to around 40K and after 15-30 minutes it will come back down.
   5. During this time the valves PV8522TCD and SCD will start to close a little. The more cryo opens CEV6721B the more the TCD and SCD valves will close.
   6. Once they are fully closed the TR and SR valves should begin to regulate the magnet pressures at setpoints.
7. Check vacuums on gages and U-tubes for sweat and that Turbos are running and vacuums are good.
8. Make log book entries
9. Check all 4K PID settings
   1. For the Buffer Dewar standard OPS Torus PID Group 8
   2. For the Torus PID Group 10
   3. For the Solenoid PID Group S3
10. Setup Alarms

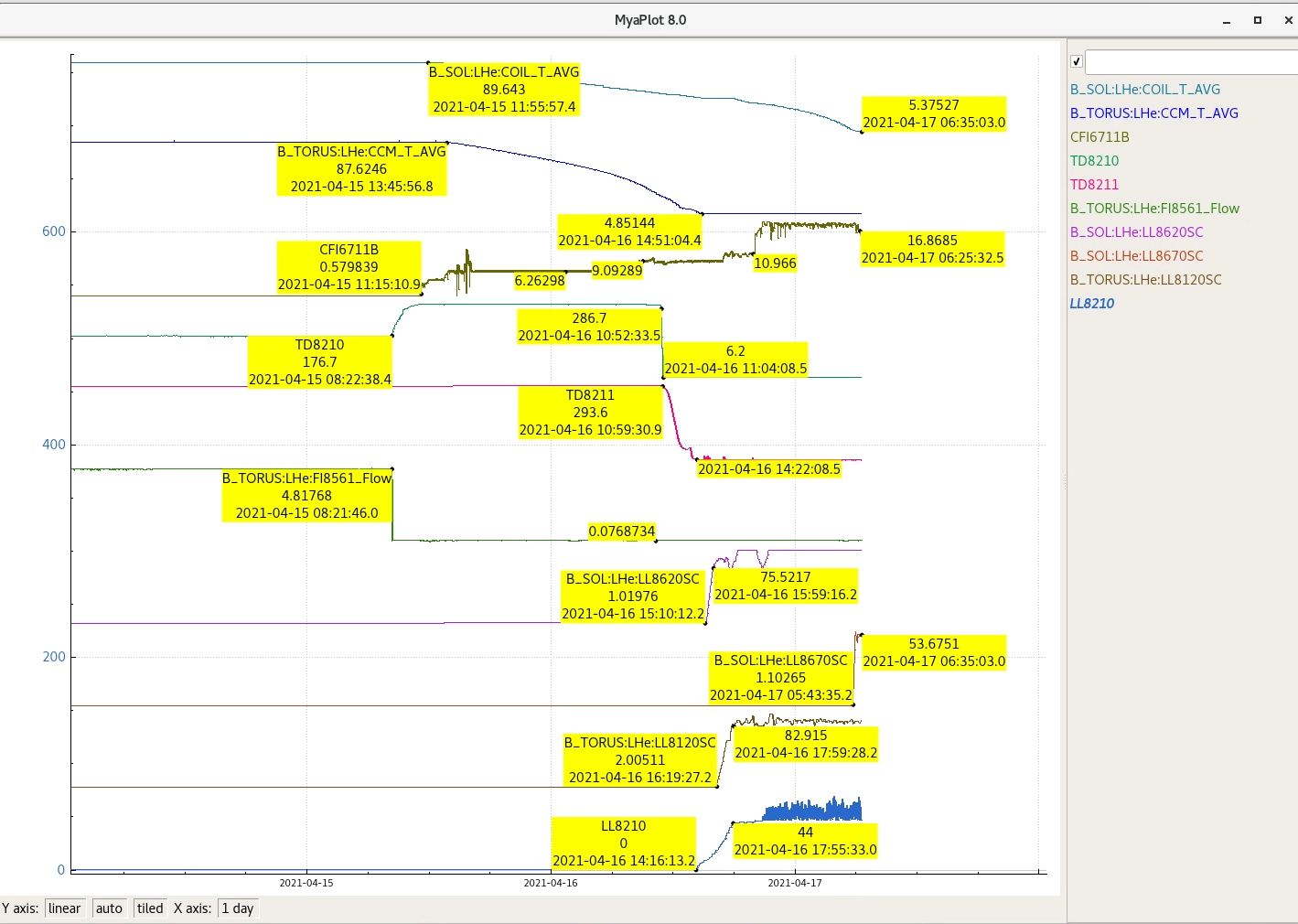
Procedure To Change PIDs When The System Is Operating

When changing PIDs parameters, carefull steps have to be taken so the system is not upset. If a PID parameter is changed, it may change the valve position so much that it impacts the system stability. Therefore, the following procedure is set up to change valve positions slowly to keep the system stabile.

1. Review current and new PIDs to understand what the inputs are and how the cascades are set up
2. Change manual setting to current valve position
3. Change the PID from Normal to Manual
   1. Now the valve is locked in the currently stabile position
4. Input the new PID parameters for the valve, including the cascade parameters, from the PID group
5. Set the PID or cascade parameters min and max to limit the valve to slightly above and below the manual setting
6. Change the PID from Manual to Normal
7. Compare the new valve position with the manual position to see if it is moving towards the min or max
8. Slowly change the min or max until the PID is controlling it
9. Verify that all PID parameters match the PID group







# Parking the Torus and Solenoid and Buffer Dewar – Going from 4.5K to 80K Update 1/2/2019

**PID Group 13**

***Discussion:***

The purpose of this process is to allow maintenance on the End Station Refrigerator or to save on refrigeration capacity if Hall B is not needed or cannot be supported. It can also be used to “decontaminate” (at least most of the nitrogen and other air gasses except water) from the system. And also to burp the Nitrogen out of the Torus Insulating vacuum.

During this process we want to keep the cold masses of the Torus and Solenoid from rising over 90K. We don’t really care if the Buffer dewar warms more because it has a small mass and can cool down quickly, but keeping a small amount of flow through it will help keep it clean from contaminates. We want the LN2 system in the DBX to operate as normal to be able to provide LN2 to the Torus shields and also to cool 4 atm helium to 80K which will be circulated through the 3 magnets and the buffer dewar. Besides keeping the magnets from warming we also want to keep all portions of the system flowing and positive pressure to keep them from getting contaminated and even to remove contamination.

The first part is to let the helium boil off from all the loads. The Torus and solenoid will empty in a few hours. The Buffer dewar should take about 2 weeks., but this should probably be forced to warm by putting a small amount of 80K helium through it such that during cooldown there is no liquid in it, this should make the 4K cooldown easier.

The Solenoid warms quite slowly it can be delayed to reduce re-cooldown time. But Buffer Dewar should be warmed if possible and flowed with 80K gas to keep it below 100K. If 4K is available before the Solenoid COIL\_T\_AVG is above 80K then this will reduce the cooldown time.

1) Set up graphs of the following signals

a. Torus Vacuums - CG8102, CG8103, TC8102, TC8103, CG8100

b. Torus Temperatures – CCM\_T\_AVG, METAL4K\_DT\_MAX, TD8111, TD8115, TD8120, TP8523

c. Torus Pressures and Total 80K flow – PT8563, PT8111, PT8115, PT8120, FI8561

d. Torus Nitrogen – LL8152CP, SHLDOUT\_T\_MAX, TP8152

e. Other - HTR8120, PV8522TCD, PV8522TR, EV8115JT, EV8111CD, LL8120DP

f. N2 Reservoir in the DBX – LL8554CP, LL8554DP, PT8554, TP8564, TP8567, EV8553, TP8555

g. ESR signals – CEV6711B.ORBV, CEV6721B.ORBV, CTD672, CTD8521 CFI6711B, CFI60DLP, CCT10N21A

h. Buffer Dewar – LL8210, TD8211, TD8210, PI8210, EV8210.ORBV

i. Solenoid- TR8610, EV8611JT\_Min.ORBV, EV8611JT.ORBV, EV8611CD.ORBV, COIL\_T\_AVG, PT8513S

General goals are: (UNTESTED as of 1/3/19) NOTE: these are not steps to be followed but to give a general idea of how the system will end up…

1. Buffer Dewar has a trickle flow of ~80K gas on the inlet to keep it clean. Outlet temperature is unimportant and will be less than 300K on the outlet TD8211 supply. This flow should not be started until the dewar is empty.
2. The helium supply path in the DBX is PV8563C Controlling on FI8561 at 3g/s and PT8563 at 2.5 atm for its Maximum Position, to the LN2 heat exchangers to PV8566T (manual at 100%) which provides to both the Torus and Buffer Dewar (backward through PV8512T which is in manual at 100%). In parallel the flow goes to PV8566S (in PID mode with 60% as Max controlling on PT8513T at 2.4 set value: YES this is the Torus pressure!! :).
3. Once fully going, the Torus EV8111BY is closed and in manual mode. EV8115JT is 100% in manual and EV8111CD is in PID with normal controls (LL8120DP for primary loop and PT8111 for \_Max loop). The return valves for the Torus are both in manual at 100% to assure flow path for both the Torus and Buffer Dewar
4. The Buffer Dewar has its EV8210 in Manual at 45% and its back pressure valve EV8210BP controlling as normal
5. The Solenoid has its supply valve EV8611JT at 65% in manual and the Cooldown valve EV8611CD in PID controlling the warm flow to the Hall FI8561 at 1.5 g/s

PROCEDURE: Follow the steps below, but keep your thinking cap on!

1. Test the blower in the vacuum system of the Torus.
2. Confirm with cryo that the warm return from Hall B is going to the CHL purifiers. And ask them to open MV6010B which is the 4 atm helium to Hall B.
3. Have the Cryo folks shut the 4K supply valve to Hall B CEV6711B at a rate of their choice and once closed have them shut the 4K return valve CEV6721B. Be sure that both these valve are reading back -6.41, at -5.4 the return valve CEV6721B can leak up to 1.5g/s
   1. The valve positions can be verified by observing the values of these valves from the “ESR VALVE BOX” portion of the buffer-dewar screen.
4. Our valves PV8522TR and PV8522SR will open and vent the magnets as the pressure builds but since their outlet is to the Cold return which has been shut at ESR then PV8522TCD and PV8522SCD will open.
5. Put PV8522TR, PV8522TCD and PV8522SCD in Manual mode at 100 (note CTD8512 may not rise above 20K indicating CEV6711B at ESR is leaking by, so notify cryo to let them know this) note: 2020/11/06 ev6711B was not leaking, as indicated by TD8512 was rising above 55k within 2hrs.
6. PV8512T: enter set-point = 0, put into manual mode.
7. EV8210: goto position = 0, Mode: manual
8. Wait for All Helium to boil off. Note: If one wants to push the warm up a bit faster the heaters HTR8120, HTR8620 and HRT8670 can be turned on.
9. As the outlet temperature of the U-tubes starts to get warm go to the Hall and feel each 4K U-tube for cold and look for sweat. The cold ones must have their insulating vacuums pumped.
10. Change EV8670BY\_Min Min value from 6 to 0 and its EV8670BY Setpoint from 0.06 to 0.1
11. Watch the vacuum in both magnets but especially the Torus. During previous Torus Burping we have seen two major burps, one at ~12 hrs after stopping flow and the second ~12 hours later. In the past we have seen vacuum burps peak at CCM\_T\_AVG at ~22 and 40K (May 10&11/2018 TC8104RP peaked at 0.26 and 0.46 torr, and TC8103 peaked at .009 and .018 torr, and on Jan 2&3/ 2019 TC8104RP peaked at 0.5 and 1 torr and TC8103 peaked at 0.02 and 0.04 torr (and TC8101 maxed at 0.93Torr)
12. Watch that turbo pumps remain on and their inlet valves stay open. These should be set to call the Hall B engineering-on-call pager
13. LN2 cooled helium can be started after the vacuum recovers by at least a factor of 10. Or if it is desired one can start cooling back to 4K by jumping to **Unparking, 80K to 4K cooldown (PID group 12.** Or one can continue to get both the magnets to stabilze at 80K by continuing below.
14. **We start 80k flow into the Torus after the Torus burps have completed and vacuum has recovered.**
15. This step will require going to the Hall, but read it all before going. Verify that PV8563W is closed in Manual. Verify that PV8563C is closed in Manual. Check PT8561 and PI8561 local to assure they are positive pressure. If they are then the system has been kept clean since last used. Open the warm helium supply valves MV8002, MV8561 and MV8562
16. Enable Torus Cooldown Alarms:
    1. METAL4K\_T\_MAX at 110K Major
    2. METAL4K\_DT\_MAX at Major at 40K (Torus PLC)
    3. Enable TD8111 Alarm at 100K Major
17. Close in manual mode PV8512S, PV8512T, PV8566S and PV8566T
18. Setup PID for EV8111BY and its \_MIN and \_MAX loops per Torus PID Sheet 13.
19. On the Torus, In manual mode Close EV8111CD. Put EV8111BY in manual at 60% and EV8115JT at 30% to bypass most of the flow to avoid warming the coils and to allow supply temperature from the DBX through the LN2 Heat Exchangers to get the Helium temperature down.
20. Put PV8566T in Manual at 10%
21. Call Cryo and let them know you will be starting to flow 2-5g/s of Helium through the magnets and back to the purifiers in the next 15 minutes.
22. Leave it in Manual mode at 0 and set all other parameters for PID for PV8563C and EV8563\_MAX, as per Torus PID Group 13
23. Leave it in Manual mode at 0 and Set up all other parameters for PID for EV8111CD and EV8111CD\_MAX, as per Torus PID Group 13
24. Clear interlocks on Torus Cooldown by changing the interlock threshold of HE\_METAL\_DT and DT2 from 50K for the Torus to 300K (This will be reduced later to ~100K?) Then hit reset (the interlock will not clear until the next step is completed)
25. Clear interlocks on Solenoid Cooldown by changing the interlock thresholds HE\_METAL\_WU\_DT and DT2 from 50 to 300K for both then hit Reset. You should see a green dot below PV8563W on the DBX screen
26. Put PV8563C\_MAX in manual at 20% and the “PV Setpoint” of PV8563C to 2g/s
27. Put PV8563C in Normal mode to start flow to the Torus, and watch the plots especially signals of flow rate and temperatures out of the LN2 boiler and into the Torus.
28. When the pressure PT8563 is above 2.5 atm put PV8563C\_MAX in Normal mode
29. Put EV8111BY in normal mode and increase the EV8111BY\_MAX manual value to 85%
30. Slowly open PV8566T in 5% steps to increase the pressure at PT8513T to at least 1.8 atm.
31. When EV8111BY is controlling flow at 1.5 g/s and PT8513T is above 1.8atm open PV8566T to 100% in manual,
32. When the temperature TD8111 is below 100K then proceed.
33. Open EV8115JT to 100%
34. IF EV8111CD PID Output is below 2% then put EV8111CD and EV8111CD\_MAX in Normal mode. EV8111BY should close automatically, and once it is fully closed put it in Manual mode at 0.
35. Check the flow on the flow meter on the wall of the Hall FI8525 it should match FI8561
36. Make a logbook entry into Torus and Cryo Logs, that Hall B Torus is flowing XX g/s of 80K helium and is at temperature XX. XX from EPICS signals.
37. Set up on-call alarms on these parameters.
    1. Torus and Solenoid : Vacuum on magnets and Turbo speeds
    2. Torus: CCM\_T\_AVG 100K, METAL4K\_T\_MAX at 100K at 40K both major
    3. Torus: TD8111 at 100K HIHI Major
    4. Make sure that the alarm handler is on for thee above signals!
38. ***Reset the interlock on the Cooldown Interlock page for the Torus***
    1. ***HE\_METAL\_DT and DT2 from 300 to 50***
    2. ***DO NOT RESET THE SOLENOID OR PV8563C will CLOSE***

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1. **The next thing is to get the Solenoid flowing (schedule/temperature dependent, if one wants it to stay cold in hopes that 4K returns soon then do not proceed unless it is already above 70K)**
2. Enable Cooldown Alarms for **Solenoid:** CM\_T\_MAX Major at 110K and CM\_DT\_MAX Major at 43K
3. Enable TR8610 alarm: HIHI Alarm Limit = 100, HIHI Alarm Severity = MAJOR
4. Verify that PV8522SCD is in Manual at 100%
5. Change the lead flow set point to 5SLM on FI8621A and B
6. Verify that PV8566S is closed in Manual Mode at 0%
7. Change Min Position of EV8670BY\_Min to 10 as shown on Solenoid PID group S5
8. Set PV8566S, PV8512S, EV8611CD, EV8611CD\_MAX, EV8611CD\_MAX\_MAX and EV8612 in Manual Mode at 0
9. Set EV8611JT per PID group S5, leave in Manual Mode at 0
10. Set PV8566S to Manual mode, 30%, This should bring PT8513S to appx the value of PT8565
11. Put EV8611JT into Normal Mode. This allows flow into the lead reservoir, beginning the u-tube cooldown. If PT8513S drops below 2.0, then increase the position of PV8566S to 70%.
12. Wait until the inlet temperature to the Solenoid TR8610 is below 100K
13. To ensure that flow continues to the Torus, increase the Min Value of EV8111CD\_Max from 10 to 25 & EV8111CD from 0 to 25.
14. To start a trickle flow from the lead reservoir to the coils once TR8610 is below 100k:
    1. Open EV8612 to 100%
    2. Set EV8611CD per PID group s5, such that it controls on the flow rate from ESR, based on input parameter FI8561.
15. If the Solenoid coils are not staying cold (<100K) then EV8611CD may need a higher maximum.
16. Set up on-call alarms on these parameters.
    1. Solenoid : Vacuum on magnets and Turbo speeds
    2. Solenoid: CM\_T\_MAX @100K, TR8610 @110K
    3. Solenoid TD8610 at 110 HIHI Major
    4. Make sure the alarm handler is on for the above signals!
17. ***Change the threshold on the interlocks below from the Cooldown Interlock page for the Solenoid***
    1. ***HE\_METAL\_WU\_DT and DT2 from 300 to 50***
18. **To get the Buffer Dewar flowing do the following steps below**
19. Wait until the dewar is empty, and that the outlet temp TD8211 is above 80K.
20. Start a plot of PI8210, TD8211, TD8210,LL8210, EV8210.ORBV and EV8210BP.ORBV
21. Set PV8512T to Manual Mode, 50%
22. Set EV8210 to Manual Mode, 40%. After 15 minutes, if the cooling rate is low on TD8210, increase the position of TD8210 to 60%

# Torus Helium Circuit warm up to 300K

**PID Group XX**

***Discussion:***

Warming the magnet may be done to improve the vacuum or just to check how much gas/water has condensed on the cold mass due to leaks, O-ring permeability or just if the magnet/detector were to be offline for a long period. It is important to follow the differential temperature constraints that are also imposed during Cooldown based on differences in each coil, and average coils to beam temperatures. Helium and Nitrogen circuits should be warmed at the same time kept to less than 50K delta T between them.

**(To be completed when needed)**

# Torus Nitrogen circuit warm up to 110K and refill

**PID Group XX**

***Discussion:***

Warming the magnet may be done to improve the vacuum or just to check how much gas/water has condensed on the cold mass due to leaks, O-ring permeability or just if the magnet/detector were to be offline for a long period. It is important to follow the differential temperature constraints that are also imposed during Cooldown based on difference between inlet and outlet temperature of the nitrogen, Helium and Nitrogen circuits should be warmed at the same time kept to less than 50K delta T between them.

A partial warm up was done to do a leak test on the N2 piping.

Start by closing the LN2 supply valve EV8555T.

Set the heater on the LN2 reservoir in the DBX HTR8554 to control at 1.35 atm to provide gas

Put PV8556T in manual mode at 65% and enable heater HTR8559 to control temperature at 115K with PID settings from the 300-80K cooldown group in the hold temperature mode.

To recool simply Close the GN2 supply valve PV8556T and step open the LN2 valve EV8555T in 10 % steps and described above in 80K ops then enable the PID for EV8555T. Again Coil A and F will lag. When the liquid collects and the valve EV8555T regulates Coil A should cool followed by Coil F

# Buffer Dewar Cooling from 300K to 80K with Torus at 80K

**PID Group 7b (3/16/17 version)**

***Discussion:***

To cool the dewar we used 80K helium cooled by LN2, the same as being used by the Torus.

To get the flow to the dewar, backward through PV8512T and we found 30% to be a good value. We are controlling the flow rate by controlling the supply valve EV8210 with fixed min and max from the EV8210A loop (min) at 10% and EV8210B loop (max) at 100%. The valve PV8563C was hunting (oscillating a lot) so I lowered the gains of this valve and put them in the PID group here.

ABORTED the CD when we found the vacuum in the 2 U-tubes is bad.

**3/22/17 Re Attempt at Buffer dewar cooling with Torus cooling too**

We started by filling the dewar to 20% in warm return and getting the torus cold full and in cold return.

One important step is to reverse flow the return U-tube of the buffer dewar. The first way I achieved this is to plot PT8120 (Torus return pressure 1.2 to 1.5 atm) and PI8210 (BD pressure 1200 to 1500mbar) on the same graph.

Ask cryo to set EV6721B to control a back pressure such that PT8120 goes to ~1.35 atm. They can do this by controlling on their CPI8521 and choosing an appropriate value. Note this sensor usually reads high so setting it to 1.35 won’t do. On this try we are choosing 1.62 atm at least to start. The cold return valve at ESR EV6721B should end up near 0.0.

Step by step open EV8210BP by 3 % at a time. 3,6,9,12 every 3-4 minutes make a change. 15, 18, 21 TD8211 is now reading 30K-40K so we have flow and are mixing with dewar flow. Note the dewar has and is holding 20%LL

,24,27,30 TD8211 got to ~80K and held there for a while. Then it started falling quite quickly to60K then even faster toward 50K at which point Denny went to the hall and grabed a phone and a screw driver to knock off the ice on MV8210CD. When the temperature got to 20K it leveled abit and we waited about 2 minutes then closed MV8201CD. I quickly opened EV8210BP to 50 then to 75%.

TD8522DR warmed to ~50K but fell quickly and the system handled this bump one could probably wait a few more minutes after the TD8211 hits 20K but be sure not to steal all the flow from the TL to ESR and such that TD8511 Warms too much

# From Previous Solenoid/DBX document

**Notes on Cryogenic processes at JLab:**

Cryogenic plants at Jefferson Lab take warm helium from 30,000 gal storage tanks at 5-18 atm of pressure through refrigerator which consists of compressors, valves, piping, heat exchangers, contamination traps, and expansion engines. The primary circuit (coldest) typically cools the helium between 2 and 5 K and then sends that helium to a load in the form of either liquid or more typically super critical helium gas at ~3 atm. This is gas that when the pressure is dropped across a valve (JT valve) it turns to liquid and is known Joule-Thompson expansion. Typical loads store some liquid helium and some use supercritical helium as the heat sink for the heat getting into the system. When the liquid helium is boiled it is no longer useful for most superconducting loads and it is returned to the refrigerator to allow re-claiming much of the work (electric power) that was put into it to get it to the liquid/supercritical state. It is critical that systems at JLab be both leak tight and clean from residual gases so that the helium stays pure. Typically, the cryogenics plants run at ~2ppm (parts per million) of non-helium molecules. The reason for this is that all other gasses become solid at liquid helium temperature and thus they will tend to collect on piping and valves and thus they will cause blockage and when severe enough that blockage will reduce efficiency and eventually cause a shutdown that will require warm up and purification of the refrigerator.

Shutdowns due to contamination while rare have happened at JLab. One best method to minimize their occurrence is to assure a leak tight system and that the system has been purified. One normally thinks that a small leak on a positive pressure system will not cause a problem. In helium systems (and other high purity gas systems) this is not the case. Gas molecules travel very fast and can swim upstream against a flow due to their molecular velocity which can be in excess of 1000m/s (more than the speed of sound in air ~350m/s). Thus helium systems must be leak tight. A secondary method used is to purify the warm helium using a purification system which contains charcoal beds at 80K. Common air gasses (N2, O2, CO2 etc.) stick to the surfaces of the cold carbon and are thus removed from the helium. The lab is so concerned about contamination in its helium that it purifies all gas that it buys to restock the refrigerators.

Helium is also a limited resource for earth and it is expensive thus leaks have a secondary issue and that is cost. The density of liquid helium is 125gram/liter and to buy the amount of gas to make 1 liter of liquid helium costs JLab ~ 5.08$/liquid liter

Solenoid Magnet Discussion and Operations

**Introduction:**

The CLAS 12 Solenoid is a superconducting magnet that is part of the CLAS12 Detector system. It is ~2m long and 2m in diameter with a 0.78m open bore. It is surrounded by detectors on all sides. Its central peak field is 5Tesla and peak field ~6.8 Tesla. At full current it will store ~20MJoule of energy (50%) more than the Torus. The weight of the solenoid cold mass is ~30000lbs. The magnet uses only helium for cooling, there is no liquid nitrogen. The solenoid cryogenics and power feed come through a vessel called the Solenoid Service Tower (SST). The SST contains most of the control valves involved with the magnet (the rest are in the DBX or in warm piping after the flows leave the SST).

There are two liquid helium reservoirs in the SST. The primary function for each defines the name of the reservoir. One reservoir is called the Lead Reservoir is named such because it houses the VCL’s. The other reservoir is called the Magnet Reservoir and its primary function is to provide steady state cooling for the magnet. The primary reason for splitting the Liquid Helium inventory into two volumes is that it allows the magnet cold mass, if necessary, to be cooled below 4.5K by pumping on the helium in the magnet reservoir. This will give more temperature margin if it is needed to achieve full field.

The lead reservoir is connected to the Distribution Box (DBX) through a set of long flexible U-tubes. These U-tubes allow the magnet to travel on rails along the beam direction w/o requiring disconnection. The primary supply and return U-tubes and the connections inside the DBX allow variable temperature helium gas (300K-4K) to be brought to and returned from the Lead Reservoir. There are 3 other flow connections to the SST. Two are L-tubes that take flow from the VCL’s to an ambient vaporizer and one is a vent for the return from both the shields and the magnet reservoir. All 5 of these lines are Vacuum insulated, but only the primary supply and return U-tubes need to have low heat load because the other 3 lines are returning gas that will be warmed to 300K before returning to the End Station Refrigerator.

Heat is removed from the magnet by conduction through copper strips that are soldered to copper buttons that are in contact with helium in a central channel in the Solenoid. In steady state the channel is fed liquid helium by a ½” OD tube from the magnet reservoir. This liquid is returned to the magnet reservoir in the SST (Solenoid Service Tower) via a 1-1/4” pipe. Flow in that pipe is used to cool the conductor splice at the interface between the solenoid and the SST. The solenoid and SST heat shields that are fed in series and are cooled by boil-off helium from the magnet reservoir. Make up liquid is fed to the channel by EV8612 from the lead reservoir

Multiple PID control loops will be described and setup so that the cooldown can be continuous but will not require 24hr staffing for monitoring or manual intervention. Interlocks will also be implemented to avoid damaging the magnet due to thermal stresses based on design values received from the magnet vendor Everson Tesla Inc.

Cooldown is expected to take ~4 weeks and will be done in two stages, 300-100K using variable temperature gas and 100-4K using 4K gas.

**Scope:**

This document is the cooldown and operating procedure for the CLAS12 Solenoid. Operation of the Torus magnet, the Distribution Can (DBX) and 500 Liter Buffer Dewar are covered in document *B000000901-P007 Hall B Cryogenics DBX and Torus Cool Down and Operating Procedure* . Because the cooling the Solenoid requires the Distribution box and its controls, all those that are pertain to solenoid cooling are described here. NOTE: Setup for some of the controls will be dependent upon the status of other loads on the system. For this draft the procedures are written to be used as if the Torus is operating, i.e. it is cold and could be powered up.

**Valve Control and PID Loops**

A spread sheet that contains all control parameters (PID settings) for each active control device (Valves and Heaters) is attached as Appendix 1. In Appendix 1 there are different **PID Groups** used for different phases of the cooldown process. As the state of the systems pass from one mode of cooldown to another, PID parameters for control elements may change or the control element may go from Normal to Manual. The spread sheet contains two check-list columns which will be filled in after functionality of a Control Loop or control interlock has been tested and found to perform properly the check boxes will be filled out. Operators are warned that there may be some states of systems that the controls may not respond as intended, though rare, these can occur due to things as strange as blockages in piping, control read-back failure, or other portions of the system failing (refrigerator, compressor, air system….).

Basic functionality of the main cryogenic control elements is described here:

***DBX Elements***

**PV8563W** provides warm gas (300K) to be mixed with cold gas (80K) to achieve variable temperature gas for cooling either the Torus or Solenoid to 100K. This valve can be controlled on a downstream pressure PT8565, PT8513S, PT8513T, or a calculated pressure P\_CDHE\_8563W\_S, P\_CDHE\_8563W\_T or a DP across itself DP\_CDHE\_8563W depending on what other parts of the system are doing. This valve also has a functionality of a PID on its maximum that can be used to limit its maximum position so that it does not overpower the cooling function desired. That is to say it won’t provide so much warm gas that the desired mixed gas temperature can’t be achieved. This can be done my controlling the Max position on the position of PV8563C.OVAL and that position gets above 90 to 95% then PV8563W max is limited.

**PV8563C** provides helium gas to two heat exchangers. The first is a gas/gas exchanger and the second it a tube in liquid exchanger where the liquid side has liquid nitrogen in it. This LN2 has two primary functions. The first is to provide LN2 for the Torus heat shields and the second is to provide cooling power for cooling helium Cooling (or Warming) the Torus or Solenoid. To provide a stable and controllable temperature there are two critical dependencies. First, the warmer heat exchanger HX 8564 is fed only gas. This can only be done if the liquid reservoir LL8554CP/DP is not overfilled. Second the same reservoir level must not get below ~30% and uncover the HX tubing. PV8563C primary PID loop controls the supply temperature to the load (solenoid or torus) it can do this based on a fixed temperature value which must be stepped down or upon a desired DT between the helium and a metal temperature. For the Torus we have used HE\_METAL\_DT or HE\_METAL\_DT2 for the Solenoid we have HE\_SMETAL\_CD\_DT, HE\_SMETAL\_CD\_DT2, HE\_SMETAL\_WU\_DT, HE\_SMETAL\_WU\_DT2. Again we have a PID for the Maximum position of this valve and it can be used to limit a maximum temperature difference of metals in the load. For the Torus we use METAL4K\_DT\_MAX. For the Solenoid we have several constraints. To allow us to combine these limits we use an algorithim to first calculate each difference then calculate the percentage of each difference from its maximum difference then finally compare each percentage and find the max percentage and use that S\_DT\_MAX\_Percent and we will limit the value to 75%.

**PV8566S** is the variable temperature supply valve to the Solenoid. It is mostly designed as a shut off valve to isolate this source from the 4K temperature supply. It could also be used to either limit the flow to the solenoid by controlling its position on directly on Flow FI8561 or on Liquid level in the N2 pot LL8554CP if it gets low.

**PV8512S** is the 4K supply valve to the Solenoid. It is mostly designed as a shut off valve to isolate this source from the variable temperature supply.

**PV8522SCD** is the cool down valve in the DBX for the Solenoid. It takes return flow from the lead reservoir to HX8524 the large ambient vaporizer on the north wall of Hall B. The flow must return through this valve until the temperature is below 8K so that the 4K supply flow is not warmed in the heat exchanger in the ESMTL. If the heat load of the SST and the U-tubes and the VCL’s is too high then it may be that this valve will be the return path and PV8522SR will remain closed.

**PV8522SR** is the cold return valve for the Solenoid. Flow from the lead reservoir flows through this valve if/when it is below 8K back to the ESR for energy recovery. It can also provide back pressure on the lead flow reservoir to drive the lead flow if the return pressure on the lead return line is a bit too high. Its control input will be PT8620

***Solenoid Service Tower Elements***

**EV8611JT** is the supply valve for the lead reservoir. Its primary function is to keep the lead reservoir liquid level at a constant value and its input parameter will be either LL8620SC or LL8620DP. It also has a cascade PID on its minimum position that will be used to keep the minimum position open enough to keep the supply temperature TR8610 at or below 6K. During CD this valve will have a small fixed position to allow a small lead flow and the operator can adjust this to keep the 4 sensors on the current leads cooling such that their temperature is lagging the average coil temperature SCOIL\_T\_AVG by less than 50K. Another option which will work is to set the valve to control on FI8621A with a set value below the controller set value. This will then limit the cooling power diverted to the lead reservoir.

**EV8611CD** is the cooldown supply valve. It will remain closed during magnet powering. Its primary function is to provide large flow capability directly to the Magnet Annulus for cooling the magnet from 300K to 4K. During the 300K-100K phase of the CD this valve will be controlled by the flow rate on FI8561 at a value that is acceptable to the cryogenics group depending on the other loads on the system. During the 100K to 4K phase of the CD it will be controlled on the 4K supply flow to Hall B CFI6711B. If the Torus is cooling then this flow will be split between the two magnets. During both phases of the cooldown the max of EV8611D will be controlled by a cascaded PID that will look at the pressure in the Magnet Reservoir PT8670. The Set point of which will be below relief valve RV8670 pressure of 2 atm. It may be necessary to control the flow rate through the magnet based on the ambient vaporizer outlet temperature as it is sized for 3g/s and thus its outlet will likely get iced up if too much flow goes through it. This will create a water drip. If implemented the outlet temperature can be monitored by TP8675A.

**EV8612** is the Magnet Reservoir supply valve. Its function is to supply make up helium to the reservoir once the magnet is cold. It will be controlled by PID with an input of the Liquid level in the Reservoir LL8670DP or LL8670SC. One must note that these levels are not equivalent. LL8670DP shows the level of the helium from the bottom of the annulus to the top of the reservoir while LL8670SC shows only the level in the 45L reservoir. This valve will be slightly open in manual mode at ~15% during the 300-100K portion of the cooldown it likely will flow backward from its normal direction because the pressure in the lead reservoir will less than in the magnet reservoir. One will be able to test this by closing EV8611JT and observing the lead flow. During the 100K to 4K cooling it will be the primary flow path to the coils. And its position can be limited to look at the flow to the purifiers CFI084 or the DT/Dt of the coils SCOIL\_DT\_Dt30 or the pressure in the magnet reservoir.

**HTR8620** is a heater in the lead flow reservoir can be used to assure there is boiloff helium to cool the current leads. So it may be needed to keep PV8522SR from fully closing. This heater has an interlock through the PLC that will disable it when LL8620SC is below 10%

**EV8621A and EV8621B** are lead flow control valves and are not controlled by user inputs but rather the PLC directly they control the flow through the leads based on a minimum of XXX slpm when the magnet is at 0 current and a max of XXX.X slpm when the magnet is at full current.

**PV8674** is an isolation valve that is only closed when the magnet is to be disconnected from the helium return (pulling the L-tube to the vaporizer). There may be a failure mode of the future vacuum pump system that may also require closing this valve

**EV8670BY** is the shield bypass valve. Its primary function is to bypass flow around the heat shields to allow more cooldown flow if the pressure drop in the shield limits the cooldown flow during cooldown. It may also be used for steady state operations if the shield limits the flow. During cooldown the control input parameter would be PT8670. The setpoint will be just above the return pressure PT8675A. This valve has cascaded PID’s on both the min and max position to allow full control flexibility. Another possible input parameter for any of the 3 PID controls for this valve is SSHLD\_DP.

**HTR8672** is a set of 3 band heaters attached to the return piping between the Solenoid Annulus helium volume and the Magnet Reservoir. This heater can increase the helium circulation of the thermosiphon and it can also increase the flow through the heat shield. As such it could be driven by one of the magnet temperature sensors or one of the calculated temperatures or temperature averages. It could also be driven by a shield outlet temperature or the average shield outlet temperature. This heater has cascaded PID’s on both the min and max position to allow full control flexibility. Finally this heater has an interlock that will disable it when the LL8670SC is below 10%. It should not have its interlock on LL8670DP unless the set value is quite high since as stated above this sensor monitors the level from the bottom of the magnet Annulus to the top of the magnet reservoir.

**Nomenclature of the Torus and DBX valves and instrumentation**

The nomenclature follows the CND (CEBAF Nomenclature Document) with details described here. Knowing the pattern will help the operator more quickly and correctly identify the hardware and should help to avoid errors in operation.

Typical signals are XXXABCDYYY

XXX is the type of hardware (LL = liquid level, SV = Solenoid Valve, PV = pneumatic valve, EV= electric valve, RV= relief valve, CV= Check Valve, HX=Heat Exchanger, HTR = heater, TD = Diode temperature sensor, TR = Cernox Temperature sensor, TP = Platinum Temperature sensor, PT=PI=Pressure transducer,…)

A is the system locator (8 is for Hall B, 6 is for ESR)

B is the system detail description (1 = Torus, 2 = Buffer Dewar and Targets, 5 = DBX, 6 = Solenoid)

C is the process circuit (1 = 4K supply, 2 = 4K return, 3 = 15K supply, 4 = 20K return, 5 = N2/LN2, 6 = Cooldown Helium 7 = Magnet Reservoir

D is a counting number that usually increases in the direction of the flow

YYY is usually empty or a set of letters that help to identify function (S = Solenoid, T = Torus C = Cold, W = Warm, BY = Bypass, CD = Cooldown, TR = Torus Return……)

**Prior to use of this procedure the following documents must be read, understood and signed by all operators**

ENP-16-59053-OSP Torus Magnet and Service Tower Cryogenic Operation

ENP-16-60975-OSP Hall B Distribution Can Operation Procedure

XXX-XX-XXXXX-OSP Hall B Solenoid Operation Procedure

**Relevant documents:**

Hall B Warm Gas Piping B00000-09-00-0701

Hall B Torus Cryogenics P&I Diagram B00000-09-00-0100

Hall B Cryogenic Distribution Can P&I Diagram B00000-09-00-0500

Hall B Solenoid Cryogenics P&I Diagram B00000-09-00-0600

Buffer Dewar 66850-E-02859

B000000402-S004 Hall B Magnet Cryogenic Instrument Description

B000000401-R015 Torus Hex Beam and Coil Strain Gages

B000000401-R016 Torus Main Supports and OOPS Strain gages and Load Cells

B000000401-R015 Torus Coils and Hex Beams Strain Gages Initial Conditions B000000401-R015

B000000401-R016 Torus Main Supports and OOPS Strain gages and Load Cells B000000401-R016

B000000901-P006 Hall B Check Lists for Cool Down of Cryogenic Systems

**Initial Conditions**

* B000000901-P006 Hall B Check Lists for Cooldown of Cryogenic Systems.pdf is checked off for all items necessary for the start of cool-down.
* U-tubes between the DBX and SST are installed
* L-Tubes between the SST and the VCL warm up vaporizer are installed
* L-tube from the Magnet reservoir to the ambient vaporizer HX8675 is installed
* System Purified and circulating helium at approximately 3ppm or less
* Set up the PID Control Loops In Appendix 1
* Setup and Test all Alarms for Cooldown

**Main Support Adjustment**

* **The Main Supports Z and R may need to be adjusted before, during and after cooling and before warming the magnet. Follow the vendors procedure as needed to keep the supports properly adjusted throughout the cool down and or warm up processes.**

**PID/Interlock Initial Verification**

Test the PID Control Loops with appropriate perturbations, initialing the “PID Verified” to Work Cells in the spread sheet (Appendix 1).

NOTES:

MOST PID Control Loops will need to be fine-tuned during the initial cooldown.

Some PID loops and may also need to be tuned differently depending on the phase of the operation.

Interlocks in general will not need to be changed. If interlocks need to be changed, D. Kashy or R. Fair must be contacted.

Upon successful verification of PID Loop/Interlock basic functionality, cooldown may begin. Basic functionality includes:

1. Controlled Device moves the full amount required in both manual and normal (“PID”) modes
2. Controlled Device moves in the correct direction to an offset in the set value vs actual value of the PID input
3. Controlled Device if it has any cascades is receiving its proper min/max from the cascaded PID
4. If Controlled Device has an interlock, the interlock has been dummy loaded and confirmed to act properly to shut the device if proper operating conditions do not exist, AND the actual trip value is reinstated into the PLC

At each phase of the cooldown verify the PID loops for that phase are working properly and fine tune as needed. D. Kashy (or his alternate) should be contacted if PID loops are not reacting properly or need fine tuning.

**Critical things to monitor or observe:**

|  |  |
| --- | --- |
| System Parameter(s) | Operator Action |
| Monitor strain gauges and load cells for signs of unusual differential thermal contraction | Call Expert if values change into an alarm state (yellow or red) |
| Temperature difference between the full 4k cold mass and the shields. (50K to start) | Reduce control temperature DT (input of PV8563C.MAX). Increase flow rate. |
| Time rate of change of the cold mass should be kept below 3K/hr SCM\_DT\_Dt30 or DT120 or DT600 | Reduce control temperature DT (input of PV8563C.MAX) |
| Maximum temperature difference in the Coil 1-4 and Bobbin Assembly 10K | Reduce control temperature DT (input of PV8563C.MAX) |
| Maximum temperature difference in the full 4K cold Mass assembly 20K | Reduce control temperature DT (input of PV8563C.MAX) |
| Ambient vaporizers getting iced past ½ of last series finned tube | Determine source(s) of flow and reduce flow as needed |
| Vacuum Jackets of Solenoid, TL, DBX, or U-tubes, sweating or icing | Call Expert, stop or slow cooldown, add pumping capacity or start pumping on static vacuum spaces |

**Contacting the Cryogenics Operators:**

During normal working hours contact CHL control room at ext 7405 or the guard shack ext 5822

During off hours contact is through the guard shack ext 5822

Joe Wilson 269-7722 office 757-715-1167 cell

Chris Perry 269-6157 office 757-371-4926 cell

Johnathan Creel 869-8910

**Initiation of cooldown:**

1. Verify the supports for the cold mass have been set to safely allow cooldown
2. Verify that interlocks and appropriate alarm setpoints have been entered and tested
3. Make a Solenoid Log entry titled with the Time, Day, Month and Year of cool down. (Make entries for all steps, there cannot be too many entries) the electronic log book is at: <https://logbooks.jlab.org/book/hbtorus>
4. Confirm data logging is activated – including Fast DAQ- (Contact Wesley Moore or Ruben Fair)
5. Start plots of critical signals relevant to the stage of the cooldown, in general these will be flows, pressures, temperatures and valve or heater positions of active control parameters for that stage of cooldown/operation, these usually are the inputs/outputs of active PID loops and temperatures, pressures, and flow rates in the flow stream

**300-100K Cooling of the Solenoind Magnet and its Heat Shields**

**PID Group S1**

***Discussion:***

Variable temperature helium gas is used to cool the solenoid. The control temperature for this helium is set at a value (45K) below the maximum metal temperature in the magnet SCM\_T\_MAX. This temperature difference (HE\_SMETAL\_CD\_DT or HE\_SMETAL\_CD\_DT2) set value may need to be changed to depending on what the actual temperature profile of the coils and bobbins look like and also the time rate of change of the coils.

As stated above the variable temperature is achieved is by mixing helium at 300K with helium at 80K. To create 80K helium 300K helium passes through two heat exchangers (HX8564 and HX8565) in the distribution box. The amount of 80K helium controlled by PV8563C and the amount of 300K helium is controlled by PV8563W. The PID for PV8563C uses temperature for its setpoint and PV8563W uses pressure for its setpoint.

It is important to monitor the inlet temperature to the Torus to verify they are not warming when this variable temperature gas flow commences. Valves that are cold can often leak through because their seats are hardened by the cold temperatures. So besides having valve PV8566T, the variable temperature gas to the Torus closed, we will prevent flow from leaking through to the Torus by keeping the supply pressure to the Solenoid lower pressure than PT8513T the 4K helium supply pressure to the Torus. Thus a variable (P\_CDHE\_8563W\_S) has been setup to do this which uses the actual Torus inlet pressure and subtracts an offset value (PV8563W\_DP\_OFFSET to give the pressure available to drive the solenoid flow. More information on these variables is available on the PID spread sheet (Appendix 1).

Cooldown stresses are limited mostly by temperature differentials. But since not all portions of the magnet are instrumented, we may also need to limit the time rate of change of the cold mass. This can be done by limiting the flow rate. The flow rate is controlled by the valve positions of the three inlet valves EV8611JT, EV8611CD and EV8612. Since most of the mass that needs to be cooled is the coils, most of the flow will be through the cooldown valve EV8611CD.

To limit the cooldown stresses generated we will limit the temperature differentials in the magnet. Each coil has two temperature sensors and they are mounted as a pair so we do not have temperature differences in individual coils. Three temperature differences will be checked and interlocked.

* S\_DT\_MAX\_Percent = Maximum percentage of the allowed values for differential temperatures. These are
  + Temperatures on the C1-C4 Bobbin Assembly at 10K
  + Temperatures of the full 4K cold Mass at 20K
  + Temperatures of the full cold mass (shield and 4K cold mass) at 50K

For details on the calculations for these values see the PID spread sheet (appendix 1)

* There are no alarms on the above signals once the magnet is below 110K

Interlocks will shut the warm and cold mixing valves PV8563W and PV8563C if the DT gets above their Major Alarm Condition and this will require expert intervention to reset the interlocks and resume the cooldown

1. Set up cooldown plots of pertinent signals for
   1. DBX: LL8554CP,PT8565, PT8513T TP8565, TD813S, TP8567, TP8564, TD8522SR, PV8563W, PV8563C, FI8561
   2. Solenoid TST: EV8611CD, EV8611JT, EV8670BY, PV8674, TR8674, TR8672, TR8673, TR8611, PT8620, TR8671,
   3. Solenoid Coil temps:
   4. Solenoid Supports:

1. Check the pressure of the Supercritical helium to the Torus on PT8513T and PT8111 (it is assumed that the Torus is running at 4K) and observe if there is a difference. Choose an offset value big enough to assure that the supply pressure to the Solenoid as read on both PT8565 and PT8513S are below the SC helium supply 0.2-0.3atm
2. Verify the primary supply and return valves for the solenoid, PV8512S and PV8522SR are in manual mode and closed
3. Open PV8522SCD 100% in manual mode
4. Verify that Warm Helium Interface valve MV6031B at ESR to the Purifiers is open (the cryogenics group will assist here and could choose to change to MV6030B and take the flow to the ESR main compressors)
5. Put the shield flow control valve PV8674 in manual mode with a set value of 100%
6. Put the Magnet reservoir flow control valve EV8670BY in manual mode with a set value of 100%
7. Open valves SV8675BY and SV8678CR which allow return flow to the quench header and confirm the dirty gas vent valve SV8678DV is closed
8. Contact the cryogenics group and ask that the 4atm helium supply to Hall B be turned on (open MV6010B and to verify that a warm return path is open MV6031B to purifiers or MV6030B to ESR compressors
9. Verify helium mixing valves in the DBX are closed PV8563C and PV8563W
10. Verify MV8561V is closed and open MV8002 and MV8561 and MV8562. Then verify that PT8561 is at least 3.0 atm
11. Set the differential pressure amount to 0.3 atm by entering 0.3 into variable PV8563\_DP\_OFFSET on the DBX control screen
12. Open EV8611CD in manual mode to 20% and EV8611JT 20% in manual mode
13. Manually open PV8563W to 5%. Check the supply pressure PT8565 to see how it is responding. If it is below 2 atm and above 1.4 atm then make the max of PV8563 5% and the min 5%. Put PV8563W in Normal mode. Slowly increase the max and lower the min while tuning the Warm supply valve PV8563W to control the supply pressure of the mixed helium gas below the Torus supply pressure by 0.2 to 0.3 atm using calculated pressure signal P\_CDHE\_8563W\_S (this signal may need lots of filtering)
14. Put PV8563C in Manual Mode and slowly open it a few percent at a time. Have someone up at the valve to report back when the valve actually moves and once it does quickly throttle it (unless it moves from the first attempt). Make the input TD8513S and the setpoint 290K (or 10K below the average coil temperature). Watch the temperature gradient develop through the magnet.
15. Flow rate can be adjusted by opening EV8611CD in manual mode
16. Watch the magnet reservoir pressure PT8670 and the Solenoid Shield pressure drop SSHLD\_DP. Setup PV8670BY to keep the shield flowing and cooling. To do this the value of the shield pressure drop must be above 0.0 atm. The amount is not clear and as the shield cools the amount of pressure drop to keep flow going through it will decrease. Setup the PID for PV8670BY to keep SSHLD\_DP at 0.1 to start and revisit this as the cooldown proceeds.
17. Setup PV8563C to control on the helium to metal DT HE\_SMETAL\_CD\_DT2 and make the starting value 10K. This will slowly be stepped up as the cooldown gets going and gradients develop and understood
18. Setup PV8563C Max position PID to control on the max percentage allowable of the DT’s specified at 90%
19. With a tight range on the Min and Max position put EV8611CD in Normal mode and tune it to control the flow rate FI8561. A PID on the max position should also be implemented to be sure we do not blow RV8670.
20. Verify that lead flow controllers EV8621A and B are working and that manual valves MV8621A and B are open and setup EV8611JT to control on FI8621A at a set value of 10. This will establish a trickle flow through the lead reservoir.
21. Check both reservoir pressures PT8670 and PT8620. PT8670 should be higher as more flow will be going through that path. Very slightly open EV8612 to establish a bit of flow through this line. A manual position of 10% should be sufficient. The flow will likely be backward, that is from the magnet annulus to the lead reservoir but that is fine.
22. When the coils get below 150K it may be that PV8563C can’t provide enough flow to keep the pressure up. (not its primary function) Thus it may be necessary to put a new PID max control on PV8653 to control it based on PV8563C.POS, this will allow the temperature to continue to cool as the flow through PV865W will be reduced to keep PV8653C from going full open.
23. When the coils get below ~120K PV8563W will be closed and its air supply isolated and 80K helium will flow through the solenoid.
24. When the coils get below 100K the next phase of the cooldown can begin.

**Torus 4K Mass cooldown 100K to 4K**

**PID Group S2**

***Discussion:***

This phase of the cooldown is done with 4K helium. 4K helium flow from the ESR to the DBX will have already been established when cooling the ESMTL, Torus and the Buffer Dewar. There will two distinct phases of this portion of the cooldown. The first will be Cooling and Filling of the Lead Reservoir. This phase will happen very quickly because there is very little mass in the Lead Reservoir. In parallel but much slower will be cooling of the magnet and the magnet reservoir and heat shields.

The general goal is to get the magnet overall to cool quickly below 100K there are two sections to the this magnet. The cold mass (coils and magnet reservoir) and the lead reservoir. Because the lead reservoir can cool and fill quickly we should prioritize its cooling if when completed it can be put on cold return (ie the rest of the system, Torus and Buffer Dewar will be ready or are already on cold return), this way we reduce the load and number of transients that the ESR sees. If nothing is on cold return then cooling all things so that they can go to cold return must be done in parallel and the section above for Un-Park all systems XXXX should be used.

For cooling of the Solenoid Coils the valve EV8611CD is primarily used, but EV8612 may also have a trickle flow and be ready to take over once EV8611CD closes (automatically via PID). EV8611 is normally set up to control on helium level for initial filling cooling, but its maximum position is limited by two things Pressure in the magnet reservoir PT8670 and the temperature of the relief valve plates TC8670\_Min. During cool down we want to avoid blowing the relief valve RV8670.

The lead flow reservoir will be back pressurized by the solenoid warm return valve PV8522SCD to ~1.4 atm in the DBX to allow driving flow to the magnet reservoir through EV8612. As the Lead reservoir starts to collect liquid helium the return from this reservoir will be switched over to Cold return PV8522SR and the flow will go back to the refrigerator. The ice that collected on HX8524 (not a lot compared to the Torus Cooldown) will start to melt and the area below this ambient vaporizer should be roped off. The lead flow controllers will control the lead flow to limit heat load into the reservoir.

To continue the magnet and shield cooldown, liquid helium will be drawn from the lead reservoir and injected at the bottom of the lead reservoir through EV8612. This flow will return to the ambient vaporizer HX8675 through PV8674 and PV8670BY as needed to keep the pressure in the magnet annulus below the pressure in the Lead Reservoir. Flow will be limited to 10 g/s or less depending on available capacity from the End Station Refrigerator and the warming power of HX8675. Flow may also be limited to assure that other Hall B loads (Torus and Buffer Dewar) stay operational if they are needed for ongoing operations. There are no restrictions to the temperature differences or time rate of change of the 4K mass during this process. The only limits on our flow are capacity of the ESR and the Purifier capacity.

To assure that the no warm helium gas mixes into the 4K helium supply, the warm supply will be isolated from the cold supply and its pressure will be vented to 2 atm (below the nominal 3atm 4K helium pressure).

When TD8522SR is between 7 and 8K the process to switch to cold return and away from ambient vaporizer HX8524 can begin. Because all the piping in the Solenoid and in the DBX is cold the switch to cold return can be done fairly easily if the ESR operators agree. The basic method is to first setup PV8522SCD to be a back pressure valve with a setpoint of 1.3atm. Then with EV6721B at ESR open, slowly open PV8522SR fully while watching TD672 and other key refrigerator parameters as well as the supply temperatures to the Torus and Solenoid TD8513T and TD8513S. Once PV7522SCD is fully closed the Solenoid Lead reservoir is on cold return and it can be re-pressurized by settings its control PID to control PT8620 at ~1.6atm to continue to drive flow through the magnet

1. Change Alarm State for HE\_SMETAL\_CD\_DT and DT2 from Minor and Major to No Alarm for these signals.
2. It is assumed that 80K helium gas is flowing to the Solenoid. Close the Warm Gas MV8561 and let pressure PI8561 and PT8563 drop to 1.1atm. Close MV8562 and Supply Control Valve PV8563C. The warm valve PV8563W should have already been closed at the end of the previous 300-100K cooldown phase
3. Watch to see that PT8563 stays less than 1.5atm
4. Verify that the warm return valve from the solenoid PV8522SCD is full open and that cold return valve PV8522SR is closed.
5. **Establish 4K supply flow to the Solenoid** by: setting EV8611JT to 100% in manual and EV8612 to 100% and slowly open PV8512S. Watch the supply flow rate CFI6711B, TD8513S and PT8513S. Use PV8512S in manual mode to keep the flow rate to the solenoid from going above a couple grams/second. (amount that CFI6711B changes)
6. As the Solenoid inlet temperature TR8610 drops the helium gas density will increase and the valve position EV8611JT must be decreased. PV8512S can then be opened to keep it from dropping the pressure. When the temperature at TD8610 is below 6K the PID’s for EV8611JT may be enabled. The primary loop controls the helium level on LL8620SC at 70%. The Min PID loop will keep the JT open enough to keep the U-tube from warming with a set value of ~5.5K so if the level is satisfied and the valve wants to go closed it will be forced to stay slightly open to keep the system flowing and stable. The Max Position Loop for EV8611JT may be controlled on CFI6711B but more likely it will be set in Manual mode with a fixed value.
7. Liquid helium will flow through EV8612 and into the magnet annulus. Temperatures in the Magnet and heat shield will continue to fall. EV8612 can be controlled by CFI60DLP (the ESR dirty line flow rate) or CFI084 (purifier flow) if we are connected to that and there are no other loads or DT/Dt or the magnet reservoir or the vaporizers outlet temperature TP8675A (this would make the most sense and so we should install a sensor here)
8. As the shield cools its pressure drop should decrease as the density of the helium will increase. This should allow PV8670BY to close if it is controlling on the calculated pressure drop SSHLD\_DP
9. As the density of the helium increases it should start to show on the helium level sensor LL8670DP since this sensor measures the pressure difference between the top and bottom of the magnet and since cold helium density is significant when compared to liquid helium.
10. When liquid starts to show up on LL8670SC, EV8611JT can be put on level control

**Steady State Solenoid Operation at 4K**

**PID Group S3**

***Discussion:***

To achieve stable temperature of the Coils will require stable pressure in the Lead reservoir and the Magnet reservoir. The lower the pressure in the magnet reservoir the cooler the coils will run to some point. But if the heat shield warms up it may be better to push more flow through the shields at a cost of running the liquid in the magnet reservoir at a higher pressure. This will lower the heat shield temperature which will have the most dramatic effect on Coil 5 but will help all coils since they are all cooled by conduction of the copper fingers. The first step increasing the pressure is to close the EV8670BY and force all of the boil off of the magnet through the shields. If this is not enough we can turn on heaters in the Magnet Reservoir circuit HTR8672 and control them on the pressure in the circuit or the shield outlet temperature.

A small amount (< 1g/s) of the 4K helium gas generated in the Solenoid is used to cool the Vapor Cooled Leads (VCL’s). Vapor cooled leads are designed to transmit the high current (2500A) from water cooled buss bars to the superconductor of the magnet. Helium “vapor” starts at 4K and warms as it flows up the leads and warms due to absorbing heat from the I2R loss of the conducting filaments in the lead. 400Watt heaters HTR8621A and HTR8621B will help to limit the ice ball size. After those heaters are ceramic breaks that have helium on the inside and air on the outside. There are male bayonets with Teflon circulation flow dampers inside to minimize the cooling of the ceramics. The flow then proceeds through vacuum insulated lines that then connect to ambient vaporizers that are designed to ice up on the outside and warm the gas to room temperature. That warm gas then goes through the flow controllers, one for each lead. Flow is controlled based on mass flow and this mass flow is a pre-programed function of current in the magnet, XXslpm (0.XXg/s) at no current and XXslpm (0.XXg/s) at full XXXX amps. With the proper amount of flow, the heat load to the 4K system is minimized and the lead is protected from overheating. If the lead reservoir is not stable because the heat loads of the solenoid and the U-tubes are too low or if there is not enough boil off gas to cool the vapor current leads, we can activate heater HTR8620 to increase the pressure in the reservoir. We can make the control parameter of this heater the position of the cold return valve PV8522SR and require it to be some percent open while regulating the pressure in the Lead reservoir at about 1.3 atm.

1. As the 4K Lead Reservoir (1.2 Atm Tank) is filling, the PID for controlling the liquid level for the primary supply valve EV8611JT can be setup and tuned. This will be a very slow loop and the valve will only need changes every few minutes (sample time long).
2. Flow from this reservoir will return cold via the Solenoid cold return valve PV8522SR. This valve will be set up to control the pressure liquid helium in 1.2 atmosphere helium reservoir in the magnet the setpoint will likely be 1.2 to 1.35 atm. If the pressure PI8620 is not enough above the warm return pressure CPI603QB, the lead flow controllers will go full open and if they still can’t provide enough flow the leads may warm and the magnet will ramp down (if energized).
3. The lead flow control valves EV8621A and EV8621B should be enabled and their flow rate set point should be set by the PLC.
4. Heaters on the lead exhaust will need to be set up to control on a temperature on the lead. Enable and tune setpoints and PID loops for HTR8121A and HTR8121B.
5. Monitor Coil temperatures and check the system stability.
6. Tune EV8612 as needed to control the helium level in the magnet reservoir
7. Once the magnet has soaked at temperature for several hours (all temperatures are changing less than 0.05K) One should see if any fine tuning of the PID’s is advantageous

NOTE: LL8670SC only measures the amount of liquid in the Magnet Reservoir while LL8670DP measures the amount of liquid in the magnet and reservoir combined and the volume per height is not linear. The nominal values for LL8670DP (based on ~0-16” of H2O) are:

~14% Magnet Annulus is empty

~40% Magnet Annulus is full

~85% piping to reservoir is full but Reservoir is empty

96% helium is at the bottom of magnet return pipe and the thermosiphon stops and the magnet the return pipe to the shield supply and magnet cooldown line

NOTE: the distance from the bottom of the Annulus to the top of the reservoir is ~128” with helium with a density of 125g/l this gives a pressure head of 16” of H20 but the transducer is a 0-25” of water so the value of LL8670DP must take this (and the density of 4K gas helium) into account to give proper readings