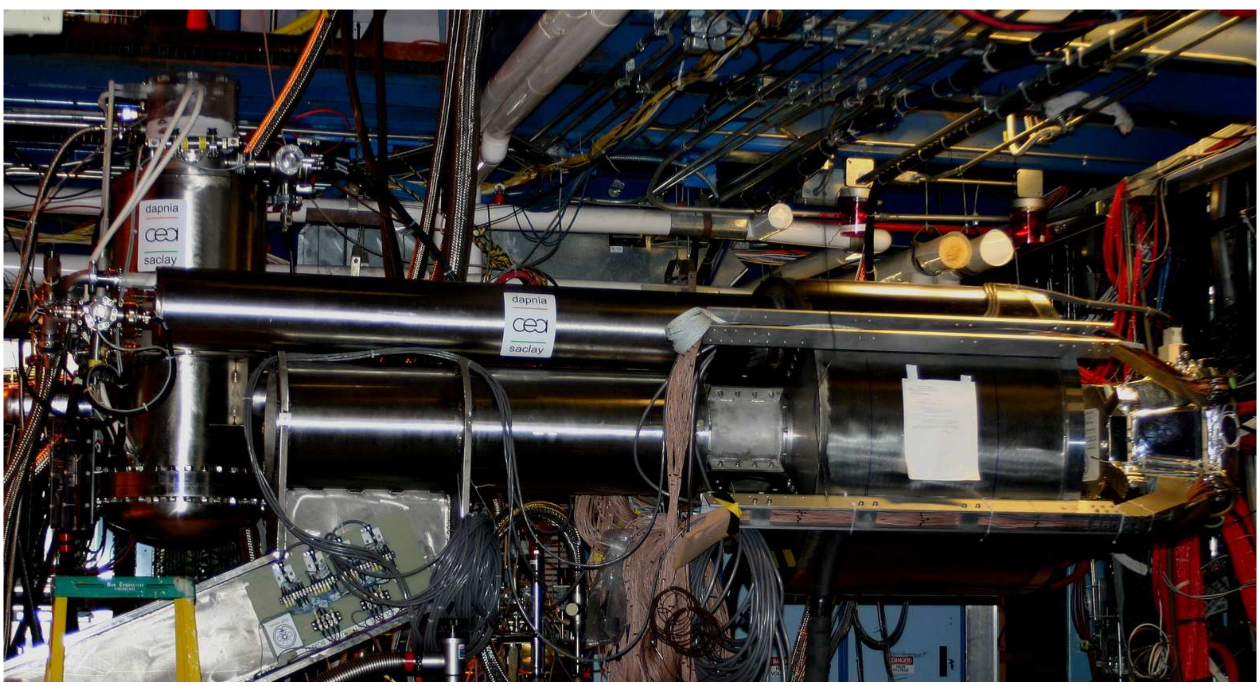
CLAS DVCS safety manual



CLAS-DVCS

Section 1.01 System description.

The CLAS-DVCS magnet is a superconductive magnet, designed and built in Saclay, to be used in JLab's Hall B CLAS spectrometer on the dedicated DVCS experiment.

The magnet provides a 4.7 T nominal field at its center point (4.5 T at the center of the target) and the fringe field must be such that it does not affect CLAS main torus field.

An additive superconductive compensation coil ensures that external magnetic shielding. For safety reasons, both magnets are connected in series to the PSU and cannot be disconnected to guarantee a permanent protection whatever the value of the current is. To reach the requested nominal field, the maximum usable current is 550 A.

The magnet has been designed to work in liquid helium bath conditions at a temperature set between 4.2 and 4.4 K. The total amount of needed liquid helium is 70litres.
The main coil, the most critical one with a 6.9 T peak field at the wire level, is completely immersed in liquid Helium. Its central part is cooled by means of a dedicated cooling circuit embedded in the mandrel. The compensation coil is only immersed to 80% level at the low point of the filling regulation but this does not affect its operation.

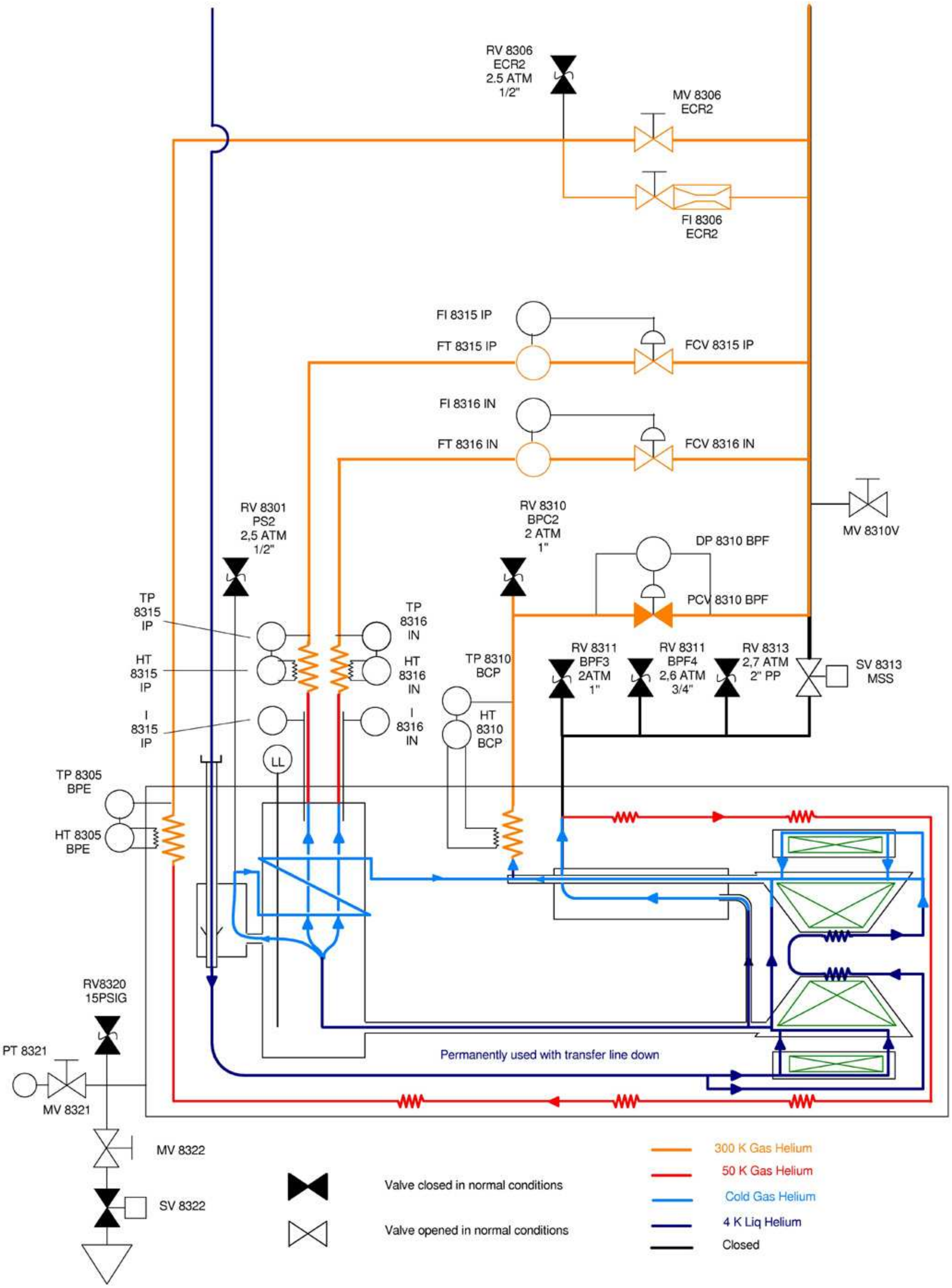
Concerning the fluids, there are two main liquid Helium reservoirs. The larger one is the magnet's (65 litres). The second one is located at the lower part of the current leads, 2 m away at the rear of the magnet. These two volumes are linked together in liquid phase through the busbar outcoming tube, and in vapor phase through the pressure balancing tube. As far as safety is concerned, one may consider therefore these two volumes as a single one. Nevertheless independent valves are monitoring both volumes to avoid useless liquid transfers in case of fast evaporation and to keep a cold source at the bottom of the current leads during the current ramping down sequence.

The magnet unloading circuit has been particularly studied as it deals with 93% of the Helium mass and as it may provide a 690 kjoules heat source in case of quench.

The magnet transition is a significant probability hazard. Therefore it had to be dealt with in a way minimizing possible consequences as far as re-operating the magnet is concerned. This situation is described in an annex to this document.

The most exceptional and dangerous situation remains the insulation vacuum breakdown. In that case, extra heat quantities are added due to the natural convection of the air which warms up the magnet cold parts while it quenches. The circuits and valves have been worked out to handle this exceptional situation so to keep the mechanical parts and the structure of the magnet unaffected.

Section 1.02 Installation schematic



Section 1.03 Magnet dimensions

The main dimensions of the CLAS-DVCS magnet are :

Aperture diameter	270 mm
External diameter	910 mm
Magnet length	910 mm
Total length	2776 mm
Total height	1661 mm
Total width	1143 mm
Cold mass at 4 K	700 kg
Cold mass at 50 K	200 kg
Total mass	1500 kg
Liquid helium capacity	65 litres

Section 1.04 Consumption of the magnet at 4,2 Kelvin.

Mass flow and Energy approach without current.

Cryo-modules	Mass flow g/s	Liq. flow @ 4,2 K l/h	P @ 4,2 K Watts	Flow @ 300K l/mn	P @ 300K Watts
Current leads at 4.2 K :	0,724	19,41	13,86		
Conduction and measurements	0,221	5,94	4,24		
Transfert line and outflows	0,026	0,70	0,50		
Sum of the energies and flow needed before powering					
Total power @ 4,2 K - minimal level	0,522	14,00	10,00	154,16	777,78
Total power @ 4,2 K - nominal level	0,971	26,05	18,60	286,82	1447,05
Power needed to maintain 50 K	0,077	*2,06*	*1,47*	*22,64*	*114,25*

Mass flow and Energy approach in nominal conditions.

Cryo-modules	Mass flow g/s	Liq. flow @ 4,2 K l/h	P @ 4,2 K Watts	Flow @ 300K l/mn	P @ 300K Watts
Current leads at 4.2 K :	0,996	26,71	19,08		
Conduction and measurements	0,221	5,94	4,24		
Transfert line and outflows	0,261	7,00	5,00		
Sum of the energies and flow needed to powering					
Total power @ 4,2 K - 0 amp	1,232	33,05	23,61	363,95	1836,16
Total power @ 4,2 K - 534 amps	1,478	39,65	28,32	436,66	2202,99
Power needed to maintain 50 K	0,077	*2,06*	*1,47*	*22,64*	*114,25*

Working conditions	Mass flow g/s	Liq. flow @ 4,2 K l/h	P @ 4,2 K Watts	Flow @ 300K l/mn	P @ 300K Watts
Sum of the energies and flow needed to powering					
	1,478	39,65	28,32		
Exit for one current lead at 4.2 K :	0,124			36,77	185,46
Exit for the 50 K shielding :	0,410			121,04	610,58
Exit for the PBF line :	0,820			242,08	1221,15

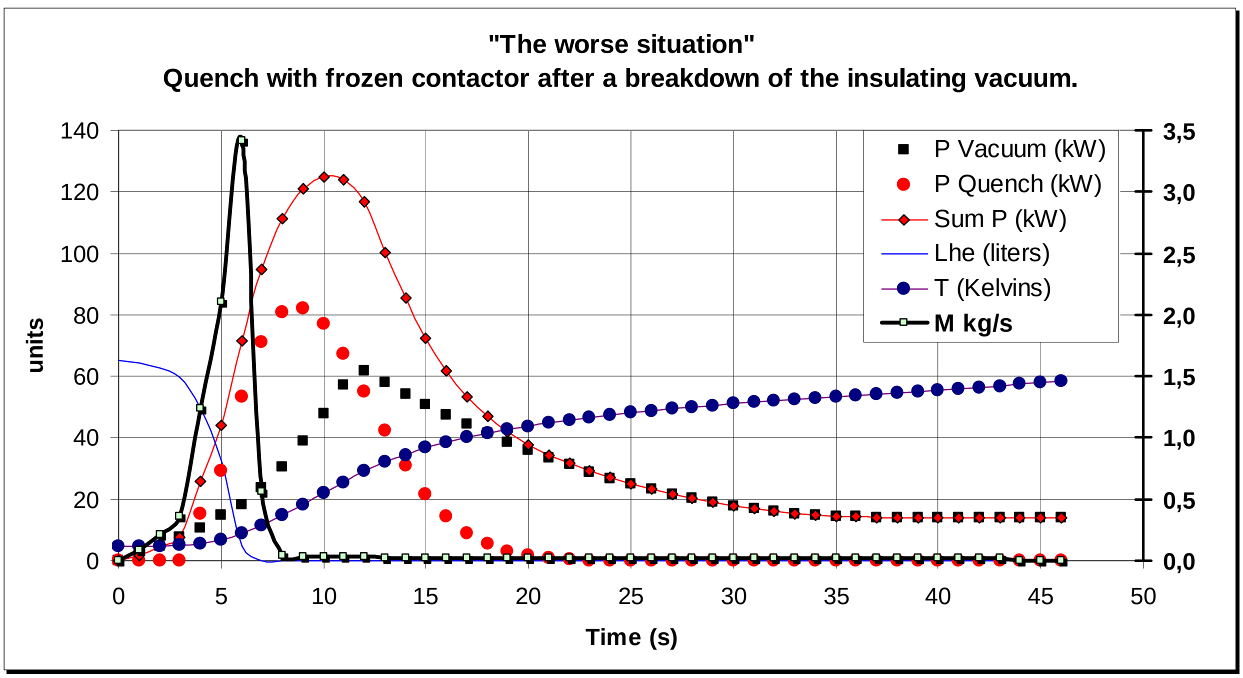
The consumption of the magnet is very dependant on the section of the niobium tin bars which have been welded under the current leads. In fact, the whole current leads plus niobium tin bars have a 2 cm² cross section of copper which makes a big conductance between liquid helium interface and warm temperature at the top of the cryostat. The consequences are that the current leads are very safe in any conditions but the energetic cost is higher than expected due to the short capacity of the current leads to exchange with the helium gas flow.

In these conditions it is impossible to keep the magnet at cold temperature during more than one hour on itself, and it is not possible to keep the current in the magnet more than a few minutes without transfer. So, with the 65 liters per hour consumption, it is now necessary to make a permanent transfer to the magnet to run in safe conditions.

We will retain that it is also possible to keep the magnet at cold temperature with a reduced consumption of # 15 liters per hour. In this case, it will take half an hour to put the level at the nominal state to power the coil.

Section 1.05 Valves calculation.

The worst foreseen situation is the insulation vacuum breakdown while the coil is powered at 534 Amps , delivering nominal field.



According to Lehmann and Zhan [1], one estimates that the dissipated power in the cryostat would then reach 2 W/cm^2 in 5 seconds. Considering that this heat addition spreads itself homogeneously on the whole 4 K surface, there will be 60 kW spread on the 3 m^2 surface at 4.2 K, to which are added 10 kW brought by the quench.

On the curves shown above, it can be seen that the heat addition due to the insulation breakdown predates clearly the quench triggering which occurs when the

[1] Safety aspects for the LHe cryostats and the transport containers (1978 IPC Business Press)

magnet temperature rises up. The cryostat discharge time is roughly equal to the establishing time of the evaporation power peak, which sets the flow to 2.4 kg/s under a pessimistic hypothesis

On the schematic display (section 1.02 page 3), one can see that the magnet has two discharge circuits of the same dimensions mounted in parallel to handle quenches and situations as described above.

Cold exhaust from the magnet to the phase's separator.

				RV BPF3 or RV BPF4	
			S.I.	U.S.	U.S.
Capacity liters of LHe :	65,0	**Mass Flow**	**1,169**	9274,033	lbs/hr
Density at 4,487 bar – kg/m3	135,56	Isentropic Coef.		1,630	
Mass – kg	8,8	C Constant		375,000	
Latent heat en J/kg :	19160,0	Discharge Coef.		0,500	
Potential Energy - J :	168825,5	Amount pressure	348764,0	50,571	psi a
Potential Power - W :	125989,2	Mass mol.	0,004	4,003	g/mol
Exchange surface - cm² :	30000,0	Temperature	7,0	12,930	Ɍ
Potentiel evaporation after 1,34 s – W :	60000,0	Compressibility	1,0	1,000	
The section of the relief valve should be :				1,758	sq in
		in mm²	1134		
The diameter should be :		in mm	38		

Time delay to emptying the cryostat	**5,1**	**s**	**M_{total} =**	**2,337**	**kg/s**
Absolute pressure in bars	**3,487**	**b**			

Warm exhaust from the magnet to the phase's separator.

				RV BPC2	
			S.I.	U.S.	U.S.
Capacity liters of LHe :	65,0	**Mass Flow**	**1,168**	9273,255	lbs/hr
Density at 4,487 bar – kg/m3	135,6	Isentropic Coef.		1,630	
Mass – kg	8,8	C Constant		375,000	
Latent heat en J/kg :	19160,0	Discharge Coef.		0,500	
Potential Energy - J :	168825,5	Amount pressure	348764,0	50,571	psi a
Potential Power - W :	125989,2	Mass mol.	0,004	4,003	g/mol
Exchange surface - cm² :	30000,0	Temperature	7,0	12,930	Ɍ
Potentiel evaporation after 1,34 s – W :	60000,0	Compressibility	1,0	1,000	
The section of the relief valve should be :				1,758	sq in
		in mm²	1134		
The diameter should be :		in mm	38		

One of this circuit is a cold line (38 mm inner diameter) connected without any loss of pressure to the valves SV MSS, RV BPF3 and RV BPF4. The second circuit is equipped with heater of very low pressure loss which would handle the 2.5 kg/s flow. We consider that the vapours exit in parallel through both equivalent circuits according to the parameters calculated in the tables above.

The important data to remember for the calculation of this type of incident are a maximum pressure of 4.5 bars and a time of 5 seconds to discharge the cryostat.

Therefore, the cryogenic circuit is protected through valves the characteristics of which are shown on the table below.

Name	Absolute opening pressure	Reference CIRCLE SEAL	Air flow at opening at 300 K	Helium flow at 300 K	Helium flow at 300 K
RV BPC2	2,0 bars	K520T18MP15	4480 l /mn	200 l/s	3,3 kg/s
RV BPF3	2,0 bars	K520T18MP15	4480 l /mn	200 l/s	3,3 kg/s
RV BPF4	2,7 bars	K520T18MP25	5320 l /mn	238 l/s	3,9 Kg/s

One has to consider, even if this is very unlikely to imagine, that one of the two circuits gets accidentally clogged. In that case, only one of the two exit circuits would work :

Cold exhaust from the magnet to the phase's separator.

				SV MSS	
			S.I.	U.S.	U.S.
Capacity liters of LHe :	65,0	**Mass Flow**	**2,337**	18547,287	lbs/hr
Density at 4,487 bar – kg/m3	144,70	Isentropic Coef.		1,630	
Mass – kg	9,4	C Constant		375,000	
Latent heat en J/kg :	19160,0	Discharge Coef.		0,500	
Potential Energy - J :	180207,4	Amount pressure	697470,9	101,133	psi a
Potential Power - W :	134483,2	Mass mol.	0,004	4,003	g/mol
Exchange surface - cm² :	30000,0	Temperature	7,0	12,930	℞
Potential evaporation after 1,34 s – W :	60000,0	Compressibility	1,0	1,000	
The section of the relief valve should be :				1,758	**sq in**
		in mm²	1134		
The diameter should be :		in mm	38		

Time delay to emptying the cryostat	**5,4**	**s**
Absolute pressure in bars	**6,974**	**b**

The maximum pressure would then reach 8 bars in a nearly identical discharge time. To face this highly improbable situation, 6 bars outburst disks (40 mm in diameter opening) are set on both circuits.

These data are the most pessimistic ones and are used to specify the maxima characteristics to handle in case of passive safety (without current and without air pressure)

Normal running of the equipment

Section 1.06 Prescriptions for carrying and setting the magnet in CLAS.

It is mandatory to conform to the conditions of transport and of handling described in the mechanical calculation, in particular to the conditions expressed in chapter 8 of that very note.

Notice : It is recommended to plug the transfer line before entering to CLAS. It is highly recommended to verify the clearance with the plugs at the top of the magnet.

Section 1.07 Connections to the MSS and the instrumentation racks

- At level 3, check that the two racks are disconnected from the mains. At level 2 check that the Danfysik PSU is disconnected too.
- Connect the cooling water pipe to the the dedicated Danfysik PSU circuits (same for vacuum pumping unit in case water is needed).
- Using a multimeter tuned to the highest sensitivity, check that both current leads are not shorted to the ground.
- Measure the value of the coil resistor.
- Connect power cables between the Danfysik PSU and the current leads.
- Connect voltage measurements.
- Check that none of the temperature diagnostic measurements wires is shorted to the ground or to the coil voltage measurement wire.
- Connect instrumentation cables.
- Connect pressurized air on the valves.
- Connect helium circuits and flush (at least twice the cryostat volume, which is about 180 litres.
- Ground the magnet vacuum vessel.

Section 1.08 Vacuum setting of the magnet

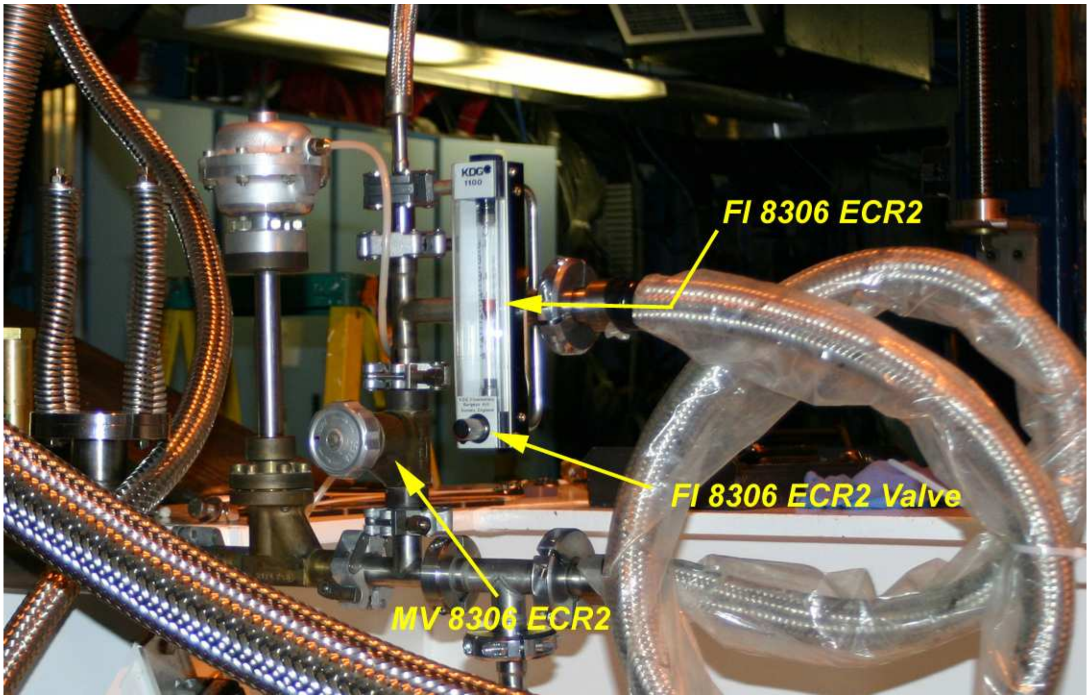
- Check that the relief valve (RV8320) is correctly set (joint).
- Open MV8322 and SV8322 valves.
- Start pumping.
- Keep pumping until minimal pressure reads 10^{-5} mbar.

Section 1.09 Setting of the S3-P3 key to control the FV MSS valve

- The use of this key should be reserved to experts only.
- During cooling down period, it is possible to control manually the FV MSS valve. To obtain a total control of FV MSS it is necessary to disconnect the J8 connector of the lower unit of the MSS rack. In this case, the MSS-Valve would be opened when key is set position #1 and closed when key is set to # 0.
- Attention : This use of FV MSS should be reserved only for cryogenics and couldn't be extended when the magnet is filled up with liquid helium.
- As soon as possible, when the magnet is cold and the MSS is connected to the magnet, the J8 cable should be connected again (on the MSS panel). WARNING : In this case, the FV MSS logics gets inversed and the valve is forced to be closed in position # 1 of the key.
- **IN ANY CASE when the magnet is powered the Key S3-P3 should be on #0 and the MSS should control the opening of this valve.**
- So it is important to remember that this key is normally set to #0 and could be used during stand by situations to force the valve closed.

Section 1.10 Magnet cooling down operations

- To cool down the magnet, the designed pipe in use is reached when the siphon line is fully plugged into its bayonet. This "low" circuit will distribute the cold incoming gas in all parts of the magnet.
- To feed helium in, opening the EV 8215 from hall B Epics panel at 50 %.
- Open completely MV8306 ECR2 to enable gas circulation in the shield and adjust the FI 8306 ECR2 valve to keep the indicator in the middle range.

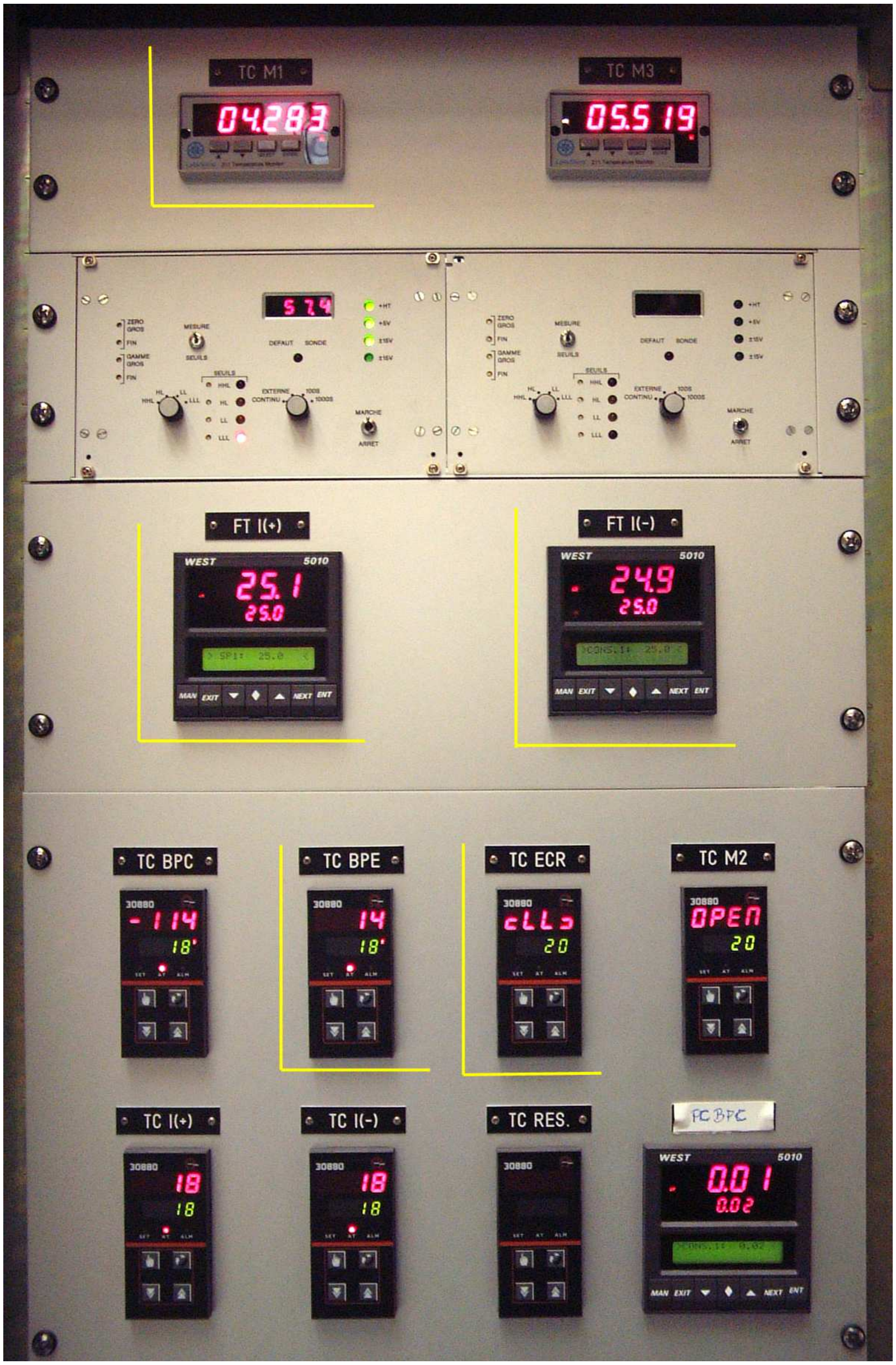


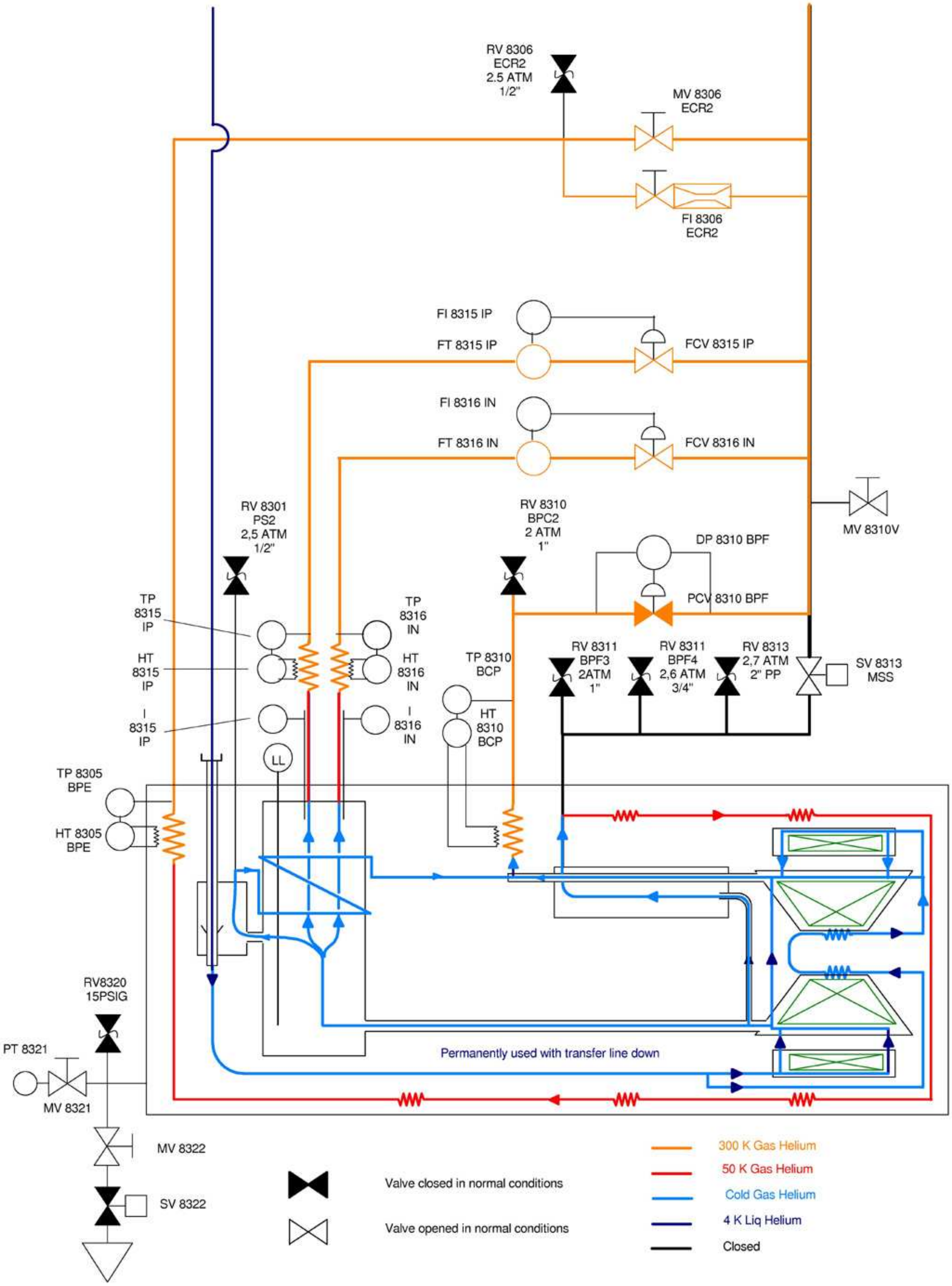
Tune flows out coming of the current leads on FT I+ and FT I-, which are controlling FCV 8315 and FCV 8316, in a way to balance the gas circulation in PC BPF towards the recovery line. DP 8310 BPF would be used to decrease the pressure in the magnet and allow easy flowing of Helium.

But during the cooling down, as long as the temperature of the magnet is higher than 20 K on TC M1 it is highly recommended to keep high pressure in the cryostat to cool down the shielding. TC ECR gives the temperature of the shielding and TC BPE gives the temperature of the heater for the shielding. It would be, at least, necessary to decrease pressure in PC BPF and to reduce gradually the flow in the MV 8306 ECR2 to not freeze TC BPE.

- The flows should be tuned so that the cooling rate of the magnet is limited to 5 K per hour. Under those conditions, the magnet should be cold and filled up in about two days. 600 liters of liquid Helium are needed.

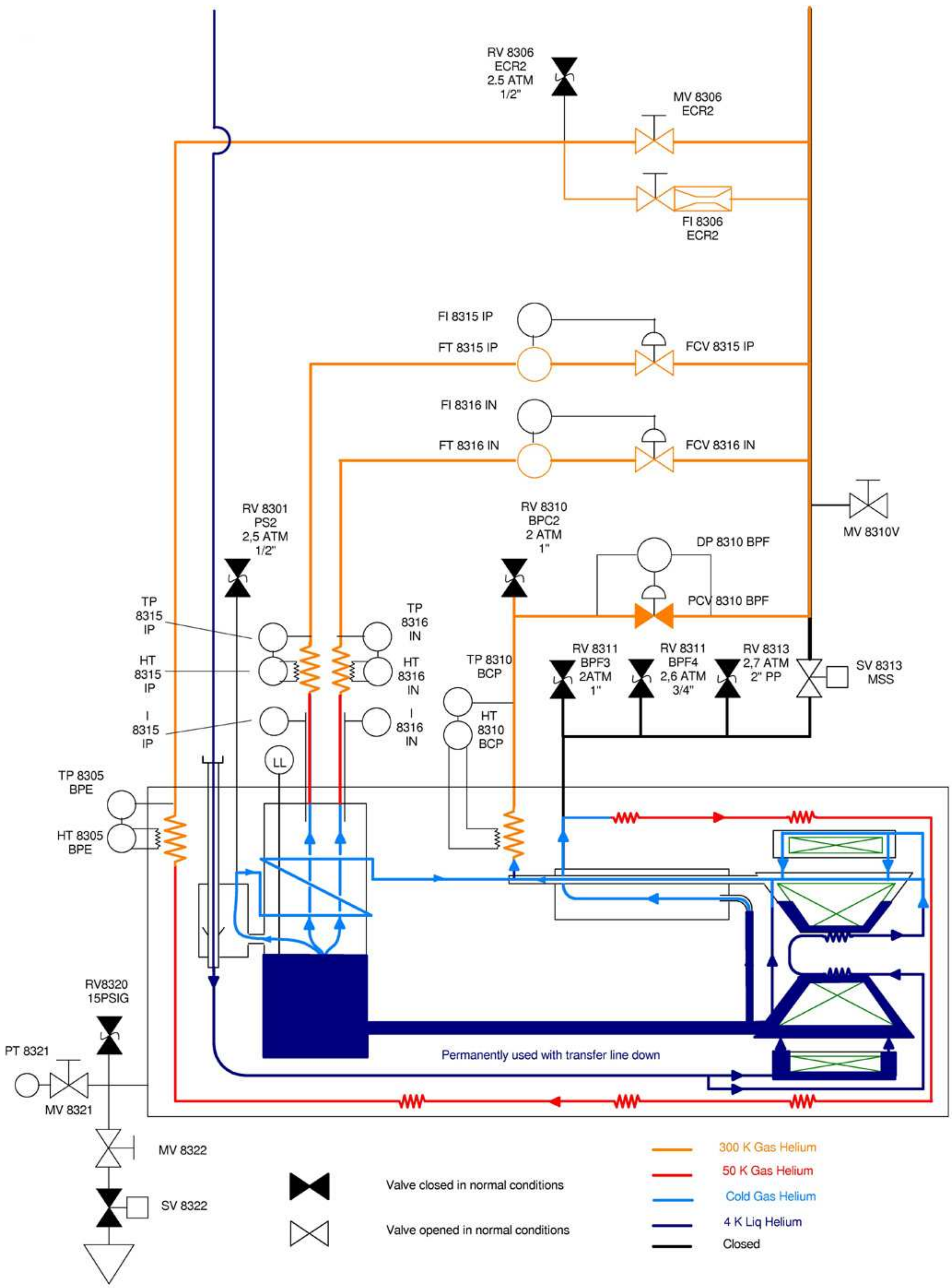
  [0.05 < set point for PC BPF < 0.10] and [5 < set point for FT I+ and FT I- < 7] are recommended, during the cooling down, to not freeze the current leads.


TC M1
TC M3
FT I(+)
FT I(-)
TC BPC
TC BPE
TC ECR
TC M2
TC I(+)
TC I(-)
TC RES.
FC BPC


RV 8306
ECR2
2.5 ATM
1/2"
MV 8306
ECR2
FI 8306
ECR2
FI 8315 IP
FT 8315 IP
FCV 8315 IP
FI 8316 IN
FT 8316 IN
FCV 8316 IN
MV 8310V
RV 8301
PS2
2,5 ATM
1/2"
RV 8310
BPC2
2 ATM
1"
DP 8310 BPF
PCV 8310 BPF
TP
8315
IP
HT
8315
IP
I
8315
IP
TP
8316
IN
HT
8316
IN
I
8316
IN
TP 8310
BCP
HT
8310
BCP
RV 8311
BPF3
2ATM
1"
RV 8311
BPF4
2,6 ATM
3/4"
RV 8313
2,7 ATM
2" PP
SV 8313
MSS
TP 8305
BPE
HT 8305
BPE
LL
RV8320
15PSIG
PT 8321
MV 8321
MV 8322
SV 8322
Permanently used with transfer line down
Valve closed in normal conditions
Valve opened in normal conditions
300 K Gas Helium
50 K Gas Helium
Cold Gas Helium
4 K Liq Helium
Closed

Section 1.11 Magnet kept at nominal cold level

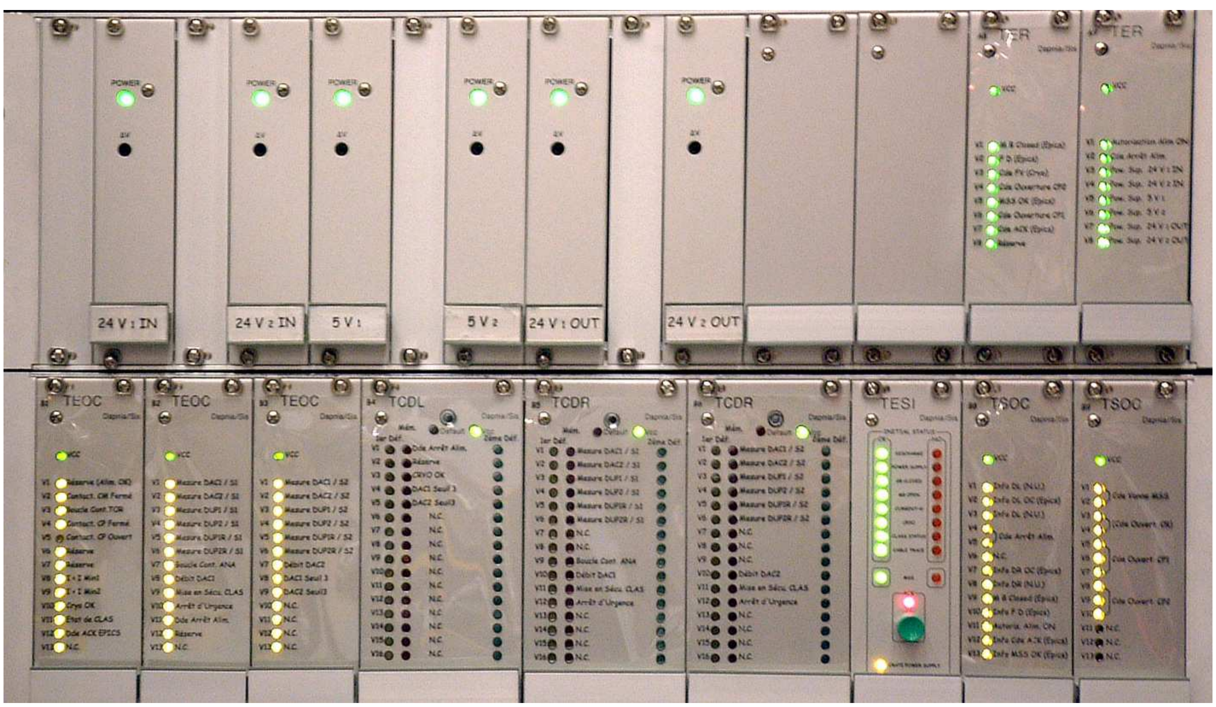
- The siphon must be kept **fully** plugged down.
- EV 8215 is opened in the range 55 % – 65 % according to the ESR status.
- MV 8306 is opened to ¼ of a turn, the FI 8306 ECR2 flowmeter is set to have a 0.6 flow.
- Ft I+ and Ft I- (instrumentation rack) are set above 20 l/mn to keep magnet filled up.
- DP 8310 BPF is set to 0.04 / 0.05 (for 50 mbars) in running conditions.
- Check the level on the LL 8301. It should be around 80 %. If not increase FT I+ and FT I- from 20 to 30 maximum. If it doesn't work it would be necessary to increase the EV 8215.



RV 8306
ECR2
2.5 ATM
1/2"
MV 8306
ECR2
FI 8306
ECR2
FI 8315 IP
FT 8315 IP
FCV 8315 IP
FI 8316 IN
FT 8316 IN
FCV 8316 IN
MV 8310V
RV 8301
PS2
2,5 ATM
1/2"
RV 8310
BPC2
2 ATM
1"
DP 8310 BPF
PCV 8310 BPF
TP
8315
IP
TP
8316
IN
HT
8315
IP
HT
8316
IN
TP 8310
BCP
RV 8311
BPF3
2ATM
1"
RV 8311
BPF4
2,6 ATM
3/4"
RV 8313
2,7 ATM
2" PP
SV 8313
MSS
I
8315
IP
I
8316
IN
HT
8310
BCP
LL
TP 8305
BPE
HT 8305
BPE
RV8320
15PSIG
PT 8321
MV 8321
Permanently used with transfer line down
MV 8322
SV 8322
Valve closed in normal conditions
Valve opened in normal conditions
300 K Gas Helium
50 K Gas Helium
Cold Gas Helium
4 K Liq Helium
Closed

Section 1.12 Powering of the magnet

- Check the level on the LL 8301. It should be between 80 % and 95 % never more.
- Increase FT I+ and FT I- from 30 to 40 maximum. If it doesn't work it would be necessary to increase the EV 8215.
- When 80 % are reached, the CRYO OK flag is green on the MSS rack.
- It is necessary, if everything seems to be OK and if the power supply is on, to acknowledge the ACK button on the MSS - TESI board.
- At this time the PSU is powered but not ON, you should have a default on the power supply because you have had a small voltage which triggered the MSS !
- To inhibit this default two operators are needed.
- One at the fourth floor will push the MSS' ACK button while the other, at the third floor, switches ON the PSU. Sometimes it is necessary to repeat this operation.
- In any case, when the PSU is ON the MSS' ACK button will be released and you will have the MSS OK light. Every thing will be on the MSS like the picture below.



- Now all the PSU controls will be available whether from PSU control panel or from the EPICS control panel.

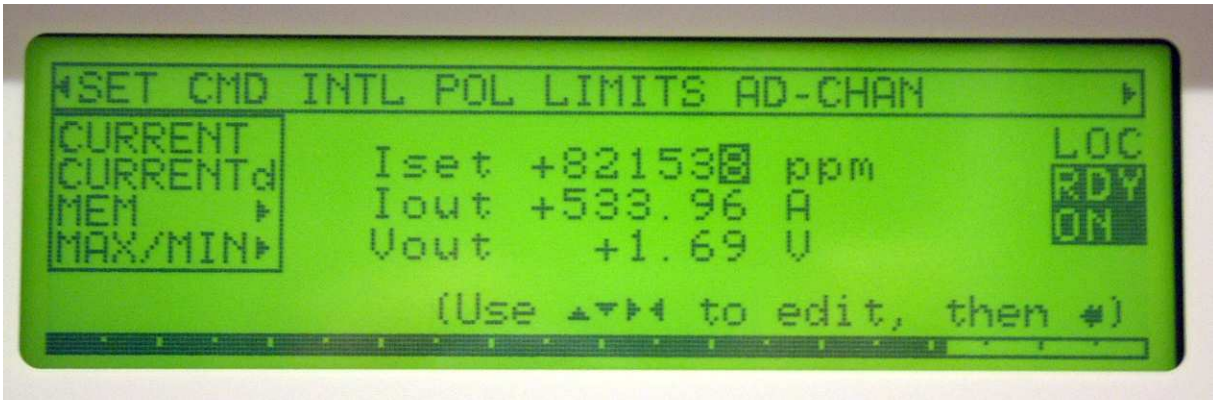
We will describe here only the PSU panel controls and the principles to power up the magnet.

- The main principles are to respect 50 amps steps (77000 ppm) in any way and to conform to ramp up or ramp down rates as following.
- It is very important to wait a few minutes at each step to let the voltage decrease. LdI / dt should reach zero before the next step.
- During the ramps (up or down) it is possible that the voltage of LdI / dt overcomes the threshold value of the MSS. In this case, it will trigger a slow discharge followed with a fast discharge. The solution is to decrease the rate for this step.

Remark : In PSU Danfysik the current unit is expressed in ppm of 650 amps and the rates are expressed in 1/255 of one amp per second.

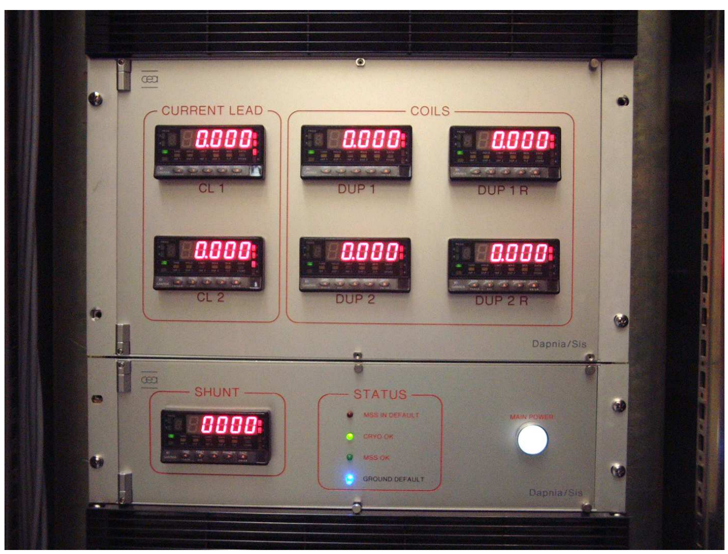
Current	**Current in ppm**	**Rate (Slew rate in Danfysik PSU menu)**
0 to 400 amps	000000 to 615385 ppm	40
400 to 450 amps	615385 to 692308 ppm	35
450 to 500 amps	692308 to 769231 ppm	30
500 to 534 amps	769231 to 821538 ppm	25

- All the controls are monitored from the circular touch panel and the two main menus to activate are the DA-CHAN to control the rate and the SET to control the current. According to the instructions of each menu, it is easy to manipulate.
- Warning the setting of the current value operates immediately without validation.
- It is not advised to change the “slew rate” during a ramp up or a ramp down.



Danfysik control panel at the nominal current. Remark : Ready appears when the value is 99% of the set value.

View of the active panels of the PSU. The lower rack is the power unit and the upper one is the control panel.



View of the voltmeters of the MSS. Remark : CL1 and CL2 stay at zero as long as the current has not reached 100 amps. The shunt value is roughly the current. DUP 1R and DUP 2R are the redundancies of DUP 1 and DUP 2.

Section 1.13 What are the triggers of the MSS.

- LdI/dt higher than the set threshold (see the MSS control panel),
- The level of helium in the magnet too low (Cryo OK disappeared in the first column),
- The flow in the current leads too small (Cryo OK disappeared in the first column),
- Discontinuity of one or more signals (“Cable Trace”),
- A Default due to the PSU (Water missing … see the PSU panel)
- The CLAS Status interlock.
- Emergency magnet interlock.

Each of these signals triggers a fast discharge. The ground default is only given as an indicator. Warning, this ground default should be taken care of as its showing means serious problem on the magnet.

Section 1.14 Stand by at cold temperature

The scheme is the same as section 2.05 but the tunings are different to minimize the helium consumption and to reduce freeze on the current leads.

DP 8310 BPF is set to 0.1 in stand by position

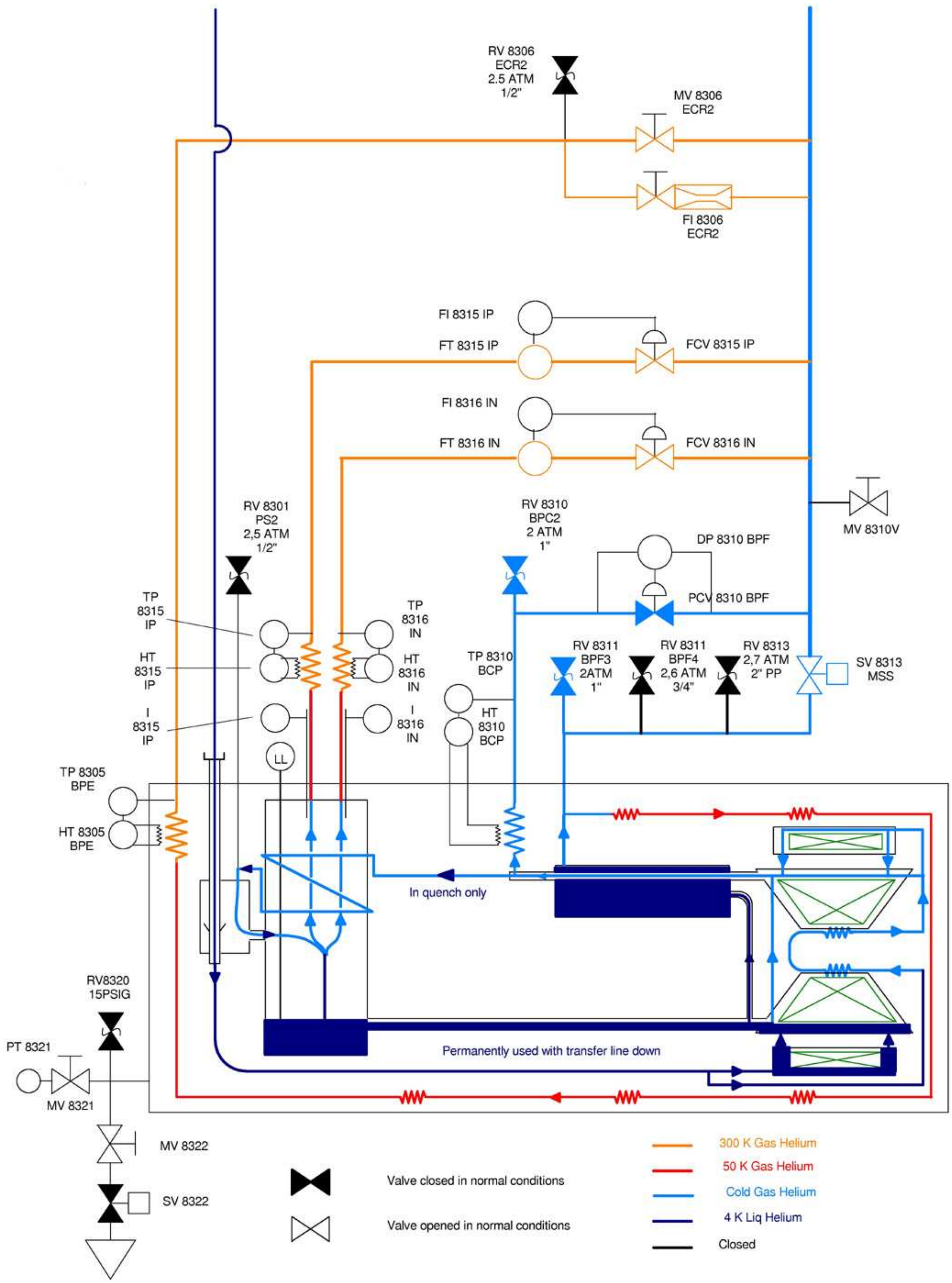
Ft I+ and Ft I- (instrumentation rack) are set between 5 and 10 l/mn to keep liquid in the magnet but not at the high level

Section 1.15 Quench and quench recovery.

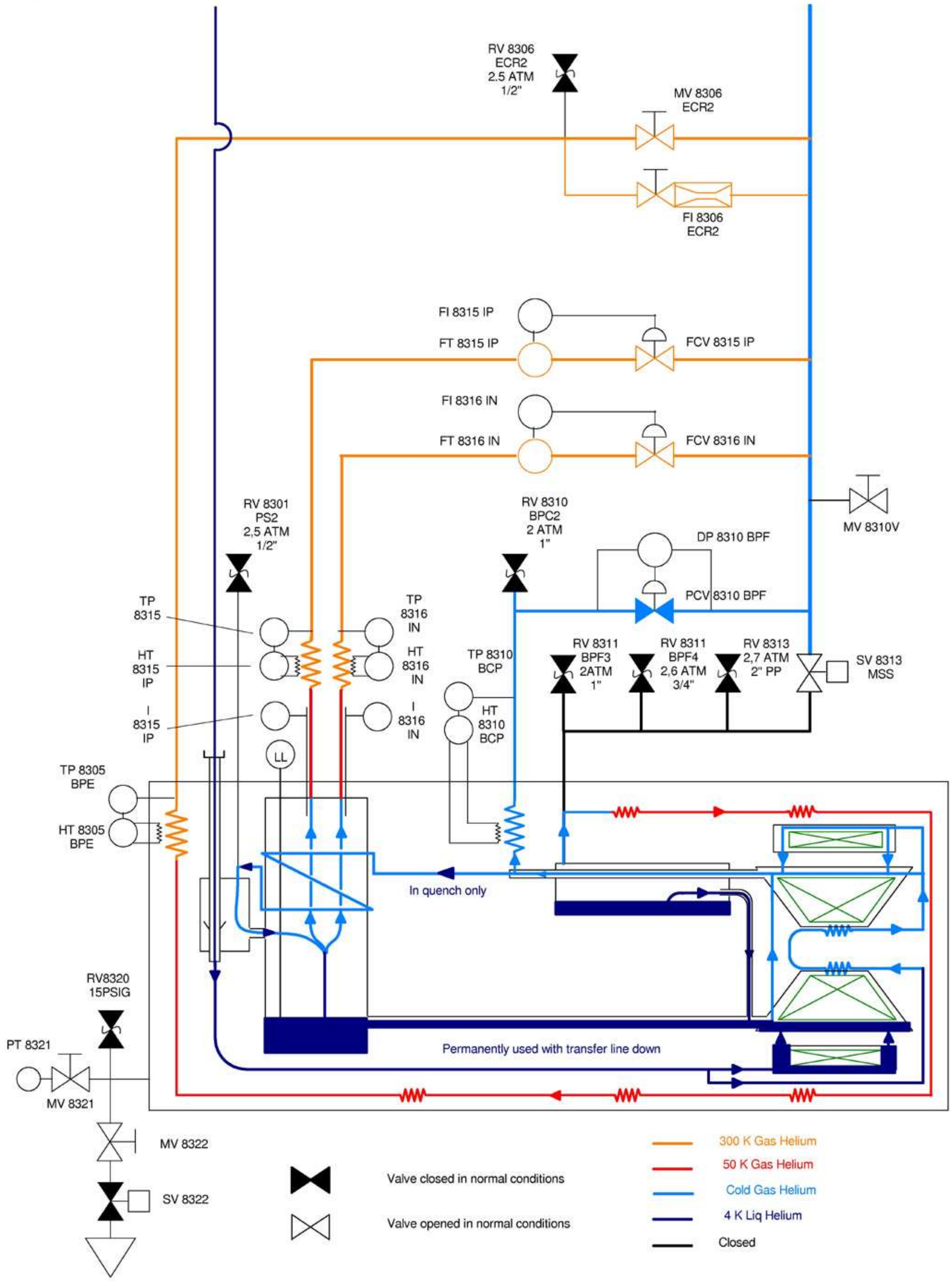
In case of quench the following steps will happen :

- Opening of the breaker and shut down of the PSU.
- Opening of the SV 8313 MSS valve (at the same time)
- The temperature in the magnet increases to about 40 K in 20 mn.

- During the increase of the temperature, the pressure will increase to about 1.5 atm and the excess of helium would be regularly stored in the upper cryostat as long as pressure in the coil is higher than recovery line pressure. It would be, at least, necessary to close the SV 8313 MSS to transfer back the helium in the coil (see section 2.04).
- The delay before refilling the magnet would be between 15 to 30 mn. When the temperature TC M1 stops to warm up, it is possible to cool down the coil. Half' an hour would be necessary to reach 4,3 K and it takes about the same time to fill the cryostat.



Quench schematic.



Quench recovery schematic.