Cryocooler XV User Manual

FMB Oxford Limited
Unit 1-4 Ferry Mills
Osney Mead, Oxford
Oxon OX2 0ES, UK
Tel: +44 (0)1865 320300
Fax: +44 (0)1865 320301
http://www.fmb-oxford.com

Contents

1. General Health and Safety Information

The user of this system is required to be aware of potential hazards which exist in and around equipment of this type and of the ways of avoiding possible injury and equipment damage which may result from inappropriate ways of working.

A description of such potential hazards and how to avoid them is given in

Appendix 1: Health and Safety.

If the equipment is used in a manner not specified in the User Manual, the protection provided by the equipment may be impaired.

Cautions will be highlighted throughout the manual to avoid equipment damage. This manual adopts the following convention:

WARNING

Indicates a potential hazard which may result in injury or death.

CAUTION

Indicates a potential hazard which may result in damage to equipment.

WARNING

The cryocooler uses Liquid Nitrogen to operate.

All operators should be fully trained in the safe handling of liquid nitrogen before working with this equipment.

1.1 Document Scope

This manual applies to the Cryocooler XV manufactured by FMB Oxford for use on monochromators or equivalent equipment.

1.2 How to Use This Manual

All personnel who are likely to operate the system or encounter any of the system components should read

Appendix 1: Health and Safety. This provides basic information aimed at highlighting the safety hazards associated with the equipment.

The purpose of this manual is to:

- Explain the purpose of the equipment.
- Explain how to operate the equipment.
- List some performance characteristics of the equipment.
- Assist with simple maintenance.

More detailed information and instructions for component parts of the system are given in the third-party manuals supplied with the system, which are listed in this manual. The following manuals provide further information.

- Barber Nicholls pump BNCP-30-000

2. Scope of Supply

The scope of supply includes the following items:

i. Cryocooler system (Insert and Dewar)
ii. Cryocooler controller, rack mounted with touchscreen display and EPICS IOC PC
iii. Cables between cryocooler and controls (5 m as standard, options for longer cables)

2.1 Options

The following equipment are standard options:

i. Low pressure fill line
ii. High pressure lines between the cryocooler and the monochromators
iii. Pump and flush manifold
iv. Insert lifting frame.
v. Insert support frame.
vi. Spares

3. System Overview

The Cryocooler XV is a high pressure, super cooled liquid nitrogen cooler designed to remove heat from a remote load via a closed circuit. The Cryocooler XV is the full-featured automated version of our system allowing complete use flexibility in remote operation via the EPICS interface and EPS digital IO.

The Cryocooler XV is particularly suited to cooling monochromator crystals. The ratio of the coefficient of thermal expansion (α), to thermal conductivity (k), for silicon, is smaller at liquid nitrogen temperature than at room temperature. Distortions of the crystal due to thermal gradients are therefore reduced if the crystal is cooled to < 90K.

It is possible to “fine tune” the cryocooler to maximise the thermal and mechanical stability at the crystal, by adjusting the pump speed, the flow rate and pressure.

3.1 Technical Specifications

The Cryocooler XV come in two pressure ratings. The LP system is rated for a 10 bar maximum normal operating pressure with the burst disc protection limiting the system to the design pressure of 14.5 bar. This option is primarily for legacy installations where the existing load pipework may have only been pressure tested to 15 bar. The STD system is intended for all other installations.

Cryocooler Performance	**LP**	**STD**
Operating Pressure	1 – 10 bar	1 – 12 bar
Pressure Stability	< 1.0 mbar RMS	
Pump Speed	15 – 90 Hz	
Cooling power (@ Pump Speed of 90 Hz)	Up to 3000W	
Liquid Nitrogen Consumption	1500 litres per day at 2500 W (continuous operation)	
Electrical Supply *	208 VAC 50/60Hz, 32 A Single Phase or 415 V 3Phase +Neutral (230 VAC per phase)	
Pneumatic Air Supply	6 barg (87 psi) [+10% -0%] Regulated. 6mm Push Fitting	
Flow Meter Type	Venturi	
Volume of liquid nitrogen bath (@ 70% Full)	65 litres (2.3 ft^3)	
Volume of Internal HP circuit (Typical)	4 litres (0.14 ft^3)	
(Volume of HP lines and load depend on individual installations)		

*Part of the Electrical load is inductive so a minimum of a Type C breaker should be fitted.

Table 1: Pressure Ratings Comparison

Nominal Pressure Rating of Safety Devices	LP*	STD*
Low Pressure Vessel relief valve	68 mbarg (1 psi)	
Internal & External High Pressure Circuit relief valve	11.2 barg (160 psi)	13.1 barg (190 psi)
HP Circuit burst disc	14.2 barg (ZOOK)	17.0 barg (ZOOK)

**Pressure ratings and device types are subject to change, always refer to the markings on your delivered unit

Table 2: Safety Device Ratings

3.2 System Components

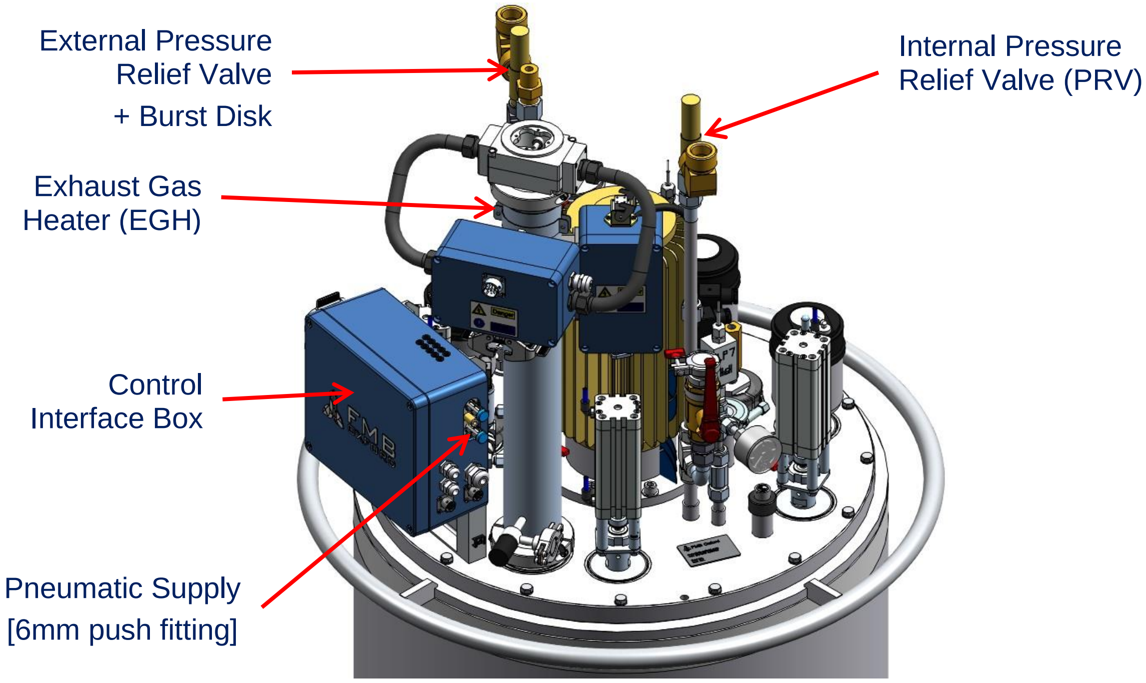

Figure 1: Cryocooler XV Component Detail

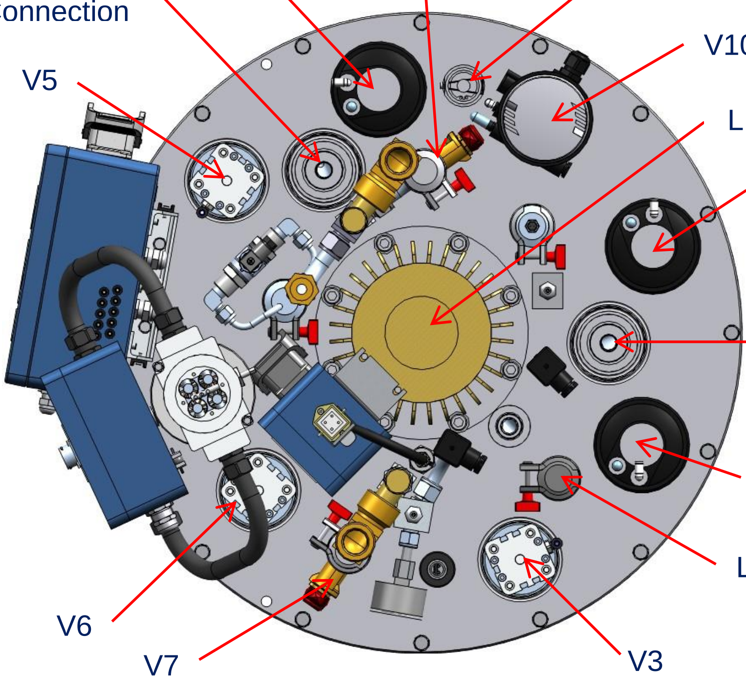

Figure 2: Cryocooler XV Component Detail

3.3 High Pressure Circuit

The super cooled high-pressure circuit removes the heat from the load and is in turn cooled by passing through a heat exchanger submerged in a bath of liquid nitrogen at atmospheric pressure. The nitrogen bath is allowed to boil, absorbing the heat from the load by evaporating the nitrogen.

The high-pressure circuit is pumped from the heat exchanger back to the load in a closed loop. The pump is submerged in the liquid nitrogen bath and is connected via shaft drive to the externally mounted motor.

The high-pressure circuit is connected to the load via a pair of high-pressure lines. These must be flexible super insulated vacuum lines (SIVL); one for the feed and one for the return to the cryocooler. Flow in and out of the lines is controlled by an on/off valve.

To control the pressure in the high-pressure circuit and to accommodate thermal expansion of the LN_2, the cryocooler incorporates a high-pressure buffer vessel. The buffer vessel has a vapour ceiling within it, which is used to generate and control the pressure in the circuit. A heater element, with proportional output, maintains the pressure in the buffer vessel by evaporating small amounts of liquid. If the heater is off the pressure will collapse, assuming the cooling from the surrounding bath is more than the external heat load applied. By this principle the high-pressure circuit pressure can be maintained, even if the load applied varies.

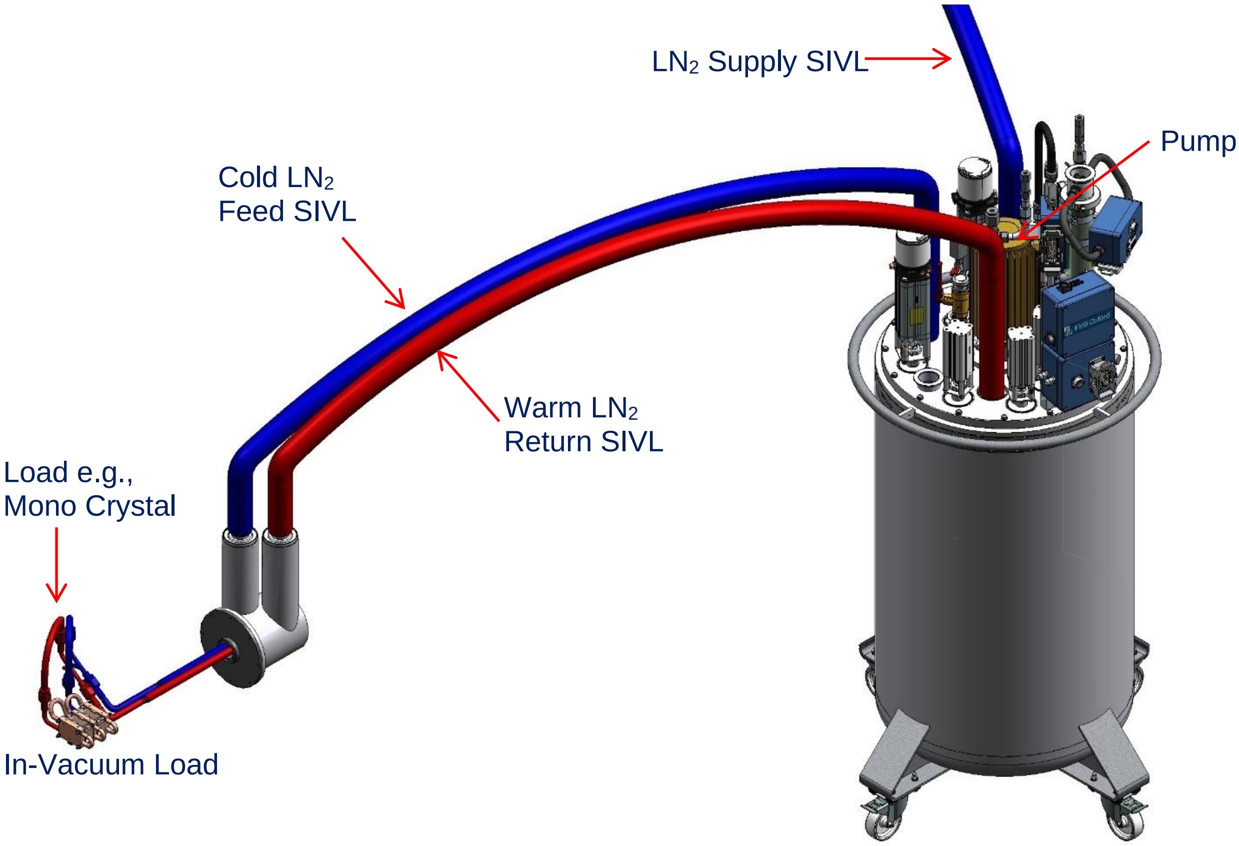

Figure 3: High Pressure Circuit

3.4 Low Pressure Bath

As the low-pressure bath boils, the liquid level in cryo-vessel drops. To maintain the level in the bath, valve V4 will open and close allowing liquid nitrogen to top up the bath from the supply source. This can be either an interchangeable dewar or, more commonly, a liquid nitrogen ring.

It will open when a low level is reached (vessel start fill) and close when a high level is reached (vessel stop fill). These levels are set from the control system and the operation of it is automatic. The bath vents to atmosphere, with no intervening valves, via the exhaust gas heater.

3.5 Exhaust Gas Heater

The pure, cold nitrogen gas (generated by the boil-off from the low-pressure bath and during filling/cool down operations) is warmed to a set temperature by the exhaust gas heater (EGH) to reduce pluming, icing and vapour clouds.

WARNING

The nitrogen exhaust gas should be ducted to a safe location, to avoid risk of asphyxiation from accumulated gas in populated areas.

The use of Oxygen monitors in the area where the gas is exhausted is recommended.

3.6 Protection from Overpressure

Please refer to the Technical Specifications (Section 3.1) for the ratings of the pressure safety devices.

The low-pressure bath has no valves to impede the release of nitrogen gas and should therefore never over-pressurise. In the unlikely event that the exhaust becomes blocked, the vessel is protected by a 1 psi check valve.

The high-pressure circuit is a closed loop which can be isolated in two sections; the circuit inside the cryocooler, and the load side outside the cryocooler (including the HP transfer lines and load). If either circuit is isolated or if the pump is stopped, there is a potential for the liquid nitrogen to boil and cause a rapid pressure build-up. Both circuits are protected by a relief valve, followed by a burst disc on the external circuit only - the internal heat load is minimal and can be controlled by the relief valve.

Operating the cryocooler normally should never result in rupturing the burst discs; however, it is recommended that users have a spare burst disc to hand. Please see spares listing for details (Section 0).

3.7 Operator Interface

A PC mounted in the control rack with a touchscreen monitor and a wireless keyboard on top of the rack acts as the operator's interface to the cryocooler control system. The PC hosts the cryocooler EPICS IOC and a local copy of the operator interface (OPI). The interface serves to view and change parameters in the control system. The interface has several screens that allow operational control, real time readings of the important parameters and trending of data that allows for trouble shooting.

The state of all valves, pressure, levels, temperatures and alarms are logged locally in a daily-generated a csv file. The logging rate can be set independently, automatic compression of old data is also included to minimise disk usage.

4. Installation

4.1 Location

The cryocooler itself should be situated in a well-ventilated non-traffic area, with about 1 metre of free space around it. Figure 4 shows the range of ambient conditions that will avoid any condensation forming on the cryocooler. Any significant condensation found in the range below indicates one of the super-insulated vacuum spaces has degraded.

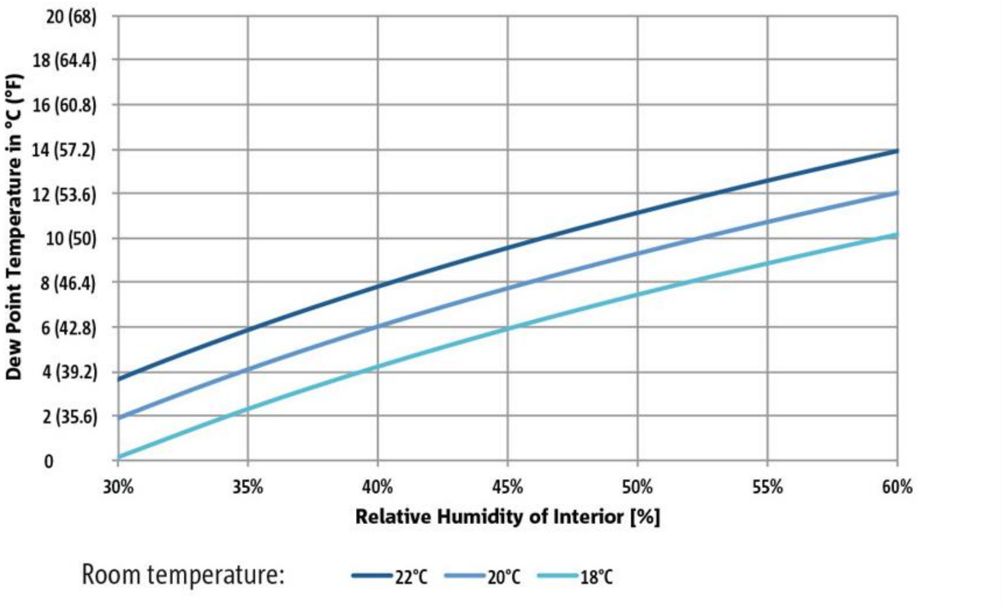

Figure 4: Condensation-Free Operating Range

The controls come in a stand-alone cabinet and should ideally be located close to the cryocooler. The standard cables between the cryocooler and its controls are 5 metres. There are four cables from the controller to the cryocooler plus an optional cable to the customer's EPS. If this is not used, a mating connector for X7 will be supplied with the correct links fitted.

4.2 Exhaust Ducting

The exhaust from the cryocooler should be ducted away from areas that might have persons passing by or other traffic. Ideally it should be ducted to a high, well-ventilated area. It is important that any nitrogen exhaust recovery systems or one-way shutters do not restrict the flow of gas or generate enough positive pressure in the vessel during filling to open the low-pressure bath check valve.

WARNING

The nitrogen exhaust gas should be ducted to a safe location, to avoid risk of asphyxiation from accumulated gas in populated areas.

The use of Oxygen monitors in the area where the gas is exhausted is recommended.

CAUTION

Low pressure bath check valve is not designed to operate during normal cryocooler operation. Frequent operation could cause premature failure and damage the dewar.

4.3 Liquid Nitrogen Supply

The cryocooler low pressure bath is constantly evaporating, so will need regular fills. The distance between the liquid nitrogen source and the cryocooler is not critical, as a SIVL should always be used. However, it is generally recommended that the total length of the supply line is less than 10 metres. The supply should be fitted with an isolation valve, to allow the system to isolated.

4.3.1 Quality of Liquid Nitrogen Supply

The system has been designed and tested to operate with a liquid nitrogen supply at a pressure of 1.5-3barg (30-45psi) if you supply is out of this range, please contact FMB Oxford. It should be noted that the lower the supply pressure the harder it is to fill.

As liquid nitrogen boils at 77K, any static nitrogen lines will have gas generated within them. The quality of liquid nitrogen is determined by the percentage of gas it carries, the lower the gas content, the higher the quality.

To maintain good stability in the cryocooler during steady state operation re-filling the liquid nitrogen supplied to the cryocooler should be less than 2% gas.

There are a number of ways to achieve this:

- The line between the cryocooler and the supply should be kept as short as possible.
- If the supply is from liquid nitrogen mains, the spur feeding the cryocooler should be fitted with a phase separator immediately before the tapping point and before the isolation valve.
- The fill line connection into the cryocooler is a bayonet; it is recommended that the connection to the mains is also a bayonet.

WARNING

Liquid nitrogen lines that can be closed at both ends MUST have a relief valve. Nitrogen expands 700 times when vaporising and will cause pressure build up, which quickly becomes destructive.

4.3.2 Supply from Interchangeable Dewars

Although not advised, the cryocooler can be reliably operated from interchangeable dewars. During a dewar exchange moist air can potentially enter the internal pipework circuit, forming ice crystals. It can be avoided using the connection configuration shown in Figure 5 and by the following steps:

1. Select the Dewar Exchange button from the main screen of the user interface or select Pause Mode and open V4.
2. Close the dewar supply valve. Isolate supply line to the cryocooler by means of an appropriate cryogenic valve before opening. Open the vent valve.
3. Replace and reconnect the new dewar.
4. Slowly open the dewar supply valve until the connection is adequately flushed with N_2 from the dewar then close the vent valve.
5. Fully open the dewar supply valve and the supply line isolation valve.
6. Allow LN_2 to cool down the supply line before closing V4 and returning to Run Mode.

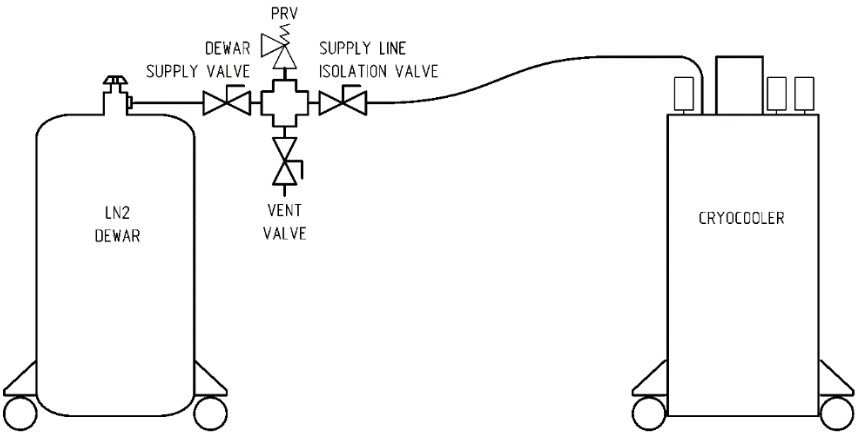

Figure 5: Recommended Dewar Connection

4.4 High Pressure Lines

The high-pressure lines between the cryocooler and the load must be super insulated vacuum lines (SIVL). They can be flexible or a mixture of flexible and rigid line depending on the length and the geometry of the path between the two. The length of the lines is limited by the heat losses and pressure drops they incur, however lines up to 30 metres are routinely used.

The high-pressure lines are connected to the cryocooler by bayonets. The connection at the load end will depend on the individual design of the monochromator or other instrument being cooled. FMB Oxford often uses VCR connections at this end, with vacuum insulation around them.

4.4.1 Connecting the External High-Pressure Lines and LN_2 Supply Lines

A Clean connection sequence document (MWI 18) is supplied with every cryocooler detailing best practice to minimise contamination during integration but is summarised below.

- Ensure that the High-Pressure Feed & Return lines are clean, particle free and have been internally blown through with dry N_2 Gas.
- Connect the High-Pressure Lines individually purging continuously.
- Clean the bayonet and purge the low-pressure supply line from the LN_2 supply to remove any particles from the inside of the line.
- Helium Leak Test the high-pressure circuit, the Helium Leak Rate should be <5 x 10^{-8} mbar L/s.

CAUTION

The existence of any particles in the system can have a significant effect on the reliability of the valve operation as well as permanently damage the internal sealing faces.

4.5 System Pump, Flush and Purge Gas Setup

There is a requirement to pump, flush and purge the system with warm nitrogen gas before cooling the cryocooler after initial installation, high-pressure circuit maintenance, or long periods of the cryocooler standing warm. The process removes water vapour from the high-pressure circuit, which would otherwise freeze and impair the cryocooler operation or damage the valves. The process is detailed in MWI 31, which is supplied with every cryocooler.

CAUTION

It is critical to ensure that the cryocooler and associated feed & transfer lines are correctly pumped, flushed and purged with dry N_2 gas prior to cool down with LN_2.

4.5.1 Pump and Flush Rig

The pump and flush rig can be built from standard vacuum equipment. The following equipment is required:

Item	Notes
NW25 Pumping Line	Clean and particle free
NW25 Pumping Tee	Clean and particle free
NW25 Isolation Valve (x2)	Manual "SpeediValve" type recommended
Roughing Pump	**Never use oil filled rotary pumps**

Table 3: Pump and Flush Equipment

Additionally, a hand-held humidity measurement gauge (Testo 605-H1 or equiv.) is recommended to check the humidity level in the system before proceeding with the automated pump, flush and purge. A pre-flush is always recommended when the humidity in the system is above 10%.

Figure 6**Error! Reference source not found.** shows the configuration required to pump and flush the system.

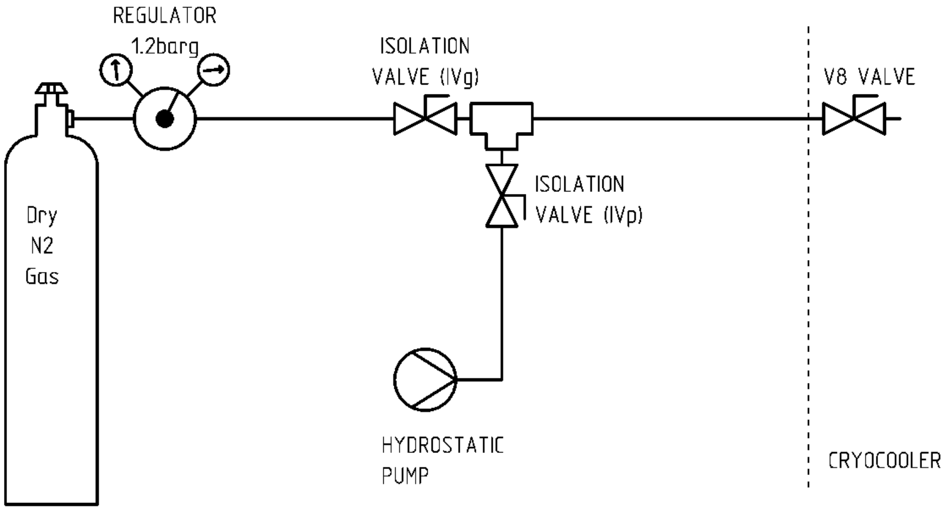

Figure 6: Pump and Flush Rig

The pump and flush rig is assembled as follows:

- Connect a NW25 pumping tee to V8 (HP Transfer Line Pump Port) NW25 fitting with a flexible pumping line.
- Connect a suitable dry roughing pump to the NW25 tee with a manual valve (IVp) to isolate the pump when flushing.
- Connect a dry N_2 purge gas feed via a manual isolation valve (IVg) to the remaining NW25 tee flange. The pressure should be above 1.0 barg and not exceed 2.0 barg. A value of 1.2 barg is typically used.

CAUTION

Purge gas should be 99.99% pure dry nitrogen. The pressure should not exceed 2 barg (29 psi).

4.6 Pneumatic Supply

The cryocooler requires a regulated 6barg (+10%, -0%) clean, dry pneumatic air supply to operate the valves.

On the Cryocooler XV, this connection is located on the right side of the Control Interface Box on the insert and features a 6mm push fitting. Failure of the air supply will be detected by the cryocooler and result in a system trip.

4.7 EPS Remote Interfacing IO

The cryocooler has three outputs for integration with the customers control system and one input, all available on X7 on the back of the control box. This is an 8way UTO trim trio plug (mating connector is UT06128SH).

The outputs are volt free normally open (NO) relay contacts (rated for 24V, 0.5A max),

the input has a fused 24V supply requiring volt free, normally open relay contacts on the customer EPS.

1. Remote Alarm (output) – normally energised if the cryocooler is operating correctly, de-energises when there is an alarm condition in the PLC control. The EPS system should not take any action on this alarm other than to notify the user so that it can be investigated without interrupting the beamline operation.
2. Remote Running (output) – normally de-energised, energises in run mode and pressure control is stable. The EPS should consider an open signal to indicate a problem with the cryocooler and should take appropriate actions for an uncooled load.
   Typically this output would be linked to the EPS controlling the Photon shutter.
3. Supply Isolate (output) – normally de-energised, energies when the Vessel level is <80% and not in ESTOP mode. Open contacts indicate that the LN_2 supply should be isolated. Typically this would be linked to the EPS controlling of the cryocooler LN_2 supply isolation valve.
4. Remote Inhibit (input) – normally open contacts from the EPS. Contacts must be closed to allow the cryocooler to cool down the load. Open contacts indicate that it is NOT safe to fill the load with LN_2 and will isolate the load if in Run conditions.
   Typically this input would be linked to the EPS vacuum state of the load.

Pin	Name	Description
A	Remote Alarm -	Relay contacts, closed if cryocooler is operating correctly. Contacts are open if in an alarm condition
B	Remote Alarm +	
C	Remote Running -	Relay contacts, closed when in run mode and in operating conditions
D	Remote Running +	
E	Supply Isolate -	Relay contacts, closed when cryocooler can control filling the vessel
F	Supply Isolate +	
G	Remote Inhibit RTN	Return from EPS relay – contacts are closed when safe to operate
H	Remote Inhibit 24V	24V output to EPS relay contacts

Table 4: Pin-out for EPS connector

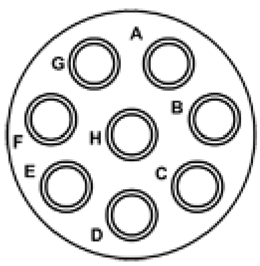

Figure 7: Mating face view of EPS Connector

5. Controls System Overview

The cryocooler control system is driven by a Siemens S7 PLC. Visualisation and interaction with the control system is via the EPICS IOC and graphical interface.

Each page of the graphical interface consists of 2 regions:

- The header bar, displaying the time, the current page, a heartbeat (switches on and off every second proving communications with the PLC is OK) and a row of buttons for changing page.
- The page data area: displaying the page (screen) of data selected by the buttons on the header bar. The default page is the Overview (Figure 8).

There are several fully automated operational modes for the cryocooler, only certain combinations of modes will be accessible at any given time, depending on the current state of the system.

The operating modes are described in more detail in Section 6 but in summary they are:

Operation Modes	Description
Pump and Flush	This ensures that all residual air and moisture is removed completely from the high-pressure circuits to eliminate ice contamination. Ice in the high-pressure circuit can cause valves and flow gauges not to function to specification at LN_2 temperature.
Stopped/System Warm	Assumes system should be warm and ensures the internal and external high-pressure circuit is < 1barg.
CC Filling	Cools and fills the internal HP circuit of the cryocooler (only) and transitions to Keep Cool once stable.
CC Cold Load Warm (Keep Cool)	Maintains the internal HP circuit at a controlled pressure and level ready to cool the load.
Load Filling	Cools down the HP lines and the load, and transitions into to run mode once stable.
Run System Cold	Controlled steady state operation at a defined HP circuit pressure with the LP bath level being maintained.
Engineering	Enables full manual control of the cryocooler, accessible only from Stopped, if password provided is correct.
Pause Mode	Suspends normal automated mode operation and enables a limited version of engineering manual control.
Emergency Stop	All control outputs to the insert are disabled. This is an automatic transition under certain circumstances, for example trips activated during run mode, sensor wiring fault or the operator pressing the local emergency stop button.
Dewar Exchange	Optional mode if running from a portable storage dewar. Puts the cryocooler in a safe state to allow an empty dewar to be replaced while minimising moisture ingress.

Table 5: Summary of Operation Modes

5.1 Overview Schematic Page

This page is accessed by pressing the Overview button and is the default screen on startup.

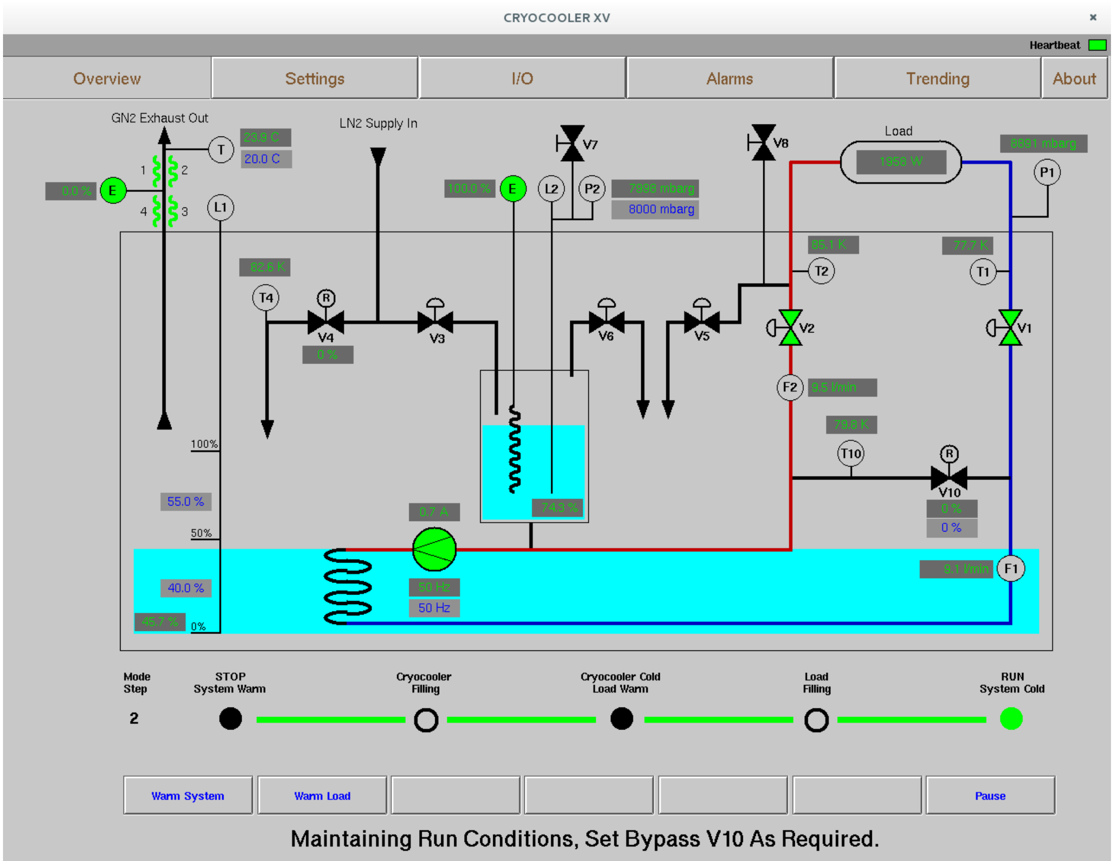

Figure 8: GUI Overview Page for Cryocooler XV

The overview page displays a representation of the P&ID, with active graphical digital elements and critical analogue data overlay.

GUI digital elements (valves, pump, and heater control) are coloured black when Closed/Off, coloured green when Open/On and coloured red when in a fault state.

The Heating elements (HP heater and Exhaust heater) have a % power output to them, so they can be on (green) but with 0% power thus no heating.

All analogue feedback data is presented as green text in a dark grey box. Set points for analogue control are displayed as blue text in light grey boxes. Additionally, there is a graphical representation of the vessel and buffer fill levels.

Valve and sensor feedback details are listed in Section 0.

Along the bottom there are 7 buttons and a progress bar above them, the progress bar displays the current state of the cryocooler and the target state when cooling the system.

The buttons give direct access to change the state of the cryocooler; the visible buttons will change depending on the current mode and user level (password protected).

5.2 Settings Page

This page is accessed by pressing the Settings button.

Figure 9: Cryocooler XV Settings

The settings page gives access to the process variables (PVs) that control the operation of the system and the local logging functionality of the IOC. During normal operation this is the only page where data can be entered.

Each PV is represented in 2 boxes; the current stored value is displayed as feedback in the dark grey box with green text, the blue text in the light grey box is the editable field.

If the value in the editable field is not the same as the feedback, then a SET button appears beside the PV allowing the data to be transmitted to the PLC.

5.2.1 Run Settings

These are available with Password Level 1 or higher active and control the operation of the cryocooler when in Run mode.

Setting	Description
P2 Set Point	The operating pressure in Run mode (determines the boiling point of LN_2).
P2 Band	Acceptable tolerance on the Target Pressure before a warning alarm and automated corrective action occurs.
Pump Speed	Operating pump speed in Run mode.
Bypass %	Percentage V10 is open by during Run mode to fine tune the flow through the load.
EGH Target	Target temperature for the exhaust gas.
Top Up Day	Day of the week to perform a forced auto top up of the buffer. Range is 0 – 8; 0 = Off, 1 = Monday, 2 = Tuesday…, 8 = everyday
Top Up Hour	Time of day to perform the forced buffer top up. Range is 0 – 23 To top up the buffer at 05:00, Top Up Hour = 5

Table 6: Run Settings Descriptions

5.2.2 Vessel Fill Settings

These are available with Password Level 1 or higher active and control the operation of the cryocooler when in run mode.

Setting	Description
Vessel is Filled from a Dewar	Enables *Dewar Exchange* on the overview screen. Temporarily pauses the system in Run mode to allow the LN_2 supply dewar to be replaced.
Start Fill %	Automated set point to start the refill of the low-pressure bath.
Stop Fill %	Automated set point to stop the refill of the low-pressure bath.

Table 7: Vessel Fill Settings Descriptions

5.2.3 PID Settings

These are available with Password Level 2 or higher active and set the parameters for the various PID control loops. Values should not be modified from the factory defaults without contacting FMB Oxford.

Setting	Description
EGH PID	Exhaust gas heater control parameters.
Buffer PID	Buffer heater stick control parameters.

Table 8: PID Settings Descriptions

5.2.4 Alarm Settings

These are available with Password Level 3 only; they are determined by the external hardware capability and the pressure relief valves fitted to the cryocooler and will be set in the factory or during commissioning.

Setting	Description
P High Trip Limit	Maximum allowable P1 or P2 pressure while in Run mode. Set at the point the PRVs begin to open.
P2 Setpoint Limit	Maximum pressure that can be set while operating in Run mode. Typically set to 10 barg or 12 barg but can be set lower if required.
Pump Speed Limit	Maximum allowable pump operating speed. Set as a function of the flow restriction of the load and prevents excessive vibration which could lead to system damage.
RTD Calibration	PT100/1000 calibration setting to correct for cable length effects.

Table 9: Alarm Settings Descriptions

5.2.5 Passwords

There 3 user level passwords, each password is a unique 4-digit number.

	Function	Code
Password level 1 (PWD1)	Gives access to the Run settings	6966
Password level 2 (PWD2)	Gives access to Engineering functions	9855
Password level 3 (PWD3)	Only required for factory configuration	FMB Access Only

Table 10: Cryocooler Passwords

5.2.6 Logging

These settings will be set in the factory or during commissioning and typically do not require any changes.

Setting	Description
Enable/Disable CSV-Data Logging	Enables/Disables logging of all parameters and settings to a local CSV text file. One file generated for each day.
Interval	Sets the interval for logging data to the csv file.

Table 11: Logging Settings Descriptions

5.3 Active Alarms Page

This page is accessed by pressing the Alarms button.

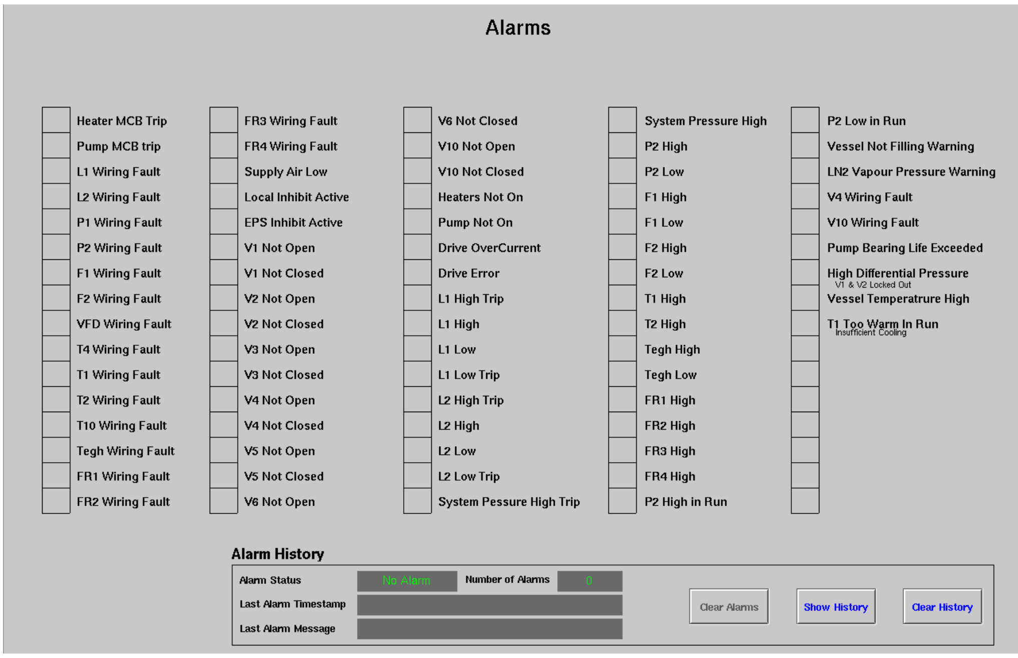

Figure 10: Cryocooler XV Alarms

All warning and trip alarms are reported here. In Run mode alarms should be checked.

If connected the audio-visual alarm will sound on alarms that must be checked, pressing the clear alarms button will silence the audio alarms for two minutes providing no new alarms occur.

5.3.1 Alarm Thresholds

Alarm	Threshold
System Pressure High warning	90% of P High Trip Limit
P2 High in Run warning	Target Pressure + Pressure band
P2 Low in Run warning	Target Pressure - Pressure band
L1 High Trip	90
L1 High warning	85
L1 Low warning	20
L1 Low Trip	10
L2 High Trip	90
L2 High warning	85
L2 Low warning	15
L2 Low Trip	10

Table 12: Alarm Thresholds

A comprehensive list of all alarm states is available in the Appendix.

5.3.2 Alarm History

Setting	Description
Alarm Status	Indicates if there are any logged alarms.
Number of Alarms	Total number of logged alarms.

Last Alarm Timestamp	Time at which latest alarm occurred.
Last Alarm Message	Type of last alarm which occurred.
Clear Alarms	Clears the alarm status, number of alarms, last timestamp and last message.
Show History	Opens alarm log text file showing all alarms with a timestamp.
Clear History	Clears the alarm history log file.

Table 13: Alarm History

5.4 IO Page

This page is accessed by pressing the I-O button displays a tabulated view of all the digital and analogue IO sensor input and control data.

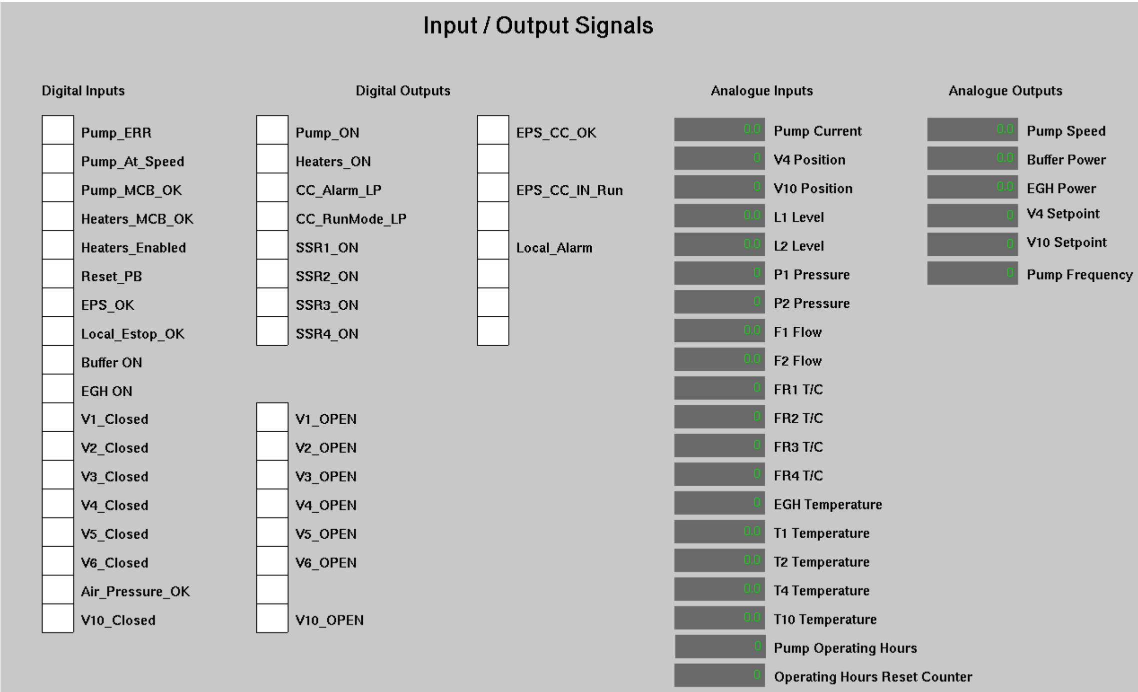

Figure 11: Cryocooler XV IO Signals

5.5 Trending

Typically, EPICS has remote data storage for all PV data however to allow the cryocooler to operate as a standalone unit, data can be logged locally (controlled on the Settings page). Daily csv files are created and saved in a dedicated folder on the pc, the data is auto-archived monthly to minimise storage. This data can be accessed from a dedicated python graphing application included and launched from the Trending button. Typical time periods are available via buttons, custom time periods can be entered directly along with standard windowing facilities.

This data is critical for FMB Oxford support and will be requested during any query.

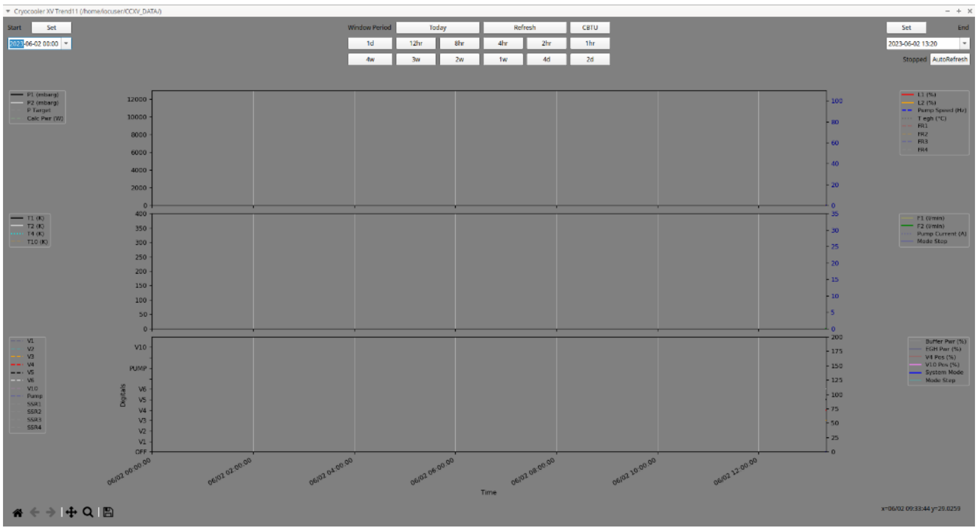

Figure 12: Cryocooler XV Trend Tool

5.6 Valve and Sensor Description

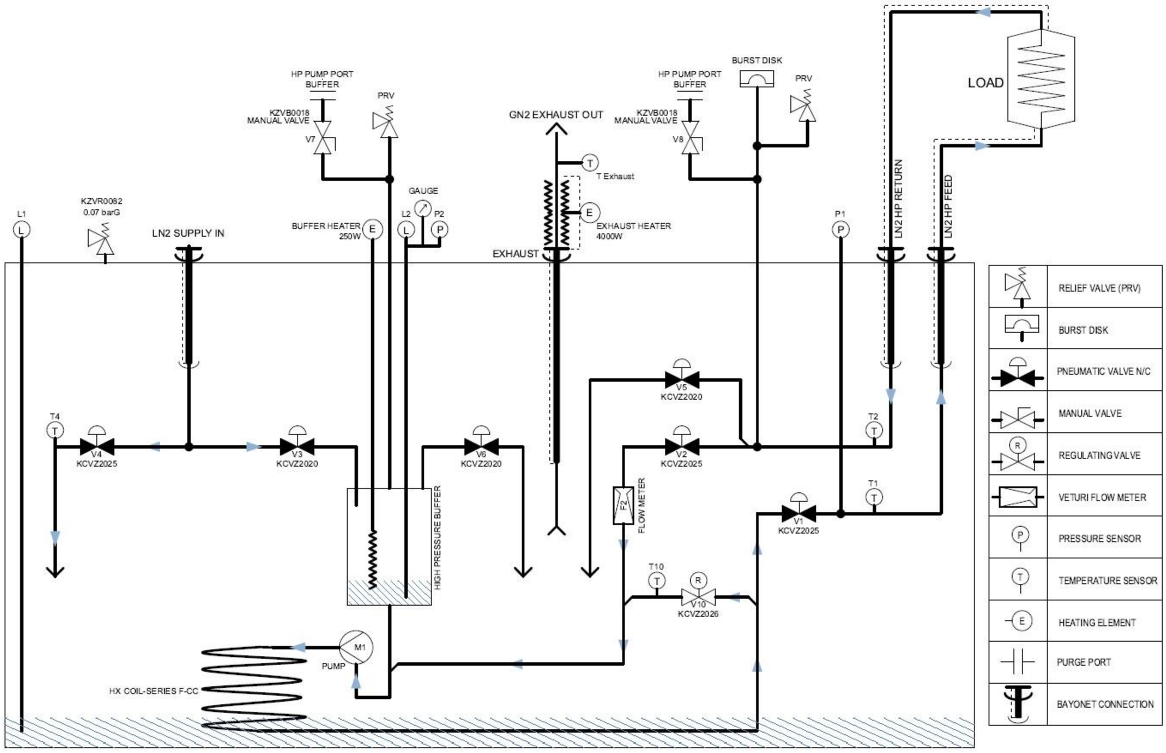

Figure 13: Cryocooler XV P&ID

Item	Description
V1	On/Off valve controlling flow from the cryocooler to the load.
V2	On/Off valve that controls the return flow from the load to the cryocooler.
V3	On/Off valve that allows the LN_2 into the HP buffer for filling the HP circuit.
V4	Valve that allows the LN_2 to fill the low-pressure bath.
V5	On/Off valve that vents the HP lines and load into the low-pressure bath.
V6	On/Off valve that vents the HP buffer into the low-pressure bath.
V7	Manual ball valve for pumping/venting the high-pressure buffer.
V8	Manual ball valve for pumping/venting the external HP lines and load.
V10	Proportional valve that regulates the internal flow through the cryocooler.
T_1	Temperature of liquid nitrogen going to the load.
T_2	Temperature of liquid nitrogen returning from the load.
T_4	Temperature of the nitrogen entering the low-pressure bath from the supply line.
T_{10}	Temperature of liquid nitrogen flowing through the bypass.
T_{EGH}	Temperature of the gas exhausting from the cryocooler.
F2	Flow of liquid nitrogen returning from the load.
P1	Pressure at the HP feed line.
P2	Pressure in the HP buffer. In Run mode, this is the pressure regulated to the Target Pressure by control of the buffer heater.
L1	Level of liquid nitrogen in the LP bath.
L2	Level of liquid nitrogen in the HP buffer.

Table 14: Valve and Sensor Descriptions

6. Operation

6.1 Factory Default Settings

The System comes pre-set with factory default settings for the FMB Oxford test setup. This configuration has a 3m supply line, 5m transfer lines and a variable load up to 3000W.

	Value	**Range**	**Units**
Target Pressure	5000	10 – 10000 (LP) 10 – 12000 (STD)	mbarg
Pressure Band	250	>10	mbarg
Pump Speed	30	15 – 90	Hz
Bypass	0	0 – 100	%
Exhaust Gas Heater Target	20	0 – 50	°C
Top Up Day of Week	0	0 – 8	
Top Up Hour of Day	0	0 – 23	

Table 15: Run Settings

	Value	**Range**	**Units**
Vessel Stop Fill Level (L1)	61	<75	%
Vessel Start Fill Level (L1)	60	>40	%

Table 16: Vessel Fill Settings

	P	**I**	**D**	**Interval**
EGH PID	7412	27407	6944	600
Buffer PID	152	2055	462	100

Table 17: PID Settings

	LP (10 bar)	**STD (12 bar)**
P High Trip Limit	11000mbarg	13000mbarg
P2 Setpoint Limit	10000mbarg	12000mbarg
Pump Speed Limit	60Hz (Typical DCM Installation)	
RTD Calibration	0 - 1.6 (Dependant on Installation)	

Table 18: Alarm Settings

6.2 Mode Transitions Overview

The diagram below details each mode and how the system moves from one to the next. The modes are described in the subsequent sections.

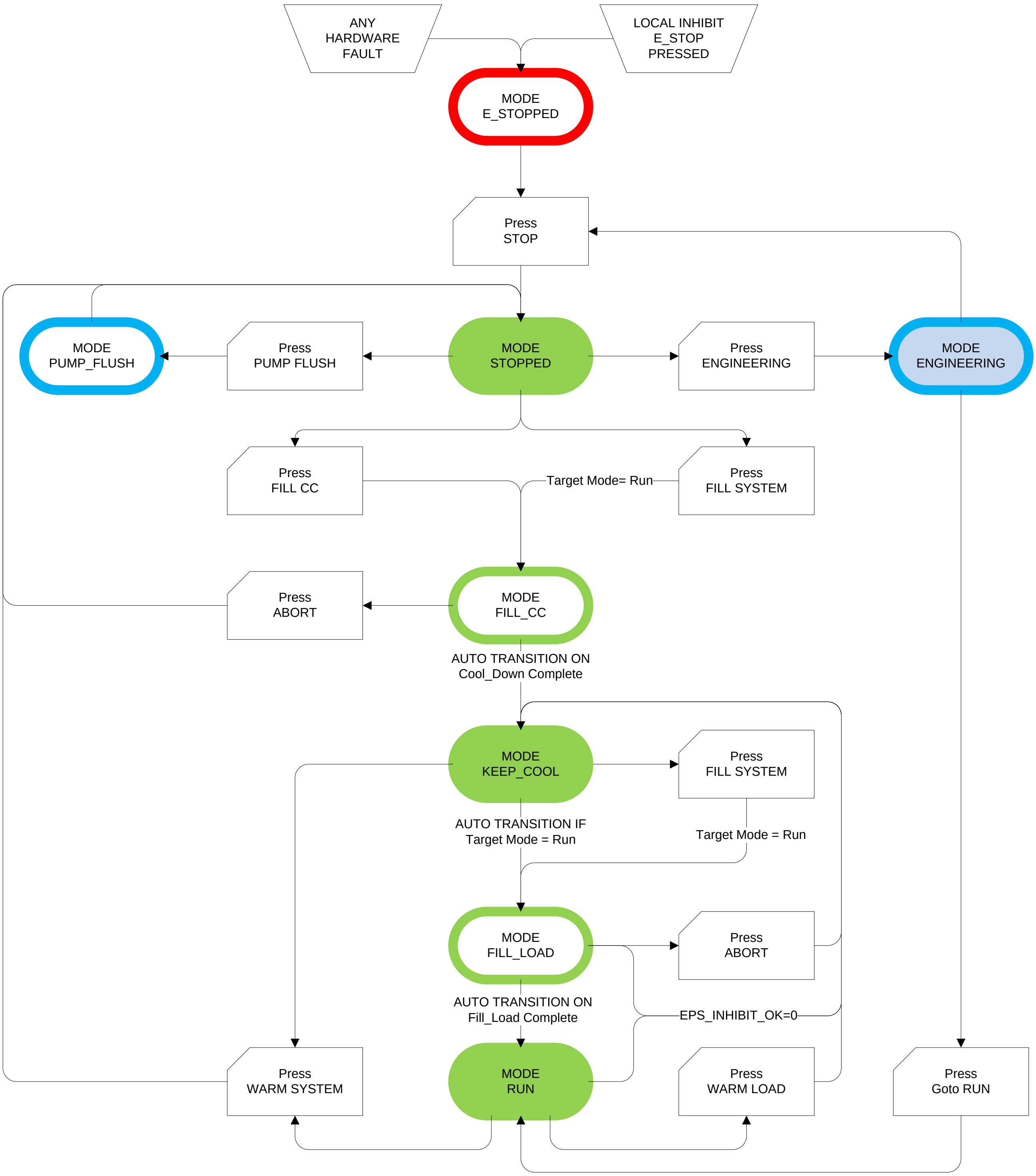

Figure 14: Overview of the XV Process, Transitions and Button Actions

6.2.1 Flow Diagram notes:

To fill the load from Stopped there are two options:

1. Press button FILL CC to fill the cryocooler. The cryocooler will then fill and wait in Mode Keep Cool. Button FILL SYSTEM must then be pressed to fill the transfer lines and load.
2. Directly press button FILL SYSTEM. This immediately, this will fill the cryocooler and then fill the load automatically as soon as it is stable.
3. Open circles represent transitional modes while solid circles represent steady state modes.

6.3 Mode Pump and Flush

This mode is required for the initial installation of the system or if the system has been warmed up and the high-pressure circuit has been opened to atmosphere or replaced.

When the system is not in operation all external ports and valves must be capped with supplied blanks and contamination into the system.

Supplied non-return valves must be fitted to the high-pressure circuit and the low-pressure bath when the system is warming up to prevent back streaming of air into the cryogenic circuits.

The objective is to ensure that the high-pressure circuit is free of particle or moisture contamination which will be detrimental to the operation of the cryocooler system. The system must be at room temperature as pumping on a cold system will not be effective.

CAUTION

Failure to correctly pump, flush and purge the associated feed & transfer lines prior to cool down with LN_2 will result in the ice contamination of the high-pressure circuit which can cause permanent damage to valves, flow meters and cause the system to function incorrectly at LN_2 temperatures.

See section 4.5 for a detailed explanation of the equipment configuration of the pump and flush rig. Figure 15**Error! Reference source not found.** shows the correct setup required to correctly pump and flush the system.

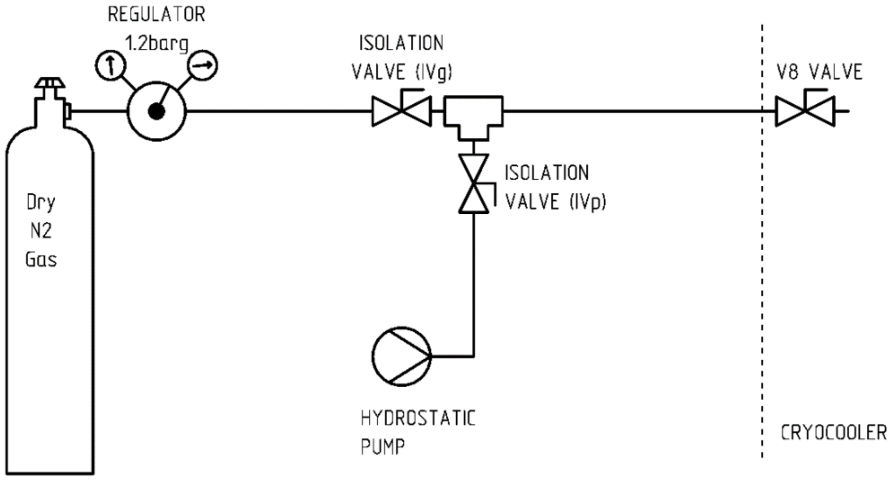

Figure 15: Pump and Flush Setup

6.3.1 Automated Pump and Flush

It is recommended that this process only be performed using the Pump and Flush mode on the Overview page with manual operation of the valves isolating the vacuum pump and N_2 gas supply. The process requires the user to control the pumping and flushing however the valve control is automatic and instructions appear on the overview page detailing what is happening and when to pump and when to flush. The process is detailed in MWI 18 supplied with the cryocooler and summarised below in Table 19

Step	Description
1	Press *PUMP & FLUSH*. Open V8 manual valve.
2	Valves V1, V2, V3 and V10 will be Open.
3	Close the N_2 purge gas supply valve (IVg). Open the pumping valve (IVp) and pump the HP Circuit to a pressure of 1 x 10^{-1} mbar (approx.) for a minimum of 15 minutes.
4	Close the pumping valve (IVp), isolating the vacuum pump. Open the N_2 purge gas supply valve (IVg) and back fill the vacuum to >1 barg.
5	Valve V4 will open for 2 minutes and then Close.
6	Valve V5 will open for 2 minutes and then Close.
7	Valve V6 will open for 2 minutes and then Close.
8	Repeat steps 3-7 three times.
9	V1, V2, V3, V4, V5 and V6 will close, and the system will return to Stopped Mode.
10	Close V8 and disconnect pump and flush equipment.

Table 19: Pump and Flush Steps

6.4 Mode Stopped

Automated holding point for the system where the internal and external HP circuits are isolated from each other, and both are considered to be warm.

Step	Description
1	Keep V10 Open Monitor External High-Pressure Circuit Monitor Internal High-Pressure Circuit

Table 20: Stopped Steps

6.5 Mode Fill CC

Automated Process mode where the low-pressure bath and the internal HP circuit are cooled down and filled with LN_2. The external HP circuit is isolated and considered warm. Once the internal HP circuit is full and stable the system will automatically transition to mode Keep Cool. This can typically take a maximum of 60 minutes and will depend on the LN_2 supply pressure and quality.

Although the exhaust gas heaters are working during cool down, it is unlikely that the PID controlling these will keep up with the initial rapid generation of cold gas. Potentially, the exhaust temperatures may get down to -30°C during this phase. Ensure that the area where the gas is exhausting is clear of personnel. If the temperature falls below -50°C, there is likely to be a problem with the exhaust heater.

It is also normal after a fill cycle for the exhaust heater to overshoot due to the sudden change of operating conditions from high cold gas flow to very little flow.

WARNING

A large amount of potentially cold nitrogen exhaust gas will be generated during cool down. The nitrogen exhaust gas should be ducted to a safe location, to avoid risk of asphyxiation from accumulated gas.

The use of Oxygen monitors in the area where the gas is exhausted is recommended.

Step	Description
1-6	Monitor External High-Pressure Circuit
1	Press *Fill CC*
2	Open V10 EGH Off Start Vessel Fill
3	EGH On Start Buffer Top Up
4	Pump On
5	Stop Buffer Top Up Monitor Internal High-Pressure Circuit Stabilise HP Circuit
6	Restart Buffer Top Up
7	Move to Keep Cool

Table 21: Fill CC Steps

6.6 Mode Keep Cool

Automated Holding Point for system where Internal HP circuit is full and cold. The External HP circuit is isolated and considered warm.

The system enters this mode if filling the cryocooler from mode Stopped or warming the load from mode Run. This mode will be skipped if filling system from mode Stopped or warming system from mode Run.

Step	Description
1	EGH On
	V10 Open
	Pump On
	Vessel Top Up On
	Buffer Top Up On
	Control Buffer Pressure
	Monitor External High-Pressure Circuit
	Monitor Internal High-Pressure Circuit

Table 22: Keep Cool Steps

6.7 Mode Fill System

Automated Process mode where the external HP circuit is being filled. Once full and stable the system automatically moves to mode Run.

Step	Description
All	EGH On Vessel Top Up On Buffer Heater Off (unless Step 11) Over Pressure Protection On Pump ON (Pump Speed set to 40Hz if Pump_SP < 40 , or 60Hz if >= 40)

7	Start Load Fill. Open V1, Open V5 if T2>95 and L1<75 (Vents N2 gas from load, reducing cooldown time) Open V2 if V5 Closed Close V10
8	Top Up Buffer Open V3, V6
9	L2>80. Close V6 L2<25 go back to Step 8 T2>200 go back to Step 7
10	T1<80 & T2<100 Open V3 & V6, Close V5
11	L2>85 Close V3, V6 Start Pressure Control (Buffer Heater On and PID controlled) L2<50 go back to Step 10 P2 within Pressure band Wait 10 minutes Proceed to Run

Table 23: Fill System Steps

6.8 Mode Run

The cryocooler will spend most of its time in this mode during operation. It is an automated holding point where internal and external HP circuits are full and connected. The current run setting set points (SP) are applied to automatically control the LN_2 pressure and flow through external HP circuit to remove heat from the load.

CAUTION

Alarms that occur during this mode require attention. Critical alarms will trip the system automatically.

Automatic re-filling the high-pressure circuit will temporarily cause instability in the cooling of the load as the pressure must be reduced to allow the supply to fill the high-pressure circuit. It is advisable before doing a long experiment to check that L2 has sufficient liquid to not trigger an autofill during the experiment. Using the Buffer Force Fill settings to trigger a top up can prevent this.

Various PV set points are available to optimise the cryocooler operation with the load; these are detailed in Section **Error! Reference source not found.**.

Step	Description
1	EGH On
	V10 Open @ SP Bypass [%]
	Pump On @ SP Pump Speed [Hz]
	Keep Vessel Top Up On @ SP Vessel Start Fill < L1 < SP Vessel Stop Fill [%]
	Keep Buffer Top Up On
	Control Buffer Pressure @ P2 = SP Run Pressure [mbarg]

	Monitor High Pressure Circuit
	Once the Bypass is set, the pressure is within the pressure tolerance band and pump speed is correct the CC running lamp is On (and Remote Running Output is Closed)

Table 24: Run Steps

6.9 Warm Up

To warm the system from Run there are two options:

1. Warm the load by pressing button WARM LOAD, taking the system back to Mode Keep Cool, this will leave the cryocooler cold and in a state that will allow the load to be refilled.
2. Warm both the load and the cryocooler by pressing button WARM SYSTEM, taking the system back to Mode Stopped.

In both cases, before leaving Run Mode you are asked to confirm the button action that was pressed. This is the ONLY occasion that manual confirmation is required. After pressing a Warm-Up button, you will be presented with confirmation buttons, OK and ABORT.

- Pressing ABORT will return you to Run Mode.
- Pressing OK will proceed with the Warm-Up.

6.9.1 Warming the Load

This state is typically used if the EPS triggers the Remote Inhibit (equipment problem) or if the vacuum vessel with the LN_2 cooled element requires venting to atmosphere. This process involves closing V1 and V2, opening V10 100% to maintain internal circulation and opening V5 to vent the liquid/gas in the transfer line and load. The internal high-pressure circuit remains sealed, and the pump continues to circulate LN_2.

CAUTION

It is not advised to open the any of the high-pressure transfer line or load connections when cold as there is a risk of air entering the lines and ice forming on the cold internal surfaces of the cryocooler.

6.9.2 Warming the System

This state is typically used if the system trips out of Run mode or if the system is not required to be in operation for a long period like a facility maintenance shutdown. This process involves closing V1 and V2, opening V10 100% and opening V5 and V6 to vent the liquid/gas in the internal pipework, transfer line and load. It should be noted that due to the lack of heat load in the vessel, warming the internal system can take some time, it is advised that the LN_2 bath is syphoned off to reduce the warmup time.

7. Optimising the Cryocooler Settings

The System comes pre-set with factory default settings for the FMB Oxford test load. This configuration uses a 3m supply line, 5m transfer lines and a variable load up to 3000W.

The default settings (listed in **Error! Reference source not found.**) will operate the cryocooler.

7.1 Cryocooler System Performance

7.1.1 Pressure Stability

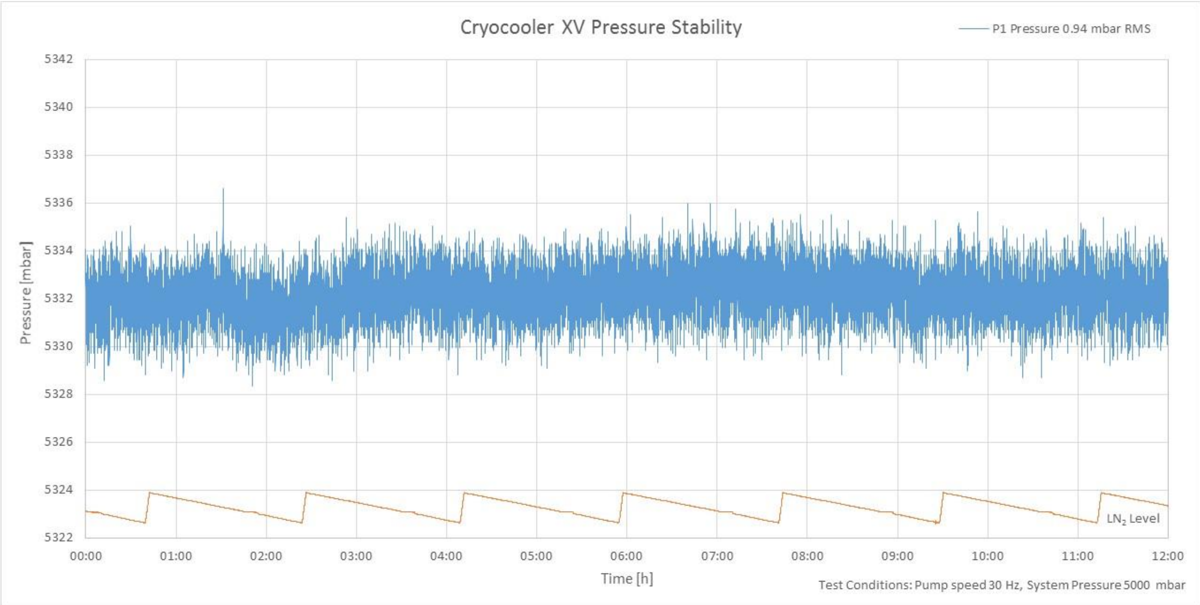

Figure 16 Pressure stability

7.1.2 Flow Performance

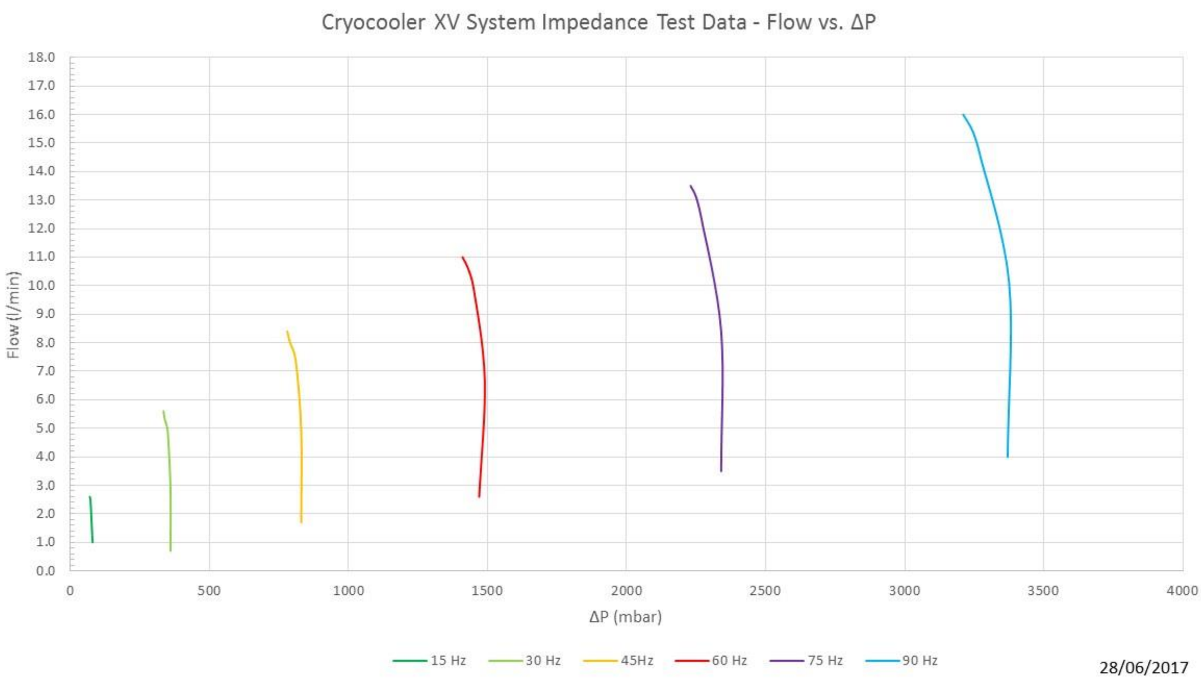

Figure 17: Flow performance

7.2 Optimisation Principles

Typically for most loads the most important criteria are:

- Temperature stability rather than absolute temperature.
- Vibration, or rather the absence of it is important.

By adjusting the target pressure, pump speed and bypass settings, best operating conditions for a given load can be achieved. However, as the transfer lines contribute to load, each system should be optimised during the commissioning phase through an iterative process.

7.2.1 LN_2 Boiling Point

The LN_2 should never be allowed to boil during normal operation. Boiling will cause a loss of pressure control and inevitably lead to additional vibrations. Figure 18 illustrates that the higher the operating pressure, the more heat can be absorbed without boiling.

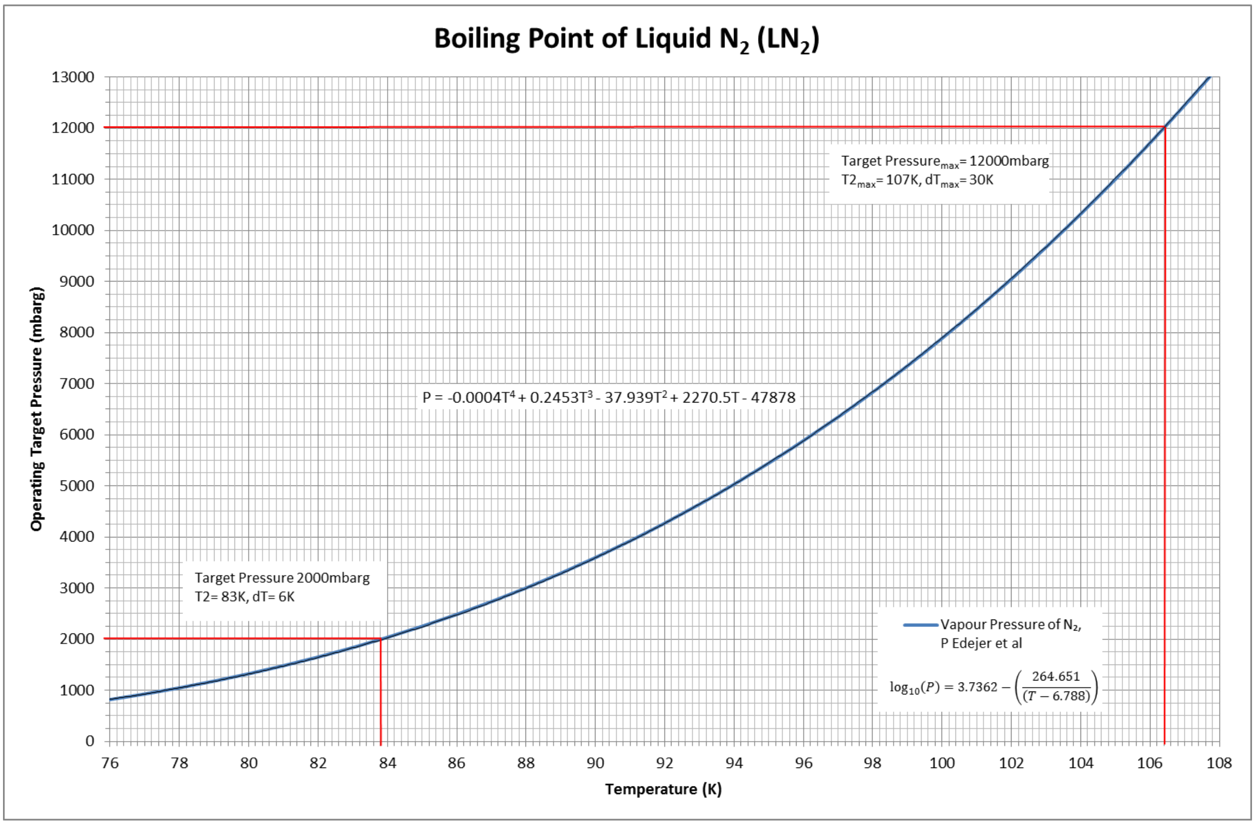

Figure 18: relationship Between Pressure and Boiling Point of LN_2

7.2.2 Manual Power Dissipation

The power that can be dissipated is directly proportional to the temperature difference across the heat exchanger and the flow through the load. However, higher pressures may also increase the transmission of any pump induced vibrations and at lower pump speeds the flow is generally less stable. Figure 19 shows the level of total power that can be dissipated over a range of pressure and load flow (F2) conditions. This calculation is done for bulk LN_2 so it should be ensured that the flow though the load maintains a Reynolds number above 4000.

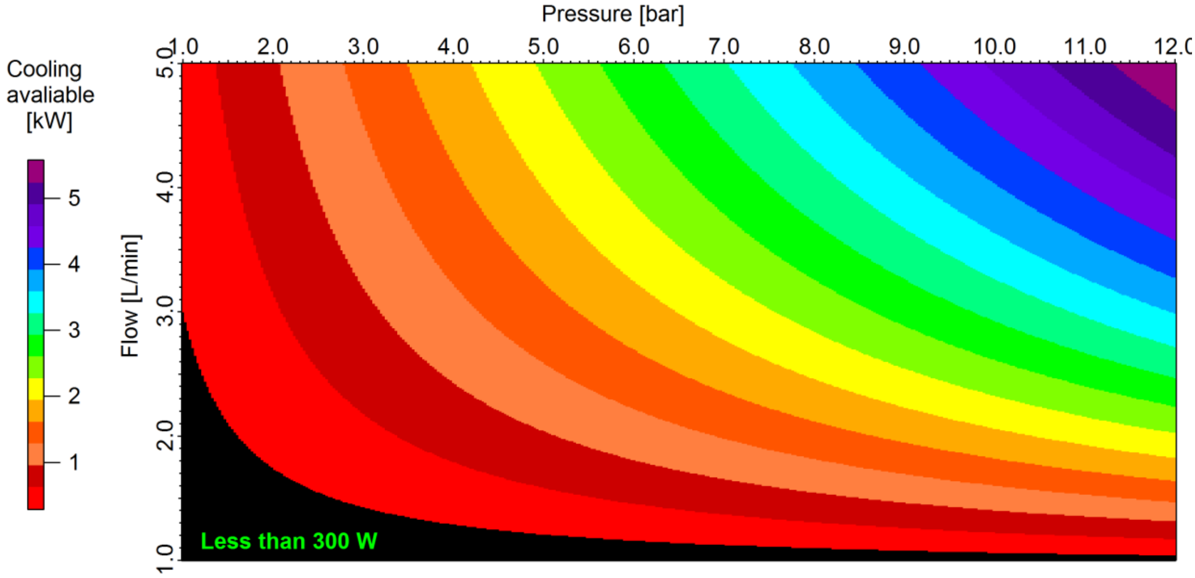

Figure 19: Available Cooling Power at Different Pressure and Flow

There is a compromise between pressure and flow. By utilising the bypass higher pump speeds can be used without increasing the flow through the load.

7.3 Cryocooler Optimisation Example

To find trends of the relative pitch vibration of a Horizontal DCM a range of pressure and flow rates were investigated, the results of which can be seen in Figure 20 The x-axis of the figure gives how much energy that can be absorbed by the circulation LN_2 before it boils. Figure 20 shows a clear correlation between flow rate and relative pitch vibration – favouring low flows. The legend shows the different LN_2 pressures the measurements were made at with the corresponding pump speed setting. The data labels on the plots show the standard deviation of the RMS vibration over the full Bragg range of the monochromator.

For the most general of cases the advice is: Use the pump between 15Hz and 20Hz and increase the pressure until the LN_2 can absorb the beam power that goes into the load plus an additional 150W for all other losses and some overhead.

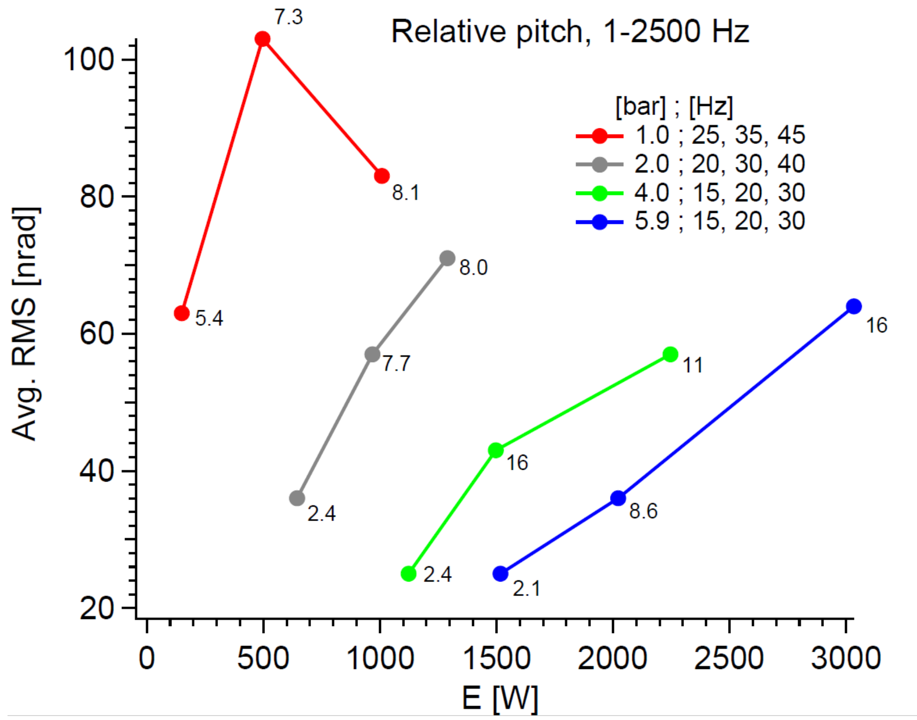

Figure 20: Relative Pitch Vibration of a Horizontal DCM at Various Cooling Powers

A more elaborate description of the vibration of the monochromator is published in JSR, http://scripts.iucr.org/cgi-bin/paper?vv5139, titled “Vibrational stability of a cryocooled horizontal double-crystal monochromator”.

8. Troubleshooting

8.1 Engineering Mode and Pause

Engineering Mode allows the user to intervene in the cryocoolers automated operation. There are two ways this can be accessed; Engineering Mode accessible only from Stop allows full manual (supervised) operation, Pause temporarily intervene with an automated process.

Engineering mode is password protected; the password is entered on the Settings page.

CAUTION

Do not operate the cryocooler in Engineering or Pause Mode unattended or for prolonged periods. Many of the alarms and safety trips are disabled which can result in damage to the cryocooler and void the warranty.

The automatic LP and HP vessels level fills are not operational in this mode.

8.1.1 Engineering Mode

Full Engineering Mode only becomes available in Stopped mode with >=PWD2 level access. The Engineering Mode button will now be visible.

Engineering Mode is helpful to return the cryocooler to normal operation after an uncontrolled shutdown. It allows a rapid step through the various sequences, without the need for dwell times. Alternatively, the operator can manually bring the relevant parameters into line to allow a return to Run mode.

Engineering Mode should only be used by those fully familiar with the normal operation of the cryocooler.

The cryocooler is inherently safe; however uninformed intervention using Engineering Mode can cost time and liquid nitrogen. It would then be better to take the time to allow the cryocooler to run though its normal operation sequence.

8.1.2 Pause Mode

Pause mode is available during automated operation (Fill CC, Keep Cool, Fill System and Run).

Selecting Pause allows the operator to toggle the on/off valves. This is useful in some operations, for example if there is a gas lock hindering the correct reading of the flow meter or the operator want to ensure the vessel levels are at their maximum before a critical experiment. Further situations where going into Pause Mode may be helpful are given in the trouble shooting guide.

Once the relevant intervention has taken place select Resume and the cryocooler will go back to automated operation, controlled by the PLC.

CAUTION

Pause Mode is not an option for running the cryocooler by manually overriding the PLC. The Series XV is an automated system and should be run as such. Do not remain in Engineering or Pause mode; the cryocooler will not operate correctly.

Clear the password to avoid unauthorised operation.

8.2 Troubleshooting Guide

The following section describes a number of issues that may prevent normal operation of the cryocooler, alongside some potential solutions. This guide should be followed prior to contacting FMB Oxford.

It is essential that you familiarise yourself with the manuals supplied with this equipment. The equipment may appear to be very robust externally but potentially contains delicate, fragile and high value optical components.

1. Cryocooler will not go into Cool Down mode	
Possible Causes	**Solution**
Remote inhibit signal is not received	No EPS: Connect supplied override connector to X7. EPS: Check pins G & H on connector X7 are being closed by the facility's EPS logic.

2. Flow meter not registering flow	
Possible Causes	**Solution**
Gas lock	Wait, these usually condense given time. Pulsing V5 and/or V2 should allow a gas lock blocking F2 to clear. Final state is V5 closed and V2 open.
Ice or debris in the flow meter	Warm up the cryocooler and pump, purge the affected flow meter with room temperature nitrogen gas 99.99% Reference Section 0. Cool down cryocooler normally.

3. Level meter not registering correctly	
Possible Causes	**Solution**
Warm cryocooler	Level probes are calibrated at LN_2 temperatures and may not read zero when warm.
Ice in probe	Warm the cryocooler to room temperature. Remove the probe from the cryocooler. Allow to dry thoroughly inside and out; this can be done in a dry location for several days. If available, the probe can be dried in warm air of 75°C to speed up the process.
Physical damage to the probe	The probe may be repairable or it may need to be replaced. Contact customerservice@fmb-oxford.com for assistance.

4. Temperature Sensor not registering correctly	
Possible Causes	**Solution**
Sensor has become detached or damaged	Contact customerservice@fmb-oxford.com

5. Failure of Valve to move	
Possible Causes	**Solution**
Failed pneumatic manifold	Remove cover from Digital IO box if no lights are on the manifold (or section of it) then unit needs replacing. Contact customerservice@fmb-oxford.com
Regulated valves fail to move	Check black cable is connected to valve. Regulated Valves may have air to the valve, but it will not move if the black analogue control cable is not connected or damaged.

6. Frequent refilling of the high-pressure buffer	
Possible Causes	**Solution**
Leak from incorrectly connected transfer lines	Next time the system is warmed, perform a helium leak test on all external connections of the high-pressure lines. Pumping should be on the V8 manual valve with all other valves closed. Helium Leak Rate should be <5 x 10^{-8}mbar l/s. Check VCR connections at load end
Leak from internal pipework	Next time the system is warmed, remove the insert from vessel and perform a helium leak test on all Swagelok/VCR fittings and the pump housing. Pumping should be on the V7 manual valve with all other valves closed. Helium Leak Rate should be <5 x 10^{-8} mbar l/s.
Faulty PRV	Leak test PRV and replace found leaking.
Worn or Damaged V3, V5 or V6 valve seat,	Do not attempt to service the valve. Contact customerservice@fmb-oxford.com

7. Condensation or frosting on any part of the cryogenics circuit	
Possible Causes	**Solution**
Failed vacuum space of the exhaust heater	Using the vacuum pump tools, evacuate the vacuum space affected to >1 x 10^{-4}mbar. If vacuum space was found at atmospheric pressure bakeout is recommended while pumping. Failed vacuum is typically related to a leak in the vacuum valve. Fully unscrew and re-grease related O-rings.
A cold touch may have developed, it will be discernible by a ball of ice	Contact customerservice@fmb-oxford.com

8. Pump has tripped and will not restart	
Possible Causes	**Solution**
The inverter in the control unit has tripped	Reset the inverter, use pause mode to turn pump off for >30s then turn back on. If still not working contact customerservice@fmb-oxford.com

9. Exhaust temperature cannot be controlled	
Possible Causes	**Solution**
At least one heater rod in the EGH has failed. Failed temperature sensor	Contact customerservice@fmb-oxford.com

Table 25: Troubleshooting

9. Maintenance

9.1 Pump

The BNCP-30-100 bearings have a lifetime of approximately 18,000hrs @ 30Hz. This is dependent on the running frequency. Pump hours are tracked by the user interface.

FMB Oxford recommends that the bearings be changed annually for customers who operate continuously at 90Hz and every 2 years for pump speeds below that. Follow the instructions in the Barber Nicholls User Manual.

9.2 Valves

The cryogenic valves used for the flow control of the system are precision machined and if operated with a particle free system have a practical service life of 5 million cycles. The Most active valve is V4, typical operation in run mode with a high heat load is a period between 5-10 minutes, resulting in significantly more than 10 years of life. They are therefore not considered maintenance items.

CAUTION

It is important to never attempt to rotate or remove a valve with it in the closed position. Permanent damage to the valve seat will occur.

9.3 Vacuum Insulated Lines, Exhaust and Dewar

The vacuum insulation will degrade over time particularly if the system is left warm. This becomes apparent if there is any condensation or frost visible on the external surfaces. It is advisable to pump the vacuum spaces at least once in a 12-month period, and prior to cool down if the system has been warm for more than 8 weeks.

It is recommended to achieve a base pressure of > 1×10^{-4} mbar.

10. Spares

10.1 Regular Maintenance Spares

Component	FMB Oxford Part No
Pump Bearing Service Kit	KCVZ0035

10.2 Recommended Spares

Component	FMB Oxford Part No
Burst disk 11.0barg (ZOOK)	KRBZ2005
Burst disk 13.3barg (BS&B)	KRBZ2002
Burst disk 15.5barg (BS&B)	KRBZ2001
Burst disk 14.2barg (ZOOK)	KRBZ2003
Burst disk 17.0barg (ZOOK)	KRBZ2004

10.3 Occasional Spares

Component	FMB Oxford Part No
Pump C-Seal	LOMZ2007
Pump Cold End Bearing	LARB2044
Low Pressure Bath Check Valve 1 psi	KZVR0082
Relief Valve 7.7barg (111psi)	KZVR2010
Relief Valve 11.0barg (160psi)	KZVR2007
Relief Valve 11.2barg (162psi)	KZVR2007
Relief Valve 13.1barg (190psi)	KZVR2006
HP Buffer Heater Stick Assembly	AMG01199_M
L1 Level Probe (1241mm long)	MQLN0001
L2 Level Probe (991mm long)	MQLN0002
Pressure Transmitter 0-200psi (Honeywell)	MQPS0005
Pressure Transmitter 0-16barg (PressureDirect)	MQPS2002
Differential Pressure Transducer (Venturi flow meter models)	MQPS2004
T1, T2, T4, T10 Pt1000 Temp Sensors	MQTT0078
Venturi Flow Meter	AGM0146

11. Appendix 1: Health and Safety

> **WARNING**
>
> Do not take risks. You have a responsibility to ensure the safe condition and safe operation of equipment.

11.1 Cryogenic Safety

Only personnel trained in cryogenic safety should be allowed to operate the cryocooler.

Potential hazards associated with liquid nitrogen are:

- Cold burns.
- Hypothermia.
- Asphyxiation.
- Fire hazards due to Oxygen enrichment.
- Explosion hazards due to pressure build up.

11.2 Cold Burns

Direct contact with liquid nitrogen, or exposed surfaces such as pipes that are cooled by liquid nitrogen constitute a risk of cold burn. Human flesh will adhere to cold surfaces, especially metal surfaces, and tear if pulled away. Avoid contact with liquid nitrogen or cold surfaces. Always wear sleeves, long trousers and gloves when handling liquid nitrogen.

11.3 Hypothermia

If exposed to the cold a person's body temperature can drop below 35°C (95°F) hypothermia can be life threatening. Do not stand in or near cold vapour clouds. Breathing in cold gas can be particularly dangerous.

11.4 Asphyxiation

Liquid nitrogen expands 700-fold as it evaporates; this means that any area where nitrogen is venting has the potential for oxygen depletion. It is highly recommended that oxygen monitoring is installed in any area where there is potential for nitrogen gas to vent, either as part of the normal operation or in the event of an equipment failure.

11.5 Fire Hazard due to Pressure Build-up

Oxygen has a boiling point, at atmospheric pressure of 90K and therefore condenses on bare pipes holding liquid nitrogen. If bare liquid nitrogen pipework looks wet (rather than iced up) or is dripping, the liquid will be pure Oxygen. If any flammable substances and an ignition source are in the vicinity this constitutes are serious fire hazard. Always insulate lines holding liquid nitrogen or cold gas.

11.6 Explosive Hazards due to Pressure Build-up

Liquid nitrogen expands 700-fold as it evaporates; if liquid nitrogen is contained in sealed pipes or vessels a pressure build up will occur and can lead to an explosive rupture. Always ensure that there is a relief valve on any pipework carrying liquid nitrogen that may be isolated by valves. If rapid boiling of the liquid nitrogen is likely, back the relief valve with a burst disc for added safety.

11.7 Electrical Safety

In normal use, the user is protected from the dangers associated with the voltage, current and power levels used by the equipment. Only personnel who are qualified to work with the voltages and currents this equipment operates at should attempt to disconnect, dismantle, or modify the equipment.

11.7.1 Potential Electrical Hazards

The following list is not intended as a complete guide to all the electrical hazards on the system, but illustrates the range of potential hazards that exist:

- Electrical shock
- Electrical burn
- Fire of electrical origin
- Electrical arcing particularly at partial vacuum

WARNING

1. All the electrical equipment supplied as part of the system should be provided with a protective ground, stud or contact washer bonding metal to metal. Do not remove protective grounds as this is dangerous. It is vitally important that the vacuum system is properly always grounded.
2. Follow local and national electrical regulations and procedures.
3. Do not defeat interlocks, remove connectors, disconnect equipment, open safety covers, dismantle or modify equipment unless you are qualified and authorized to do so and you are fully conversant with its operation and potential hazards or have total assurance through your local electrical permit to work system that the equipment has been made safe.
4. Make sure that the mains supply is fused at an appropriate rating and that it can be isolated locally via a clearly labelled, clearly visible and easily accessible isolating switch. Isolate the supply before carrying out any maintenance work.

11.8 Mechanical Handling Safety

WARNING

1. Lifting points are provided for safe handling of components and safe handling practice must be observed to comply with local regulations.
2. Check that lifting points are used only for the job intended.
3. The system itself and some components are heavy and require careful handling. Use safe lifting procedures for heavy items to prevent possible strain injury.

11.9 Safe Mechanical Practice

In normal use, personnel are not required to undertake mechanical work. Servicing or repair may, however, necessitate access to any part of the system. Only suitably qualified personnel should attempt to dismantle, modify or repair equipment.

11.10 Moving Parts

There is a number of moving parts in the system.

WARNING

Injury could result if body parts become caught in moving mechanisms.

Keep clothing, hands and others body parts away from moving mechanisms.

12. Appendix 2 Utilities and Additional Information

12.1 Utilities

Power (with Inductive Loads)	208V AC 50/60Hz, 32A Single Phase or 230V AC 50/60Hz 16A 3 Phase Min Type C Breaker
Liquid Nitrogen	1500 Litres per day at 2.5kW
Purge nitrogen gas	Dry nitrogen 1-2barg (99.99% Pure)
Pneumatic air	Dry, clean air regulated at 6barg (+10%, -0%)

12.2 Environment

Ambient temperature	0°C to 35°C
Storage temperature	0°C to 40°C
Relative humidity	10 – 95% Non-condensing

12.3 Controls System and PC

Controls Configuration	Mobile floor standing 19” rackmount cabinet. Front panel mounted status indicators & disconnect Rear cable connections to rear
Operator Interface	22” IPS multitouch TFT Display Wireless Keyboard/touchpad
PLC	Siemens S7-1500
PC	1U Intel NUC PC
Operating System	Ubunto 20 (with EPICS)
Rack	600mm x 600mm x 21U

12.4 Nominal Weight, Lifting Points, and External Dimensions

12.4.1 Nominal Weight

Part of system	**Nominal Weight**
Full assembly (empty)	440kg
Top flange and Internal assembly	320kg
Liquid Nitrogen (@60% Full)	70kg
Control rack	120kg

12.4.2 Lifting and Handling

The complete assembly fitted with castors for ease of movement.

CAUTION

The vessel has a small footprint and is top heavy, especially when empty / warm. Great care should be taken when pushing on its castors not to cause it to tip over.

CAUTION

The cryocooler vessel is shipped with a lifting bracket fitted to the top flange. This should always be used for lifting the cryocooler vessel.

12.4.3 External Dimensions

Consult Appendix 5: Drawings for information of the external dimensions of the cryocooler, such as the total height and vessel footprint and the location of the centre of gravity.

13. Appendix 3: Alarms Table

Name	DB80.DBX0+	Description	PUMP FLUSH	ENG PAUSE	STOP	FILL CC	KEEP COOL	FILL LOAD	RUN	NOTES
MCB_Heater	0.0	Heater MCB Trip	T-ES	T-ES	T-ES	T-ES	T-ES	T-ES	T-ES	
MCB_Pump	0.1	Pump MCB Trip	T-ES	T-ES	T-ES	T-ES	T-ES	T-ES	T-ES	
WF_L1	0.2	L1 Wiring Fault	T-ES	T-ES	T-ES	T-ES	T-ES	T-ES	T-ES	
WF_L2	0.3	L2 Wiring Fault	T-ES	T-ES	T-ES	T-ES	T-ES	T-ES	T-ES	
WF_P1	0.4	P1 Wiring Fault			T-ES	T-ES	T-ES	T-ES	T-ES	
WF_P2	0.5	P2 Wiring Fault			T-ES	T-ES	T-ES	T-ES	T-ES	
WF_TF1	0.6	TF1 Wiring Fault	T-ES1	T-ES1	T-ES1	T-ES1	T-ES1	T-ES1	T-ES1	
WF_TF2	0.7	TF2 Wiring Fault	T-ES	T-ES	T-ES	T-ES	T-ES	T-ES	T-ES	
WF_VFD	1.0	VF1 Wiring Fault	T-ES	T-ES	T-ES	T-ES	T-ES	T-ES	T-ES	
WF_T4	1.1	VF2 Wiring Fault	T-ES	T-ES	T-ES	T-ES	T-ES	T-ES	T-ES	
WF_T1	1.2	T1 Wiring Fault	T-ES	T-ES	T-ES	T-ES	T-ES	T-ES	T-ES	
WF_T2	1.3	T2 Wiring Fault	T-ES	T-ES	T-ES	T-ES	T-ES	T-ES	T-ES	
WF_T10	1.4	T10 Wiring Fault	T-ES	T-ES	T-ES	T-ES	T-ES	T-ES	T-ES	
WF_Tegh	1.5	T EGH Wiring Fault	T-ES	T-ES	T-ES	T-ES	T-ES	T-ES	T-ES	
WF_FR1	1.6	FR1 TC Wiring Fault								
WF_FR2	1.7	FR2 TC Wiring Fault								
WF_FR3	2.0	FR3 TC Wiring Fault								
WF_FR4	2.1	FR4 TC Wiring Fault								
No_Air	2.2	No Air - Pressure sensor <6bar	T-ES	T-ES	T-ES	T-ES	T-ES	T-ES	T-ES	
Inhibit_LOCAL	2.3	Local Inhibit (ESTOP) Pressed	T-ES	T-ES	T-ES	T-ES	T-ES	T-ES	T-ES	
Inhibit_EPS	2.4	EPS Inhibit NOT closed						T-KC	T-KC	
V1_NO	2.5	V1 Not Open (after Request)	W2	W2		W2	W2	W2	W2	
V1_NC	2.6	V1 Not Closed (after Request)	W2	W2		W2	W2	W2	W2	
V2_NO	2.7	V2 Not Open (after Request)	W2	W2		W2	W2	W2	W2	
V2_NC	3.0	V2 Not Closed (after Request)	W2	W2		W2	W2	W2	W2	
N3_NO	3.1	V3 Not Open (after Request)	W2	W2		W2	W2	W2	W2	
V3_NC	3.2	V3 Not Closed (after Request)	W2	W2		W2	W2	W2	W2	
V4_NO	3.3	V4 Not Open (after Request)	W2	W2		W2	W2	W2	W2	
V4_NC	3.4	V4 Not Closed (after Request)	W2	W2		W2	W2	W2	W2	
V5_NO	3.5	V5 Not Open (after Request)	W2	W2		W2	W2	W2	W2	
V5_NC	3.6	V5 Not Closed (after Request)	W2	W2		W2	W2	W2	W2	
V6_NO	3.7	V6 Not Open (after Request)	W2	W2		W2	W2	W2	W2	
V6_NC	4.0	V6 Not Closed (after Request)	W2	W2		W2	W2	W2	W2	
V10_NO	4.1	V10 Not Open (after Request)	W2	W2		W2	W2	W2	W2	
V10_NC	4.2	V10 Not Closed (after Request)	W2	W2		W2	W2	W2	W2	
HEATERS_NO	4.3	Heater Not On (after Request)							W	
PUMP_NO	4.4	Pump Not On (after Request)					T-S		T-S	
VFD_OC	4.5	Pump Over Current							W	
VFD_ERR	4.6	Pump VFD Error							W	
L1_HT	4.7	L1 Level High Trip				W	T-S	W	T-S	90%
L1_H	5.0	L1 Level High					W		W	85%
L1_L	5.1	L1 Level Low					W		W	20%
L1_LT	5.2	L1 Level Low Trip (below safe Run Limit)					T-S		T-S	10%
L2_HT	5.3	L2 Level High Trip					T-S		T-S	90%
L2_H	5.4	L2 Level High					W		W	85%
L2_L	5.5	L2 Level Low					W		W	25%
L2_LT	5.6	L2 Level Low Trip					T-S		T-S	10%
SystemPressure_HT	5.7	P1 or P2 High Trip							T-S	
P1_H	6.0	P1 High							W	
P2_HT	6.1	P2 High Trip							T-S	
P2_H	6.2	P2 High							W	
F1_H	6.3	F1 High							W1	>25 for 10s
F1_L	6.4	F1 Low							W1	<1 for 10s
F2_H	6.5	F2 High							W	>25 for 10s
F2_L	6.6	F2 Low							W	<1 for 30s
T1_H	6.7	T1 High							W	
T2_H	7.0	T2 High							W	
Tegh_H	7.1	Tegh High							W	
Tegh_L	7.2	Tegh Low							W	
FR1_H	7.3	FR1 High							W	>400C
FR2_H	7.4	FR2 High							W	>400C
FR3_H	7.5	FR3 High							W	>400C
FR4_H	7.6	FR4 High							W	>400C
P2_H_RUN	7.7	Run P2 High P2> SP+band							W	
P2_L_RUN	8.0	Run P2 Low P2<SP-band							W	
VesselNotFilling	8.1	Acive if the Vessel fails to fill (no supply)							W	
LN2_VP_Warning	8.2	Run mode LN2 boiling							W	
V4_WF	8.3	Wiring Fault for V4 regulated output	T-ES2	T-ES2	T-ES2	T-ES2	T-ES2	T-ES2	T-ES2	
V10_WF	8.4	Wiring Fault for V10 regulated output	T-ES	T-ES	T-ES	T-ES	T-ES	T-ES	T-ES	
PumpOdometerExceeded	8.5	Odometer Exceeded	W	W	W	W	W	W	W	
HighDiferentialPressure	8.6	P1>>P2 V1 & V2 Lockout	W	W	W	W				2barg
VesselTempHigh	8.7	The temperature inside the Vessel Is unusually High	T-ES	T-ES	T-ES	T-ES	T-ES	T-ES	T-ES	T[1..10]>350K
	T-ES	Trip to ESTOP								
	T-ES1	Trip to Estop (active only if F1 present)								
	T-ES2	Trip to Estop (active only if V4 Regulated)								
	T-KC	Trip to Keep Cool								
	W	Warning Only								
	W1	Warning (active only if F1 present)								
	W2	Warning (active only if Valve limits present)								

Figure 21: Alarms Table

14. Appendix 4: Test Reports

15. Appendix 5: Drawings

16. Appendix 6: Third Party User Manuals and Certificates