3. Hardware Description

3.1 Overall System

3.1.1 Specifications

Table 3.1-1 Specifications

Description	**Specification**
Type Number	Series C +
Performance Data	Continuous cooling of loads up to 2.5 kW Flow rate controllable up to 5 U.S. gallons per minute Pressure controllable up to 75psi.
Dimensions	Remote control rack: 910mm x 600mm x 600mm Cryo-Cooler Vessel diameter : 835 mm (working space diameter): 1200 mm
Slinging Points , and Tackle Provided	The cryo-cooler vessel is shipped with a lifting bracket fitted to the top flange, which should be used whenever lifting the cryo-cooler vessel.
Accessories Fitted	Dwyer Series 1600 Temperature / Process Control PoWrMaster G3U AC Motor Speed Control Barber Nichols Liquid Nitrogen Pump Lake Shore Cryopump Monitor Model 819 Micro Motion Elite Sensor CMF025 (Optional) Micro Motion ELITE Model RTF9739 Transmitter (Optional) Sensotec (RDP) 415 Pressure Transmitter
Utilities required	Power: 208V AC 3 phase mains input to control rack. Liquid Nitrogen: 1600 litres per day at full power (continuous operation) 600 litres for 8 hours operation at 2.5kW
Operating conditions	Ambient temperature: -10 °C to 40 °C Humidity: 0 to 90% non-condensing

Specifications for the accessories fitted to the system can be found in the manufacturers' manuals and data sheets.

3.1.2 System Layout

The diagram below shows a typical layout for a cryo-cooler system.

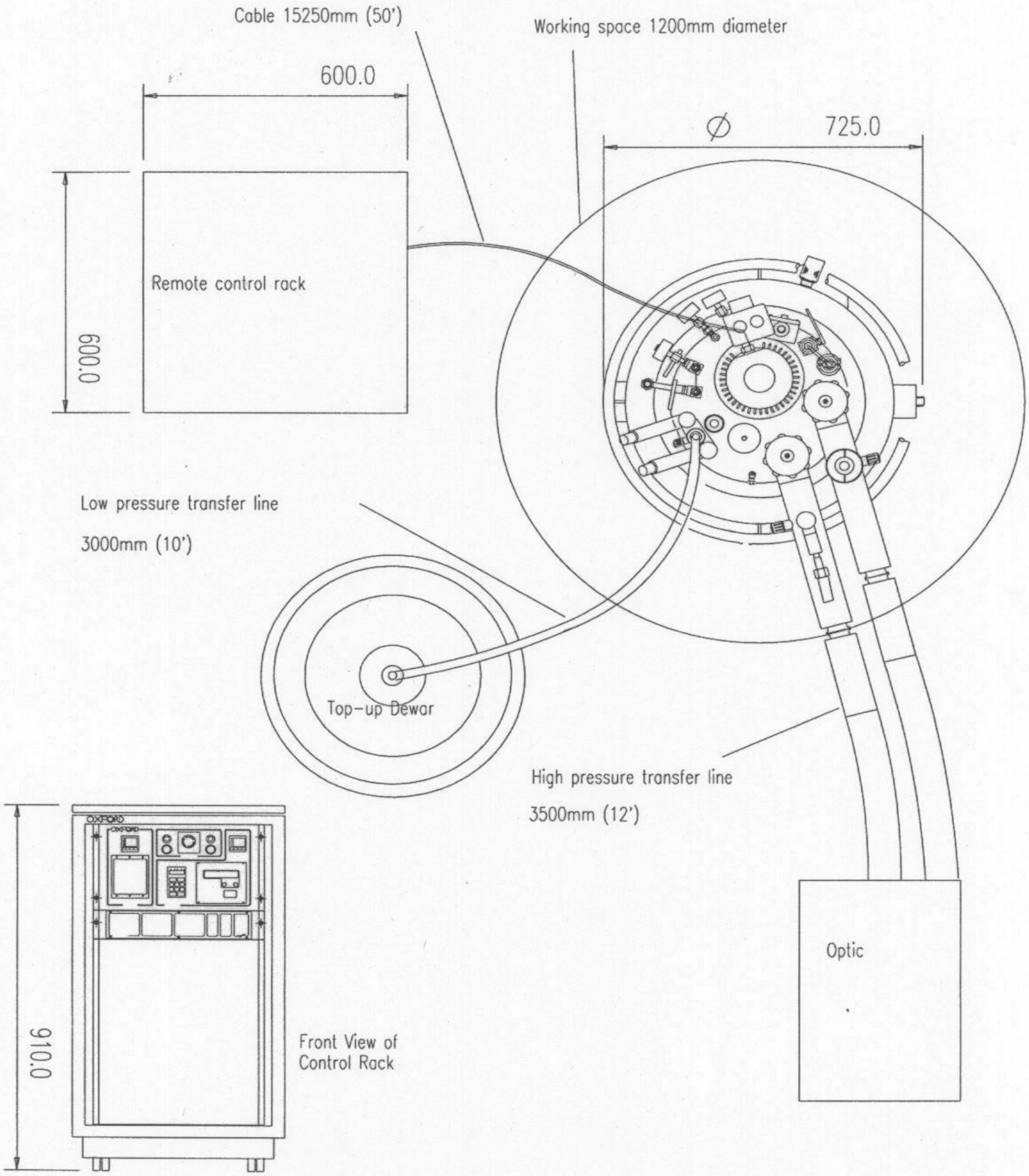
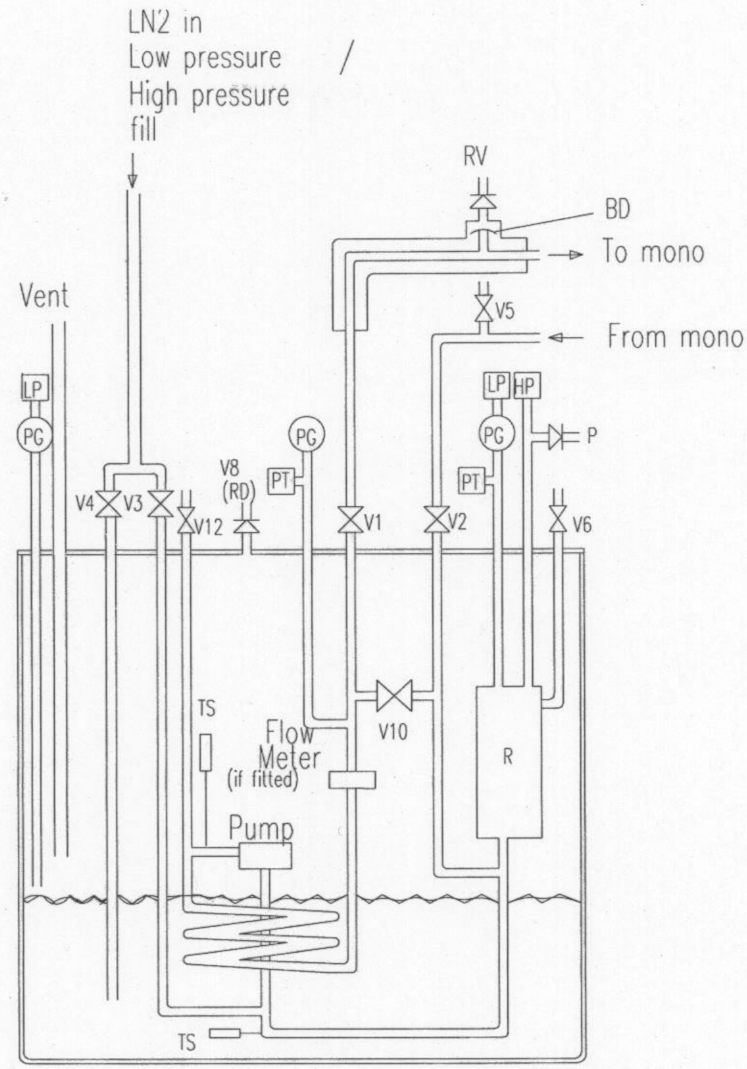


Figure 3.1-1 Typical Layout of Cryo-cooler

3.1.3 Theory of Operation

The Oxford Instruments Cryo-cooler is a closed loop liquid nitrogen cooler, which provides pure liquid nitrogen for cooling monochromator optics. Nitrogen vapour has been eliminated from the circulating liquid, so that there are no vibrations due to boiling liquid in the cooling circuit.

A schematic diagram of the cryo-cooler is shown in the diagram below.



V1 – Isolation valve
V2 – Isolation valve
V3 – High pressure top up valve
V4 – Low pressure top up valve
V5 – High pressure vent valve (instrument)
V6 – High pressure vent valve (reservoir gas)
V8 (RD) – Pressure release (disc)
V12 – Heat exchanger vent valve
V10 – Bypass valve
R – Reservoir
PU – Nitrogen pump
RV – Pressure release valve
TS – Temperature sensor
PT – Pressure transmitter
PG – Pressure gauge
HP – Heater probe
LP – Level probe
BD – Burst Disc

Figure 3.1-2 Schematic Diagram of Closed Loop in Nitrogen Cooler

There are two separate nitrogen circuits: the low pressure circuit and the high pressure circuit (or closed loop circuit).

The liquid nitrogen in the low pressure circuit provides the cooling for the liquid nitrogen in the high pressure circuit. The low pressure circuit is therefore automatically re-filled with liquid nitrogen regularly (via a solenoid valve), as it boils off and nitrogen gas is vented from the vessel.

Low Pressure Circuit

During normal operation the liquid nitrogen bath is continuously kept topped up to the required level through the top-up valve V4.

The level of the liquid in the bath is displayed on a liquid nitrogen level meter on the control rack. When this liquid nitrogen level meter displays 45%, the sub-cooler coil (of the high pressure circuit) is covered. The fill point on the liquid nitrogen level meter is set at the 45% level, and this automatically operates the solenoid valve on the top-up dewar. The full point, which turns off the solenoid valve, is set to 55%. The liquid nitrogen in the vessel continuously boils off and is vented through the vent tube.

High pressure circuit (Closed Loop Circuit)

The high pressure circuit is a closed loop circuit ie the circuit is filled with liquid nitrogen when the system is started.

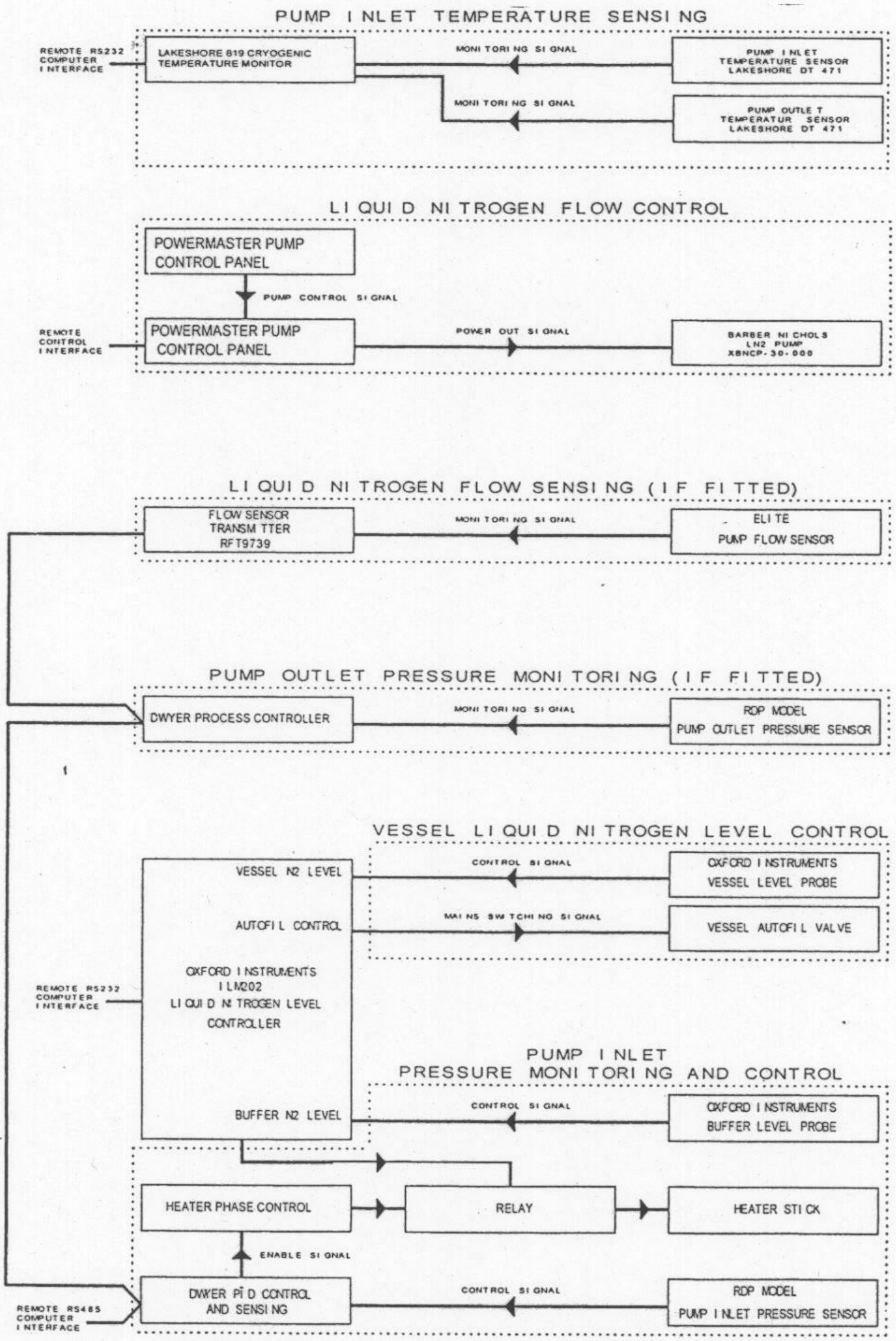
The closed-loop is filled with liquid nitrogen through the closed-loop liquid nitrogen fill valve, V3. The closed loop is fitted with vent valves V5, V6, V12 to vent any nitrogen gas generated during cool-down.

A high pressure reservoir of liquid nitrogen maintains the required level of liquid nitrogen at the pump inlet. Above the reservoir there is a pocket of nitrogen gas. The pressure in the closed loop is increased by boiling off some of the liquid nitrogen in the reservoir using a heater in the reservoir. The boiled off gas collects in the gas pocket, thus increasing its pressure. The pressure in the circuit is thus controlled by automatically adjusting the heater power to maintain the required pressure setpoint. The pressure which controls this process is measured at the reservoir which is at the same pressure as the liquid nitrogen pump inlet.

The liquid nitrogen pump circulates the liquid nitrogen around the closed loop. The outlet of the pump is connected to the sub-cooler.

The sub-cooler is a heat exchanger which is positioned in the cryo-cooler vessel. During normal operation it is completely covered with the liquid nitrogen of the bath in the low pressure circuit. The high pressure liquid nitrogen is thus cooled by liquid nitrogen in the bath. The liquid leaves the sub-cooler where the flow can be directed to cool the monochromator crystal (by opening V1 and V2 and closing V10) or to bypass the monochromator (by opening V10 and closing V1 and V2). The flow is then directed back past the reservoir.

Controls



3.1-3 Block Diagram of the Control System

A pressure sensor in the reservoir (the reservoir pressure is the same as the inlet pressure to the liquid nitrogen pump) feeds a 4 to 20 mA signal to the process controller in the control rack. This process controller converts this signal into a pressure reading using a calibration that has been entered into it using the menus. The controller displays the pressure (in PSI) on the upper display.

The Dwyer process controller controls the operation of the heater in the nitrogen reservoir of the high pressure circuit, by checking the required pressure (which has been entered by the user) and the actual pressure at the inlet to the pump, then increasing the heater power if the pressure is too low.

The control rack also monitors the liquid level in the sub-cooler vessel and the liquid level in the high pressure reservoir, using nitrogen level probes.

The temperature at the pump inlet is measured by a silicon diode type temperature sensor and dispayed on the temperature monitor.

Operating Values

Maximum recommended values for operation of the cooler are shown below.

Table 3.1-2 Theoretical Operating Values

Reservoir Temperature (K)	Return Temperature (K)	P Safe (PSIG)	Flow rate (l/min)	Flow rate (US Gal/min)	Maximum available cooling power in the optics (Watts)
80	81.0	10	5	1.32	100
80	85.0	20	5	1.32	600
80	87.0	30	5	1.32	900
80	89.5	40	5	1.32	1200
80	90.5	50	5	1.32	1500
80	81.0	10	10	2.64	100
80	85.0	20	10	2.64	500
80	87.0	30	10	2.64	1000
80	89.5	40	10	2.64	1500
80	90.5	50	10	2.64	2000
80	81.0	10	15	3.96	0
80	85.0	20	15	3.96	1000
80	87.0	30	15	3.96	1500
80	89.5	40	15	3.96	2000
80	90.5	50	15	3.96	2500

The cryo-cooler system has been shown to be able to dissipate heat loads of 2.5kW with a flow rate of 11l/min and a pressure of 40 p.s.i. The actual flow rate and pressure required to achieve this heat load dissipation may vary by ± 10%. The maximum recommended heat load is 2.5kW.

It is possible to choose either one of two modes of operation :

1. high flow rate with lower temperature difference, but higher vibration, or
2. low flow rate with higher temperature difference, but lower vibration.

Typical operational values of flow versus frequency are shown in the table below.

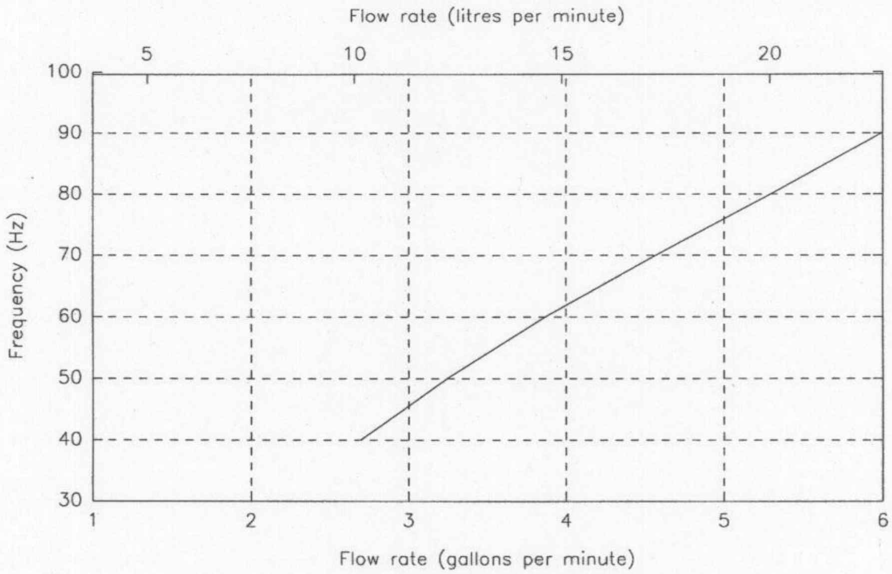


Figure 3.1-4 Graph showing typical values of frequency versus flow rate in US gallons / minute

Description

The system consists of a vacuum insulated cryo-cooler vessel, control rack and interconnecting cables. The main components of the system are:

Sub-cooler Vessel
Barber Nichols Pump
Sub-cooler Coil
Cryogenic Valves
High Pressure Reservoir and Control Circuit
Transfer Lines
Control Rack and Instrumentation

The diagram below shows a cross sectional view through the cryocooler, which indicates the positions of the main components.

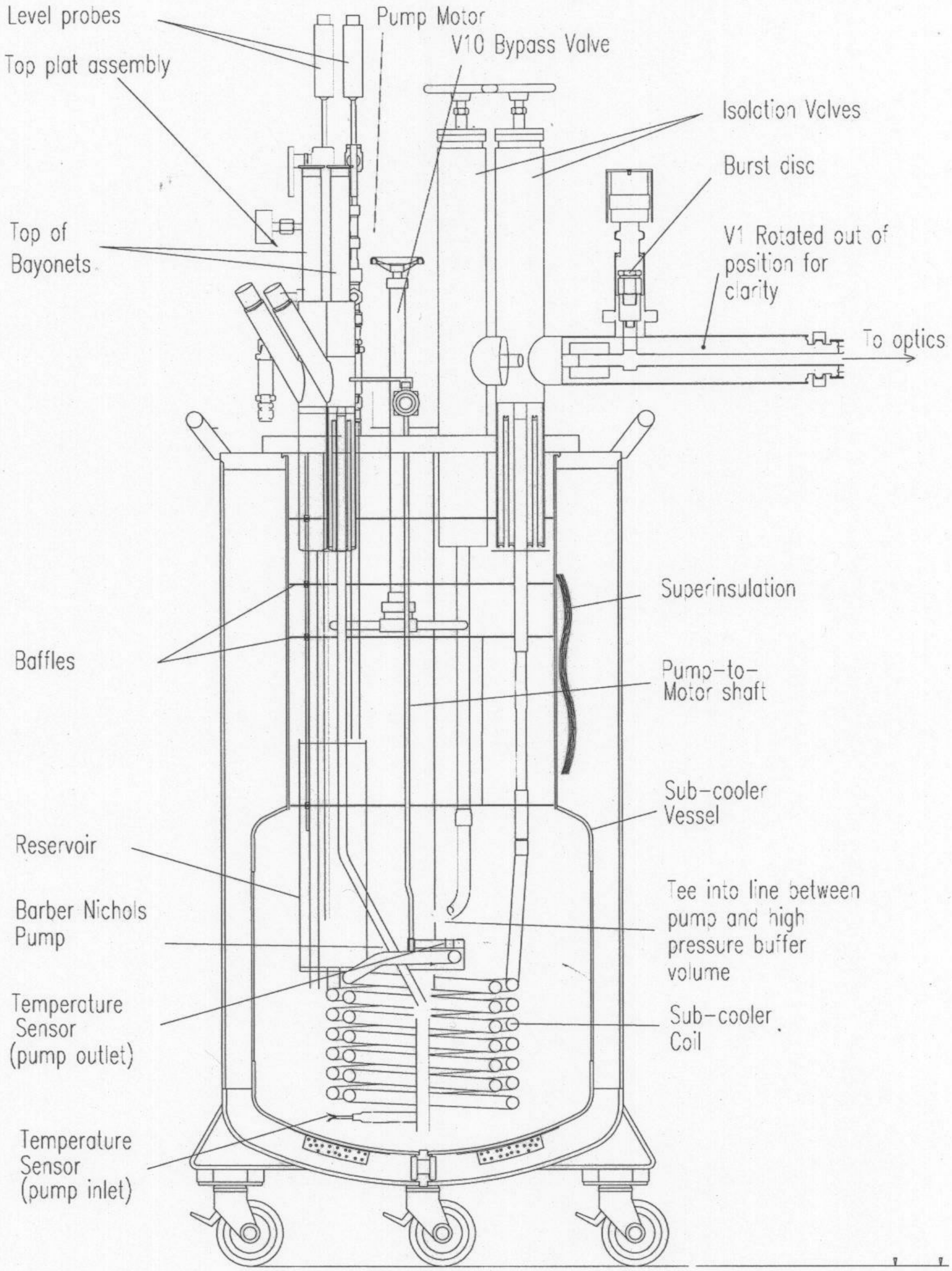


Figure 3.1-5 Cross-sectional View of the Cryo-cooler vessel showing the position of the internal components

The position of the services on the top plate assembly are shown in the following diagrams of the top plate. The position of the valves are shown on a separate diagram for clarity (refer to section 3.5 of this manual).

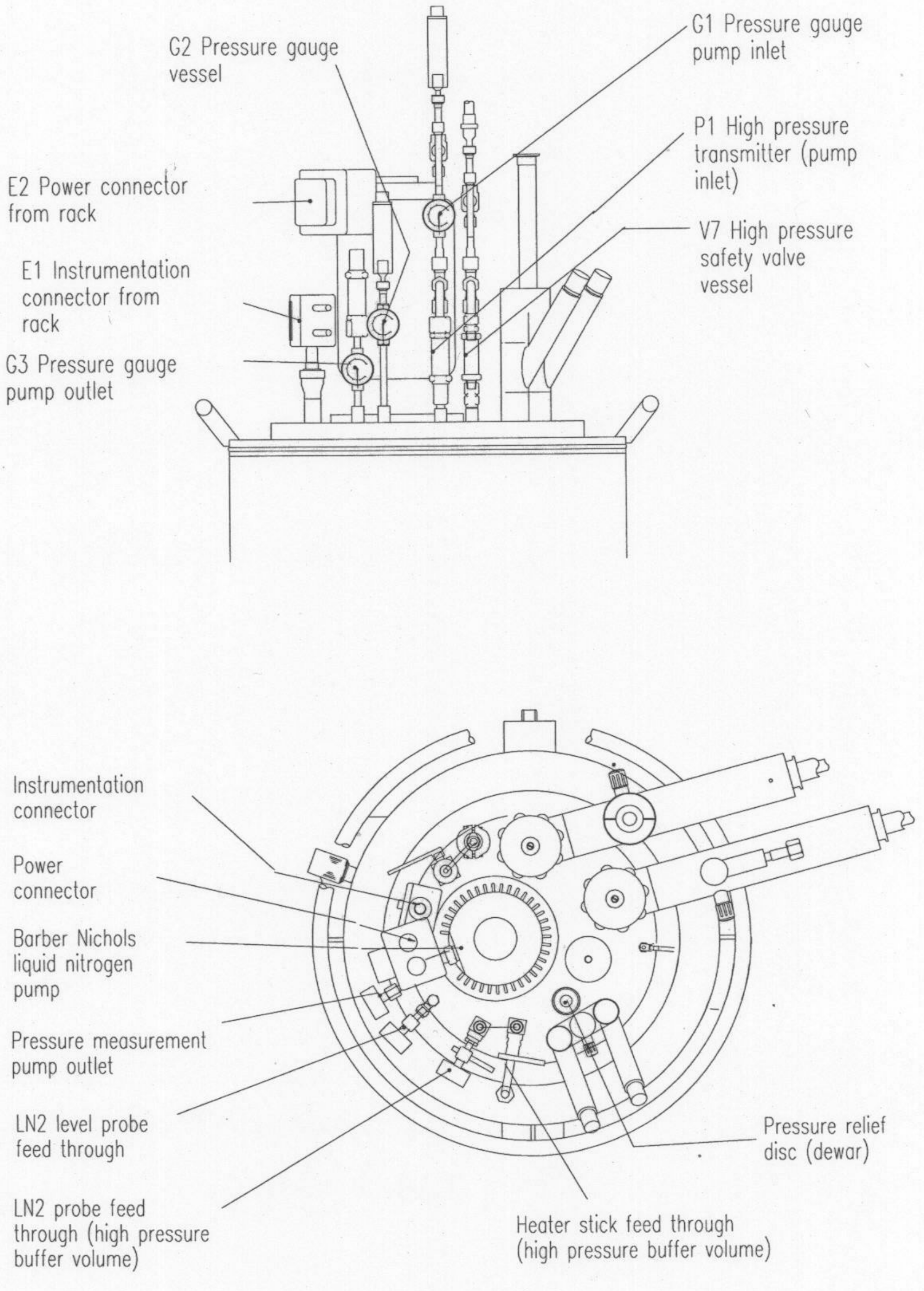


Figure 3.1-6 Views of the top of the Cryo-cooler showing the position of the Services

Drawings

The following drawing numbers apply:

AMA00400	Top assembly, comprising
AMG00200	Dewar
AMG01100	Pumping System
CMG00750	Control rack, including
CMG00850	Control unit
CMG00900	Power distribution unit
AMG00300	High pressure delivery lines (two per system or as ordered)
AMG00400	Low pressure fill line (one per system)

3.2 Sub-Cooler Vessel

The cryo-cooler vessel is a double walled, vacuum insulated, stainless stel vessel. The inner pipework and pump all hang from the top plate which is bolted to the top ring of the vessel. The vacuum space between the inner and outer walls of the vessel contains a molecular sieve cryosorb to maintain the vacuum when the vessel is cold. The vacuum space is protected by a vacuum relief port. The inner vessel is wrapped with superinsulation. The vessel is mounted on lockable wheels. The wheels are locked in position by pressing on the wheel clamp. The vessel has a grab handle for moving it around easily.

3.3 Barber Nichols Pump

The liquid nitrogen in the closed loop is circulated by a Barber Nichols BNCP-30 centrifugal pump. The pump head is directly connected to the high pressure closed loop pipework. The pump housing and impeller are in liquid nitrogen.

The pump speed is controlled via a PoWrmaster G3U-20P7 AC motor controller mounted in the control rack. The motor can provide 0.78 hp at 90 Hz. The motor is controlled by a variable frequency drive, which allows the pump speed to be set to give the desired head and flow.

More detailed information on the Barber Nichols pump (including information about frequency and flow rate) and the PoWr master motor controller is contained in the suppliers documentation supplied with the cryo-cooler.

3.4 Sub-cooler Coil

The sub-cooler coil is positioned at the lowest point in the vessel so that it is completely covered in liquid nitrogen during normal operation. The coil consists of around 12 metres of copper tubing. It is made as a double spiral to save space.

3.5 Cryogenic Valves

The cryogenic valves are supplied by Circle Seal Controls Inc. The feed and return valves from the optic are 3/4" vacuum jacketed, angle pattern CV8 series valves. The smaller valves on the high pressure and low pressure top-up lines are 1/2" mini vacuum jacketed, Y pattern valves. Data sheets on these valves are included in the Appendices. The by-pass valve is 1/2" bronze cryogenic gate valve.

The diagram below shows the top of the cryocooler with the positions of the valves indicated.

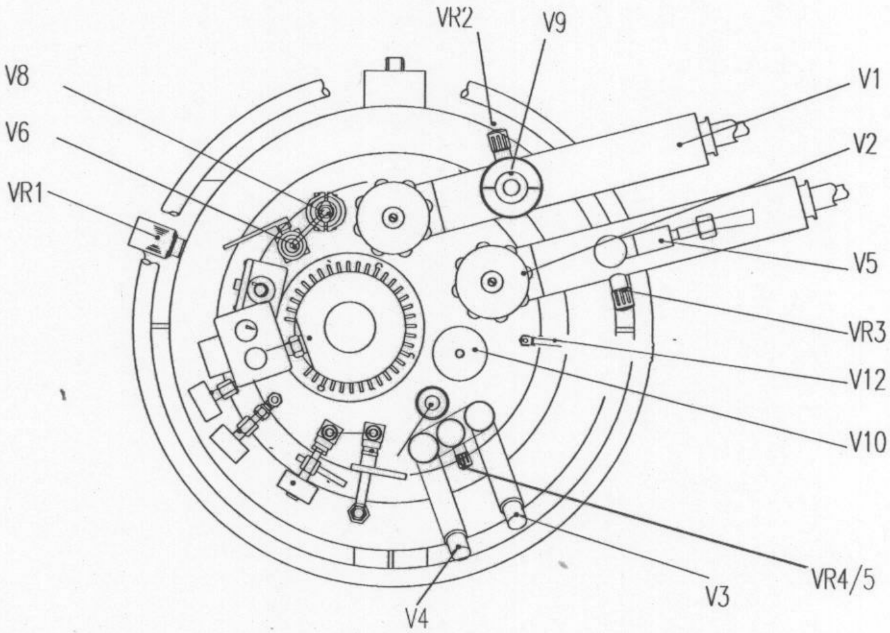


Figure 3.5-1 View of the Top Plate Showing the Position of the Valves

The table below lists the valves and type used in the cryo-cooler. Data sheets on these valves are included in the Appendices.

Valve Ref	Description	Valve Type	Oxford Inst Part No
V1	Liquid Supply Valve to Optic	Cryolab 3/4" CV8 Series	KCVZ0028
V2	Liquid Return Valve from Optic	Cryolab 3/4" CV8 Series	KCVZ0028
V3	High Pressure Loop Top-up valve	Cryolab 1/2" Mini Series - Y Pattern	KCVZ0033
V4	Vessel Top-up Valve	Cryolab 1/2" Mini Series - Y Pattern	KCVZ0033
Valve Ref	Description	Valve Type	Oxford Inst Part No
V5	Optic Return Manual Vent Valve	Cryolab 1/2" Mini Series	KCVZ0027
V6	High Pressure Reservoir Vent	1/4" Ball valve	KZVB0024
V7	High Pressure Reservoir Relief	Circle Seal K-5120-2MP-100	KZVR0047
V8	Vessel Relief Valve	Circle Seal K-520 1" 1psi	KZVR0027
V9	Optic Feed Transfer Line Relief	Burst disc	KRBZ0022
V10	By-pass Valve	1/2" Bronze Gate valve	KCVZ0032
V11	Vessel Relief Valve	Circle Seal K-520 1/2" 5 psi	KZVR0027

V12	Sub-cooler Coil Vent Valve	1/4" ball valve	KZVB0024
	Low Pressure Transfer Line Relief	Circle Seal 25 psi	KZVR0021
	Vessel Top-up Valve	Asco Solenoid Type 8263 240V NC	KVVZ0021

3.6 High Pressure Reservoir and Pressure Control

Control of the pressure in the high pressure loop is achieved by boiling away some of the liquid in this reservoir, using a 120 Watt heating element immersed in the liquid. The pressure is controlled by controlling the heater power to maintain the required pressure setpoint.

3.7 Transfer Lines

High pressure and low pressure, vacuum insulated, transfer lines are supplied with the cryo-cooler. High pressure transfer lines to the optic chamber have bayonet couplings at the cryo-cooler end and VCR couplings at the optic end. The low pressure line has a mini bayonet coupling at the cooler end and a Swagelock fitting at the dewar end.

3.8 Control Rack and Instrumentation

All cryo-cooler control units are mounted in a standard 19" control rack. The rack contains all the displays necessary for monitoring and controlling pressure, temperature and flow rate.

Drawing CMG00750 shows the layout and wiring diagrams for the control rack and signal and power distribution boxes mounted on the cryocooler unit. Mains power at 208 V AC 60 Hz enters at the connector at the lower rear of the rack. This goes directly to the power distribution panel at the rear of the rack, from which mains power is delivered to each unit in the rack.

All mains outputs on the distribution box are 208V AC.

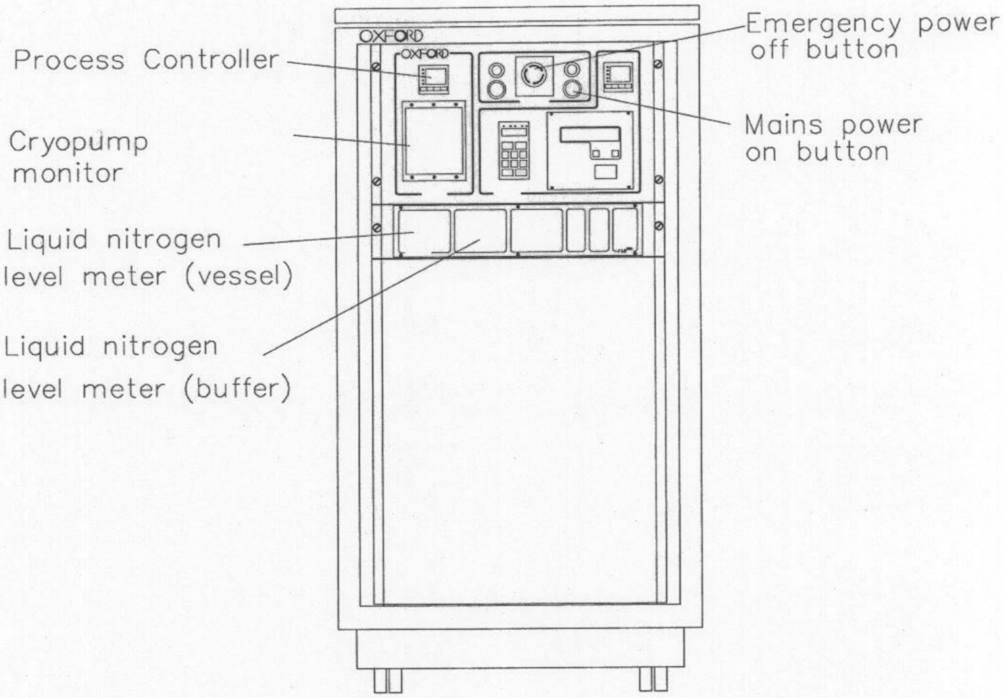


Figure 3.8-1 Front View of Remote Control Rack

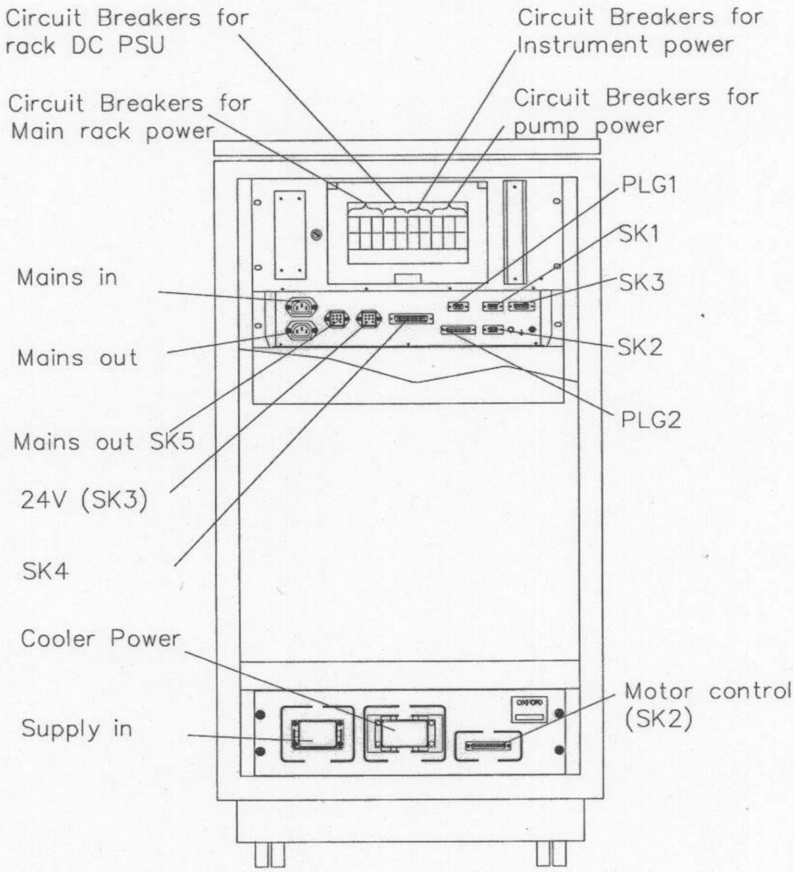


Figure 3.8-2 Rear View of control Rack

3.8.1 Control Rack

The control rack is a mobile standard half height 19" rack with Emergency Off mains isolation and power distribution box. All temperature and pressure displays are mounted in the rack which is connected to the cryo-cooler via a 50' cable. The rack operates with 208 V AC mains power.

Mains power is always present on the distribution panel when the mains power cable PL1 is connected to the rack.

3.8.2 Power distribution panel

The power distribution panel is mounted at the rear of the rack. It houses all the circuit breakers needed to power the cryocooler system. There is a 24V power supply mounted on the panel to provide 24V DC for the mains contactor and pressure transducers in the cooler unit.

Control of the main contactor is via the power control buttons on the front panel of the rack control unit.

The circuit breakers are as follows :

16A :	3-phase breaker isolating rack from input mains power on PLG1 on rear panel
10A :	3-phase breaker isolating power to pump controller
6A :	2- phase breaker isolating power to rack control unit
1A :	2- phase breaker isolating 24V DC power supply.

3.8.3 Rack control unit

The rack control unit is mounted at the top of the control rack. It houses all the control and monitoring units for flow, pressure, temperature, and pump control. The power control buttons (**ON, OFF**) and power indication lamps (**MAINS ON, RACK ACTIVE**), control, and are powered by, the power distribution panel at the rear of the rack (see section 3.8.1). The **EMO** button will remove power from the control unit, **but there will still be mains power at the distribution panel.** (see section 3.8.1 above)

Drawing CMG00850 shows the layout and wiring of the main control unit. All units recieve mains power from the terminal blocks mounted at the rear of the unit. All sensor connections to the cryocooler are via a 50-way D-connector (SKT4) on the rear panel.

The motor control display unit is connected to the main pump control unit, at the base of the control rack, by a 15w D connector SKT3.

3.8.3.1 Pressure Monitoring and Pressure Control

The pressure raising heater is interlocked to the high pressure reservoir level meter relay. If the level falls below 40%, power to the heater is disabled.

Pressure Transducer This is a Sensotec 2-wire pressure transmitter and is mounted to measure pressure at the pump inlet (and outlet where fitted). The transducer gives a 4-20mA signal and the pressure is displayed on Dwyer 1600 series controller.

Heater control The heater power on the cryocooler controlled by the inlet pressure controller and a phase angle power control.

Pressure Gauges These are mounted on stalks on the top plate and monitor the pressure at the pump inlet, pump outlet and vessel.

Separate documentation is provided on the Dwyer 1600 series controller. Refer to that documentation for a detailed description. Data sheets are provided in the Appendices which describe the pressure transmitter.

3.8.3.2 Temperature Monitoring

Temperature Sensor This is a Lakeshore DT-470 silicon diode sensor and is mounted to measure the temperature in the closed loop circuit at the pump inlet and outlet (when fitted). The temperature is displayed on a Lakeshore 819 temperature monitor.

Separate documentation is provided which explains the set-up and operation of the Lakeshore 819 temperature monitor. Data sheets on this sensor is included in the Appendices.

3.8.3.3 Flow monitoring (if fitted)

Flow sensor This is a Micromotion CMF025 flow sensor mounted inside the cryocooler vessel. The sensor signals are connected to the RFT9739 Transmitter mounted in the rack control rack.

Separate documentation is provided which explains the set-up and operation of the Micromotion units. Data sheets are included in the Appendices.

3.8.4 Liquid Nitrogen Level Monitoring

The cryo-cooler has an Oxford Instruments ILM nitrogen level meter and two liquid nitrogen level probes to monitor the liquid level in the sub-cooler vessel and to monitor the level in the high pressure reservoir. The meter receives power via the rack control unit (see section 3.8.2) when the rack is active. Probe connections are connected to the cryocooler via two 9w D connectors (SKT1,2)

The vessel is topped-up automatically via a solenoid valve mounted at the end of the top-up transfer line. This valve is controlled by a relay in the level meter. The vessel fill point is 45% and the full point 55%.

The nitrogen level probes consist of concentric tubes where liquid level is determined by the capacitance of the co-axial tubes. The levels are displayed on a 2-channel level meter.

Refer to the separate operators manual for a detailed explanation of the set-up and operation of the nitrogen level meter.

3.8.5 Remote Control and Monitoring

All the control and monitoring units in the control rack (with the exception of the motor control unit) have remote monitoring connections. The Dwyer pressure controllers and the Flow Transmitter are connected to an RS485 connection via PLG1 on the rear panel of the rack control unit.

The remote connections are on the back of the controller unit:

Plg 1	RS485	Screen	Pin 1
		TxA	Pin 4
		TxB	Pin 5

The Lakeshore 818 has a RS232 connection via PLG2 on the rear panel of the rack control unit.

The ILM meter has an RS232 connection on the rear panel of the ILM meter.