THE OXFORD WHOLE BODY IMAGING MAGNET

OPERATORS HANDBOOK

INSTALLATION AND OPERATION

OXFORD

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Oxford Magnet Technology Ltd
Wharf Road,
Eynsham,
Oxford,
OX8 1BP,
England

Telephone: Oxford 880880 Telex: 838786

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NOTES FOR READERS

This handbook provides all the information and instruction necessary to correctly install and prepare a unit for operation.

In addition to the comprehensive safety precautions which operators must observe at all times, the descriptive matter and useful technical notes are provided to establish a valuable data base. Maintenance information is also provided.

Revised and additional pages will be issued from time to time, clearly marked to identify the section in which they are to be filed. A revised record of these pages will be issued on each occasion and should be filed in place of the existing Revision Record to provide evidence that the new pages have been received and filed.

Old pages must be discarded.

The following meanings are ascribed to the words in boxes which precede notices.

> **WARNING:**
> ***The procedure must be followed precisely to avoid the possibility of personal injury.***

> **Caution:**
> *Follow this procedure to avoid damage to components.*

> NOTE:
> *This method makes the job easier.*

SAFETY

For personal safety and the protection of the equipment it is most important that all operators and persons in the vicinity of a magnet are aware of precautions they must observe.

In addition to the general information given overleaf, more detailed safety instructions, clearly marked with extra Notes, Cautions and Warnings are made throughout this Handbook where appropriate. Particular attention is drawn to Section 4 - Operation.

WHEN HANDLING CRYOGENIC LIQUIDS

DO	Wear protective clothing and gloves made of non-absorbant material.
DO	Wear goggles.
DO	Assemble the equipment and prepare the fittings in advance.
DO	Ensure there is adequate ventilation.
DO	Make the area a no-smoking zone.
DO	Check that all fittings are correctly seated and leak tight.
DO	Ensure vessels containing cryogenic liquids have pressure relief valves.
DO	Ensure that boiled-off gas has an escape route.
DON'T	Leave safety valves closed or cause a pressure build up inside vessels.
DON'T	Splash liquid on 'O' rings or connectors.
DON'T	Place 'O' rings on fittings that are already cold.
DON'T	Leave vessels unattended when liquid is being transferred.

Skin contact with cryogenic liquids will cause burns, especially where liquid is trapped against the skin by clothing. It is therefore important to wear clothing which is non-absorbant so that any spillage will run off and not remain against the skin.

It is important to have good ventilation in any rooms where cryogenic liquids are being handled. Both liquid helium and liquid nitrogen are odourless, colourless and non-toxic. Their danger lies in their extreme low temperature, their high liquid to gas expansion ratio and their ability to displace oxygen. Large volumes of nitrogen or helium gas which may be produced when cooling a cryostat could displace much of the oxygen in a small room and could therefore lead to asphyxiation without warning.

Rooms in which cryogenic liquids are being handled should be designated no-smoking areas. While nitrogen and helium do not support combustion, their extreme cold can cause oxygen from the air to condense on cold surfaces and may increase the oxygen concentration locally. There is a particular fire danger if the cold surfaces are covered with oil or grease which is itself combustible.

Any escape of cold gas past an 'O' ring, or liquid splashed on an 'O' ring will cause it to harden, preventing it being tightened until it has warmed up again. The 'O' ring may crack and need replacing.

EXCESSIVE GAS PRESSURE

The bursting-discs in the service turret will shatter if the pressure in either the helium or nitrogen reservoirs exceeds atmospheric pressure by more than 340 millibars (5 psi).

If loss of vacuum is caused by liquid helium or nitrogen entering the vacuum space, a safety plate fitted to the outer vacuum case automatically releases to prevent the build-up of pressure in the casing.

THE MAGNETIC FIELD

Providing these precautions are strictly observed there is no evidence that a magnetic field has any damaging effect on human beings.

DO Display an illuminated warning that the magnet is operating.

DO Display a warning that persons fitted with a pacemaker must keep away.

DO Remove magnetic materials (watches, keys, cheque cards and credit cards, buckles, steel-toed safety boots etc.).

DON'T Use tools of a magnetic material.

DON'T Allow waste bins, vacuum cleaners or other magnetic materials near the magnet.

EMERGENCY MAGNET DISCHARGE

In an emergency, the magnet can be discharged quickly by opening the magnet switch. If an Emergency Rundown Unit is fitted, press the red 'OPERATE' button.

WARNING:
Before operating the magnet switch or Rundown Unit in an emergency, make sure no person is standing on or near the top of the magnet as a jet of very cold gas will escape from the safety blow-off ports and will severely burn any personnel in its path. Warn other personnel to keep away.

1 GENERAL INFORMATION

1 GENERAL INFORMATION

1.1 THE MAGNET SYSTEM

The Whole Body Imaging Magnet System comprises a superconducting magnet within a cryostat, together with associated electronic instrumentation and power supplies. Magnet shimming coils and gradient coils are often included.

1.2 THE MAGNET SYSTEM COMPONENTS

1 In addition to the Cryostat containing the magnet, see fig. 1.1, the following equipment is supplied.

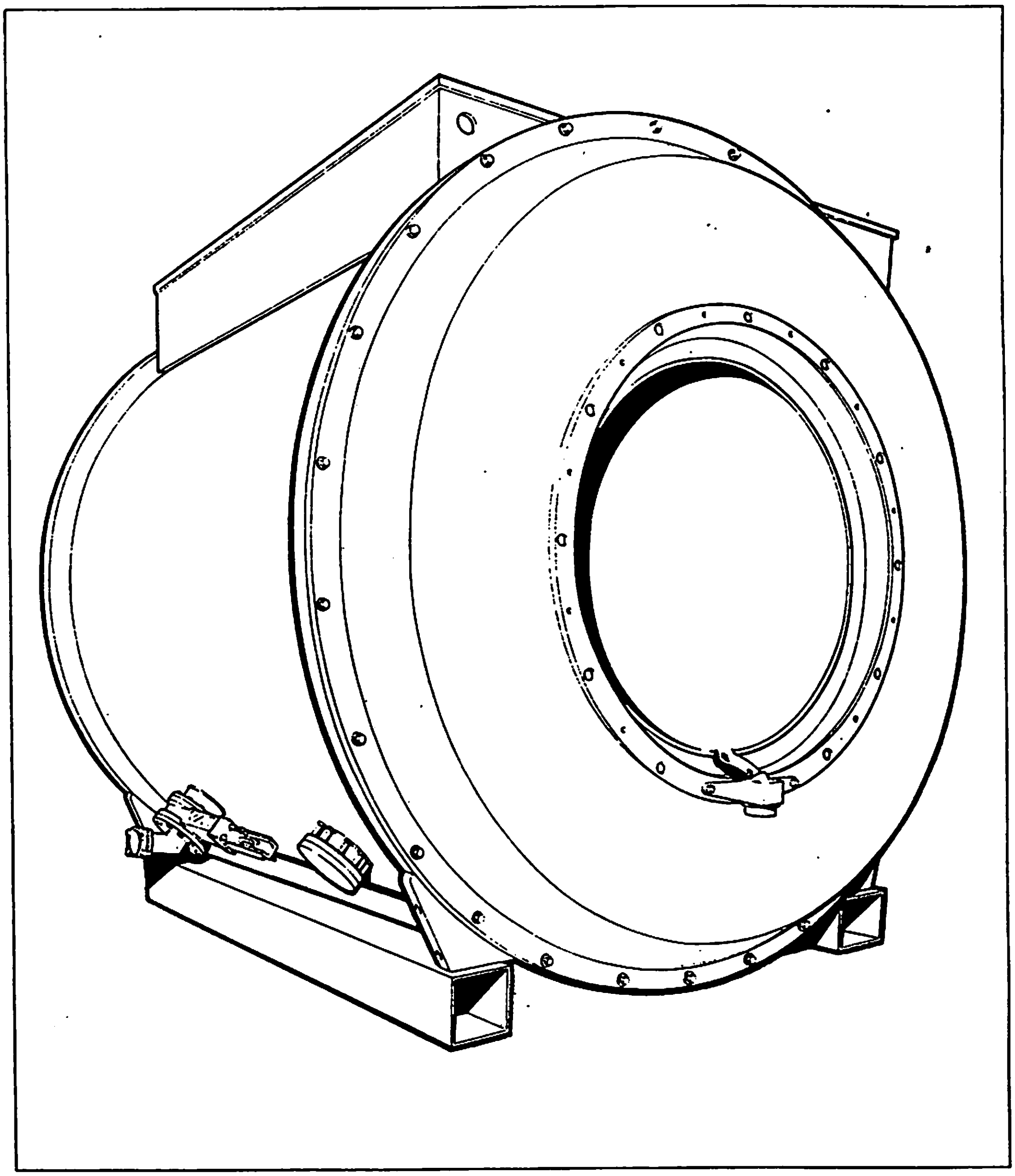

Figure 1.1

The Magnet Power Supply Unit (Type 2115 or 2137) which can also incorporate the liquid helium and liquid nitrogen level meters available separately.

Demountable current lead.
Interconnecting current cables.
Magnet switch heater cables.
Level sensor cables.
Helium transfer tube.
Nitrogen fill tube.
Nitrogen pre-cool tube.
Magnet field plotting table.
Parts ('O' rings, washers, seals etc.) for maintenance.

2 In most instances a set of resistive shim coils, a shim power supply, gradient coils and gradient coil power supplies will also be supplied.

3 An emergency run-down unit (Model 2630A) can also be supplied for rapid discharge of the magnetic field.

1.3 NOMINAL DIMENSIONS

1.3.1 Unistat Cryostat

Room temperature clear bore:	1050mm
Patient access clear bore with shim set (if fitted):	920mm
Patient access clear bore with gradient set (if fitted):	750mm
Overall diameter:	1955mm
Overall length:	2290mm with magnet only 2350mm with shim set 2368mm with shim and gradient set
Overall height:	2400mm
Minimum ceiling height:	2740mm
Height at central field:	1070mm

1.3.2 Magnet Power Supply

	Model 2115	Model 2137	
Height:	915mm	1840mm	(These dimensions include the cryogen level meters)
Width:	585mm	600mm	
Depth:	585mm	890mm	

1.3.3 Resistive Shim Power Supply

	Model 2313	Model 2314
Height:	1840mm	1840mm
Width:	600mm	600mm
Depth:	800mm	800mm

1.3.4 Gradient Coil Power Amplifier

	Model 2234	Model 2235	Model 2236	
Height:	1840mm	1840mm	1840mm	(Three of the same model are required)
Width:	600mm	600mm	600mm	
Depth:	890mm	890mm	890mm	

1.3.5 Emergency Run-down Unit

Model 2630A

Height:	200mm
Width:	300mm
Depth:	190mm

1.4 WEIGHTS (Approximate)

1.4.1 Unistat Cryostat (without shims)

	0.5T Magnet	1.0T Magnet	1.5T Magnet	2.0T Magnet
Dry:	5000kg	5850kg	6350kg	7450kg
With Cryogens:	5650kg	6350kg	6850kg	7800kg

1.4.2 Shim Set

Weight:	500kg

1.4.3 Gradient Set

Weight:	400kg

1.4.4 Magnet Power Supply

	Model 2115	Model 2137
Weight (including cryogen level meters:	150kg	200kg

1.4.5 Resistive Shim Power Supply

	Model 2313	Model 2314
Weight:	270kg	270kg

1.4.6 Gradient Coil Power Amplifier

	Model 2234	Model 2235	Model 2236
Weight (for each one of three):	485kg	585kg	535kg

1.4.7 Emergency Run-down Unit

Model 2630A

Weight:	4kg

1.5 CRYOGEN CAPACITIES

The volume of liquid varies with the field rating of the magnet. The minimum volume is the minimum amount required to ensure safe operation and the maximum volume does not include the extra amount needed to pre-cool the cryostat prior to filling with liquids.

Nominal Field Rating	0.5T		1.0T		1.5T		2.0T	
Cryogen Type	N_2	He_4	N_2	He_4	N_2	He_4	N_2	He_4
Minimum Safe Amount (litres)	120	650	120	575	120	550	120	400
Maximum Volume (litres)	575	1300	575	1150	575	1100	575	800

1.6 ENVIRONMENTAL SAFETY

1 The location of the magnet site will have been chosen with regard for the effect of environmental iron, such as steel roof supports, iron or steel reinforcements in concrete floors and pillars, on magnet homogeneity and the effect of the magnets stray field on its environment. Guidelines for site selection are given in the Oxford Magnet Technology publication *Magnets in Clinical Use—Site Planning Guide*.

2 The presence of a large superconducting magnet demands that precautions are taken and all personnel are fully in accord and appreciative of them at all times.

3 The effects of the large magnetic field, the possibility of escaping gases and the result of a sudden loss of the field, are matters which must be properly understood and attention is drawn to the information on safety on page viii.

2 TECHNICAL INFORMATION

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2.1 THE CRYOSTAT

1 The Oxford Cryostat, essentially consisting of two concentric reservoirs housed in an outer vacuum vessel, is designed to provide the optimum access to the magnetic field and minimise the consumption of liquid cryogens.

2 A system of suspension rods is employed to support the liquid nitrogen reservoir and the helium reservoir containing the magnet coils within the outer vacuum vessel. This design provides accurate location together with a very low heat load.

3 Liquid helium evaporation is reduced by the enthalpy-cooled shield located between the reservoir and the 77K liquid nitrogen-cooled shields. Further reductions are achieved by layers of aluminised mylar super-insulation between each metal surface.

4 Service access to the magnet and cryogen reservoirs is provided at the turret on top of the cryostat.

2.1.1 The Cryostat Service Turret

Electrical sockets connect to the magnet switch heaters, the level monitoring probes inside the helium and nitrogen reservoirs, the carbon thermometer probes and the heaters for an emergency rundown of the magnet. The current lead insertion port, helium and nitrogen transfer and recovery ports and pressure release discs are all accessible on the turret, see Fig. 2.1.

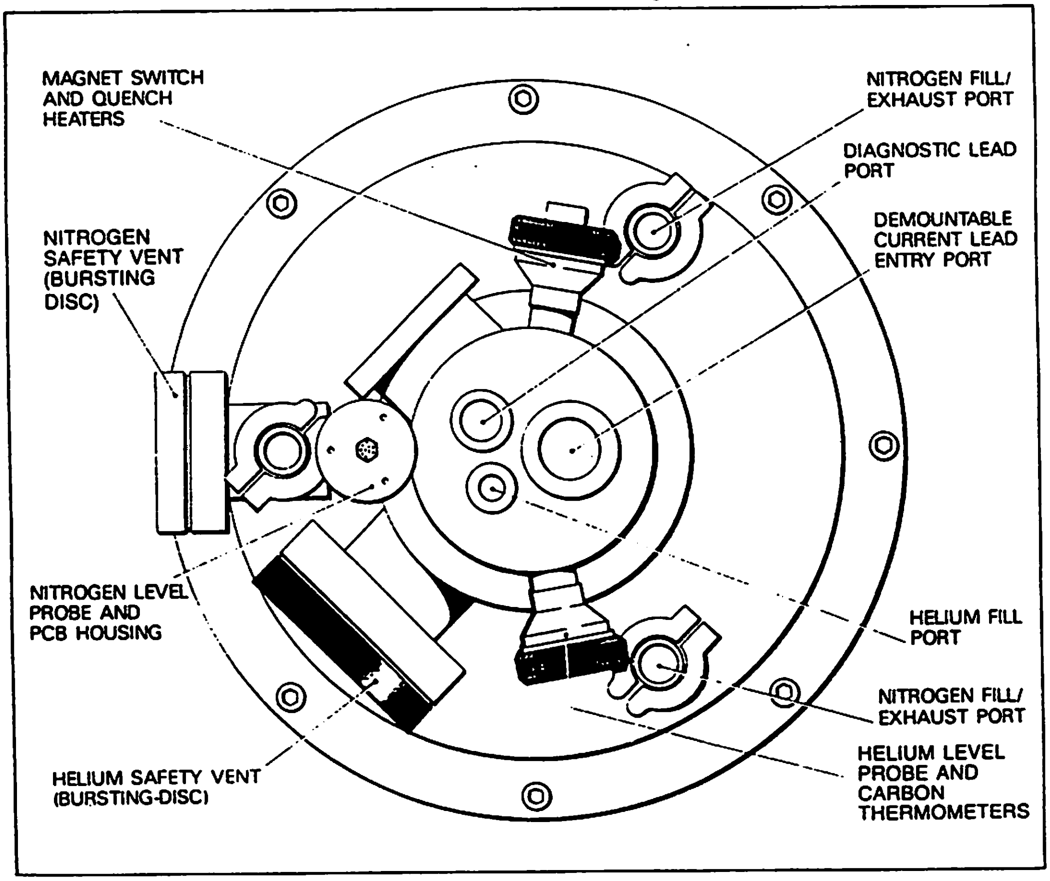


Figure 2.1

2.2 CRYOGENIC LIQUIDS THERMODYNAMIC DATA

1 The following table details some of the physical properties of liquid nitrogen and liquid helium, with those for liquid hydrogen and oxygen being given for comparison.

2 The latent heat of vapourisation of helium is nearly one-sixtieth that of nitrogen. This means that one joule of energy will boil off sixty times the volume of helium liquid as it will of liquid nitrogen.

3 The enthalpy can be thought of as the amount of heat needed to raise the temperature of the cold gas. It can be seen that this is much higher for helium than it is for nitrogen. This property is exploited by using helium exhaust gas to cool the cryostat radiation shield.

2.2.1 Physical Properties of Cryogenic Liquids

Cryogenic liquid	Normal Boiling Point (K)	Specific latent heat (kJ/kg)	Amount of liquid evaporated by 1 watt (l/hr)	Liquid density (g/ml) (kg/m³) $\times 10^{-3}$	Gas density at NTP (kg/m³) $\times 10^{-3}$
Helium	4.2	21	1.38	125	0.179
Hydrogen	20.4	443	0.115	71	0.0899
Nitrogen	77.2	198	0.023	808	1.25
Oxygen	90.2	213	0.015	1140	1.43

Cryogenic liquid	Liquid/gas (at NTP) volume ratio	Enthalpy change (gas) boiling point to 77k (kJ/kg)	Enthalpy change (gas) 77K to 300K (kJ/kg)
Helium	1:700	384	1542
Hydrogen	1:790	590	2900
Nitrogen	1:680	—	234
Oxygen	1:797	193 (from boiling point to 300K)	

2.3 THE SUPERCONDUCTING MAGNET

Superconducting material exhibits zero resistance when cooled to its critical transition temperature. A current set up in a closed loop

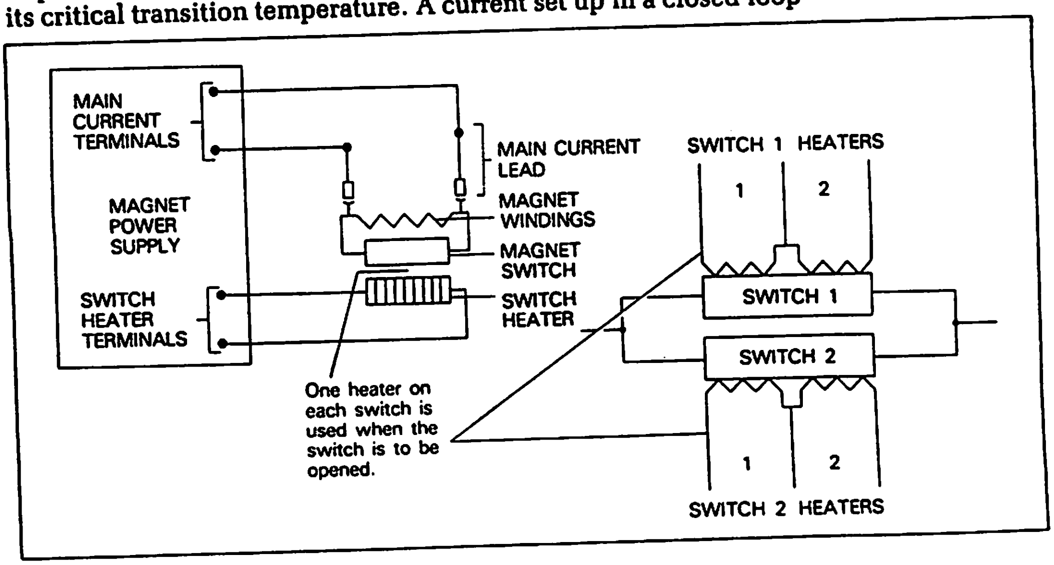


Figure 2.2

of wire made from such material will be maintained at its set value for a very long period (a time constant of the order of 1000 years for some materials) without any driving voltage. A power supply is required to set up the current, but is switched off once the current is established.

2.3.1 The Magnet Switches

1 The magnet consists of several windings (Fig. 2.2) joined together to form a closed loop. A small section of the loop is divided into two parallel parts which are called magnet switches, each of which has two electrical coils wound around it. When current is passed through one heater on each part, the switches become resistive, effectively creating an open-circuit section in the loop.

2 Current from the Magnet Power Supply Unit flows through the magnet windings, and a small amount flows through each switch. The amount flowing through a switch, and the parallel-connected protection resistor, depends on the rate of change of field in the magnet. When the pre-set current level is reached the Magnet Power Supply Unit delivers a constant current to the winding and no current flows through the switch. There is no inductive driving voltage because the rate of change of current is zero and the magnet is now in the constant current mode.

3 When the magnet switch heaters are switched off the switches cool and revert to zero resistance. The current in the windings then begins to flow in the switches, the closed loop is completed and the Magnet Power Supply can be run down and switched off.

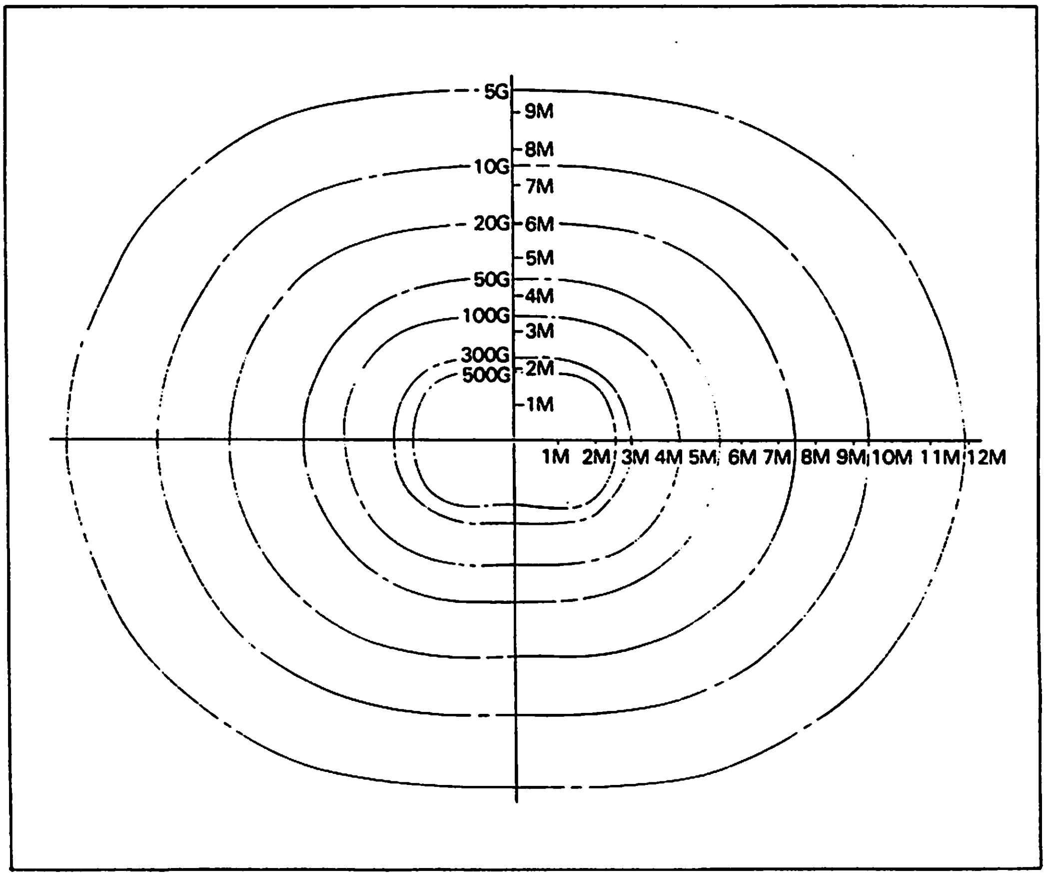


Figure 2.3

2.3.2 Persistent Mode

While the magnet current is flowing in a closed loop, the magnet is termed as being in the 'persistent' mode. Once the magnet is operating in persistent mode, remove the demountable current lead which conveys the current from the Power Supply Unit to the magnet windings. This reduces consumption of the cryogenic liquids being used to maintain the magnet in its superconducting state. An example of the fringe field generated by a typical 1.5T system is illustrated in Fig. 2.3.

2.3.4 A Transient Quench

Electrical transients may sometimes be produced when a power supply is switched on. If the Magnet Power Supply Unit is connected to the magnet and the magnet is already energised in the persistent mode, such a transient may open the magnet switch. This will cause the magnetic field to collapse. To prevent this happening, short-circuit links are connected across the Magnet Power Supply output terminals, when their output current is zero and before the supply is switched on.

2.3.5 Field Decay

A property of superconductors, termed 'flux flow', causes the current established in a magnet in persistent mode to gradually flow nearer to the outside of a wire, rather than the inside, and eventually reach an equilibrium position. This phenomenon leads to an apparent field decay for the first few days when a magnet has been put into persistent mode, but the effect eventually settles out. Because it is very dependent on the microscopic structure of the superconductor, it is difficult to predict the exact value and time constant of this effect and it will be slightly different from one magnet to another. Typically the field may appear to decay at about one part in 10^6 per hour over the first few days, gradually decreasing to a base rate determined by the residual resistance inherent in the joints.

2.4 SPECIFICATIONS (Typical)

2.4.1 Cryogenic Performance

	0.5T Magnet	1.0T Magnet	1.5T Magnet	2.0T Magnet
Liquid Nitrogen boil-off:	1.0 *l*/hr	1.0 *l*/hr	1.0 *l*/hr	1.0 *l*/hr
Time between refill:	20 days	20 days	20 days	20 days
Liquid Helium boil-off:	0.4 *l*/hr	0.4 *l*/hr	0.4 *l*/hr	0.4 *l*/hr
Time between refill:	53 days	49 days	41 days	33 days

2.4.2 Magnet Power Supply Application

Model number to use:	2115	2115	2137	2137

2.4.3 Homogeneity and Field Stability

Homogeneity and field stability specifications apply to all magnets.

Basic homogeneity:	750ppm over 50cm dsv 200 over 30cm dsv
With resistive shim set:	40ppm over 50cm dsv 10ppm over 30cm dsv <0.1ppm over 10cm dsv
Field stability:	less than 0.1ppm per hour

2.4.4 Resistive Shim Coils

Channel	0.5T Magnet Strength	0.5T Magnet Res.	1.0T Magnet Strength	1.0T Magnet Res.	1.5T Magnet Strength	1.5T Magnet Res.	2.0T Magnet Strength	2.0T Magnet Res.
Z_0	69.4	2.2	33.5	2.2	21.0	2.2	14.0	2.2
Z_1	100.2	2.1	50.1	2.1	33.4	2.1	25.1	2.1
Z_2	90.6	2.2	45.3	2.2	30.2	2.2	22.7	2.2
Z_3	24.8	2.2	12.4	2.2	8.2	2.2	6.2	2.2
Z_4	16.8	2.2	8.4	2.2	5.6	2.2	4.2	2.2
X	74.0	4.8	37.0	4.8	24.7	4.8	18.5	4.8
Y	74.0	4.8	37.0	4.8	24.7	4.8	18.5	4.8
ZX	10.4	2.9	5.2	5.3	3.5	5.3	2.6	5.3
ZY	10.4	2.9	5.2	5.3	3.5	5.3	2.6	5.3
Z^2X	6.6	5.3	3.3	5.4	2.2	5.4	1.7	5.4
Z^2Y	6.6	5.3	3.3	5.4	2.2	5.4	1.7	5.4
XY	10.4	4.9	5.2	5.0	3.5	5.0	2.6	5.0
$X^2 - Y^2$	10.5	4.9	5.2	5.0	3.5	5.0	2.6	5.0

Strengths are nominal, in ppm/Amp on 50cm dsv. Resistances are nominal in ohms.

$\frac{10V}{4A} = 2.5\Omega$

$\frac{45}{9} = 5\Omega$

2.4.5 The Magnet Power Supply Unit

The Power Supply Unit is specifically designed for use with superconducting magnets. It is a water-cooled unit.

The supply operates as a current source with the required current easily set by two ten-turn potentiometers that provide coarse and fine control. An adjustable voltage limit is incorporated into the design to prevent the voltage on the magnet coil from exceeding the value set either positive or negative.

A 4½-digit LED meter is located on the front panel for high-resolution display of the output current. This can also be switched to conveniently monitor the output voltage.

A current sweeping facility is included in the system with easy push-button selection of functions. These include 'Sweep to set point', 'Sweep to zero' and 'Hold'. A rotary switch provides rapid choice of ten sweep rates from 200mA/min to 200A/min.

A second pre-set current source providing up to 600mA at up to 40V is fitted for operation of the superconducting switch heaters of the magnet coil.

The unit contains a comprehensive selection of safety devices. The temperatures of the heatsink and various other locations within the supply are monitored together with the cooling water flow. The system will then switch off if overheating is likely to occur.

In the event of a mains failure the unit will close down safely. Passive circuits hold the magnet voltage down to protect it and prevent damage.

	Model 2115	Model 2137
Maximum output current:	150A continuous	350A continuous
Maximum output voltage:	−10V to +10V	−2V to +2V
Switch heater current:	600mA maximum	600mA maximum
Current settability:	2 in 10^5	2 in 10^5
Current stability:	50ppm/°C	50ppm/°C
Current sweeping:	Sweep to set point Sweep to zero Hold	Sweep to set point Sweep to zero Hold
Sweep rates:	200mA/min to 200A/min	200mA/min to 200A/min
Cooling:		
Maximum operating pressure:	7 bar	7 bar
Maximum inlet temperature:	25°C	25°C
Pressure drop and flow rate for 10°C water temperature rise:	0.3 bar, 2 litre/min	1.5 bar, 7.5 litre/min
Circuit protection:	Overheating, water flow failure, mains failure	
Power consumption:	3.5kVA	5.5kVA
AC supply:	Single phase. 100−120V or 200−240V 47 to 63Hz.	Three-phase and earth, no neutral required. 200V, 208V, 380V, 400V, 415V, 440V, 480V, +10%, −15%. 47 to 63Hz.

2.4.6 Liquid Helium Level Meter 4016

This is a compact electronic unit that uses a superconducting wire sensor to give fast and precise indication of the helium level.

The wire sensor is fixed into position within the cryostat so that the length of the wire sensor above the liquid helium remains resistive, while the submerged portion becomes superconducting.

The sensor resistance is monitored by measuring the voltage across the wire when a small known current is passed. The fraction of the wire that is superconducting is then obtained by comparison with the normal resistance of the entire sensor, and this is directly related to the depth of liquid helium.

In order to reduce the power dissipated and minimise helium evaporation, the current is usually pulsed at either 10 or 150 second intervals and the subsequent reading stored in the instrument.

A 3½-digit LCD is situated on the front panel to give a direct indication on the helium level. An output is also supplied to operate a chart recorder if necessary, providing useful information about the change of level with time.

Two internal potentiometers can be adjusted to give two pre-set levels at which changeover contacts operate. These can be used to ring audible alarms, initiate automatic filling or, if necessary, open the superconducting switch and ensure safe discharge of the magnet by the power supply. Another two potentiometers introduce varying hysteresis into either set of changeover contacts. This conveniently enables only one switch to both start and stop automatic filling at the required levels.

The Helium Level Meter is supplied mounted in the Magnet Power Supply Unit but can be removed for free-standing operation.

Sensing system:	Superconducting wire
Indication:	3½-digit LCD
Recorder output:	500mV into 50kohm
Level trips:	Two independently pre-set potentiometers operate changeover contacts
	Rating 250V 3A, AC or DC
	Max load 80W DC or 200VA AC
Accuracy:	2% at full scale
Helium boil-off	150ml hr^{-1} with continuous reading
	25ml hr^{-1} reading every 10s
	5ml hr^{-1} reading every 150s
	4ml hr^{-1} with unit turned off
Magnetic field tolerance:	Unaffected up to 4T
Probe temp tolerance:	± 1°K at 4.2°K
Weight:	2.05kg
Power requirements:	100/240V AC, 50-60Hz

2.4.7 Liquid Nitrogen Level Meter 4037

This is a compact electronic unit that uses a co-axial capacitive probe to give fast and precise indication of the nitrogen level.

The co-axial probe is fixed into position within the cryostat so that the submerged portion has a dielectric constant of the liquid nitrogen while the length above the surface has a dielectric constant of nitrogen gas.

The capacitance is monitored by a sensing circuit built into the probe head to eliminate any effects of cable capacitance. The fraction of the probe that is submerged, and hence the depth of liquid nitrogen, is simply obtained by comparison with its known possible range of capacitance.

A moving coil meter is situated on the front panel to give a direct indication of the nitrogen level. An output is also supplied to operate a chart recorder if necessary, providing useful information about the change of level with time.

Two internal potentiometers can be adjusted to give two pre-set levels at which changeover contacts operate. These can be used to ring audible alarms and initiate automatic filling. Another two potentiometers introduce varying hysteresis into either set of changeover contacts. This conveniently enables only one switch to both start and stop automatic filling at the required levels.

The Nitrogen Level Meter is supplied mounted in the Magnet Power Supply Unit but can be removed for free-standing operation.

Sensing system:	Co-axial Capacitor
Indication:	Moving Coil Meter
Recorder output:	500mV into 50kohm
Level trips:	Two independently pre-set potentiometers operate changeover contacts Rating 250V 3A, AC or DC Max load 80W DC or 200VA AC
Accuracy:	2% at full scale
Nitrogen boil-off:	5ml hr^{-1} without gas cooling
Magnetic field tolerance:	Unaffected
Weight:	2.10kg
Power requirements:	8VA

2.4.8 Resistive Shim Power Supplies (Models 2313 and 2314)

The 2313 Power Supply is intended for use with Oxford resistive shim coil sets. The shim coils and their associated power supplies provide fine adjustment of the magnetic field within the imaging system. In this way the homogeneity of the field can be optimised over the working volume.

The supply has thirteen independently adjustable channels that are each a bipolar constant current source. These are all water cooled and fed from a common DC supply. The unit is therefore able to drive up to thirteen shim coils.

The output currents can all be adjusted individually by ten-turn potentiometers on the front panel. Alternatively, they can be set remotely via a series of differential analogue inputs, that each produce an output current proportional to the input voltage. This allows convenient and rapid shimming of the magnet under computer control. A further digital connection enables remote selection of on/off and provides indication of the major fault conditions.

A 4½-digit LED display is also located on the front panel for high-resolution monitoring of both the output currents and voltages. This can be switched to each of the thirteen channels.

The unit contains a comprehensive selection of safety devices. The output current of each channel is internally limited to prevent over-dissipation of its devices. The temperatures of the heatsink and various other locations within the supply are monitored together with the cooling water flow. The system will then switch off if a temperature rise above safe limits is likely to occur. Furthermore, in the event of a mains failure the unit will close down safely and a solenoid valve shuts off the cooling water. This valve conveniently stops the water flow when the unit is turned off.

The front panel also contains LED fault indicators for over current, phase failure, water failure, and over temperature.

Model 2314 is an increased power version available to provide higher output current on certain axial shim channels if required.

Model 2313

Output:	2 channels up to ± 20A 3 channels up to ± 12A 8 channels up to ± 10A

Model 2314

Output:	5 channels up to ± 20A 8 channels up to ± 10A

Model 2313 and Model 2314

Maximum output voltage:	± 40V all channels
Minimum load resistance for full current operation:	1.3ohm for 20A and 12A channels 3.1ohm for 10A channels
Maximum load resistance for full current operation:	2.0ohm for 20A channels 3.33ohm for 12A channels 4.0ohm for 10A channels
Ripple and noise:	Less than 0.1% RMS of full output
Current settability:	2 parts in 1000 of full output using the calibrated 10-turn potentiometers

Model 2313 and Model 2314 (continued)

Current stability:	100ppm/°C
Remote control:	Differential analogue inputs with 5V common mode range. ± 5V signal swings current over full bipolar range. Remote operation of on/off and indication of major fault conditions
Water Cooling:	Maximum operating pressure 7 bar Maximum inlet temperature 25°C For a 10°C temperature rise, flow rate is 7 litre/min, pressure drop is 2 bar
AC Supply:	Three phase and earth, no neutral required 200V, 208V, 380V, 400V, 415V, 440V, 480V, + 10%, - 15% 47 to 63Hz
Power consumption:	7kVA maximum

2.4.9 Power Amplifiers for Gradient Coils (Models 2234, 2235 and 2236)

The Oxford Magnet Technology Model 2235 Power Amplifier is one of a range of instruments used to drive gradient coils within an NMR imaging system to produce time-varying magnetic fields. Three amplifiers are needed to power each gradient coil set.

The 2235 is specifically intended to drive a gradient coil within a superconducting magnet to provide field gradients of up to 8mT/metre.

Power amplifiers and gradient coils are matched to give bipolar flat-topped field gradient pulses. They can also produce sine waves or other wave forms of field gradient within the general rise time envelope. Each amplifier uses a bipolar current design in a bridge configuration working between positive and negative rails.

The input to each power amplifier is a differential analogue signal representing the required field gradient. Eddy current effects in the magnet are electronically compensated by the amplifiers. First-order field gradients (X, Y and Z) from the main magnet can be compensated for using the gradient coils. A DC offset control is provided on each power amplifier, to set the required operating current.

A digital connection to the unit allows remote selection of 'ON' or 'STANDBY' and also provides remote indication of fault conditions.

The power amplifier incorporates a number of in-built safety devices. Each power transistor is individually fused and is electronically isolated from the supply in the event of failure. If this occurs the faulty device is quickly identified by an adjacent LED. Should more than five power transistors fail, the system automatically and safely closes down to protect the remaining semi-conductors from overload.

Cooling water flow and the temperature of the heatsinks and various other locations within the amplifiers are continuously monitored. If overheating is likely to occur the system will close down safely.

To economise on water an automatic solenoid valve shuts off the supply when the unit is switched off or the heatsink temperature falls below a preset value.

Each amplifier is contained in a single cabinet mounted on castors for easy positioning.

Model 2235

Gradient:	8mT/metre
Magnet type:	Superconducting
Rise time:	1.0ms to flat top from zero
Flat top:	± 2% (± 5% for first 0.25ms)
Duty cycle:	40%
Maximum frequency sine wave at full gradient:	150Hz
Input:	Differential analogue input with 5V common mode range + 5V signal for positive full specified gradient
Remote control:	Opération of 'Standby' or 'On' and indication of major fault conditions via a single digital connection
AC Supply:	3 phase and earth (neutral not required) 200, 208, 380, 400, 415, 440, 480V, ± 10% 47 to 63Hz
Power consumption:	Peak approx 60kVA for each amplifier Mean approx 16.2kVA for each amplifier Mean power is 0.4 times the power at 100% static field
Water cooling:	Maximum operating pressure is 7 bar Maximum water inlet temperature is 25°C For 15°C water temperature rise, pressure drop is 4 bar, flow rate is 20 litre/min per amplifier

Model 2234

Gradient:	3mT/metre
Specification:	Comparable to Model 2235

Model 2236

Gradient:	5mT/metre
Specification:	Comparable to Model 2236

2.4.10 Emergency Run-down Unit (Model 2630A)

This unit is designed for use with superconducting magnets which have been fitted with electrical heaters within the windings which, when energised, will cause the magnet to quench and therefore rapidly de-energise in the case of an emergency.

The unit is designed to provide emergency power for up to four quench heater circuits from an internal float charged Ni-Cd battery. The minimum available output from the unit (assuming battery test is passed) is 8A at 20V for at least three minutes. A fully charged battery pack in good condition, however, should maintain this output for approximately six minutes.

Once the ERDU has been used to initiate a magnet run down, the battery will be fully discharged. Re-charging requires a constant current of 200mA for 16 hours which cannot be achieved on the built-in trickle charger. The Oxford 2631 battery charger, or similar instrument, should be used for this purpose. For further information see Section 2.2. of the ERDU Manual.

The ERDU may be activated by connection to any remote STOP controls via connector 'XA3 REMOTE'. Full details of switch and cable requirements can be found in Section 2.3 of the ERDU manual.

The continuity of the quench heater circuits can be checked without initiating a quench.

AC Supply:	100-120; 200-240V AC single phase, 50-60Hz 5VA max
Output current:	2.0A max each heater.
Output voltage:	24V DC nominal
Heater resistance:	12ohm nominal
Battery test:	Fail when insufficient reserve capacity for total 8A output for three minutes at 20V

3 INSTALLATION

The installation and commissioning of the Magnet System will normally be performed by trained Oxford personnel.

The instructions for operation of the system are detailed in Section 4 and assume that the cryostat has been fully installed and in particular has been fully evacuated and leak tested in both the warm and cold conditions.

In the interests of safety and providing complete information, the operating instructions also contain information on cooling with cryogens, leak testing and energising the magnet. This information would be required, for instance, following a routine annual maintenance procedure.

4 OPERATION

4 OPERATION

4.1 SAFETY

1 For personal safety and the protection of the equipment it is most important that all operators and persons in the vicinity of a magnet are aware of precautions they must observe.

> **WARNING:**
> *Read the following safety information and instructions before attempting to perform any of the operating instructions.*

4.1.1 When Handling Cryogenic Liquids

DO Wear protective clothing and gloves made of non-absorbent material.

DO Wear goggles.

DO Assemble the equipment and prepare the fittings in advance.

DO Ensure there is adequate ventilation.

DO Make the area a no-smoking zone.

DO Check that all fittings are correctly seated and leak-tight.

DO Ensure vessels containing cryogenic liquids have pressure relief valves.

DO Ensure that boiled-off gas has an escape route.

DON'T Leave safety valves closed or cause a pressure build up inside vessels.

DON'T Splash liquid on 'O' rings or connectors.

DON'T Place 'O' rings on fittings that are already cold.

DON'T Leave vessels unattended when liquid is being transferred.

1 Skin contact with cryogenic liquids will cause burns, especially where liquid is trapped against the skin by clothing. It is therefore important to wear clothing which is non-absorbent so that any spillage will run off and not remain against the skin.

2 It is important to have good ventilation in any rooms where cryogenic liquids are being handled. Both liquid helium and liquid nitrogen are odourless, colourless and non-toxic. Their danger lies in their extreme low temperature, their high liquid to gas expansion ratio and their ability to displace oxygen. Large volumes of nitrogen or helium gas which may be produced when cooling a Cryostat could displace much of the oxygen in a small room and could therefore lead to asphyxiation without warning.

3 Rooms in which cryogenic liquids are being handled should be designated no-smoking areas. While nitrogen and helium do not support combustion, their extreme cold can cause oxygen from the air to condense on cold surfaces and may increase the oxygen concentration locally. There is a particular fire danger if the cold surfaces are covered with oil or grease which is itself combustible.

4.1.2 Excessive gas pressure

The bursting-discs in the service turret will shatter if the pressure in either the helium or nitrogen reservoirs exceeds atmospheric pressure by more than 340 millibars (5psi).

4.1.3 Loss of vacuum

If loss of vacuum is caused by liquid helium or nitrogen entering the vacuum space, a safety plate fitted to the outer vacuum case automatically releases to prevent the build-up of pressure in the casing.

4.1.4 Storing Cryogenic Liquids

1 Cryogenic liquids are stored and transported in special vessels (dewars) which are vacuum-insulated. Liquid nitrogen requires less insulation than liquid helium and has a different dewar.

2 Dewars for use within 10 meters of a magnet must be made of non-magnetic materials.

4.1.5 Transferring liquids

1 Liquid nitrogen can be transferred into the Cryostat vessels at room temperature if ventilation is sufficient to release escaping gas.

> **Caution:**
> *Liquid helium can be transferred from one vacuum-insulated vessel to another only when the receiving vessel is at or below 77K.*

2 Liquid helium is transferred by inserting one leg of the transfer tube slowly into the helium storage vessel at zero pressure and the other leg slowly into the receiving vessel. The supplying vessel exhaust valve is closed and pressure is generated above the liquid to push it through the transfer tube.

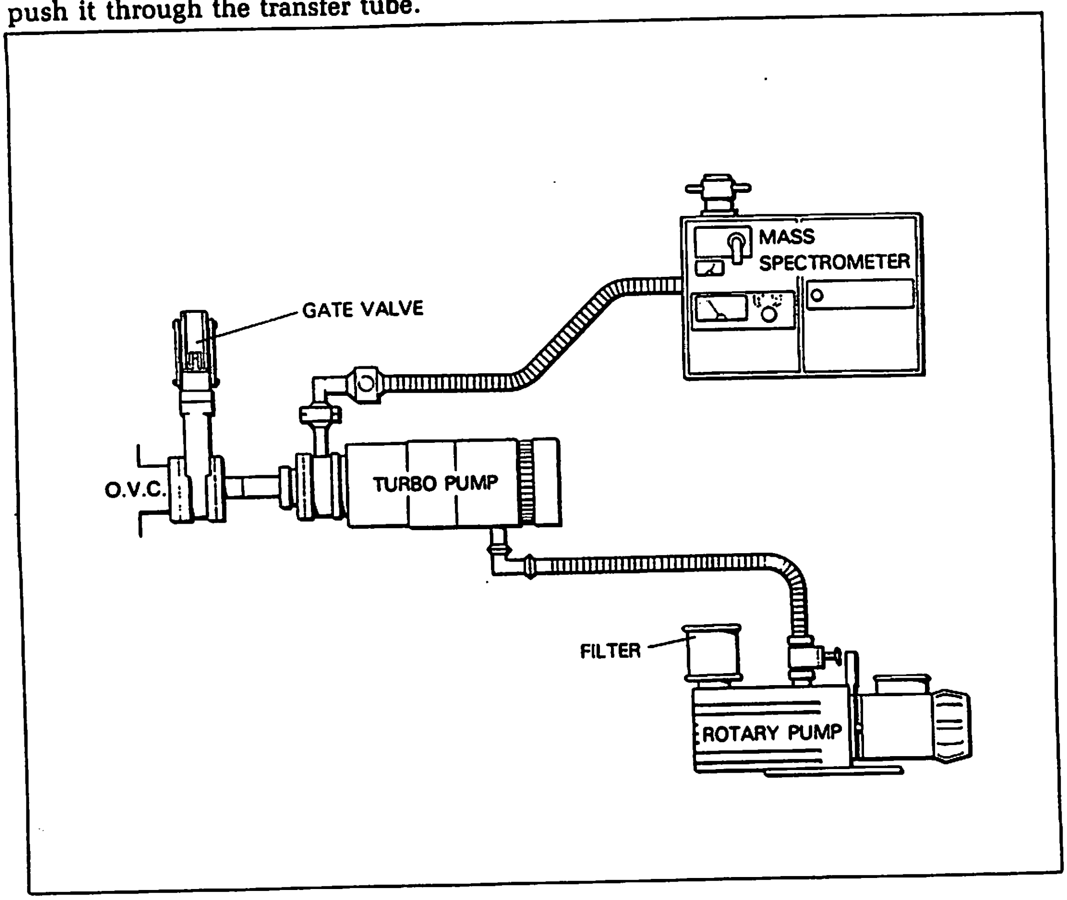


Figure 4.1

ORIGINAL ISSUE DATE 1/12/84	REVISION No REVISION CODE DATE						OXFORD

> **Caution:**
> *If liquid is splashed on an 'O' ring, the ring will harden and may crack and need replacing.*

4.2 SETTING UP

This section gives instruction on how to fill the Cryostat with liquid helium and nitrogen, and how to establish the magnetic field. The setting up operation must be performed in the sequence in which it is given here, beginning with section 4.2.2 and continuing until 4.2.10 has been completed.

Even though the cryostat should have been fully leak tested,it is still desirable to perform the additional leak checks indicated in the following instructions. The vacuum space should be continuously pumped by a turbo-molecular pump and the mass spectrometer should be connected during all operations from 4.2.2 through to 4.2.6 (12). See Fig. 4.1

4.2.1 Equipment and Materials

1 The following equipment and materials are required:
   - Ohmmeter (Multimeter) to measure up to 1500ohm.
   - 200 litre/min. capacity rotary vacuum pump.
   - Vacuum gauges to cover the range 10^{-6} – 1000mbar.
   - 3000 litres of liquid nitrogen.
   - 2000 litres of liquid helium.

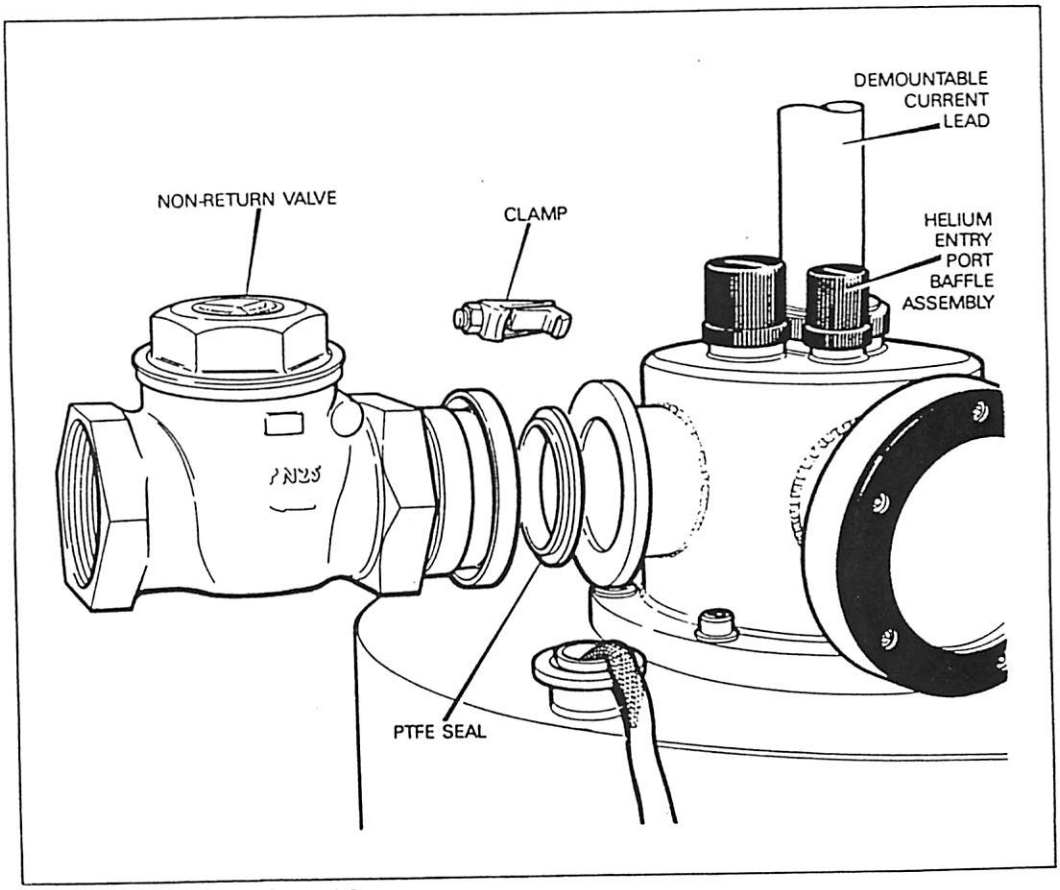


Figure 4.2

Nitrogen pre-cool tube.
Nitrogen fill tube.
Helium transfer tube.
Appropriate fittings and adaptors for making connections to the dewars, the Cryostat and other equipment.
Blanking plate for bursting-disc ports.
Spare bursting discs.
Nuclear Magnetic Resonance (NMR) Field measuring system.
Helium Mass Spectrometer Leak detector.
Helium gas.
Fan heater or warm-air gun.
Turbo Molecular pump or high-capacity diffusion pump.
Vacuum lines and fittings.

4.2.2 Pre-cooling the Magnet

1 This procedure uses liquid nitrogen. ***Proceed only when the pressure in the outer vacuum case is less than 10^{-5}mbar.***

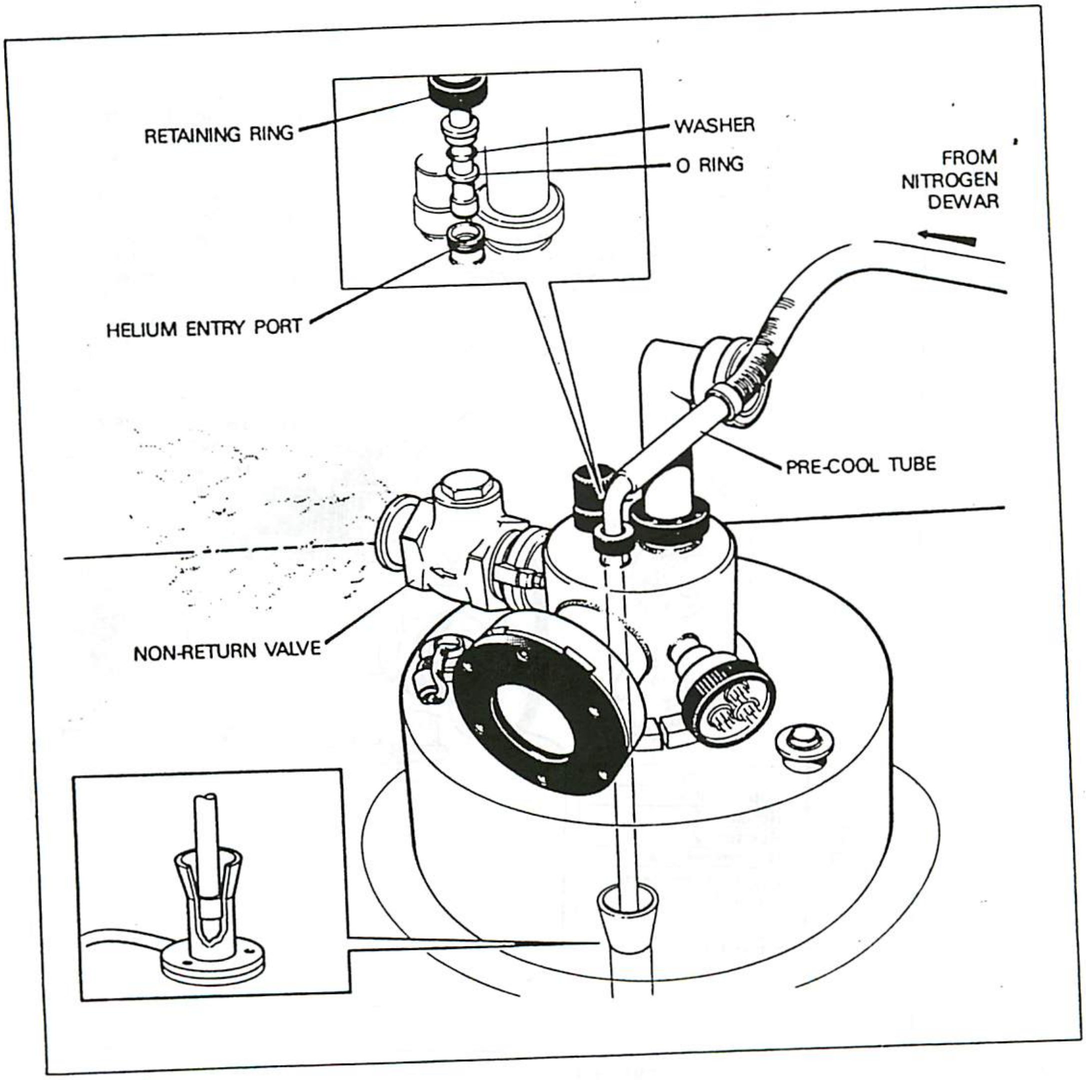


Figure 4.3

2 Ensure that the mating flange surfaces of the turret and exhaust non-return valve (Fig. 4.2) are undamaged and clean. Fit the valve to the turret flange with the exhaust end away (arrow pointing away) from the turret using a PTFE seal and 3 clamps, equally spaced.

3 Insert the demountable current lead into the services turret entry port and ensure it engages with the magnet connector. This will prevent ice forming on the connector while cooling the system down.

4 Remove the baffle assembly from the helium entry port and transfer the retaining ring, washer and 'O' ring to the nitrogen pre-cool tube. Check that the seal is not damaged. Fit the extension leg and PTFE seal to the tube and enter the nitrogen pre-cool tube in the helium entry port on the services turret (Fig. 4.3).

5 Push the tube down to seat the tube PTFE seal firmly in the cone which is on top of the magnet windings assembly inside the cryostat. The cone feeds into a tube which directs the cryogens to the bottom of the helium reservoir.

6 Connect the flange end of the nitrogen pre-cool tube to the outlet of the liquid nitrogen dewar, fabricating a suitable coupling if necessary.

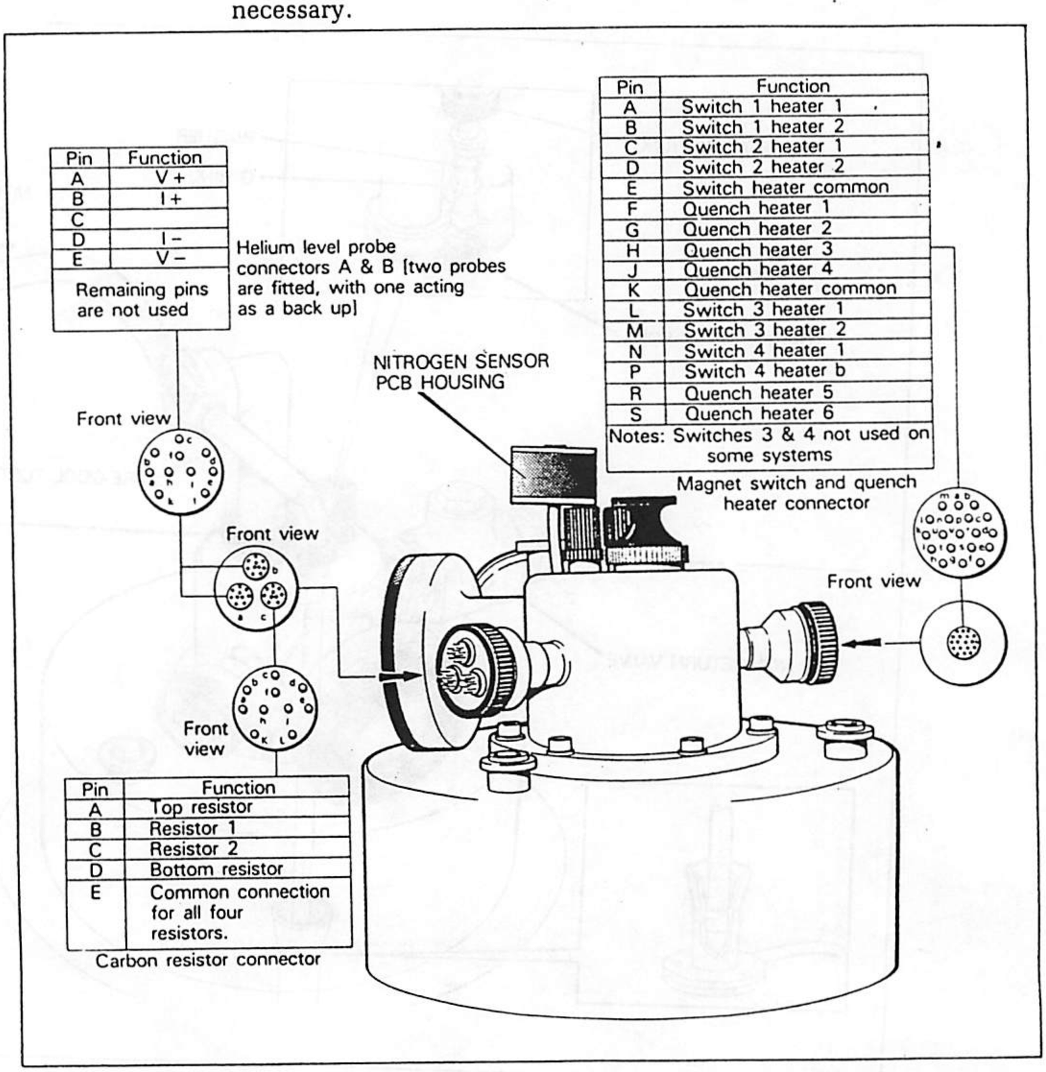


Figure 4.4

> **Caution:**
> *Use a flexible metal hose. Avoid using rubber or plastic tubing for the coupling as this can split or shatter when cooled by the liquid flowing through it.*

7 As filling commences, nitrogen gas will escape through the exhaust non-return valve (Fig. 4.3).

> **WARNING:**
> ***Ensure that ventilation in the room is sufficient to dispel the large amount of gaseous nitrogen exhausted from the Cryostat. The concentration of nitrogen within the room may otherwise increase to a level which could cause asphyxia.***

8 Connect the ohmmeter between pins D and E at the carbon resistor connector on the services turret (Fig. 4.4) to monitor the resistance of the carbon resistor located at the bottom of the reservoir.

9 Pressurise the nitrogen dewar to approximately 500 millibar (7.5 psi) to initiate the flow of liquid. Only cold gas will transfer initially, until the connecting lines have cooled sufficiently. It will be 6 to 8 hours before liquid Nitrogen entering the helium reservoir remains liquid. Protect 'O' ring seals from cold tubes and exhausting gas, using insulation or a fan heater as appropriate.

10 Transfer the ohmmeter connection from pin D to pin C (Fig. 4.4) when the ohmmeter indication has increased from about 100 ohm to about 125 ohm (at 77K). This reading indicates that the helium reservoir is about a quarter full and the liquid nitrogen has risen to cover the bottom resistor.

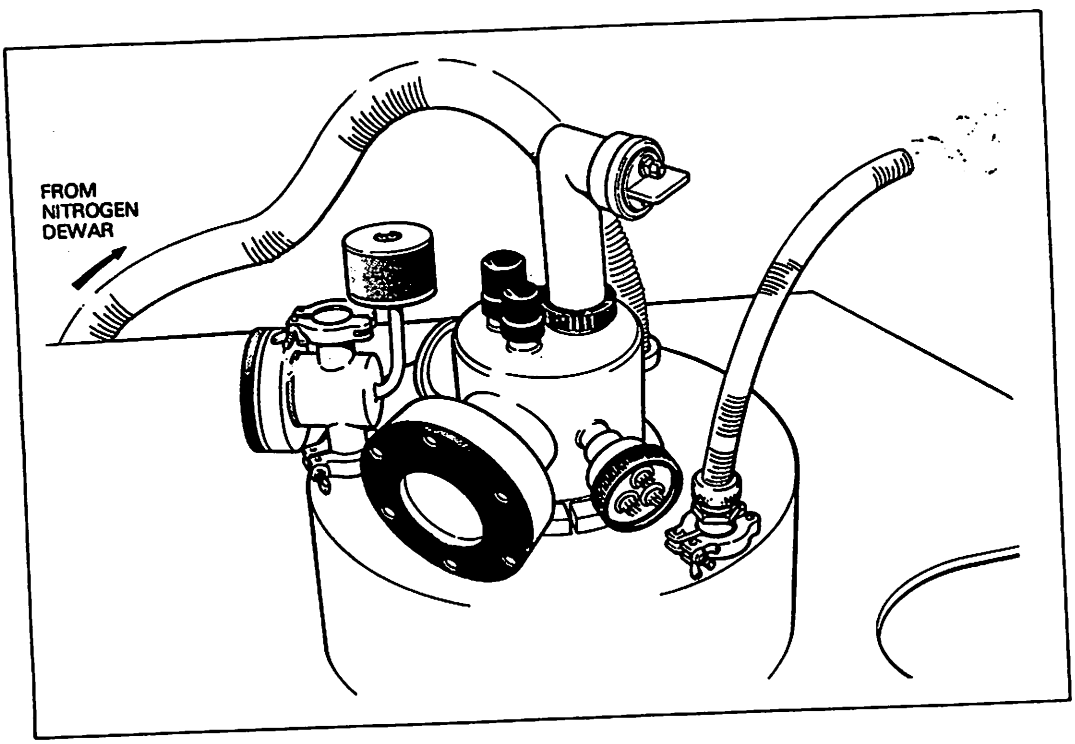


Figure 4.5

11 Maintain the transfer on the liquid nitrogen for several hours, until the helium reservoir is about half filled. The resistance indicated by the ohmmeter now connected between pins C and E should be approximately 125 ohm (see Fig. 4.4).

Caution:
Do not overfill the helium reservoir and allow the liquid nitrogen to overflow as this will freeze 'O' rings and could result in loss of vacuum.

12 De-pressurise the nitrogen dewar and disconnect the nitrogen pre-cool tube from the outlet of the dewar. Withdraw the pre-cool tube from the entry port and replace the baffle with washer and 'O' ring. Allow the reservoir to cool for about one week.

13 Finally recheck the resistance of the carbon resistors. The magnet is cold when all readings are approximately 125 ohm after a period of approximately 24 hours after filling.

4.2.3 Filling the Liquid Nitrogen Reservoir

1 Switch on the nitrogen level meter. See the Nitrogen Level Meter Manual and Section 4.2.8.

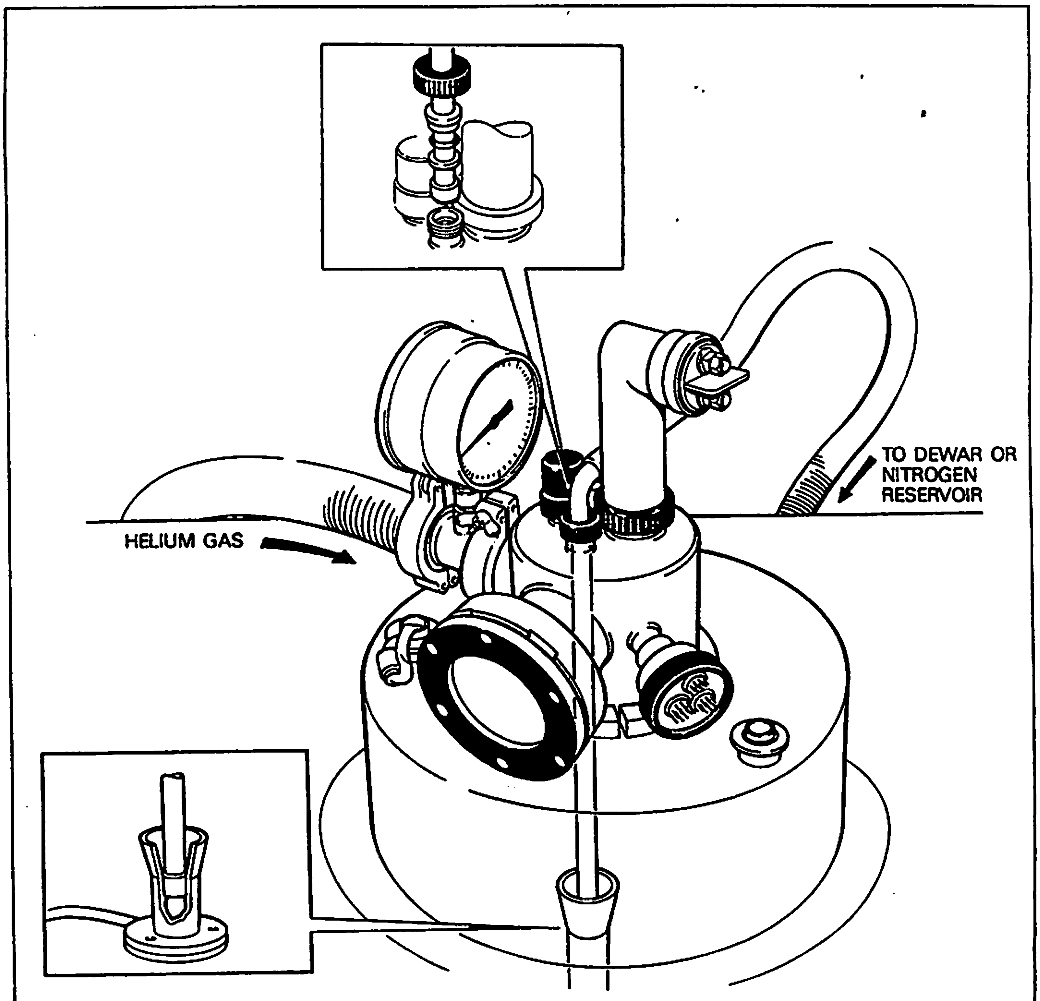


Figure 4.6

2 Connect one end of the nitrogen fill tube to the nitrogen storage dewar and connect the other end to the nitrogen entry port (Fig. 4.5). Blank off the port on the nitrogen bursting disc housing and do not use the port either to fill or vent the reservoir during pre-cooling. Connect a vent line to the third port.

> **Caution:**
> *Do not allow the pressures in the nitrogen storage dewar to exceed 7.5 psi. Excess pressure may damage the reservoir.*

3 Re-pressurise the nitrogen storage dewar to approximately 5 to 7.5 psi. After approximately one hour the liquid going into the reservoir will begin to collect and the level meter will indicate that the liquid is rising.

4 Stop the filling process and test for leaks using a mass specrometer round external joints, 'O' rings and valves. Test the nitrogen vessel for leaking at low levels of liquid nitrogen by flushing helium gas into it for a short time.

5 Continue the filling process until the level meter indicates 100% when reservoir is full.

6 De-pressurise the nitrogen dewar and remove the nitrogen fill tube and exhaust tubes.

4.2.4 **Removing Liquid Nitrogen for the Helium Reservoir**

1 The liquid nitrogen used for pre-cooling the helium reservoir can be removed after the recommended period of one week. This ensures that the temperature of the magnet and helium shield have stabilised at 77K.

2 Remove the baffle and, transferring the retaining ring, washer and 'O' ring, insert the nitrogen pre-cool tube in the helium entry port, ensuring that the pre-cool tube seal is seated in the magnet cone. (Fig. 4.6)

3 The liquid nitrogen in the helium reservoir can be transferred through the pre-cool tube either into the Cryostat nitrogen reservoir or back into the nitrogen dewar and the free end of the tube should be connected accordingly.

4 To hold the pressure, fit a blanking plate on the helium bursting-disc port and ensure that it is leak tight.

5 Remove the non-return valve from the helium exhaust port and, using a suitable adaptor, attach the hose from the helium gas cylinder to the exhaust port.

6 Close off all unused ports on the helium services turret, ensuring that they are leak tight.

7 Adjust the regulator on the helium gas cylinder to pressurise the helium reservoir to approximately 200 to 270mbar (3 to 4psi) but do not exceed 400mbar (5psi).

> NOTE:
> *If the liquid nitrogen is not flowing after about 10 minutes, then the nitrogen pre-cool tube or the helium entry port cone and extension tube may be blocked. Remove the nitrogen pre-cool tube for examination and repeat the procedure. If there is a blockage inside the Cryostat tube, blowing warm helium gas at 140 - 200mbar (2 - 3psi) via the nitrogen pre-cool tube seated in the cone should clear it. If this does not succeed the system may have to be warmed in order to free the blockage.*

8 While liquid nitrogen is flowing from the nitrogen pre-cool tube, it may be necessary at intervals to push the pre-cool tube down into the cone to reseal it.

9 During the following steps 10 to 12, observe the helium mass spectrometer for indication of a leak in the helium reservoir. A leak will become evident as the helium gas pushes the liquid nitrogen level below the point of the leak.

10 It may take several hours to expel the liquid nitrogen from the helium reservoir. When the flow of liquid is seen to stop and a drop in pressure in the helium reservoir occurs, then most of the liquid nitrogen has been transferred. Check that the nitrogen pre-cool tube has not contracted and prematurely ended the flow.

11 Re-pressurise the helium reservoir and watch for liquid issuing from the nitrogen pre-cool tube.

12 Repeat steps 10 and 11 until no liquid flow is seen when the helium reservoir is re-pressurised.

13 Stop the flow of helium gas by closing the helium gas cylinder regulator valve.

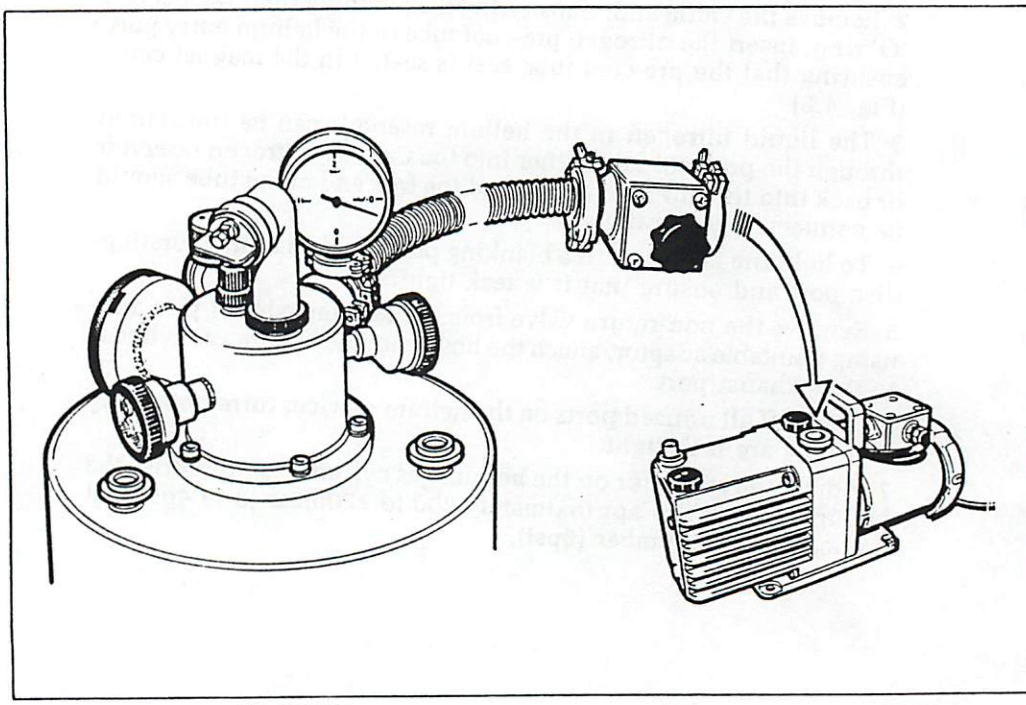


Figure 4.7

14 Remove the nitrogen pre-cool tube and close off the helium entry port with its baffle, plug and seal.

15 Disconnect the helium gas supply from the helium exhaust port.

Caution:
The helium reservoir must not be evacuated unless the Cryostat outer vacuum case has already been evacuated. Failure to take this precaution will result in serious damage to the helium reservoir.

16 Attach the rotary vacuum pump (Fig. 4.7) to the helium exhaust port, incorporating the vacuum gauge at the top of the pumping line near the Cryostat or, by using the appropriate adaptor, at the entry port at the top of the services turret.

NOTE:
It is necessary to have a port which can be closed off with a vacuum valve at the end of the pumping line to allow helium gas to be let into the helium reservoir (see step 19).

17 Begin pumping helium/nitrogen gas out of the helium reservoir, observing the vacuum gauge reading.

NOTE:
A pause in the pressure decrease rate at approximately 105 to 120mbar indicates that there is still some liquid nitrogen in the helium reservoir, which is solidifying. Repeat steps 5 to 7 to try to blow out the remaining nitrogen. Repeat steps 15 and 16 when this has been done.

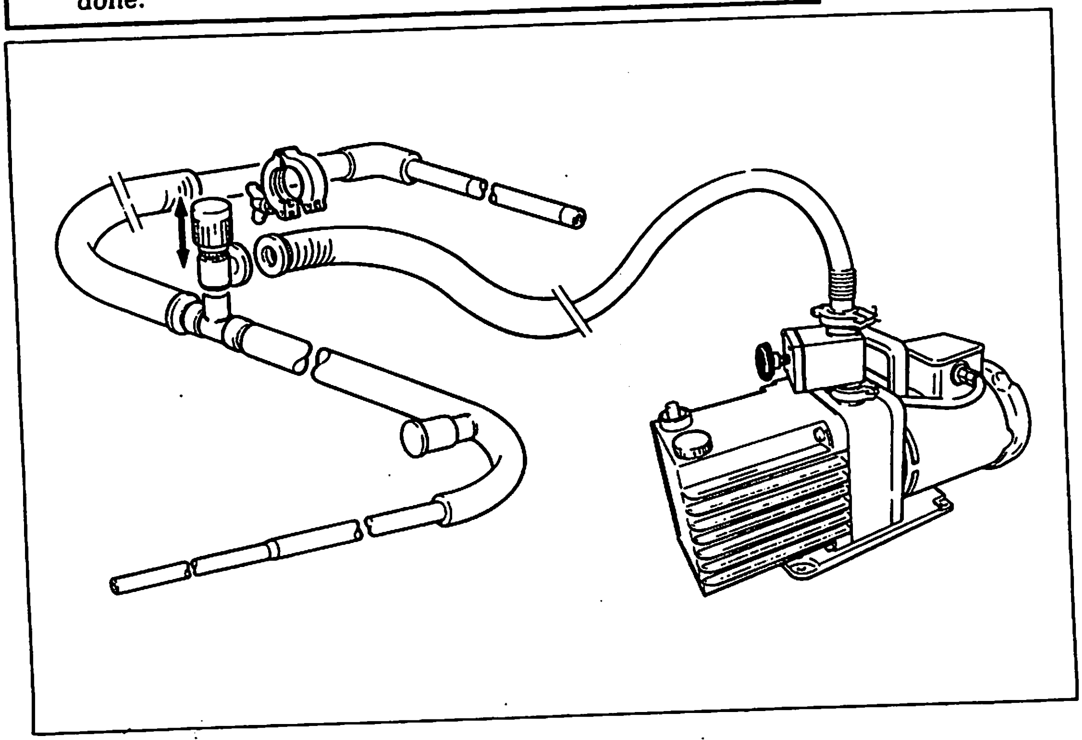


Figure 4.8

18 Stop pumping when the vacuum reaches 200mbar or less. Close the valve, switch off and disconnect the pump.

19 Connect the helium gas cylinder to the vacuum valve on the pumping line and open the vacuum valve to admit helium gas into the helium reservoir until atmospheric pressure is reached and the gauge reads zero. Monitor the helium mass spectrometer for leaks in the helium reservoir while the vessel is at 77K.

20 Repeat steps 17 to 19 at least twice down to 100mbar. Leak test all the 'O' rings now that the Cryostat is cold.

21 Remove the helium mass spectrometer and fit a blanking disc to the adaptor.

4.2.5 Evacuating the Helium Transfer Tube

1 The helium transfer tube is vacuum insulated and requires evacuating before it is first used and at two-monthly intervals thereafter. The two sections can be separated and each has an evacuation port (Fig. 4.8). If frost or cold spots appear on the tube while in use, transfer must cease until the tube has been evacuated.

2 Attach the transfer tube pump-out fitting to the evacuating port on one section of the helium transfer tube, ensuring that it is seating correctly.

3 Lightly grease the 'O' ring seal and connect the vacuum pumping system to the transfer tube pump-out fitting, ensuring that the seal is correctly located.

4 Rotate the knob on the transfer tube pump-out fitting in a counter-clockwise direction to open the valve. Switch on the pump to evacuate the helium transfer tube down to 10^{-4}mbar.

5 Rotate the knob on the tube pump-out fitting in a clockwise direction to shut the valve on the helium transfer tube.

6 Switch off the vacuum pumping system, disconnect it from the helium transfer tube pump-out fitting and remove the fitting from the transfer tube.

7 Repeat steps 2 to 6 to evacuate the other section of the helium transfer tube.

4.2.6 Filling the Helium Reservoir with Liquid Helium

1 Connect the helium exhaust port to the helium recovery system. If a recovery system is not available, ensure that the non-return valve is fitted to the exhaust port (with the arrow pointing away from the turret) and that the room is well ventilated.

2 Assemble the helium transfer tube and fit extensions to lengthen the dewar leg until, when inserted in the dewar, the end is no less than 7mm (¼in.) above the bottom where ice may block the transfer tube. Fit a PTFE seal to the short leg of the transfer tube.

3 Remove the blanking plate from the helium bursting disc housing and replace the bursting disc.

4 Slacken the ring nut and remove the plug from the helium transfer entry port, leaving the baffle in position while the nut and seal is being transferred to the short leg of the transfer tube.

5 Move the helium dewar close enough to the magnet system so that the transfer tube will reach without bending.

6 If the helium dewar is pressurised, release the pressure slowly to zero to avoid the loss of liquid.

7 Insert the long leg of the tube slowly into the dewar, checking that the dewar fitting makes a good seal, remove the baffle and insert the short leg into the helium entry port. Push the short leg down until it is seated firmly in the entry port cone and tighten the nut on the 'O' ring seal.

Caution:
Do not allow exhausting cold gas to be directed around 'O' ring seals. They may crack and cause leakage.

WARNING:
Only use helium gas to pressurise helium liquid.

8 Allow the liquid helium dewar to pressurise slowly to a maximum of 1psi as the tube is inserted. After a few minutes cold helium gas will issue from the helium reservoir exhaust (Fig. 4.9).

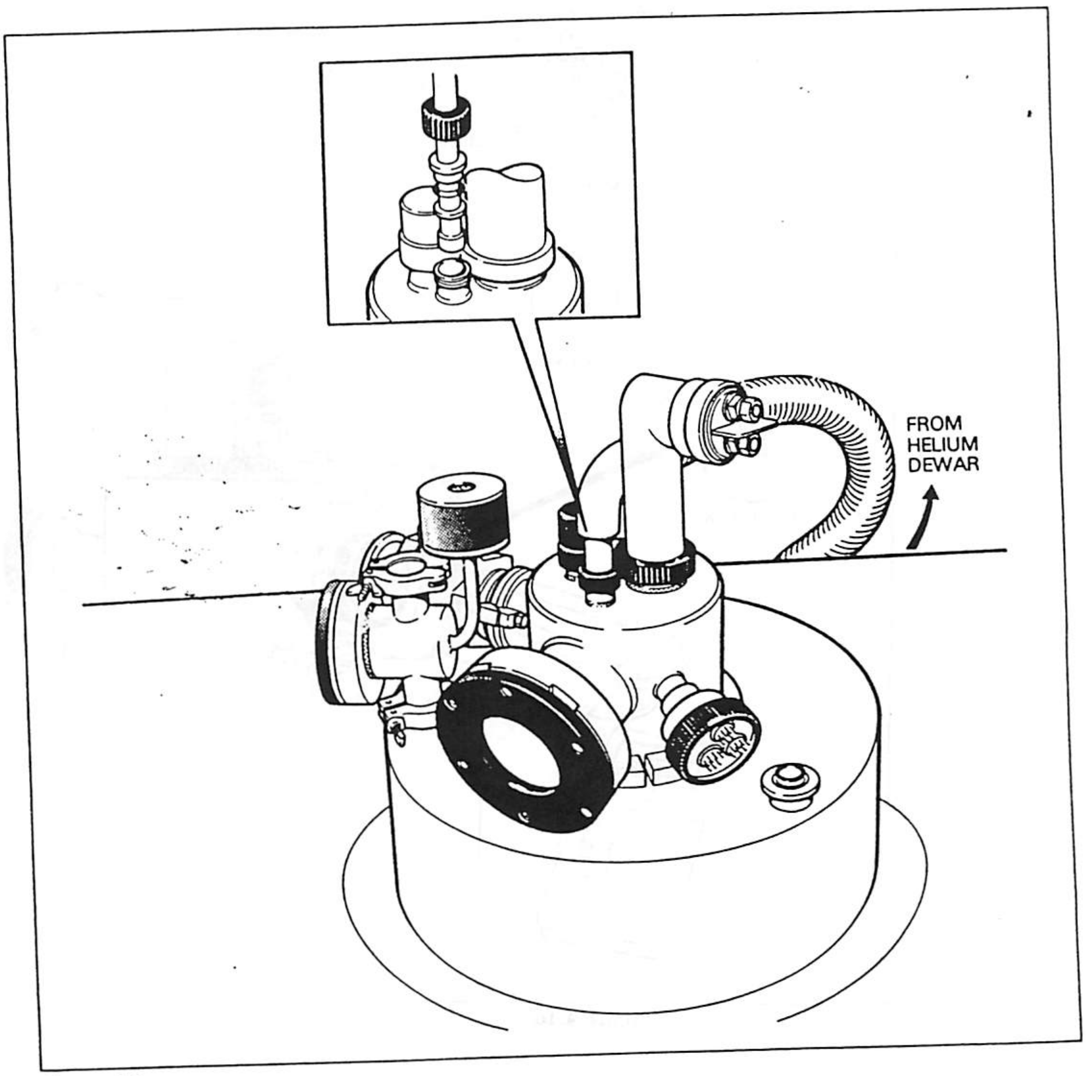


Figure 4.9

> NOTE:
> *If cold gas does not appear, lift the transfer tube 100mm out of the cone. If helium exhaust gas then fails to appear, the transfer tube is blocked and the helium dewar pressure must be released and the transfer tube removed from both the Cryostat and the helium dewar. Blow some warm dry helium gas through the tube. If, when the transfer tube is re-installed and step 8 is repeated, there is still no helium transfer, there is a blockage in the Cryostat. Blow warm helium gas at 140–200mbar (2.3psi) via the helium transfer tube seated firmly in the transfer entry port cone to clear it. If this method fails the system must be warmed to clear the blockage.*

9 Connect the ohmmeter between pins D and E at the carbon resistor connector on the services turret (see Fig. 4.10) to monitor the resistance of the resistor located at the bottom of the helium reservoir.

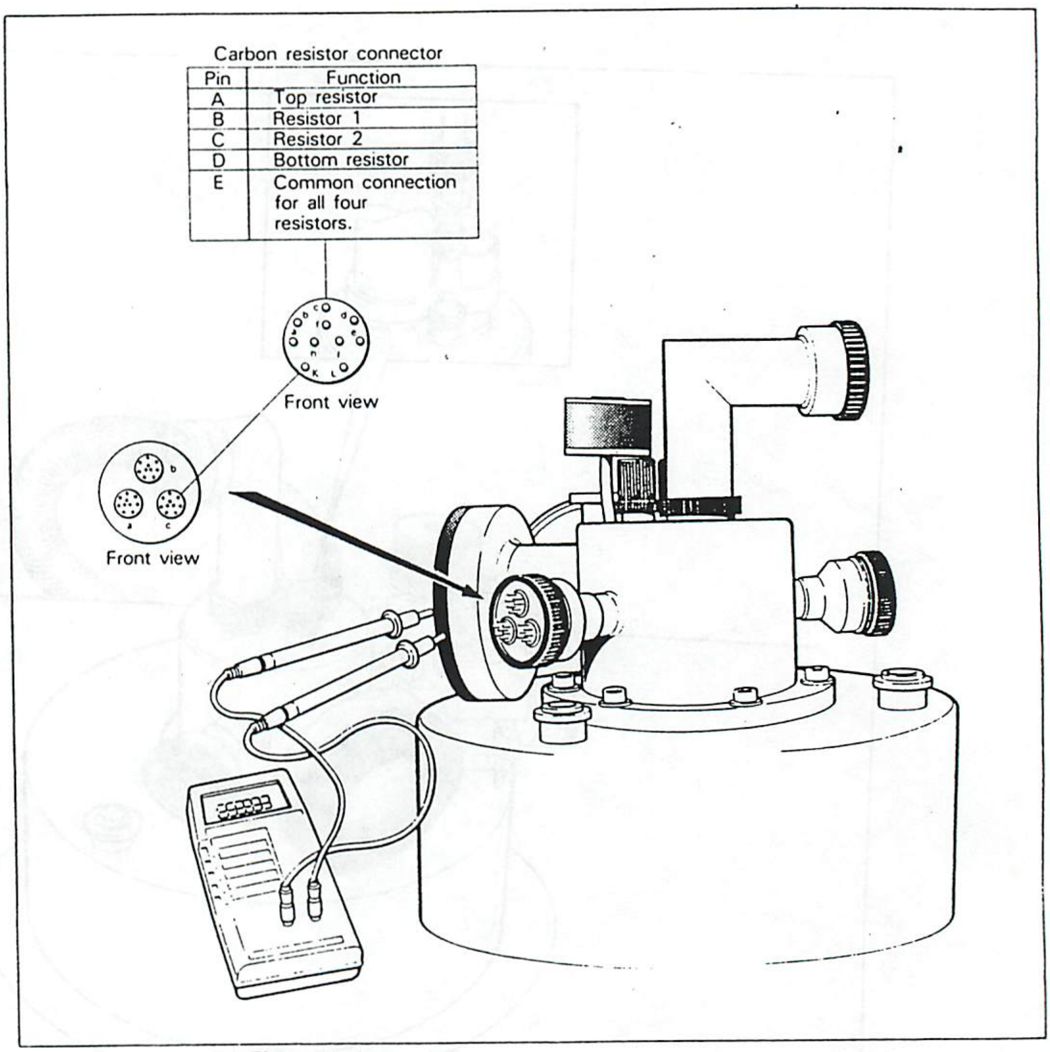


Figure 4.10

10 Observe that the ohmmeter indication starts to increase from about 125 ohm (at 77K) about ½ to 1 hour after starting the liquid helium transfer. When the ohmmeter indication has increased to approximately 1100 to 1200 ohm (at 4.2K) remove the ohmmeter.

11 Switch on the Helium Level Meter to monitor the increasing helium level. See the Liquid Helium Meter Manual and Section 4.2.8.

12 Pressurise the dewar to a maximum of 30 – 70 mbar (½ to 1 psi). The transfer rate should be about 2 litres/min. It will take 3½ to 6 hours before liquid helium begins to collect in the helium reservoir. 600 to 900 litres of liquid helium are needed to reduce the temperature of the magnet and the helium reservoir from 77K to 4.2K. 1300 to 1500 litres are needed to fill the helium reservoir.

13 When the liquid helium begins to collect in the reservoir, close the vacuum gate valve, remove the turbo molecular pump and fit a blanking plate (see Fig. 4.11).

14 When the Liquid Helium Level Meter registers 70%, depressurise the liquid helium dewar by slowly opening the vent valve on the dewar. Fill to 100% after energising the magnet (see Section 5.6.2).

15 Thaw and warm the 'O' ring seal, slacken the helium entry port nut, remove the helium transfer tube from the turret and immediately close off the helium entry port with the plug and baffle and secure with the nut.

16 Remove the helium transfer tube from the liquid helium dewar, warm it and store in a dry place. Move the liquid helium dewar away from the Cryostat.

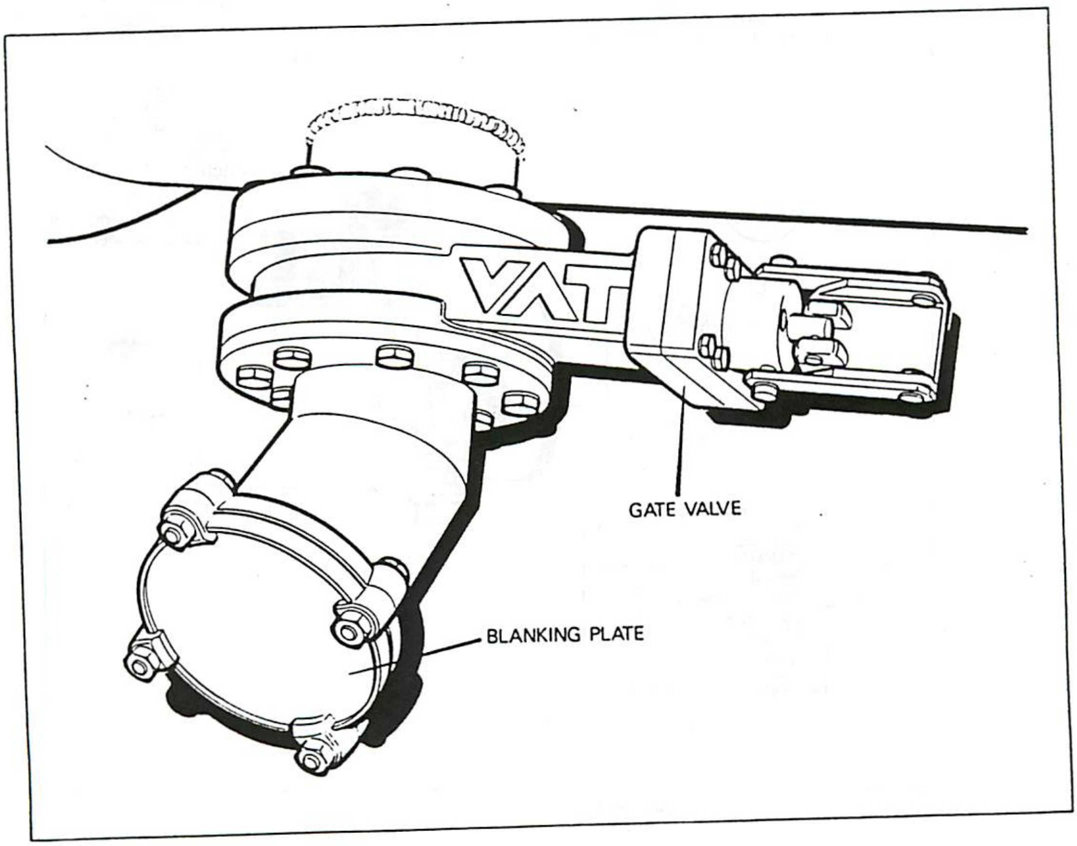


Figure 4.11

17 Switch the Liquid Helium Meter sample rate from fast to slow to reduce the consumption of helium. Set the sampling time constant, (see Liquid Helium Level Meter Manual).

18 Check that there are no openings for leaks into or out of the services turret.

19 Record the cryogenic liquid levels in the Performance Log (see Section 5.5). When the magnet has cooled down to 4.2K for the first time, the static boil-off rate will remain quite high for the first 24 hours and it will take 8 to 10 days to reduce to the 0.4 litre/hr quoted in the performance specification in Section 2.4.1 as all the shields reach their base temperature.

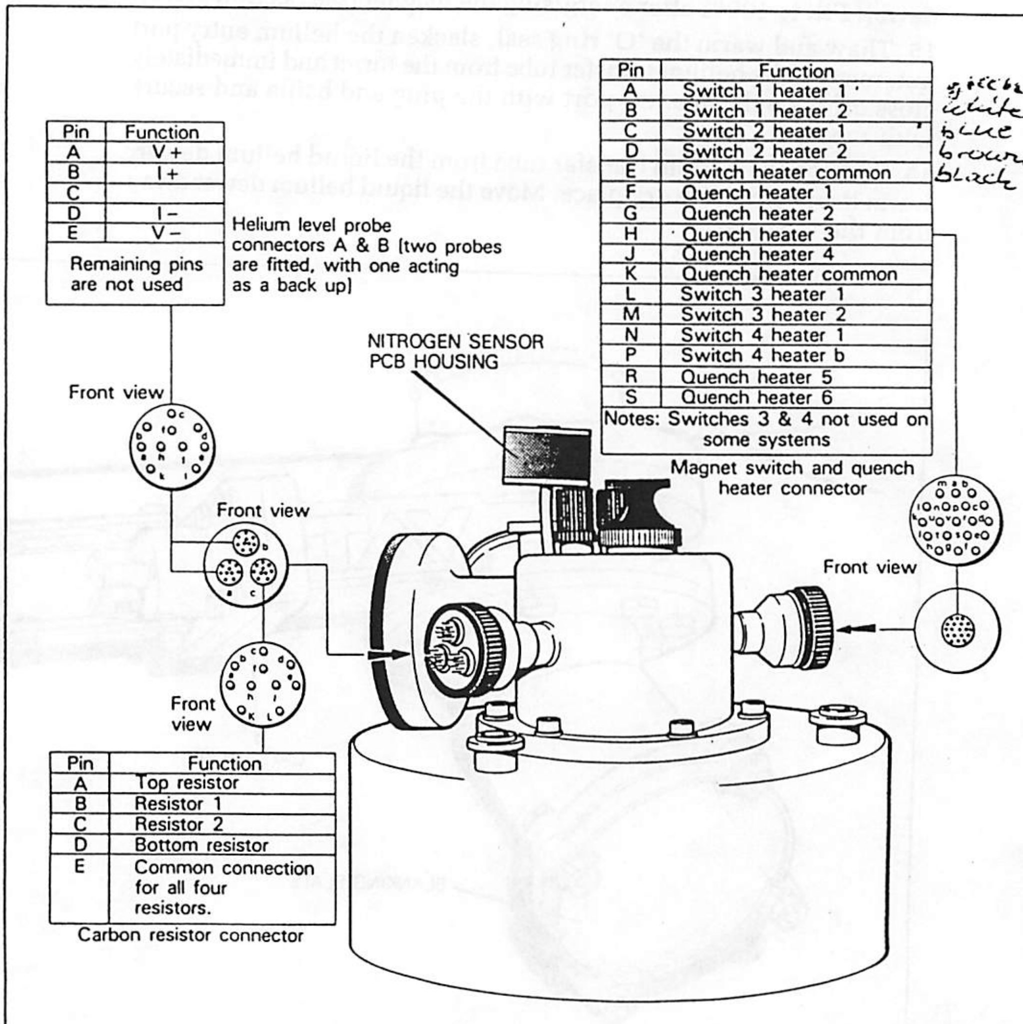
4.2.7 Adding Liquid to a Reservoir

NITROGEN

See *Preventive Maintenance*, Section 5.6.1

HELIUM

See *Preventive Maintenance*, Section 5.6.2



Pin	Function
A	V+
B	I+
C	
D	I−
E	V−
Remaining pins are not used	

Pin	Function
A	Switch 1 heater 1
B	Switch 1 heater 2
C	Switch 2 heater 1
D	Switch 2 heater 2
E	Switch heater common
F	Quench heater 1
G	Quench heater 2
H	Quench heater 3
J	Quench heater 4
K	Quench heater common
L	Switch 3 heater 1
M	Switch 3 heater 2
N	Switch 4 heater 1
P	Switch 4 heater b
R	Quench heater 5
S	Quench heater 6
Notes: Switches 3 & 4 not used on some systems	

Pin	Function
A	Top resistor
B	Resistor 1
C	Resistor 2
D	Bottom resistor
E	Common connection for all four resistors.

Figure 4.12

4.2.8 Connecting the Electronic Equipment

Read the appropriate Instruction Manual for the Magnet Power Supply, Level Meters etc.

> **WARNING:**
> ***Do not follow this procedure if the magnet is already energised.***

1 Install the electronic equipment cabinet, incorporating the Magnet Power Supply, the Liquid Helium Level Meter and the Liquid Nitrogen Level Meter, ensuring that their mains transformer tappings are correctly set for the voltage of the main electrical supply and that the fuses are of the correct rating (refer to the appropriate equipment manuals).

2 Connect the Magnet Power Supply to the cooling water system and turn on the water supply.

3 Ensure that the instrument power switches are set to their off positions and connect the electronic equipment cabinet to the main electrical supply.

4 Check the electrical continuity of the demountable current lead at the services turret. Check the electrical connections of the switch heaters, nitrogen probe, helium probe and quench heaters (see Fig. 4.12).

5 Connect the magnet power supply unit to the demountable current lead on the services turret using the interconnecting cables and observing polarity. Connect the two smaller cables to their respective terminals. The small cables allow the power supply unit to measure the voltage induced at the demountable current lead and eliminate the voltage drop along the current carrying cables.

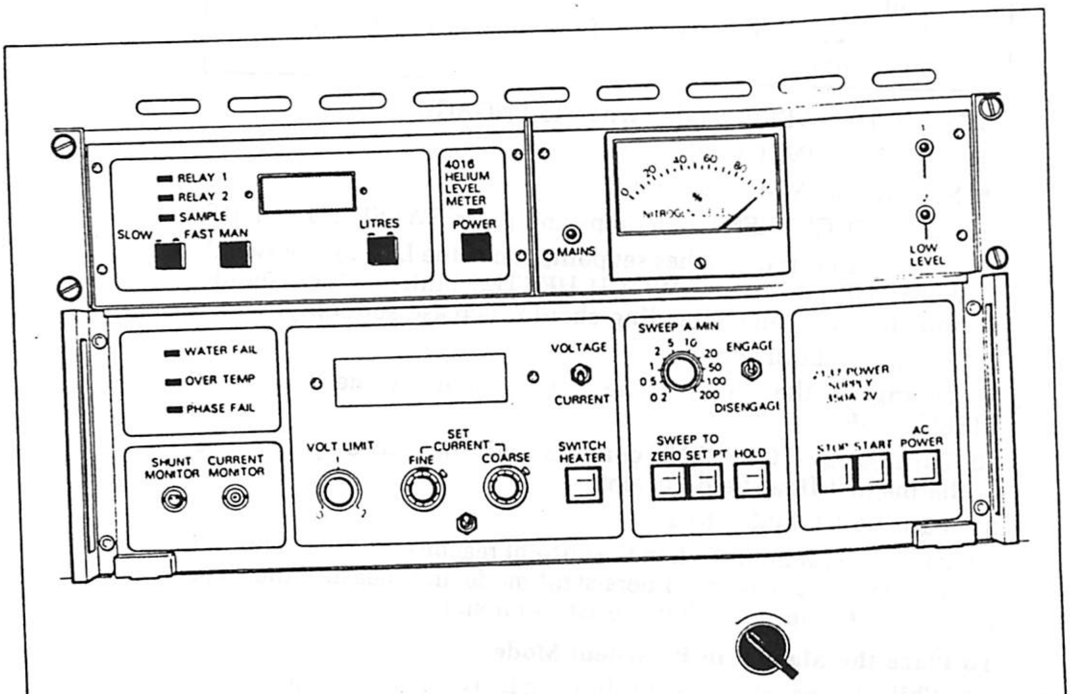


Figure 4.13

13 When the set point is reached (i.e. the LED display shows the predetermined current setting) check the voltage reading again, which should be below 0.5 volt.

14 Press the SWEEP TO ZERO button to remove the current from the leads.

Energising the Magnet with Sweep Generator Mode.

> **Caution:**
> *Do not use this procedure if the magnet is fitted with superconducting shims.*

15 Move the SWEEP toggle switch to ENGAGE.

16 Set VOLT LIMIT to 2.

17 Set SWEEP A/MIN control to 10.

18 Turn SET CURRENT to 5 amps and press SWEEP TO SET PT.

19 When the current reaches set point, move the LED toggle Switch to VOLTAGE and press SWITCH HEATER button which should illuminate. The voltage reading should increase suddenly, indicating that the switches have opened.

20 Set SWEEP A/MIN control to 1.

21 Move the LED switch to CURRENT and turn the SET CURRENT controls until the LED displays 70% of the magnet final field current.

22 Press SWEEP TO SET PT. After several hours, when the current reaches the 70% set point figure, place the magnet in Persistent Mode (see 33) and measure the field to confirm the magnet characteristics on site.

Energising the Magnet with Constant Voltage Mode

> **Caution:**
> *Do not use this procedure if the magnet is fitted with superconducting shims.*

23 Move the SWEEP toggle switch to ENGAGE.

24 Set VOLT LIMIT to 2.

25 Set SWEEP A/MIN control to 1.

26 Turn SET CURRENT to 5 amps and press SWEEP TO SET PT.

27 When the current reaches set point, move the LED toggle switch to VOLTAGE and press SWITCH HEATER button which should illuminate. The voltage reading should increase suddenly.

28 Set VOLT LIMIT to 0.

29 Disengage the sweep generator by moving the switch to DISENGAGE.

30 Turn the SET CURRENT controls until the LED displays 70% of the magnet final field current.

31 Turn VOLT LIMIT to ~~2.~~ 1.5

32 After several hours, when the current reaches the 70% set point figure, place the magnet in persistent mode and measure the field to confirm the magnet characteristics on site.

To Place the Magnet in Persistent Mode

33 While the magnet current is flowing in a closed loop, the magnet is termed as being in Persistent Mode.

6 Connect the switch heater lead (or Emergency Run Down Unit if supplied) to the services turret and power supply unit.

7 Connect the Liquid Helium Meter and the Liquid Nitrogen Level Meter to their respective connectors on the services turret using the cables supplied.

4.2.9 **Energising the Magnet**

1 Before energising the magnet remove the blanking disc from the demountable current lead vent port. The vent port should be connected to a helium recovery system or a suitable pipe to vent the gas safely from the area.

> **WARNING:**
> ***Failure to vent the helium gas through the D.C.L. will cause overheating which may burn out the current lead and cause the magnet to quench.***

> **WARNING:**
> ***Check that the blanking plate has been removed from the helium safety vent and that the bursting disc has been replaced.***

> *Caution:*
> *Do not begin the magnet energisation procedure unless the Cryostat helium reservoir is at least 70 to 80% full.*

> NOTE:
> *The control names printed in capital letters in the following steps refer to controls on the Magnet Power Supply Unit.*

2 Switch on the mains supply.

3 Ensure that the SET CURRENT FINE and COARSE controls and the VOLT LIMIT control are set to zero and then press the AC POWER pushbutton (Fig. 4.13).

4 If the unit is to be used in the sweep mode, ensure that the SWEEP A/MIN control is set to the required value.

5 Press the START pushbutton and check that it illuminates. Ensure that the SWITCH HEATER pushbutton is in the off position and the lamp is extinguished.

Remove shorting Link

To Run up Leads to Final Magnet Current With Switches Closed

6 Put VOLTAGE/CURRENT toggle switch to CURRENT.

7 Refer to the operating data supplied and turn SET CURRENT to the number of amps required by the magnet final field (the set point), using the COARSE and FINE controls and pressing the toggle switch to operate the LED display.

set current 0
engage sweep
engage hold
Set Volt Limit = 1.0
Then set I. to St. PT.

8 Set VOLT LIMIT to 1.

9 Engage the sweep generator by moving the toggle switch to ENGAGE position.

10 Set SWEEP A/MIN control to 10.

11 Press SWEEP TO SET PT. The lamp will flash until the set point is reached.

12 After the current reading has increased to between 5 and 10 amps, flip the VOLTAGE/CURRENT switch to VOLTAGE to take a reading, which should be less than 0.1 volt.

> **Caution:**
> *It is important to observe and record the current reading (set point) and polarity for future reference.*

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34 Press SWITCH HEATER to turn off the switch heater and allow two minutes for the switch to cool.

35 Move the SWEEP toggle switch to ENGAGE.

36 Turn SWEEP A/MIN to 10.

37 Press SWEEP TO ZERO.

38 When the current has reduced to zero on the LED (toggle at current), connect shorting links across the Magnet Power Supply unit main output terminals and across the switch heater terminals.

39 Press POWER SUPPLY STOP.

40 Press AC POWER to turn the power supply off. The magnet is now in Persistent Mode.

Energising to Full Field

41 Measure the field strength and basic homogeneity using NMR plotting equipment (see Section 4.3) and confirm that their values are normal.

42 Press AC POWER.

43 Press POWER SUPPLY START.

44 Remove the shorting links from the Power Supply Unit output terminals.

45 Turn SWEEP A/MIN to 10.

46 Press SWEEP TO SET POINT. When set point is reached press SWITCH HEATER to operate the switch heater.

47 Set VOLT LIMIT to 1.

48 Press HOLD.

49 Turn SET CURRENT controls until the LED displays 100% of the magnet final field current.

50 Move the sweep toggle switch to DISENGAGE to run field up to 100%.

51 After the current has run up to the set point, increase the set point by 1 amp. When current has reached the new set point, reduce the set point figure by 1.5. Wait for this set point to be reached and then increase the figure by 0.5 and wait for the field, current and the voltage to stabilise.

52 Press SWITCH HEATER to turn off the switch heater and allow two minutes for the switch to cool.

53 Move the SWEEP toggle switch to ENGAGE.

54 Turn SWEEP A/MIN to 10.

55 Press SWEEP TO ZERO.

56 When the current has reduced to zero on the LED (toggle at current), connect shorting links across the Magnet Power Supply Unit main output terminals and across the switch heater terminals.

57 Press POWER SUPPLY STOP.

58 Press AC POWER to turn the power supply off. The magnet is now in Persistent Mode.

4.2.10 Removing the Current Lead

1 The current lead is removed from the services turret to reduce the consumption of liquid helium.

2 Remove the interconnecting current cables from the top of the demountable current lead on the Cryostat services turret and from the rear of the Magnet Power Supply.

3 Remove the switch heater connections from the rear of the Magnet Power Supply.

4 If fitted, disconnect the vent pipework from the demountable current lead vent port and put the blanking disc in the vent port.

5 Remove any ice build-up from around the current lead entry using a 'hot air gun'. Remove the water with paper tissues.

> **Caution:**
> *Do not twist the lead to remove it.*

6 Loosen the retaining nut, while holding the demountable current lead in place. Pull the lead out quickly to prevent air entering the helium reservoir, as this may form ice on the main magnet connector.

7 Immediately fit the blanking plug into the demountable lead entry port and secure it in place with the 'O' ring, washer and nut. Ensure a good seal.

8 Switch on the Liquid Helium Level Meter and check the indication. Top up the helium reservoir if the indicated level is less than 50%. (Refer to Section 5: PREVENTIVE MAINTENANCE for the topping up procedure).

4.3 SHIMMING THE MAGNET

When first energised, the field produced by the magnet will contain many inhomogeneities caused by iron in the environment and by small winding tolerances in the magnet. Resistive shim coils are used to reduce these inhomogeneities in a procedure known as shimming. To obtain an idea of the shimming necessary, Nuclear Magnetic Resonance (NMR) field measuring equipment, with a resolution of approximately 5 parts in 10^7, is used to measure the magnetic field at a number of points. These data are then analysed to determine which shim coils are to be energised. The process of measurement and adjustment of shimming is repeated until the desired homogeneity is achieved.

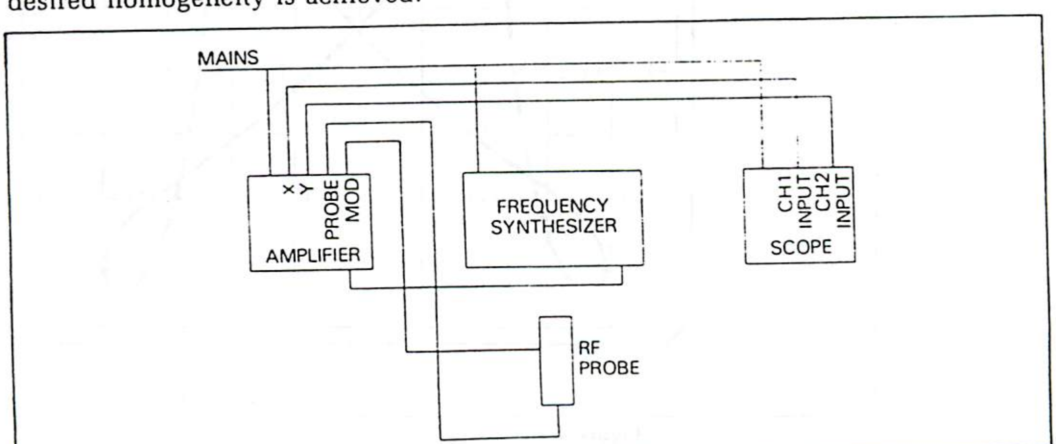

Figure 4.14

1 Connect the NMR Field Measuring equipment as shown in the diagram (Fig. 4.14).

2 Balance the probe by setting the RF amplifier zero at the base frequency being used.

3 Find the signal on the oscilloscope (Fig. 4.15).

4 Take the bare magnet plot and analyse the data to determine the field gradients.

5 The calibration of the shim set (if provided), in ppm/A, is listed in the Operating Data.

6 Divide the gradients in the bare magnet plot by the ppm/A for each shim respectively.

7 Set these currents on the shim supply and then plot again.

8 Divide the gradients in this plot by the ppm/A for each shim and add the previous set current.

9 Repeat 7 and 8 until the required homogeneity of the field is obtained.

4.4 CHANGING THE MAGNET CURRENT

> **Caution:**
> *Do not follow this procedure if the magnet is fitted with superconducting shims. The magnet would quench.*

1 The demountable current lead has to be re-inserted at the services turret. The Cryostat is cold, and care must be taken to reduce to a minimum the inlet of air because solid air could block the port or the electrical sockets and make it difficult to insert the demountable current lead.

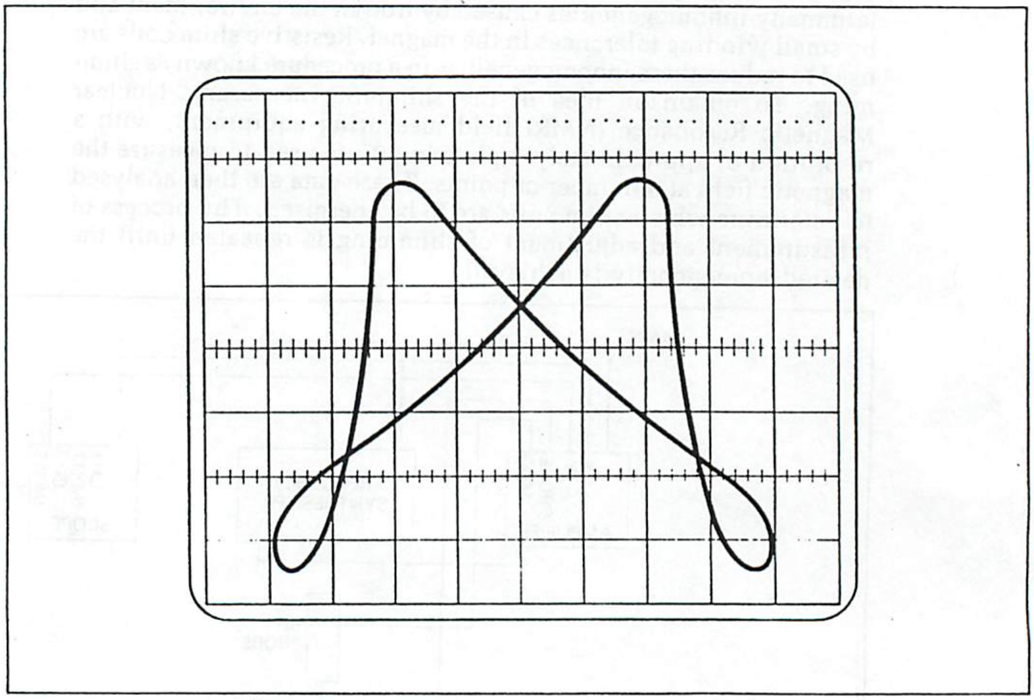

Figure 4.15

2 Unscrew the nut from the current lead entry port on the services turret and transfer the nut, washer and 'O' ring to the current lead, replacing the plug in the entry post to reduce the entry of air.

3 Remove the entry port plug and quickly, but with care, insert the end of the demountable current lead into the entry port and push the lead about one third of the way into the services turret.

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4 Slowly lower the demountable current lead down into progressively colder parts of the Cryostat, allowing it to cool slowly. The current lead will need to be inserted more slowly the further into the Cryostat it goes. When about two thirds of the way in, a spongy resistance may be felt. This is due to small amounts of air having solidified around the walls of the tube.

> NOTE:
> *If any but the slightest blockage is felt then investigate how this may have occured by checking for air leaks into the demountable current lead port and other points.*
>
> *If a strong resistance is felt, a large amount of solid air may be present. If anything but minimal force is needed to push the demountable current lead home, withdraw it and de-ice the port by warming and re-inserting the probe or blowing the helium gas onto the ice blockage.*

> **Caution:**
> *Do not attempt to force anything down the port to dislodge the blockage as this will only result in the solidified air dropping into the socket which is more difficult to clear because it is in the helium reservoir.*

5 Continue to lower the demountable current lead until the end just rests on the socket.

> NOTE:
> *The vent hole blanking disc should be left on the demountable current lead until step 12.*

6 Gently rotate the demountable current lead until the pins are felt to engage and the lead drops a short distance.

When the current lead has engaged, push it firmly into place.

> **Caution:**
> *Do not use undue force to twist the demountable current lead. If resistance is felt, lift the head slightly to feel for the correct locating position. Always rotate the lead in a clockwise direction to locate.*

7 Tighten the nut onto the entry port, ensuring that the 'O' ring is correctly located.

> **Caution:**
> *DO NOT attempt to check the electrical continuity of the demountable current lead. Check that the shorting links are connected across the output terminals of the Magnet Power Supply.*

8 Connect the Magnet Power Supply to the demountable current lead on the services turret using the interconnecting current cables. Ensure that the polarity of the connections is correct.

9 Move the sweep toggle switch to ENGAGE (Fig. 4.16).

10 Adjust SET CURRENT to the current recorded when the magnet was last placed in persistent mode (see **Caution** Step 33, Section 4.2.9 Energising the Magnet).

11 Press the START button and check that it illuminates. Ensure that the SWITCH HEATER button is in the off position with the lamp extinguished.

> **WARNING:**
> ***Failure to vent the helium gas through the D.C.L. will cause overheating which may burn out the current lead and cause the magnet to quench.***

12 Remove the blanking disc from the demountable current lead vent port and connect the vent line or helium recovery system to the port.

13 Set SWEEP A/MIN control to 10.

14 Remove the shorting links from the Magnet Power Supply Unit main output terminals.

15 Press SWEEP TO SET PT. The lamp will continue to flash until the set point is reached.

16 When the set point is reached, check the voltage reading again and it should be below 0.5V.

17 Connect the switch heater lead between the terminals at the rear of the unit and the superconducting switch heater connector on the services turret.

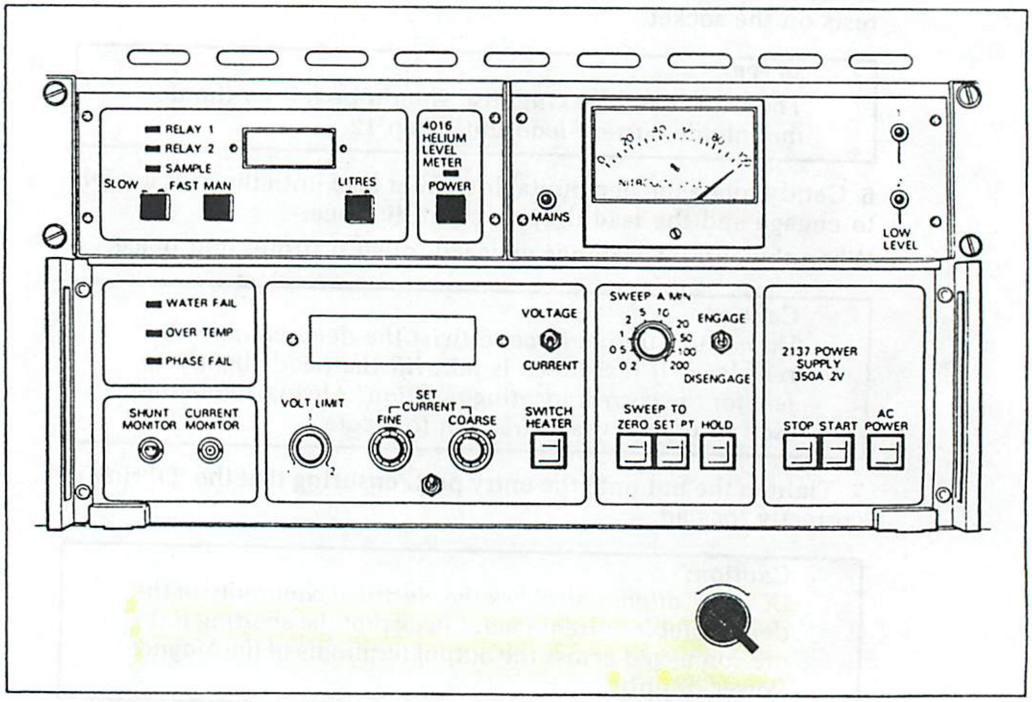

Figure 4.16

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18 Remove the shorting links from the Magnet Power Supply Unit switch heater output terminals.

19 Press the SWITCH HEATER button, which should illuminate.

20 Set SWEEP A/MIN control to 0.2./1 A

21 Wait approximately one minute and then slowly rotate the SET CURRENT COARSE/FINE controls to establish the required value of the magnet current. Check that the switch has opened.

22 Wait for the current to stabilise, noting the changing voltage.

23 Adjust SET CURRENT to the required field change and press SWEEP TO SET POINT.

24 Wait until set point is reached.

25 After the current has reached the set point, monitor the falling voltage and wait till the voltage has stabilised.

> **Caution:**
> *It is important to observe and record the current reading (set point) and polarity for future reference.*

26 Press SWITCH HEATER to turn off the switch heater and allow two minutes for the switch to cool.

27 Move the SWEEP toggle switch to ENGAGE.

28 Turn SWEEP A/MIN to 10.

29 Press SWEEP TO ZERO.

30 When the current has reduced to zero on the LED (toggle at current), connect shorting links across the Magnet Power Supply unit main output terminals and across the switch heater terminals.

31 Press POWER SUPPLY STOP.

32 Press AC POWER. The magnet is now in Persistent Mode.

4.5 RUNNING THE MAGNET CURRENT DOWN TO ZERO

1 Follow the procedure for changing the magnet current (Section 4.4) up to and including step 22.

2 Adjust SET CURRENT to zero and press SWEEP TO ZERO.

3 Wait until the current has reduced to zero.

4 Press SWITCH HEATER to turn off the switch heater and allow 2 minutes for the switch to cool.

5 Connect shorting links across both the magnet current output terminals and the switch heater output terminals.

6 Press POWER SUPPLY STOP.

7 Press AC POWER.

5 PREVENTIVE MAINTENANCE

5 PREVENTIVE MAINTENANCE

Observe the safety precautions (see page v and Section 4.1)

5.1 EQUIPMENT AND MATERIALS

1 The following equipment and materials are required:

Gas flow meters

Non-magnetic dewar containing 500 litres of liquid nitrogen.

> NOTE:
> *Some Liquid Nitrogen Storage Vessels are of the self-pressurising type in which the normal boil-off from the vessel is used to increase the pressure inside the vessel to effect a transfer. This type will prove more convenient in the long term. Alternatively the pressure can be derived from a cylinder of compressed gas - pure nitrogen or pure helium of commercial welding grade - with an appropriate reducing valve to provide a pressure of about 350 mbar (5 psi).*

Non-magnetic dewar containing 500 litres of liquid helium

Nitrogen fill tube.

Helium transfer tube.

Length of suitable hose for connection between the Nitrogen transfer entry port on the Cryostat Services Turret and the Nitrogen dewar.

> NOTE:
> *A permanent fixture may consist of 12 to 16mm thin-walled stainless steel or copper tube lagged with foam or similar insulation and permanently connected to a remote filling point. The length of such a system should be kept short because the amount of nitrogen needed to cool the connecting pipe could make the system uneconomical.*

Appropriate fittings and adapters for making connections to the dewars, the Cryostat and other equipment.

5.2 EVERY WEEK

1 The Cryostat should be inspected to see if any fault conditions are developing, e.g. cold spots, iced service turret, high boil-off.

2 Check the liquid nitrogen boil-off rate (see Section 5.4.1).

3 Check the liquid helium boil-off rate (see Section 5.4.2).

4 Check the services turret entry ports for ice.

5 Enter liquid levels and flow rates etc. in Performance Log.

5.3 EVERY 2 MONTHS

1 Evacuate the helium transfer tube (see Section 4.2.5).

5.4 ROUTINE CHECKING PROCEDURES

5.4.1 Liquid Nitrogen Boil-off Rate

1 The liquid nitrogen boil-off rate should be checked every week by noting the reading on the Liquid Nitrogen Level Meter. As a precaution against the meter indicating an incorrect level, it is important to measure the actual flow-rate of gas to make sure that the boil-off rate is not increasing. This can be done by having a remote flow meter connected to a port on the nitrogen vessel (see Fig. 5.1)

NOTE:
The Liquid Nitrogen Level Meter is calibrated at the factory to give a reading which represents the height of liquid in the reservoir. Because the reservoir is an annular space, a non-linear relationship holds between the level indicated on the meter and the volume of liquid remaining. The rate of decrease of level will therefore also be non-linear assuming a constant boil-off rate.

2 Record the level and flow-rate and compare them with the previous ones entered in the Performance Log. A slowly increasing boil-off rate may indicate a small leak into the vacuum space.

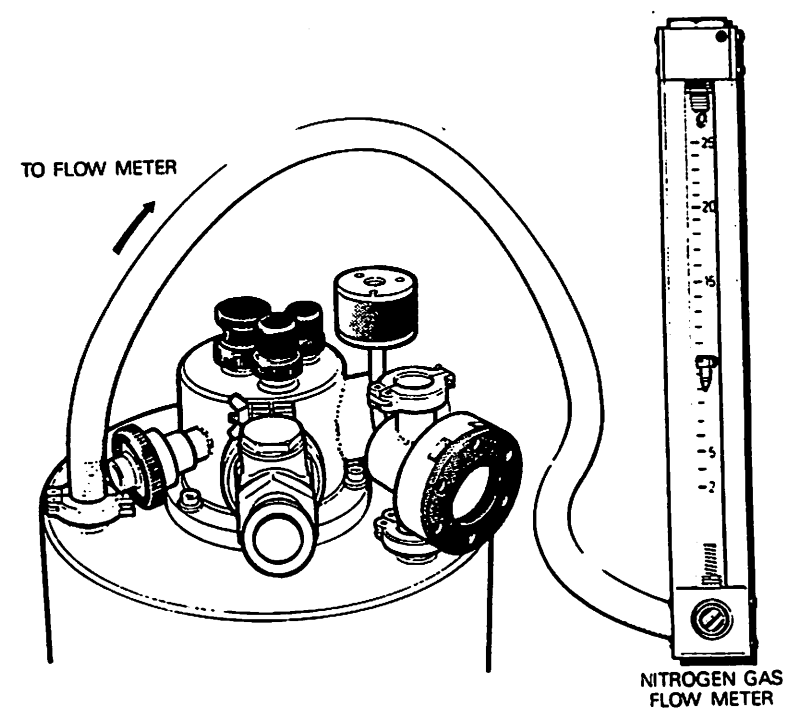

Figure 5.1

3 The normal boil-off rate of liquid nitrogen permits a scheduled re-fill of approximately 200 litres every 7 days which should bring the nitrogen level up to 100%.

> NOTE:
> *If the nitrogen vessel is allowed to run out of liquid nitrogen, the internal shields will begin to warm up and the helium boil-off rate will increase. When the nitrogen vessel itself warms up the Nitrogen Level Meter may give a false reading as the capacitance of the warm probe can equal the 'cold' capacitance at some intermediate level.*

5.4.2 Liquid Helium Boil-off Rate

1 The liquid helium boil-off rate should be checked every day by noting the reading on the Liquid Helium Level Meter. Switch the meter off as soon as the check has been made to reduce the consumption of helium. Check carefully that all fittings to the helium vessel are leak tight and that no gas leaks exist in the system.

2 Connect a flow-meter at the outlet of the non-return valve on the helium recovery port (see Fig. 5.2) to measure the actual boil-off rate.

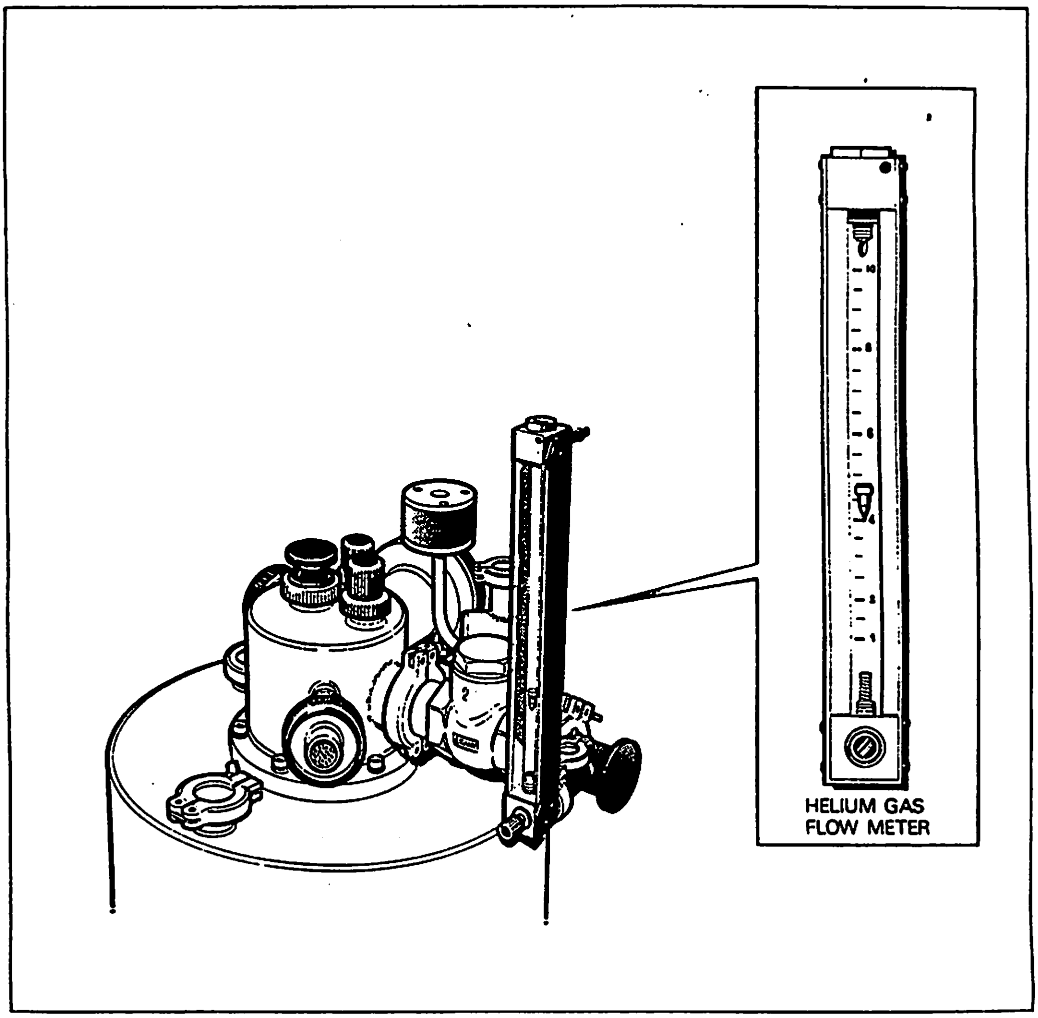

Figure 5.2

3 Record the level and flow-rate in the Performance Log and compare with previous values. A slowly increasing boil-off rate could indicate a small leak into the vacuum space. A consistently increasing boil-off rate indicates that helium gas is entering the vacuum space. A short-term increase in boil-off rate, later returning to a lower one, may indicate a pocket of outgassed air moving from the vacuum vessel or insulation and condensing onto the helium reservoir. Increasing ice formation on the services turret would indicate a high boil-off.

5.4.3 Checking the Services Turret for Ice

1 Small air leaks into the helium vessel will form blockages of solidified air in the necks of tubes. In the mildest cases this will result in difficulty in inserting the transfer tube, current lead, etc. In the most severe case it could prevent the escape of exhausting gas and cause a pressure build-up inside the helium vessel.

2 For this reason it is important to check, when the liquid vessels are being topped-up, that all fittings are secure and air-tight and that the non-return valve fitted to the helium recovery port is operating correctly. After a helium top-up, the fittings may be frosted and difficult to tighten properly. They should be checked an hour or so later when they have warmed up, and retightened if necessary.

> **Caution:**
> *Do not attempt to check the electrical continuity of the magnet switch heater as the current from a test meter will open the superconducting switch and will result in quenching the magnetic field.*

3 Check the helium transfer neck for ice every week by removing the fittings and feeling down the tube with a small diameter thin-walled stainless steel tube.

4 The checking itself can admit some air if not done carefully, and it is recommended that this be done a few days before a scheduled helium top-up.

5 Small amounts of ice around the walls of the magnet current lead entry port or helium transfer entry port are not serious. If large amounts are present, then steps must be taken to remove the ice and a possible air leak into the neck must be investigated.

5.5 PERFORMANCE LOG

1 It is essential to keep a log of all helium and nitrogen top-up operations and of any other events such as running a different current into the magnet. Failure to do this may hide a slowly developing fault and may hinder correct diagnosis of a fault should one arise.

2 A Performance Log booklet is included at the back of the manual.

5.6 CRYOGENIC LIQUID TOPPING-UP PROCEDURES

5.6.1 Liquid Nitrogen

1 It is recommended that the topping-up procedure is done on a regular basis, every Friday afternoon for example, regardless of whether the level has reached its estimated lower limit.

2 By adopting a regular re-filling schedule, the amount of cryogens required each 7 days is kept to a minimum both in quantity and ease of handling.

3 In the event of a non-permanent nitrogen filling supply, where the liquid nitrogen storage dewar has to be taken to the magnet to enable a top-up to take place, great care must be taken to ensure that the storage dewar is of non-magnetic construction. This can be verified with the aid of a small permanent magnet.

> **Caution:**
> *Never take a magnetic dewar into a magnet room.*

4 Connect one end of the fill tube to the outlet of the liquid nitrogen storage dewar and the other end to the nitrogen entry on the services turret. Before transferring liquid it may be necessary to remove the nitrogen bursting-disc from the nitrogen exhaust on the turret to avoid accidental rupture due to over-pressure whilst filling.

5 Open the valve on the storage dewar slowly and keep the flow at a low level for approximately 1 minute. This will enable the fill tube and couplings to stabilise to the sudden low temperature, minimising leaks at couplings.

6 The pressure applied to the storage dewar should not have to be raised above 200 – 270 mbar (3 – 4 psi) to initiate the flow of nitrogen which should start immediately. To ensure an efficient transfer a higher pressure may be required where a long fill tube is employed.

7 The Nitrogen Level Meter reading should be noted at the start of the transfer and the meter should be watched carefully during the transfer. As soon as the meter reads 100% the storage dewar should be de-pressurised to stop the transfer. 200 litres of nitrogen will take approximately 45 minutes to transfer.

> **Caution:**
> *Do not allow the liquid nitrogen to overflow from the magnet as this could cause the 'O' ring at the extreme base of the turret to become frozen, which could result in a vacuum leak.*

8 The couplings on the nitrogen fill tube should be warmed up using a hot air blower and then disconnected. The bursting-disc should be replaced immediately, all traces of ice built up during the nitrogen fill should be removed and all excess water mopped up.

9 Note the Nitrogen Level Meter reading in the Performance Log and also note the amount of liquid used.

5.6.2 Liquid Helium

1 The helium should be topped-up on a regular scheduled basis every 14 days and a supply of 200 litres should be available to maintain the helium transfer schedule which will take approximately 60 to 90 minutes.

2 Boil-off at 12 litres per 24 hours, after 14 days would require 168 litres in addition to transfer losses to bring the level back to 100%

> **Caution:**
> *The minimum acceptable level of helium is 50%, measured on the Liquid Helium Meter, to ensure that the whole of the magnet remains below its super-conducting transition temperature.*

> NOTE:
> *The meter reading is a non-linear function of the liquid level. This is partly due to the annular shape of the space and partly to items which displace some liquid volume.*

3 Check the condition of the helium transfer tube and if necessary, re-evacuate the tube (see Section 4.2.5: Evacuating the Helium Transfer Tube).

4 Check that the storage dewar is of a non-magnetic construction with the aid of a small permanent magnet.

5 During transport a rise in internal pressure will have taken place in the storage dewar. Any rise above 200 mbars (3 psi) is usually vented via a built-in safety valve. All pressure *must* be released before the transfer tube is inserted into the storage dewar, by opening the valve just enough to release the pressure slowly. Releasing the pressure quickly will result in up to 50% of the liquid in the dewar boiling-off, due to the sudden pressure and therefore temperature change taking place.

6 Manoeuvre the helium storage dewar close enough to the magnet to enable the transfer tube eventually to be inserted in both the dewar and the magnet services turret.

7 Switch the Helium Level Meter to fast sampling rate and note the reading.

8 Before inserting the helium transfer tube into the storage dewar, fit extension tubes to lengthen the leg to enable it to reach the bottom of the dewar and blow room temperature helium gas through the tube to remove any moisture or dirt which may have accumulated.

> **Caution:**
> *Do not bring helium gas cylinders into the magnet room*

9 Remove the helium transfer entry plug assembly from the services turret on the magnet and place the 'O' ring compression washer and screwed cap onto the magnet leg of the tube. The loose plug should be replaced in the helium transfer tube to avoid an ingress of air into the system.

10 Lower the long dewar leg of the transfer tube very slowly into the storage dewar to allow the relatively hot leg to cool down to the helium temperature. Leave the tube inserted about half-way.

11 As soon as the transfer tube is inserted into the dewar, gas should start exhausting from the other leg. This gas will quickly become cold and white and it may be necessary to insert the dewar leg further to ensure enough pressure is available to continue pre-cooling the tube. The formation of ice along the helium transfer tube indicates poor vacuum insulation and the need to evacuate the tube.

12 The white helium will very quickly change into a dense bluish white plume. The helium transfer entry plug should be removed from the turret and the short leg of the tube inserted as quickly as possible about 15cm into the magnet.

13 Push the storage dewar leg of the tube slowly down until the end is about 2cm above the bottom of the storage dewar.

> **Caution:**
> *It is not uncommon for a small amount of ice to be present in the bottom of the storage dewar. This ice can block the transfer tube which will mean going back to step 8.*

> **Caution:**
> *Push the magnet leg of the tube down until it touches the cone. Upon reaching the cone, immediately withdraw approximately 4cm to ensure that helium gas cannot be made to percolate around the magnet windings and cause a quench.*

14 Once the tube has been positioned in the storage dewar, the pressure in the storage dewar should be raised slowly to 200 mbar (3 psi) maximum using helium gas.

15 The helium meter should be set on the fast rate as a change in level should happen within 2 – 3 minutes of starting a transfer. Once the level reaches 100%, the storage dewar should be depressurised. Warm the 'O' ring seal, withdraw the magnet leg quickly and replace the helium transfer entry plug immediately afterwards.

> **Caution:**
> *Whilst inserting and withdrawing a tube from either the magnet or storage dewar, avoid spraying helium around the magnet 'O' ring seals.*

16 Replace the 'O' ring, compression washer and screwed cap back on to the helium transfer entry on the services turret, ensuring the seal is leak-tight. Log the helium level and the amount of helium used in the Performance Log.

17 Switch the Helium Level Meter back to slow sampling rate.

6 CORRECTIVE MAINTENANCE

6 CORRECTIVE MAINTENANCE

6.1 EQUIPMENT REQUIRED

Hot air blower with long extension nozzle.

A high vacuum pumping system. The recommended arrangement is shown in Fig. 3.13.

Helium mass spectrometer.
Fan (to blow helium gas from the vicinity of the Cryostat).
Cylinder of helium gas (welding grade is adequate) with pressure regulator for 0 to 400 mbar (0 to 5 psi).
3m of hose of diameter suitable for attaching to the helium cylinder.
Long, small-diameter tube to attach to the hose for spraying helium gas into the Cryostat helium transfer entry port.
Spare bursting-discs.

6.2 FAULT CORRECTION

6.2.1 High Helium Boil-off

Possible cause - *Low nitrogen level*

1 Check the Performance Log for the date of the last top-up of liquid nitrogen, quantity used and repeatability of the Liquid Nitrogen Level Meter reading, i.e. before and after topping-up.

2 Fill the nitrogen reservoir beyond the meter reading of 100%.

> **Caution:**
> *Over-filling must be done very carefully to avoid liquid nitrogen being spilled over the services turret.*

3 It should take approximately 10 - 15 minutes after the 100% reading before liquid starts to overflow.

4 If, after 15 minutes, liquid does not appear it may be necessary to check the calibration of the Liquid Nitrogen Level Meter. (Refer to Liquid Nitrogen Level Meter manual).

Possible cause - *Loss of vacuum due to frozen 'O' ring.*

5 Liquid nitrogen being spilled over the services turret during the routine additon of nitrogen will cause loss of vacuum by freezing the 'O' ring at the base of the services turret.

6 The base of the lower services turret should be warmed up to room temperature as quickly as possible using a hot air blower. This will allow the 'O' ring to become flexible and so form a seal.

7 The vacuum should return to normal quite quickly as indicated by the return to normal of the helium boil-off rate.

8 Providing no helium gas was present around the 'O' ring seal at the time of the spillage, the Cryostat should return to almost normal after 4 to 5 hours.

Possible cause - *Helium reservoir leak.*

9 If the high boil-off continues after checking the nitrogen level and the 'O' ring, assume that there is helium gas in the vacuum space. THE FOLLOWING STEPS MUST BE TAKEN AS QUICKLY AS POSSIBLE.

10 Run the magnet down to avoid the quench which will occur as the helium level gets lower.

11 Connect a suitable high vacuum pumping system and helium sensitive mass-spectrometer to the OVC gate valve and switch on.

After the pumping system and mass-spectrometer have reached their working pressure of 10^{-5}mbar open the OVC valve.

12 If helium gas is present in the OVC it will register on quite a high range on the mass-spectrometer and, if the gas leaked by a frozen 'O' ring, the signal on the mass-spectrometer should, over a period of 2 to 3 hours, show a positive decrease.

13 The helium boil-off should now show signs of decreasing and it is advisable to leave the pumping system on the OVC for at least 24 hours.

14 After the 24 hours, the reading on the mass-spectrometer should be noted and the OVC valve should be closed.

15 Take a second reading on the mass-spectrometer with a valve closed. This reading will probably indicate a higher helium signal than the previous reading and is a good indication that most, if not all, of the helium gas in the OVC has been removed.

16 After two hours open the OVC valve and take a reading on the mass-spectrometer. If the reading has not changed from the one taken after the 24-hour pumping period, the system is satisfactory.

17 Remove the pumps and mass-spectrometer and top-up the helium and nitrogen levels.

18 Re-energise the magnet and check the helium boil-off over the next 3 or 4 days to confirm that the system has reverted to the specified rate of boil-off.

6.2.2 High Nitrogen Boil-off

Possible cause – *Low helium level and low nitrogen level*

1 It is unusual for only one cryogen to have a high boil-off rate.

2 Check the Performance Log for the date of the last top-up of helium, the amount used and the Helium Level Meter readings before and after increasing the level.

3 Check the Nitrogen Level Meter (see Section 6.3.1).

4 Although it is extremely rare for a fault to develop in the helium level monitoring system, a check on the validity of the 100% reading on the Helium Level Meter can be made as follows.

5 Top up the helium level until the meter reads 100%.

6 Remove the Helium Level Meter from its rack mounting and remake the power and probe connections.

7 Partially remove the ten-pin probe lead from its socket (do not remove it far enough to break the electrical connection).

8 Connect a suitable DVM to pins A and E on the partially removed socket and adjust the DVM to read 0 - 50 volts DC.

9 When the SAMPLE button on the front panel of the Helium Level Meter is depressed, the voltage reading should be between 0 and 0.5 volts, while the Helium Level Meter reads 100%.

If the Helium Level Meter reads greater or less than 100%, this can be adjusted back to 100% by altering the FSD adjustment on the back of the Level Meter.

The voltage measured at pins A and E must be 0 - 0.5 volts before the FSD is adjusted to 100%.

6.2.3 **Magnet Quench**

Possible Cause - *Ramping up the current too quickly.*

1 If the bursting-disc has ruptured fit a new bursting-disc or blanking plate to prevent air entering the helium reservoir as soon as the exhausting helium gas flow has decreased sufficiently.

2 Air entering the reservoir will freeze in the neck tube and prevent access to the services at the magnet terminal plate and DCL terminals and restrict the boil-off of the remaining helium.

3 To remove the ice pass warm helium gas through one of the service entry ports until it melts. This operation may take several hours.

4 If the ice will not melt, remove the service entry housing from the turret, taking care not to damage the wiring running down the neck tube, and pass helium gas through an entry port to free the baffles if that is necessary.

5 Use a hot air blower with an extension tube long enough to reach the ice and clear the DCL terminals, diagnostic socket and helium transfer port.

6 Restore the nitrogen and helium liquid levels as necessary and re-run the magnet more slowly.

APPENDICES

APPENDIX 2

PERFORMANCE LOG

Booklet supplied at back of manual.

PERFORMANCE LOG

SPECIMEN

Date	Time	Activity	He Level START	He Level FINISH	N_2 Level START	N_2 Level FINISH	Comments

ORIGINAL ISSUE DATE 1/12/84	REVISION No						OXFORD
	REVISION CODE						
	DATE						