Operator's Handbook

Superconducting Magnet System

Supplied to:	Dr R Scheuermann PSI Switzerland
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1. Introduction

1.1. Safety

Warning: **It is your responsibility to ensure your own safety, and the safety of the people working around you.**

Danger: **Cryogenic fluids and high magnetic fields are potentially hazardous, and you must take precautions to ensure your own safety. The Oxford Instruments booklet *Safety Matters* has been included in this manual. It contains essential information and detailed recommendations about the precautions that you should take. Any additional information that applies specifically to your system is provided separately in the 'Safety' section of this manual.**

1.2. Warnings

Before you attempt to install or operate this equipment for the first time, please make sure that you are aware of the precautions that you must take to ensure your safety. In particular, please read the 'Safety' section of this manual.

Caution: Please read this manual carefully before assembling or commissioning the system. It is possible to damage the system beyond repair if the correct procedures are not followed.

Caution: Oxford Instruments cannot accept responsibility for damage to the system caused by failure to observe the correct procedures laid down in this manual. The warranty may be affected if the system is misused, or the recommendations in this handbook are not followed.

1.3. Important Note

This manual is part of the product that you have bought. Please keep it for the whole life of the product and make sure that you incorporate any amendments, which might be sent to you. If you sell or give away the product to someone else, please give them the manual too.

1.4. Important Health and Safety Notice

Important Health and Safety Notice

When returning components for service or repair it is essential that the item is shipped together with a signed declaration that the product has not been exposed to any hazardous contamination or that appropriate decontamination procedures have been carried out so that the product is safe to handle.

1.5. Conventions used in this manual

The following conventions have been followed in this manual:

Danger: **Indicates that the hazard may cause death or severe injury if the instructions are not followed carefully.**

Warning: **Indicates that the hazard may cause injury.**

Caution: Indicates that the hazard may cause damage to equipment.

Note: Something that needs to be brought to the customer's attention.

Tip: Indicates a helpful hint that may be of use to the customer.

1.6. Disposal and recycling instructions

Before disposing of this equipment, it is important to check with the appropriate local organisations to obtain advice on local rules and regulations about disposal and recycling.

You **must** contact Oxford Instruments Nanoscience Customer Support (giving full product details) before any disposal begins.

1.7. How to use this manual

Each of the main sections in the manual is separated from the others by a divider card. Use the divider card index which you see when you open the front cover or the table of contents to find the section that you want to read, quickly and easily.

Some diagrams are in a separate section. A few of these diagrams are folded so that you can pull them out and see them while reading the text which refers to them.

Additional manuals may be provided with your system to describe the details of some of the component parts. In particular, most electronic equipment is supplied complete with a manual, and you may need to refer to these separate documents to find out how to carry out some of the operations if you are not familiar with the equipment.

1.8. Stray Magnetic Field and Siting Issues

The effects of stray magnetic fields on system performance and the environment can often require complex finite element modelling. The following information is provided as a guideline only.

1.8.1. Static Steel

The presence of steel in close proximity to the magnet can cause two possible problems;

1. Excess force on the cryostat components leading to damage to the magnet support system or poor cryogenic performance.

2. Perturbations of the magnetic field leading to poor homogeneity.

In order to avoid these problems it is necessary to ensure that there is no structural steel within the 30 gauss field contour. This distance can be determined from the system stray field plot

Items such as steel beams or pillars and concrete reinforcing can cause problems, in particular any nonsymmetric steel in the structure.

It is possible that steel in the building will become magnetised and cause areas of increased field at some distance from the system, in particular steel beams may cause increased field areas in adjacent rooms that may affect VDU's.

1.8.2. Moving Steel

The effect of moving steel can be the same as detailed above with the added problem of field disturbances that may be visible in experimental results. Objects such as vehicles or elevators should be well outside the 1 gauss contour. Large steel equipment, such as gas bottles or pallet trucks, should be kept well outside the 10 gauss contour, movement of this equipment should be controlled as even at this distance effects may be observed. These distances can be determined from the system stray field plot. The relative position and steel content of doors and windows should also be determined.

1.8.3. Approximations to force calculation

The force between the magnet and a ferromagnetic object can be approximated if the magnetic field gradient is known. The critical limit is = 500 G/m; any iron located on this line is exerting a force on the magnet equal to its mass. Any iron within the region bounded by this line is exerting a greater force which can be approximated as force = (mass of iron object) x (field gradient at that point) / 500; e.g. A 5kg iron mass centred on the 1000 G/m line will exert a force = 5 x 1000/500 = 10 kgf = approx. 100N. However, note that this is only a guideline.

Caution: If there is any significant amount of ferromagnetic material within 2 metres of magnet centre field, contact Oxford Instruments for advice.

1.8.4. Field Limits for Devices (Unshielded Magnet Systems)

The following can affect the system and should be positioned outside of the following limits:

1 gauss

- Motor vehicles
- Elevators

10 gauss

- Large steel equipment

30 gauss

- Typical structural steel beams

The following will be affected by the magnetic field and should be outside of the following limits:

1 gauss

- Image intensifiers
- Electron microscopes
- Accurate measuring scales
- X-ray machines
- Graphics terminals

5 gauss

- Pacemakers
- Public access without warning signs
- Cathode ray tubes

10 gauss

- Computers
- Watches and clocks
- Credit cards

20 gauss

- Magnetic storage media

50 gauss

- Magnet power supply

1.9. Other manuals supplied with the system

The following documents (marked ✓) are also supplied with the system.

Safety Matters	✓
Practical Cryogenics	✓
Lambda point controller	✓
ILM200 family of cryogen level meters	✓
ITC503 temperature controller (re-condensing controller)	✓
IPS120-10 superconducting magnet power supply	✓
ISS10 superconducting shim coil power supply	✓
SRP-082B Installation, Operation, and Maintenance Manual	✓

The following pages describe the system and give some information about the principle of operation. If you are experienced you may not need to read the Introduction in detail but you must read the warnings contained in it.

1.10. Superconducting magnets

The world's first commercial superconducting magnet was produced *by* Oxford Instruments, and now, more than 40 years later the company still leads the world, with fields higher than 20 T available. This technology allows customers to produce extremely high magnetic fields in laboratory scale cryostats without the kW to MW power supplies needed for non-superconducting magnets. In most cases the cost of refrigeration for a superconducting system is much less than the cost of the power required to run an equivalent resistive electromagnet.

The magnet consists of a number of coaxial solenoid sections wound using multi-filamentary superconducting wire. It is constructed using the Magnabond system, an integration of proprietary techniques developed by Oxford Instruments. It gives a structure which is both physically and thermally stable under the large Lorentz forces generated during operation.

Additional coils may be fitted to the basic windings to modify the shape of the field. 'Compensation coils' are often used to improve the homogeneity at the centre of field by reducing the rate at which the field drops at the ends of the coils (due to finite winding length effects). They are usually wired in series with the main coils so that they are energised with the magnet. 'Shim coils' (or shims) are used to remove residual field gradients; they may be wired in series with the main coils to give a basic level of correction or independently to give finer adjustment. Shims may be either cold superconducting coils or room temperature 'normal' coils. 'Cancellation coils' are often fitted to one end (or sometimes both ends) of a magnet to give a low field region quite close to the centre of field; for example < 10 mT (or 100 gauss) may be achieved over a region only 30 cm away from the centre of field of a 15 T magnet.

1.10.1. Persistent mode operation using the superconducting switch

One of the main advantages of the superconducting magnet is its ability to operate in 'persistent mode'. In this type of operation, the superconducting circuit is closed to form a continuous loop, and the power supply can then be switched off, leaving the magnet 'at field'. The field decays only very slowly, at a rate depending on the inductance, the design and number of superconducting joints and the choice of conductor. A decay rate of 1 part in 10^4 relative per hour is easily achieved in a typical small magnet, but this can be improved to 1 in 10^7 relative per hour for specific applications (for example, high resolution NMR spectroscopy). Persistent mode operation is achieved using a superconducting switch which is often fitted to the magnet in parallel with the main windings. The diagram on page 12 shows a typical simple circuit with a switch fitted.

When the magnet is to be energised, the switch is warmed by the switch heater to hold it open, (that is 'normal' or non-superconducting). In this state, although the resistance of the switch is typically only a few ohms, it is so much higher than that of the magnet that almost all of the current flows through the magnet. Soon after the magnet reaches the desired field the induced voltage across the switch drops to zero and all of the current then flows through the magnet. The switch is closed by turning off the heater, (to allow it to return to the superconducting state). After a few tens of seconds the current in the magnet leads is slowly reduced by 'running down' the power supply. (This process is sometimes called 'running down the leads'.) As the current in the leads drops, the current flowing through the switch gradually rises, until it carries the full current of the magnet.

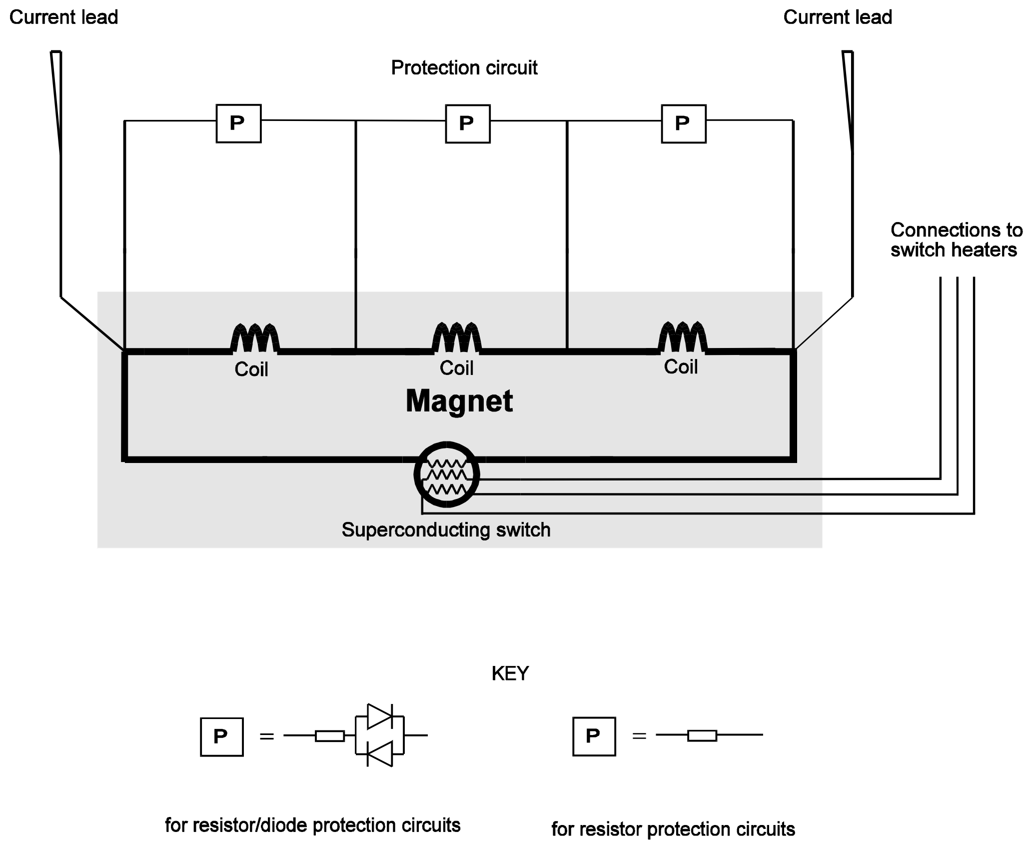


Figure 1 Simple resistor or resistor/diode protection circuit. (See the key at the bottom.)

1.10.2. Quenches

The magnet will only function properly providing that all of the conductors remain in the superconducting state. If any part of the windings goes 'normal' or resistive, the current passing through it will cause ohmic heating (I^2R); in turn this heating increases the size of the normal zone. Once the process has started, it is possible to stop it only if the disturbance is very small, or the magnet is 'stabilised'. Otherwise, the normal zone propagates rapidly through the whole of the coil, and may spread into other parts of the magnet. All the stored energy in the magnet is dissipated rapidly, causing the liquid helium to boil off very quickly and often warming the magnet to a temperature significantly above 4.2 K. This is called a 'quench'.

The stability of the magnet is strongly influenced by the design of both the conductor and the windings. Only a very small amount of energy is required to start a quench, and this releases a very large amount of stored energy. Even microscopic movements of the wires in the coils may be sufficient to quench the magnet.

A quench often helps the windings to settle, and normal operation can continue after refilling the cryostat with liquid helium. Indeed in a brand new magnet several quenches may be experienced before the magnet reaches its design field, and the quenches occur at progressively higher fields. This procedure is known as 'training', and it is quite normal. The training is carried out in the factory. It is unusual for the magnet to quench after it has left the factory, and you may run a superconducting magnet system for years without seeing a quench. However, if a new magnet quenches on its first run after transport (as occasionally happens) this should not be a great cause for concern, because it is possible that vibration has disturbed the magnet slightly. One or two training quenches should be sufficient to restore the magnet to its full specification.

1.11. MD20 Low loss cryostats for superconducting magnets with helium re-condensing

Oxford Instruments MD20 low loss liquid helium cryostats are characterised by a main upper body containing liquid helium reservoir and thermal radiation shield cooled by the first stage of the pulsed tube refrigerator and a lower ‘tail’ section housing the superconducting magnet. The layout of the tail section depends on the experimental requirements and variants are available providing various forms of access to the high flux density region. The tail sections of these cryostats are radiation shielded by thermally conductive shields connected to the base of the cryostat thermal shield.

The principal uses for such systems are related to neutron and X ray scattering as well as optical studies with principally split pair magnets orientated in either horizontal or vertical directions.

The thermal shield and liquid helium reservoir are thermally isolated by using

- Low thermal conductivity materials
- High vacuum chamber between the reservoirs/shields and room temperature (OVC)
- Multi-layer superinsulation

Experimental access is provided in various forms from the top of the cryostat or the side of the magnet tail and may be into an integrated variable temperature insert, into liquid helium or at ambient temperature.

The cryogen reservoir is protected against overpressure by the use of relief valves. The outer vacuum space is also protected in a similar way against over-pressure in the event of a catastrophic failure of the cryogen reservoir.

Warning: **Do not tamper with these safety devices or attempt to modify them.**

1.11.1. Principle of gas re-condensing

The system is equipped with a mechanical cooler which allows the capture of all or part of evaporated helium gas re-condensing it into liquid. Depending on operating mode and particular design of the system, liquid helium autonomy can be increased substantially with helium re-condensing.

Most mechanical coolers are two stage cryorefrigerators (cryocoolers) based on the Pulse Tube or the Gifford-McMahon Cycles. The cooler is mounted within the cryostat with its first cooling stage thermally attached to the cryostat thermal shield. Typical temperature of this shield is of order of 40-60 K and it mainly intended for intercepting thermal loads from room temperature. The second stage of the cooler is thermally connected with the liquid helium reservoir and is used for capturing evaporated helium and re-condensing it.

In some operational modes (e.g. during magnet energisation) cooling power of the cooler is not sufficient to re-condense all evaporated helium and therefore some of the gas will escape the cryostat as in conventional vapour shielded system. In many operational modes however the cooling power available exceeds the total heat load of the cryostat and in order to balance heat load and cooling power the system is equipped with a pressure control system. This consists of a pressure sensor connected to the helium volume inputting to an electronic pressure control unit which supplies heating power to heaters mounted within the reservoir.

Danger: **The system should always be set to operate above atmospheric pressure. Failure to do so may result in air entering and blocking the necks which can lead to uncontrolled raise in system pressure and damage to the system components.**

In many cases the excess refrigeration power may be employed to condense helium gas from ambient temperature. Typical sources may be the exhaust gas from a pump used to pump helium through an integrated variable temperature insert or lambda point refrigerator. In certain circumstances it is also possible to condense helium gas into liquid from an external storage source such as a recovery system. In this way helium that is lost from the reservoir during periods of high heat load (energising the magnet for instance) may be replenished during times when spare refrigeration capacity is available.

When operating in the external gas condensing mode it is important to ensure that the gas supply is clean and it is strongly recommended that a sorption trap be used in the gas supply or return line to avoid any contamination (e.g. air or oil vapours) entering the system and creating neck blockages.

1.11.2. Helium reservoir internal structure

Mechanical support system is provided within the helium reservoir of the MD20 cryostat. This provides mechanical support for the current leads, protection circuit, and other accessories. It is built into the helium reservoir and there are no user serviceable parts.

The cryogen transfer tube entry port is used to transfer cryogens into or out of the liquid helium reservoir. During pre-cooling with liquid nitrogen a liquid nitrogen transfer tube is inserted into this port. During cooling to 4.2 K with liquid helium a vacuum insulated helium transfer tube is employed. Below the port there is a conical fitting designed to seal to the end of either tube. This is connected to the upper end of a tube which goes to the bottom of the helium reservoir. Plug the transfer tube or blow out tube into this cone if you want to transfer liquid to the bottom of the reservoir or blow out all of the liquid. This is particularly important when the liquid nitrogen is blown out at the end of the pre-cooling process and when liquid helium is transferred into the system to cool it to 4.2 K.

Warning: **All the service ports should be sealed when the system is cold, to prevent air from entering the system. If they are not being used fit the plugs that we have provided.**

1.11.3. Magnet current leads

The magnet current leads are optimised to carry the maximum operating current of the magnet and introduce as little heat as possible to the liquid helium. In some systems the current leads are demountable. These can be removed to minimise the liquid helium boil-off while the magnet is in persistent mode, (but only at the expense of higher helium consumption while the current is sweeping).

1.11.4. Magnet protection circuit

The magnet protection circuit is used automatically in the event of a quench:

- To dissipate the energy stored in the magnet
- To make sure that high voltages are not produced.

Protection resistors (and diodes if appropriate) are provided for all magnet sections. The resistors are mounted in the helium reservoir. Diodes are used in the protection circuit to prevent current flow in the resistors helping maintain proportionality between supplied current and flux density during sweeping. (However, in cases where a superconducting switch is fitted, a small current will inevitably flow through this component.) The diodes also reduce the heat load from ohmic heating in the protection resistors and hence reduce system boil off while the magnet is sweeping. If the magnet quenches, the barrier voltage of the diodes is exceeded and the protection comes into operation automatically.

1.12. The refrigeration system

1.12.1. Sumitomo SRP-082B refrigerator description

The refrigeration system is supplied by the Cryogenics group of Sumitomo Heavy Industries and operates on the pulse tube principle using a closed helium gas cycle. It is an integral part of the magnet system providing the necessary cooling power for a zero helium loss system.

The refrigeration system comprises a cold head (SRP-082B), a compressor (F-70), interconnecting gas-lines, a cryostat interface and helium condensation surface.

The cold head, which is fitted to the cryostat via an integrated recondensing turret, is separated from the compressor which is housed in a separate rack, and connected by an electrical cable and high pressure gas lines.

A separate helium vessel pressure control system is supplied with the refrigerator to ensure that the pressure in the helium vessel never falls below atmospheric thus preventing the possibility of air and ice leakage into the system. The control system applies heat to the helium vessel heater(s) and controls the helium vessel pressure at the desired set point.

Full details of the operating parameters and maintenance procedures for the refrigerator and compressor will be found in the appropriate operating manual

1.12.2. Helium reservoir pressure control

In order to prevent the system sucking in air, the helium vessel is maintained above normal atmospheric pressure by active pressure control. A pressure transducer with a 0-10V output is used to monitor the helium vessel internal pressure. The transducer measures absolute pressure which allows keeping stable operating parameters regardless atmospheric changes. The transducer indication range is -200 - +200 mbar (gauge) for convenience.

The transducer is used to maintain pressure of approximately 5 mbarg (i.e. about 0.08 p.s.i. gauge) in the helium vessel by the use of a heater(s) fitted within the vessel and a PID control loop on one channel of an ITC503 temperature controller (see the test results for specific channel, limits and PID parameters). The gauge operates from an external 15V DC supply which provides the power for the 0-10V signal loop which is measured by the ITC503. The helium vessel heater is powered by proportional output of the ITC.

The system is equipped with 75 mbar (1 p.s.i.g.) check valve which allows the venting of excess gas to atmosphere (e.g. during ramping the magnet) rather than the pressure relief valves which are safety features used only in case of quench or catastrophic system failure.

The following steps must always be observed when operating the system.

- The refrigerator must not be started until all liquid nitrogen has been removed from the system. Any nitrogen in the system will be quickly frozen by the refrigerator which could impair both magnet operation and cooling performance. It may be necessary to warm the system to room temperature to recover from this situation.
- It is not recommended to disconnect the helium flex lines during cold head removal and replacement (for servicing etc.) Refer to manufacturer's instructions for further information.

- A pressure control system must be used to prevent a vacuum being generated in the helium vessel. If a vacuum were present in the helium vessel it would present a risk of sucking in air which when condensed on the cold internal surfaces would block essential helium venting ports and impair the cryogenic performance of the system. Recommended pressure set point is 5 to 20 mbarg. Lower values may present a danger of creating negative pressure in the system during periods of high atmospheric pressure. Higher values may lead to gas losses via possible minor leak paths in the top manifolds and losses when the system is depressurised (for servicing etc.)
- A ball valve is fitted to and manual pressure gauge should be fitted the system to allow depressurisation during cold head exchanges etc. The pressure should also be reduced by reducing the pressure control set point on the PID controller to minimise any gas loss when the system is opened.

1.12.3. Starting the refrigerator

Complete the following checks on the PT refrigerator before operation (refer to the manufacturer's manual for further information):

- Mains electricity wired in correctly
- Cooling water is flowing sufficiently and at the correct temperature
- Helium charge pressure is correct
- helium flex lines are connected to the cold head
- motor drive is connected to the cold head

Warning **Do not start the refrigerator on the system until after all the liquid nitrogen has been removed and the helium vessel has been pumped and flushed with helium gas. Failure to observe this warning will result in solid nitrogen forming in the service turret, requiring the system to be warmed to room temperature and re-cooled before proceeding.**

1.13. Fischer electrical connectors

High quality Fischer electrical connectors are used on these systems. These connectors have a self-locking mechanism to prevent the connection being accidentally broken if the cable is pulled.

Caution: Do not attempt to remove the connector by unscrewing the knurled black nut, as the wiring may be damaged. It is also likely that the nut maintains compression of a vacuum seal between the hermetic connector and the cryostat and that air will be admitted to a vacuum or helium space.

To remove the Fischer connector from its mating part on the cryostat it is important to pull the correct piece. You will notice that part of the outside of the connector seems to be loose on the body of the connector. This is the locking mechanism. Pull this part away from the mating connector to break the connection. However, if you try to pull the connector out using the cable or another part of the body the connector and it’s mating part will remain locked together.

2. Safety

The following safety information is included. It is important that you read it.

Safety Matters part number USC0001

3. Assembly and thermometry

3.1. Unpacking the system

The system should be unpacked carefully and inspected for any damage that may have been caused during shipment from Oxford Instruments. It should also be checked to ensure that none of the components are missing. If any problems are encountered you should contact Oxford Instruments (through our agent or subsidiary if appropriate).

The cryostat and other parts may be fitted with internal packing to prevent movement of the inner parts during shipment Consult section 3.4 below for specific instructions related to your system.

Warning: **Inspect any safety critical equipment (such as the relief valves and lifting eyes) prior to assembly. If any of this equipment shows sign of damage please contact Oxford Instruments, Superconductivity, Customer Support before assembling the system.**

3.2. Commissioning requirements for cryogenic systems

If you are planning to install a laboratory scale cryogenic system you are likely to need most of the following equipment. Some of it may be supplied with the system; other items may only be needed occasionally. If your system contains a superconducting magnet, ^{3}He refrigerator or dilution refrigerator there are additional requirements, and these are listed separately.

3.2.1. Safety equipment

- Personnel protection equipment including gloves and goggles
- Hazard warning signs to make sure that anyone approaching the system is aware of the potential hazards

3.2.2. Tools

- Spanners or wrenches (open ended metric set). 5 to 19 mm
- Allen keys (metric set) 1.5 to 12 mm
- Screw drivers, pliers, side cutters etc.
- Hot air gun
- Electrical soldering iron
- Digital multimeter (with low current ohms range).

3.2.3. Lifting equipment

- Suitable method of lifting the system from the delivery vehicle
- Suitable hoist or crane for use in the laboratory
- Lifting sling and shackles to suit the lifting points on the system

If you do not have access to lifting equipment above the position where you run the system you can use a trolley to transport the system to the hoist. It may be necessary to remove the system from the trolley when you are running it.

3.2.4. Vacuum equipment

- High vacuum pumping system to evacuate the insulating vacuum spaces, including a diffusion or turbomolecular pump and a liquid nitrogen cooled trap, flexible metal pumping lines for connection to the cryostat and a two stage backing pump. It should be capable of reaching a pressure of 10^{-6} mbar.
- A mass spectrometer leak detector system is required sometimes, especially when the system is commissioned, for routine leak testing operations.
- Oil mist filters fitted to all rotary pump exhausts.
- A range of vacuum fittings (ISO KF fittings (also known as NW or DN) are used as standard)

Caution: It is important to remember that turbo-molecular pumps have a low compression ratio for helium gas. Therefore you should always use a two stage rotary pump as a backing pump.

3.2.5. Cryogens and gas supplies

- Liquid nitrogen in a self pressurising dewar
- Liquid helium
- A supply of recovery grade helium gas with a regulator, at a pressure variable between 0 and approximately 1 bar gauge.

3.2.6. Consumables

- Roll of mylar adhesive tape
- Roll of aluminium adhesive tape
- Tube of vacuum grease
- Pair of cotton gloves for handling clean items
- 'Scotchbrite' or equivalent mild abrasive for polishing or removing old indium wire from joint faces.
- Metal polish and degreasing agent or solvent for general cleaning.
- Indium wire (1mm diameter)
- Rubber soccer ball bladders (2 needed).
- Assorted latex rubber and polythene tubing
- Fishing line or dental floss

3.2.7. Other equipment

- Helium transfer tube (or 'siphon')
- Level meters for cryogen reservoirs (if required) or a suitable 'dipstick'
- Suitable gas flow meters may be useful sometimes

3.3. Additional requirements for superconducting magnet systems

In addition to the items listed above, superconducting magnet systems typically have the following requirements.

- Additional hazard warning signs, barriers or controlled entry systems appropriate for magnet systems
- A suitable power supply for the magnet and superconducting switch and where required a suitable shim coil power supply.
- If you have a helium recovery system in your laboratory it should be capable of handling (or safely releasing) the large amount of gas generated in the event of a quench.

If there are magnetic items in the floor (for example reinforcement in concrete floors)

- Wooden or non-magnetic platform strong enough to support the system. It should typically be 25 cm high. (This may need to be higher for high field or high homogeneity systems.)

If there is any significant amount of magnetic material within 2 metres of the magnet field centre contact Oxford Instruments for advice.

Note: High homogeneity magnets are particularly susceptible to the presence of magnetic materials. The shape of the magnetic field can be altered significantly, and this may affect your experiment. If you have any doubts or concerns contact Oxford Instruments.

3.4. Assembling the system

3.4.1. Unpacking the cryostat

This system is shipped completely assembled and contains a single transit fitting in the centre of the base of the cryostat. This fitting is secured from the outer vacuum tail to the superconducting magnet reservoir and also supports the radiation shield. The fitting is shown on drawing P13015. It is secured to the outer vacuum tail by means of three M4 cap screws and to a boss on the base of the magnet reservoir with a central M12 Cap screw.

As will be seen on the general assembly drawings the magnet is held centrally within the outer vacuum tail by means of four low conductivity tie rods which screw into the same boss as the transit spacer. The outer terminations of these rods are secured with nuts and large washers to provide tension (hand tight only) and sealed with covers. **The system is shipped with these spacer rods in position and under normal circumstances will require no tightening or other attention. If the system has to be stripped down for maintainence then the procedure for removing the tails outlined below should be followed.**

The cryostat will require supporting on a hoist in order to remove the transit fitting. The first step is to remove the central screw. There should be no movement of the helium reservoir as the screw is removed and this should be confirmed by checking that it screws back into the bush easily before final removal. Next the three M4 screws are removed and the transit fitting pulled out of the tail. Two M6 screws may be fitted into the holes provided to aid in this operation. The transit fitting should be retained in case the system has to be transported in future

The aperture in the radiation tail is closed with the cover and securing screws provided. The hole in the superinsulation blanked is then filled with the superinsulation pad provided secured in position with aluminised Mylar tape.

The aperture in the outer vacuum tail is closed with the cover and securing screws provided. Ensure that the O-ring is in position and has been cleaned and lightly greased with silicon vacuum grease.

3.4.2. Removal and re-fitting the tails for internal maintainence

In the event that the outer and radiation tails have to be removed for maintainence of internal components the following procedure should be followed.

Check that the system is completely warm in order to avoid condensation of water onto cold surfaces when the vaccum space is vented.

Vent the vacuum space to warm, dry nitrogen gas.

Push the copper bore tube out of its location and remove. Note that this is quite a difficult operation as the O-ring seals at each end are very tight and there are no features on the tube to provide grip. It has been found that the best method is to employ leather gloves (such as welding gloves) pressing outwards and along the tube from within.

In order to remove the outer vacuum tail the magnet centralising rods have to be removed. These are accessed by removing the covers and removed by unscrewing. Note that there are two different rod lengths to suit the tail dimensions. It is best to mark each position and the rod and its associated components to ensure they are returned to the same positions on re-assembly.

Once the spacer rods have been removed the outer vacuum tail can be removed by extracting the securing screws at the joint to the main cryostat body and lifting the system clear of the tail using a suitable hoist. During this operation the relative positions of the two flanges should be noted. The simplest method to ensure correct re-assembly is to make an indexing mark with a felt tip pen on the two flanges before disconnection.

Once the outer vaccum tail is removed the system must remain suspended. **Under no circumstances should the attempts be made to support the system weight from the base of the radiation tail.**

The radiation tail is attached to the main cryostat radiation shield with screws around the upper connecting flange and the bore tube is secured to the tail with a fixed flange at one end and a contact ring at the other. To remove the bore tube remove the securing screws and pull out from the tail (The fixed flange and hence direction of removal can be identified by the soldered joint between flange and tube.)

As with the outer vacuum tail alignment marks should be made before removal from the upper part of the system.

Replacement of the tails is essentially the reverse of the obove procedure. All thermal contact surfaces on the radiation shield assembly must be lightly greased with high conductivity grease (such as Apiezon M). All vacuum surfaces must be cleaned and all O-rings cleaned, lightly greased and correctly positioned.

Fitting of the spacer rods is quite difficult as it has to be performed without direct visible access to the location threads in the bush on the base of the helium reservoir. It is adviseable to replace the transit fitting before the rods are fitted as this ensures that the magnet is correctly located when the rods are tightened and prevents them being inserted too far into the boss. The rods should be screwed in until they bottom onto the transit spacer securing screw and then backed off ½ turn. Fit the washers and nuts then tighten by hand in pairs to ensure equal tension in both opposing rods. Fit the second nut to each rod to lock them in position. Remove the transit fitting ensuring that the central screw re-fits easily indicating that the magnet is correctly positioned. Fit the transit fitting radiation shield cover, superinsulation pad and outer vacuum jacket cover together with the spacer rod covers.

Re-fit bore tube in the same way as it was removed noting taking great care not to trap or damage the O-rings. Significant amounts of vacuum grease on the O-rings will aid the process and the tube should be rotated as it slides into position.

3.4.3. Evacuating the cryostat

Before you use the system you should pump the isolation vacuum space to high vacuum using a diffusion or turbomolecular pump system (fitted with a cold trap to collect condensable vapours) and perform a full leak check with a mass spectrometer leak detector. The procedure for vacuum leak testing is described in section 4 of the document.

Even if the vacuum space has been left under vacuum since the last run, the surfaces inside it are likely to outgas and the vacuum will not be sufficiently high. There may be a sorbtion pump in the vacuum space to help to maintain the vacuum while the system is cold, and re-evacuating whenever the system is warm helps to keep it clean. If possible you should pump the vacuum space overnight (or longer), until the pressure at the pump drops to $< 5\times10^{-5}$ mbar.

3.5. Assembling the lambda point refrigerator pumping system

Assembly of the pumping system is shown in drawing A11477 and shows the complete circuit from the lambda point refrigerator pumping port through the pumping and re-condensing return at the PTR neck and main helium exhaust manifold.

Pressure relief valves are fitted within the circuit to ensure that no part of the circuit can become over-pressurised in the event of valves being closed out of sequence.

Valves V1 and V2 are provide such that the charcoal cold trap may be removed for decontamination without venting the rest of the pumping circuit. This operation should only take place when the pump is not operating and after the cold trap has been removed from the liquid nitrogen Dewar. Note that the pump supplied with the system is of the ‘oil free’ type so the cold trap is employed only as an extreme precaution. With the lambda point refrigerator not operating it is possible to re-organise the cold trap and associated valves and lines to act as a filter for externally supplied helium gas used for refilling the system during periods when spare refrigeration capacity is available.

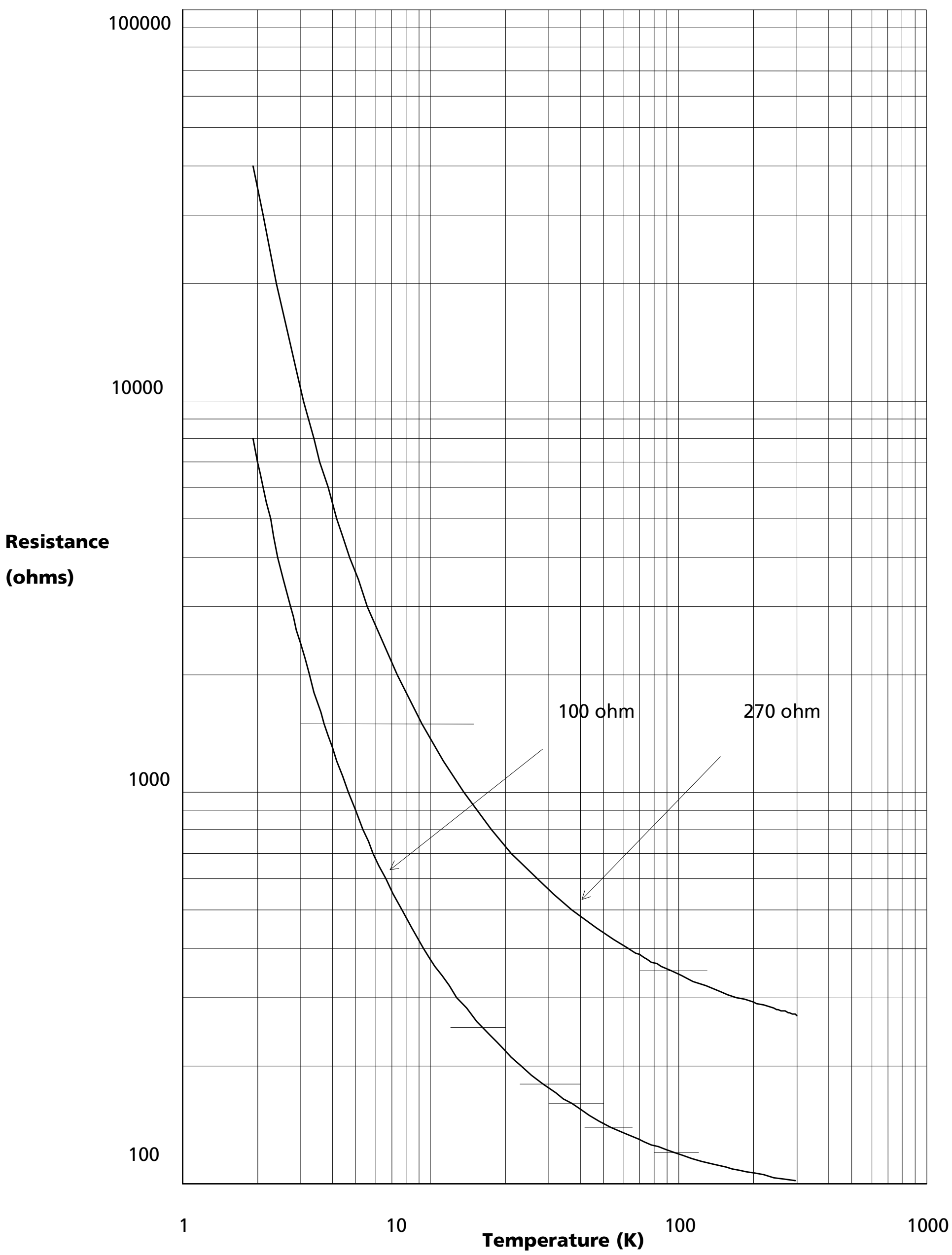
Valves V3 and V4 control the direction of helium gas flow from the pump, either to a recovery system (if this exists) or back to the top of the cryostat. Note that the main exhaust manifold is normally connected to helium recovery so strictly speaking gas flow need only be diverted through valve V3 if the flow rate is extreme such as when the lambda point refrigerator is first started and high cooling power is being employed to cool the magnet to 2.2 K.

It is vital to ensure that the circuit is maintained in a leak tight state as any air leaks amy introduce contamination into the PTR neck causing reduced re-condensing efficiency and in extreme cases blocking of the cryostat exhausts.

3.6. Allen Bradley resistors as thermometers

The temperature of the liquid helium and magnet are monitored with uncalibrated Allen Bradley resistor temperature sensors. The curves below show typical calibration data for the two values of nominal resistance sensors employed for this purpose. More data on the resistance values at various temperatures for the sensors fitted to this system will be found in section 10 of theis document.

Typical calibration curves of 100 and 270 ohm Allen Bradley resistors



4. Pre-cooling the system

4.1. Preparing the system for pre-cooling

4.1.1. Electrical checks

Check the wiring carefully using a multi-meter. Make sure that the resistance between all pins on the electrical connectors is as expected. The magnet windings should be electrically insulated from all the other wiring to greater than 1 MΩ.

Check the following:

- Magnet to switch heater
- Magnet to cryostat (ground)
- Magnet to all other diagnostic wiring

4.1.2. Evacuating the OVC

Evacuate the outer vacuum chamber (OVC) of the cryostat for at least 24 hours before you precool the system. It may be under vacuum already. If you want the optimum boil off performance it is important to pump the OVC with a high vacuum pump, not just a rotary pump. A 50 mm (or larger) diffusion pump fitted with a cold trap to collect condensable vapours is best because it pumps all gases well, (including helium). A turbomolecular pump with a cold trap (and backed by a two stage rotary pump) can be used but if there is any helium in the vacuum space it will take a long time to pump it away because these pumps have a low compression ratio for light molecules. Always use pumping lines which are at least 25 mm diameter and as short as possible. Do not use lines which have previously been used to carry helium gas.

It is possible to cool the system down without pumping the OVC with a diffusion pump but the system boil off is likely to be increased. We recommend that you always pump the OVC to a high vacuum before you cool down the system.

4.1.3. External leak testing

We recommend that you always check the system for leaks before pre-cooling. If you have little experience of using a mass spectrometer leak detector you may find the advice in the booklet "*Practical Cryogenics*" helpful.

Connect the leak detector to the OVC valve. Pump the OVC until the helium signal drops to the 10^{-8} mbar·l/s range on the leak detector (or a range with higher sensitivity). Spray helium gas over all external joints in the cryostat vacuum case. Any response on the leak detector should be investigated and leaks rectified before leak testing the internal components of the system

4.1.4. Pumping and flushing the helium reservoir

This operation is typically part of the leak testing procedure and it also enables other parts of the system to be flushed and filled with clean helium gas for example to prevent the risk of blockages caused by frozen air or moisture..

Warning; **Do not pump on the main helium reservoir unless the OVC is already under vacuum. It may collapse if you do!**

Disconnect the helium recovery system from the cryostat. Connect a rotary pump to the exhaust of the helium reservoir and close any needle valves such as those connected to variable temperature inserts or a lambda point refrigerator.

Pump out the helium reservoir to a rough vacuum (typically 1 mbar) to remove the air and moisture. Fill the helium reservoir with clean helium gas. There should be no response from the leak detector.

Evacuate helium flow circuits in variable temperature inserts or lambda point refrigerators then open the needle valves to fill these spaces with helium gas at 1 atmosphere pressure. Again there should be no response from the leak detector.

It is recommended that any variable temperature insert of lambda point refrigerator circuits are isolated from the main reservoir by closing the valve and filled with clean helium gas with a bladder attached to the exhaust port

When the system has been well proven, the leak test may be omitted completely. However, there is always a risk of wasting time and liquid helium if the leak tests are not carried out. Any signs of external or internal vacuum leaks should be investigated and cured before commencing with system cool-down

4.1.5. Checking the wiring

Check that the control and experimental wiring is correctly connected.

4.2. Pre-cooling the system

Make sure that you have carried out the preparations described for each part of the system before you start to pre-cool it. These are described in the other pages of this section of the manual.

Warning: ***Practical Cryogenics*** **gives some background information about transferring liquid nitrogen. Refer to it if you are unsure of the correct procedures. It is also important to be aware of the correct safety procedures, as described in the booklet** ***Safety Matters*** **which has been included with this system.**

Disconnect the main helium reservoir from the helium recovery line (if you have one in your laboratory). Some systems have to be pre-cooled slowly to make sure that they are not damaged by thermal shock. If so, precautions are given in the description of the preparations that you should carry out before pre-cooling the system. Insert the liquid nitrogen "blow out tube" through the siphon port. If there is a siphon extension cone fitting in the system push the tube into it and if the tube has a threaded end screw it fully home.

Connect a suitable tube from the top of the blow out tube to a liquid nitrogen storage dewar and transfer liquid nitrogen into the reservoir. Fill the helium reservoir with liquid nitrogen and leave the cryostat to pre-cool. It may take several hours to pre-cool the system, depending on its type.

Always wait until the liquid nitrogen has stopped boiling violently.

Caution: The OVC can be pumped during the pre-cooling procedure as long as there is a cold trap between the pump and the cryostat to prevent oil backstreaming. However, we advise that it should be isolated from the pump before the helium transfer is started.

Warning: **Ensure that all the components are correctly bolted together before cooling down the system.**

5. Cooling the system to 4.2 K

Please read the whole of this section and make sure that you understand it before you proceed. This is possibly the most difficult part of the operation of the system because to do it most efficiently you have to carry out several operations at the same time. For example, you can carry out leak tests on several components together while the helium reservoir is pumped and flushed with helium gas.

5.1. Preparing the system for operations at 77 K

Insert the liquid nitrogen blow out tube into the siphon port. If there is a siphon cone on your system push the blow out tube into it, and if there is a thread on the blow out tube screw it into the siphon cone. Connect the top of this tube to a separate storage dewar and blow the liquid into it.

5.2. Blowing out the liquid nitrogen

Blow the liquid nitrogen out of the main bath using a slight overpressure of helium gas supplied through the exhaust port. 200 mbar should be sufficient. When all the liquid nitrogen has been removed withdraw the blow out tube and insert the bung in the siphon port.

You can see that liquid nitrogen is no longer being blown out of the helium reservoir by observing the following signs:

- The pressure drops in the main bath
- The flexible part of the blow out tube is no longer vibrating noticeably
- The metal part of the blow out tube nearest to the cryostat is no longer 'wet' on the outside
- The plume of gas from the receiving vessel may change in character

If you are not planning to pump and flush the helium reservoir as described below it is wise to wait until the resistance of the Allen Bradley resistors (if fitted) drops by one or two ohms from the 77 K value measured when the reservoir was full with liquid nitrogen. This ensures that the reservoir has warmed slightly above 77 K and confirms that all the liquid nitrogen has been removed. Re-connect the helium recovery line.

5.3. Pumping and flushing the helium reservoir

It is wise to pump and flush the helium reservoir of your system (through the exhaust port) to carry out leak tests or to make sure that the liquid nitrogen has been removed completely. Complex systems with small capillary tubes could be blocked or superconducting magnets may be affected by frozen nitrogen.

If you are planning to test the system for leaks you can do many of the tests while you pump and flush the helium reservoir. Read the leak testing section for all the other parts of the system before you carry out this procedure.

Monitor the Allen Bradley resistors in the helium reservoir (if fitted) while you pump the reservoir. If you see their resistance rising as the pressure drops this is an indication that the liquid nitrogen has not been thoroughly removed, and you must try again to blow it all out.

Pump out the helium bath using the auxiliary pump to ensure that no liquid is left. The pressure should fall steadily to about 1 mbar. If this does not happen (for example, the pressure hesitates at 100 mbar) it indicates that the liquid has not all been removed. Vent the main bath to atmospheric pressure with helium gas, make sure that the blow out tube reaches the bottom of the helium reservoir, and try again to blow out any remaining liquid.

A good method to ensure that no liquid nitrogen is trapped within capilliaries leading to needle valves connected to variable temperature inserts or lambda point refrigerators is to vent the main reservoir to clean helium gas via these items. Connect a source of clean gas to the exhaust then open the needle valve and observe the pressure rise in the main reservoir.

If you want to be absolutely sure that there is no liquid nitrogen in the reservoir after this process is complete, wait until the resistance of the Allen Bradley resistors drops by one or two ohms from the 77 K value measured when the reservoir was full of liquid nitrogen. This ensures that the reservoir has warmed slightly above 77 K and confirms that all the liquid nitrogen has been removed.

If you want to check that there are no leaks from the liquid helium reservoir to the OVC you can do this by observing the helium signal in the OVC while the helium reservoir is filled with helium gas. Most cold leaks can be detected at 77 K, so there is little risk of a leak developing as the system is cooled to 4.2 K. However, if you have used the system without problems for a few weeks you may feel confident enough to run it without further testing. Close the OVC valve after you have completed the leak tests.

5.4. Cooling systems to 4.2 K

Liquid helium has a very low latent heat of evaporation but the gas has high enthalpy. This means that it is very easy to evaporate the liquid but it is difficult to warm up the gas so produced. Liquid helium therefore has to be transferred very carefully. If you do not transfer it properly you may lose all the liquid from your storage dewar without collecting any in your system. Follow these instructions to get an efficient liquid helium transfer.

When you are cooling down a system to 4.2 K it is very important to transfer the liquid helium to the lowest point in the helium reservoir. If the system is warmer than 4.2 K the liquid boils almost immediately as it leaves the vacuum insulated transfer tube (or siphon). Very little cooling is obtained from this evaporation. However, this gas then has to pass over the equipment in the helium reservoir to reach the exhaust line, and this provides very useful cooling power. If you transfer the liquid helium into the system slowly you can make sure that the gas emerging from the exhaust line is not too cold. This ensures that you do not waste any cooling power. If you do transfer the liquid too quickly you may see liquid air running from the recovery line, indicating that the cooling power is being wasted.

5.4.1. Preparations for the helium transfer

Check that the leg lengths of the transfer tube are suitable. The storage dewar leg should be able to reach below the liquid level (and preferably reach the bottom of the dewar). The system leg should be able to reach the lowest point in the helium reservoir (or the siphon cone if one is fitted). Position the liquid helium storage vessel so that the transfer tube can be easily inserted to both the storage dewar and the system, and blow some helium gas through the transfer tube to remove the air.

Remove the non-return valve from the exhaust port of the helium reservoir.

Warning: **If you have a helium recovery system, connect the exhaust line of the cryostat's helium reservoir and the storage dewar to it. It is important to make sure that the impedance of the recovery line is low enough to allow an efficient helium transfer. The recovery line should be at least 25 mm diameter. Contact your recovery system administrator for advice if you need it.**

If you do not have a recovery system, make sure that the exhaust is free to vent but that there is no risk that the system will be filled with air condensed from the atmosphere. You can do this by connecting a flexible line a few meters long to the exhaust port. Let the other end lie on the floor. The helium in this line is lighter than air and tends to prevent air from rising to the exhaust port. However, when the helium transfer is complete, or if the system is to be left open to air for more than a few minutes, you should put a one way valve on the cryostat exhaust port.

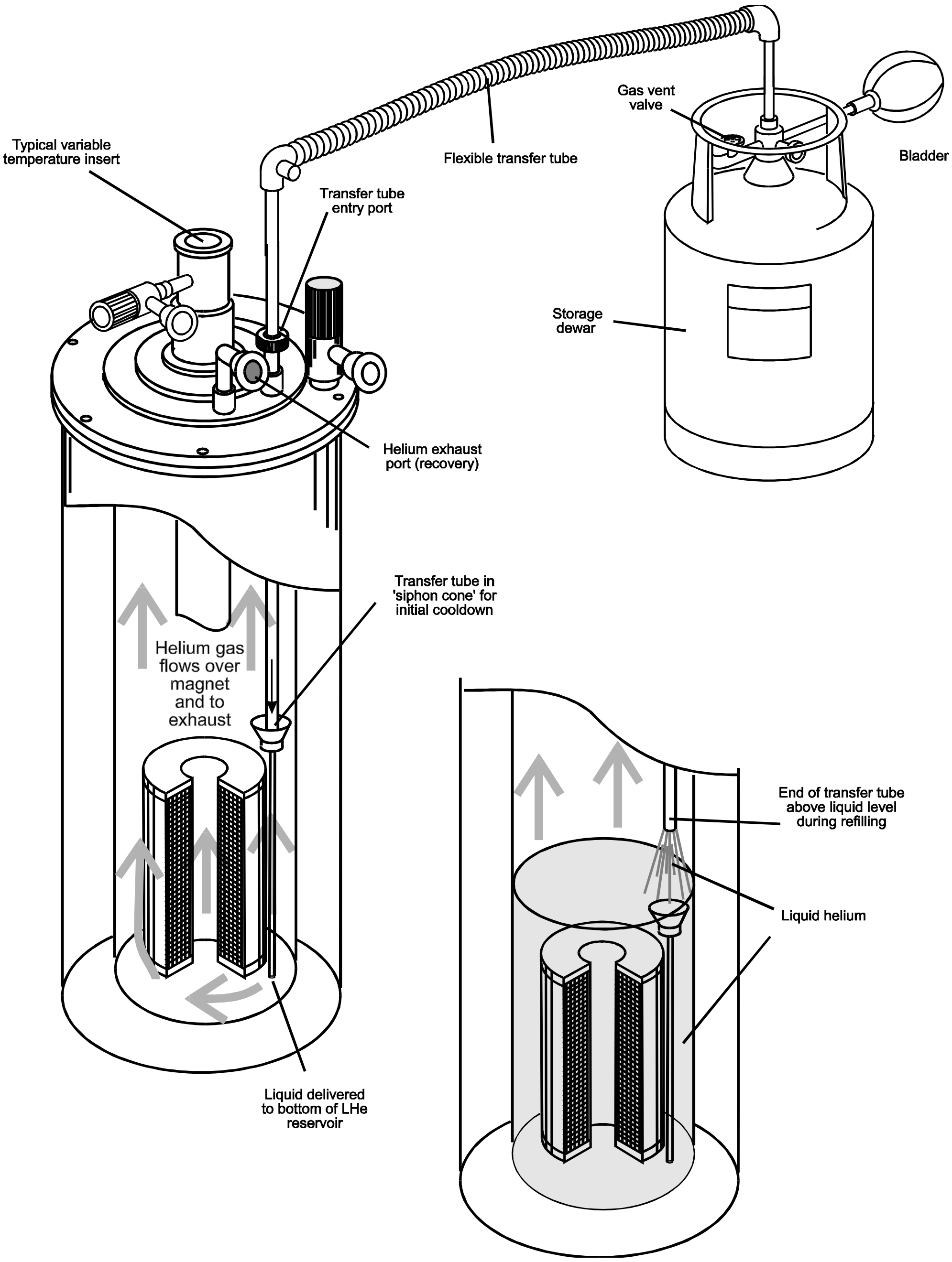


Figure 2 Transferring liquid helium into a typical laboratory cryostat.
Your system may not look like the one shown in the diagram.

5.4.2. Transferring liquid helium

Remove the plugs from the system's transfer tube entry port and the top of the storage vessel. Insert the transfer tube legs into the system and into the storage Dewar slowly, allowing the Dewar leg to cool gradually. Make sure that the end of the transfer tube in the cryostat reaches the bottom of the helium reservoir (or the siphon cone if fitted).

Ensure that the 25 mm ball valve in the exhaust line from the manifold is open as significantly greater flow that the pressure relief vale can accommodate will be present during helium transfer

Close the exhaust line on the storage Dewar and pressurise it slightly to start the liquid transfer. (This is generally done by gently squeezing a rubber bladder). The transfer rate should be such that the vent pipe is frozen for not more than 2 m (6 ft.) of its length. The initial transfer rate should be equivalent to between 4 and 10 litres of liquid per hour.

Close the OVC valve on the cryostat. There is no need to continue to pump it.

When liquid starts to collect in the helium reservoir the exhaust gas flow rate will be seen to drop noticeably (as the ice on the recovery line starts to melt). The pressure on the storage dewar can then be increased to transfer the liquid more quickly.

When the liquid helium reservoir has been filled, stop the transfer by releasing the pressure in the storage vessel. Remove the transfer tube and replace the bungs.

The booklet *Practical Cryogenics* contains a list of solutions to the problems commonly encountered in liquid helium transfers. Refer to this booklet if you are having problems.

Caution: Remember to replace the non-return valve on the helium reservoir exhaust.

5.4.3. Starting the pulse tube refrigerator (PTR)

Once the flow of He established you can start the pulse tube refrigerator (PTR). Check that pressure in the He circuit of the PTR is within specified range. Make sure that the compressor is connected to water cooling system and water is circulating. Refer to the manufacturer's documentation for flow and temperature specifications of cooling water. Once the pulse tube is started make sure that it makes appropriate noise and that high and low pressures on the compressor gauges are within specified ranges. Refer to the manufacturer's documentation for the specifications.

5.4.4. Setting up the pressure control system

Usually at this stage of the operation the system will have positive pressure in the He reservoir and pressure control system is not needed. It is advisable however to have it set up and running to provide additional protection against creating negative pressure in the He reservoir in an event of inadvertent transfer interruption.

He reservoir pressure is measured with an electronic pressure gauge usually attached to the helium exhaust manifold (see general assembly drawing for the exact positon). Pressure is measured by one of the ITC503's input channels. (See test results for the channel and range description). Make sure that pressure readings are sensible as the gauge may give false readings (usually off scale) when over-cooled in fast He transfer. At this stage of the system operation it is recommended to adjust the pressure control set point to~20 mbarg.

5.4.5. Cheking the lambda point refrigerator circuit at 4.2 K

Open the needle valve and allow cold gas to flow into the lambda point refrigerator which will be at a pressure below atmospheric due to contraction of the gas within the cold parts as the system has been cooled. If all is well the pressure within the lambda point refrigerator circuit will rise quite quickly. If all is well then close the needle valve when the pressure reaches approximately atmospheric..

6. Running the system

6.1. Stabilising the system at 4.2 K

On this system the main exhaust line is connected to the manifold with a 25 mm ball valve which serves as the main exhasust path. For operation in re-condensing mode the exhaust has to be connected to the recovery system (or vent line) via a low pressure relief valve to allow a positive pressure to be maintained within the helium reservoir. A pressure relief valve is fitted in parallel with the ball valve for this purpose and becomes active when the ball valve is closed. Adjust the set point of pressure control system to the value of ~20 mbarg (or the highest normal pressure at your altitude above sea level + 10 mbar) and make sure that pressure is controlled at this level. For the expected ITC503 output voltage to the pressure control heater see the test results section of this manual.

6.2. Running the magnet at 4.2 K

6.2.1. Introduction

The magnetic flux density is proportional to the current supplied to the magnet. The voltage available from the power supply determines the maximum sweep rate.

The current range of Oxford Instruments superconducting magnet power supplies (including the IPS120-10) work in 'current control mode' with a voltage trip. This means that if the power supply's output voltage reaches the hardware voltage limit the power supply will trip and go into the HOLD state. The current will be kept constant in this state.

You can set a sweep rate limit in software to suit the maximum allowable sweep rate for the magnet or to prevent the output voltage reaching the hardware limit during normal operation. If the power supply reaches this limit it will reduce the sweep rate accordingly and a 'limiting' warning light will come on to indicate that the magnet is not sweeping at the set rate.

Older power supplies or those from other manufacturers may work in different modes and the relevant documentation should be consulted.

A magnet power supply is typically used to carry out the following operations:

- To supply power to the superconducting switch heater to open the switch (if fitted)
- To energise the magnet to the required field (or current) and hold it there
- To sweep the magnet to a set field at a defined rate
- To put the magnet into persistent mode if a constant field is required (so that the power supply can be switched off) and only if the magnet has a superconducting switch.
- To change the field direction by reversing the polarity of the current
- To run a programmed series of sweeps and holds

Power supplies can be run manually or under computer control. Oxford Instruments can supply software packages which are used to program the system. ObjectBench allows you to carry out a sequence of operations, so that experimental results can be taken automatically. Alternatively, B-T environment software provides a simplified user interface for the system through National Instruments LabView®, and you can write sequences of operations for the whole system and experimental apparatus.

Some magnets can be run to higher fields if they are cooled to 2.2 K. They are usually cooled to this temperature by a lambda point refrigerator (or by pumping the whole helium reservoir with a rotary pump). If your magnet is not specified to run to higher currents at 2.2 K do not attempt to energise it above the 4.2 K field. If you do this you could cause permanent mechanical damage to the magnet and invalidate the warranty.

This magnet is fitted with a set of shim coils used to improve the flux density homogeneity. These shim coils are supplied with current from a single channel power supply which is multiplexed to the various shim coils in the set via the opening and closing of superconducting switches fitted to each coil.

Note: Operation of this magnet is specifically designed to be performed in an automated sequence using a specially written computer programme in LabView. Details of the software are shown in the separate guide and only the operational steps are discussed here. It is possible to operate the system in manual mode however this is not recommended due to the complexity involved and no instructions for this mode of operation are included.

6.2.2. Automatic control functions

The control software supplied with this system is designed to allow automated changing of the central flux density by the simple selection of a new value and the clicking on a single control button on the control interface. Changing central flux density involves the following automated steps:

1. Run all shim currents to zero
2. Put ISS10 shim coil power supply into dump mode holding Z1 & Z2 switches open and cycling X & Y shim switches open
3. Run main power supply to existing flux density current and open main magnet switch
4. Run main power supply to new current for selected new flux density
5. Perform demagnetisation procedure (user settable number of cycles and initial over-shoot amplitude)
6. Place the main magnet into persistent mode
7. Set new currents for each shim coil from interpolated data table
8. Cycle the shim currents to minimise interactions (user selectable total number of cycles)

A number of safety interlocks are included in the software and built into the electronics hardware supplied. In particular these interlocks are designed to prevent the magnet being operated when it is not at the correct temperature (4.2 or 2.2 k) and also to run the magnet down in a controlled manner if the helium level drops below the minimum set.

For 4.2 K operation account has to be taken of the slightly raised pressure that the helium reservoir operates at. This raised pressure results in temperatures above 4.2 K in normal operation and the limiting temperature may be set in the software to account for this.

When running the magnet at 2.2 K there is a large thermal margin such that the limiting temperature in this mode may be set significantly above 2.2 K to enable operation when the magnet is not at the base limit set by the lambda point refrigerator operation. Temperatures as high as 2.3 K may be set for this parameter and in operation the indicated magnet temperature may rise to > 3 K during a magnet sweep from 8 to 9.5 tesla at 0.25 tesla min^{-1}.

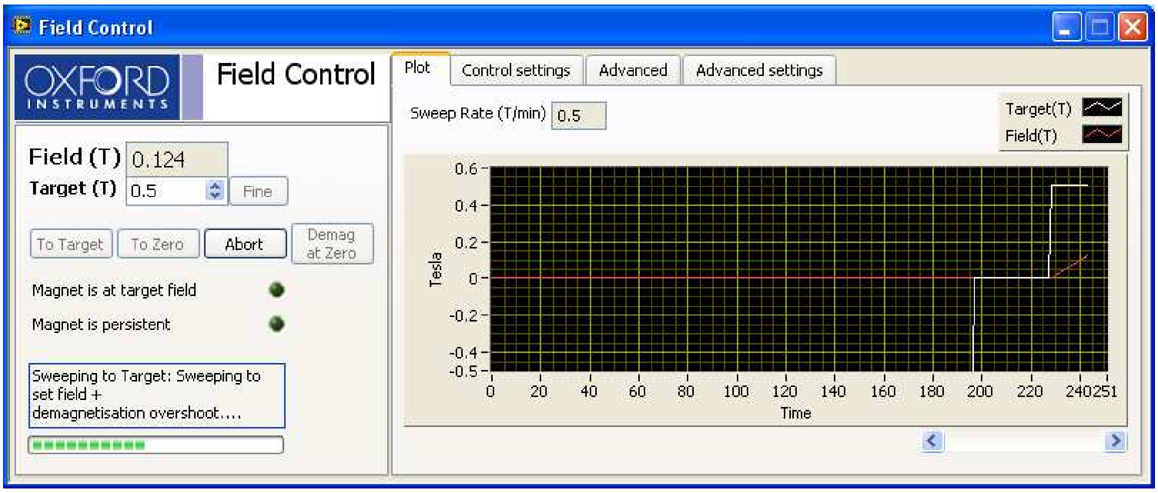
There are two interlocks which may run the magnet down in the event of low helium level. In the first a software control uses information from the helium level meter to initiate either a warning message or an automated run down. In the second hardwired contacts in the level meter are closed at a predetermined level which initiates the same function independently. In both cases the ISS10 is first set into shim current dump mode before the main magnet is taken out of persistent mode and the magnet run down to zero.

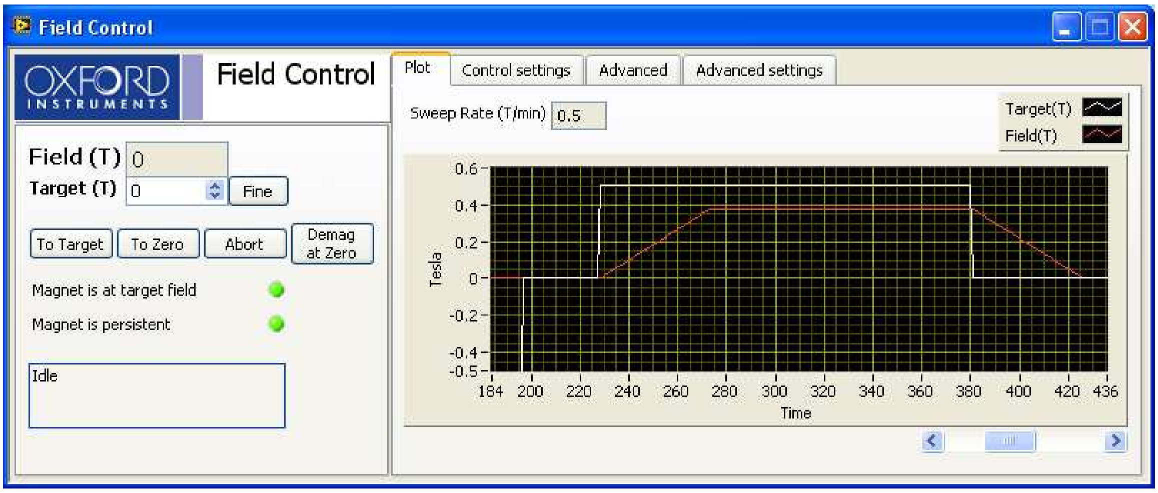
Note: **Due to the special configuration of the wiring required to enable all the required functions the final step of the emergency run-down procedure is not followed. At this step the shim switch heater outputs from the ISS10 should be deactivated following the closing of the main switch heater however as there is no connection from the IPS120-10 switch heater output to the ISS10 this does not occur. In the event of an automated run-down sequence being initiated it is important to switch off the switch heaters using the front panel controls (see the ISS10 manual.**

The main LabView control window titled Field Control contains a number of tabbed pages – 'Plot', Control Settings', 'Advanced' and 'Advanced settings'.

6.2.2.1. The Plot page

The 'Plot' page displays a time vs flux density plot displayed in real time. This is the page that has to be selected in order to iniate a magnet sweep. The following two screen shots show this page in two modes. In the first the magnet is sweeping and in the second the magnet is in persistent mode at zero flux density.





Note that the white trace shows the set point whilst the red trace shows the actual value of flux density.

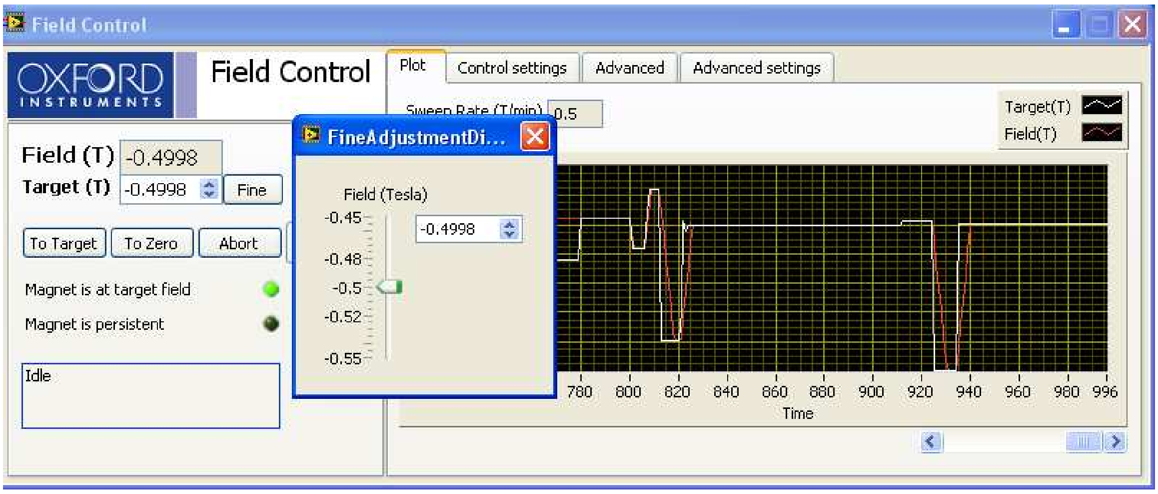
The main control buttons and input fields on the main page to the left are the 'To Target', 'To Zero' and 'Abort' buttons together with the 'Target' input field which may be incremented using the arrows or typed in directly. The functions of the 'To Target' and To Zero' buttons is obvious. The Abort button allows any sweeping operation to be stopped with the current flux density value held. Depending on the point in the sweep procedure the software determines what the next step should be when a new sweep is initiated. For the sequence of events when this button is pressed see the software guide.

The other two butons in this area are the 'Fine' and Demag at Zero' buttons which allow for a very small deviation from the current set flux density and a separate wide range demag procedure at zero flux density respectively.

The 'fine' flux density limit is restricted to a small value due to coupling between the main magnet and the shims and allows for fine adjustment without recourse to shim dumping and restting. The limiting range for this adjustment is ±0.05 tesla and the actual value being set in a window displayed from the 'Advanced settings' tab described later.

Selecting fine control first shows a dialog to warn the user that non-persistent mode is about to be selected followed by a message about the switch being opened (once the leads have been run up to the required current) for the appropriate switch opening delay (default setting 30 seconds).

A window showing a slider control for fine adjustment is then displayed as shown below.



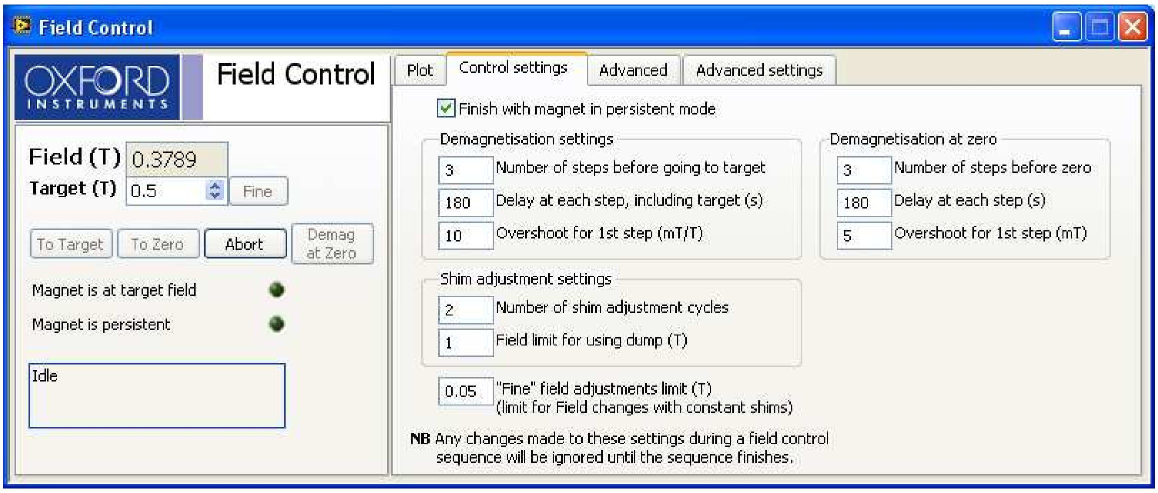
Moving the slider up and down adjust the target output current of the IPS120-10 to the required value and the magnet follows with the normal time constant delay. Closing the slider window sets the magnet into persistent mode at the new value. Subsequent operation of the fine adjustment routine gives the same original range (maximum ±0.05 tesla from the original persistent value) to ensure that the total deviation remains within safe limits. To alter the flux density to a value outside the displayed range the magnet must be ramped to a new persistent value before operating in 'Fine' mode again.

The demag at zero function allows for many more steps and greater starting magnitude to be employed than is the case with the automated demag sequence that is used as part of the main flux density changing routine.

On the plot tab page there is one display field showing the sweep rate. For safe magnet operation the maximum value entered via the 'Main coil' page on the 'AdvancedSettingsDialog. VI' entered from the 'Advanced settings' tab should not exceed 0.5 T min^{-1}. The power supply firmware sets a maximum value just greater than 0.5 tesla min^{-1} in order that the power supply does not go into ramp limiting mode.

6.2.2.2. The Control settings page

The 'Control Settings' page contains most of the input variable entries related to the automated sequencing together with the 'fine' flux density increment setting and the demag at zero input parameters. This page is shown in the screen shot below.



The demagnetisation setting default values are 3 decreasing value steps which start by an overshoot in the direction of the sweep, 180 seconds wait at each step and 10 mT/T target flux density for the magnitude of the first step. These values have been found to provide a satisfactory degree of flux density settling enhancement.

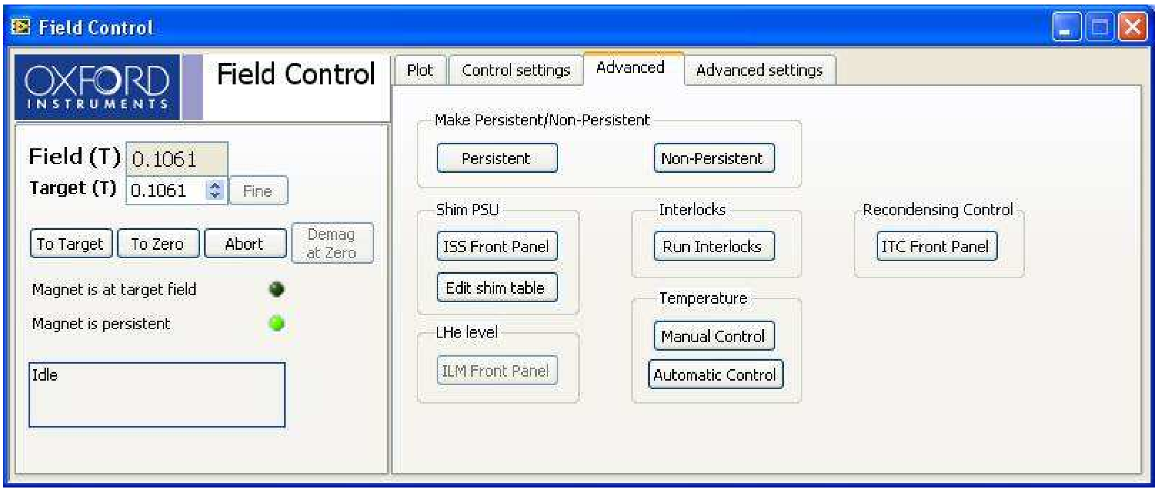
There are just two shim adjustment parameters. The first sets how many times the shims are cycled during the setting routine with the first being the initial setting of each current. The resetting of the currents to reduce any interactions is then made by 1 (or more) cycles at the same set values. A single extra cycle has been found to be satisfactory and this gives a default value for this parameter of 2.

The demagnetisation at zero input parameters are similar to the normal demagnetisation parameters as described above however the first step over-shoot value is an absolute rather than a relative value. Initial tests employed a 13 step procedure with an initial over-shoot value of 0.2 tesla and a delay of 180 seconds.

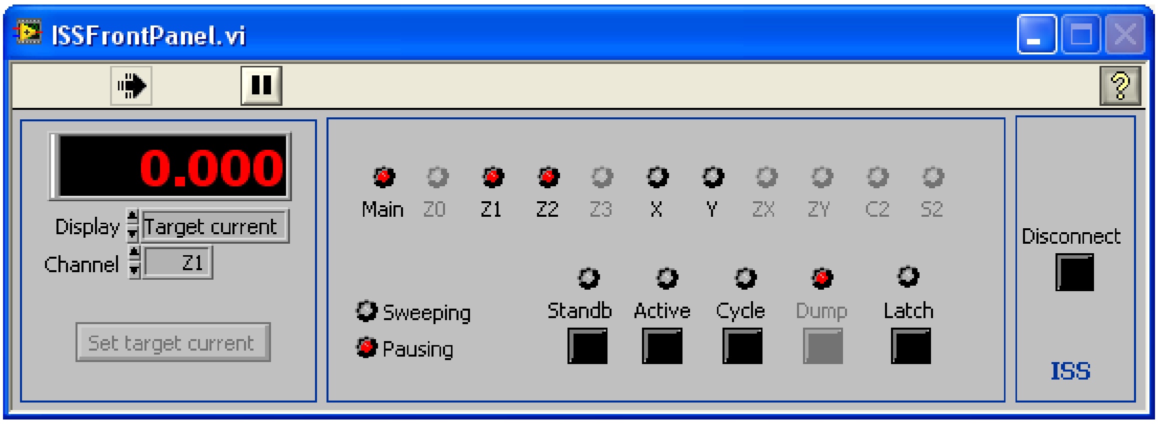
At the bottom of this page is the setting window for the ‘Fine’ flux density limit. This has a maximum range of 0.05 tesla.

6.2.2.3. The Advanced page

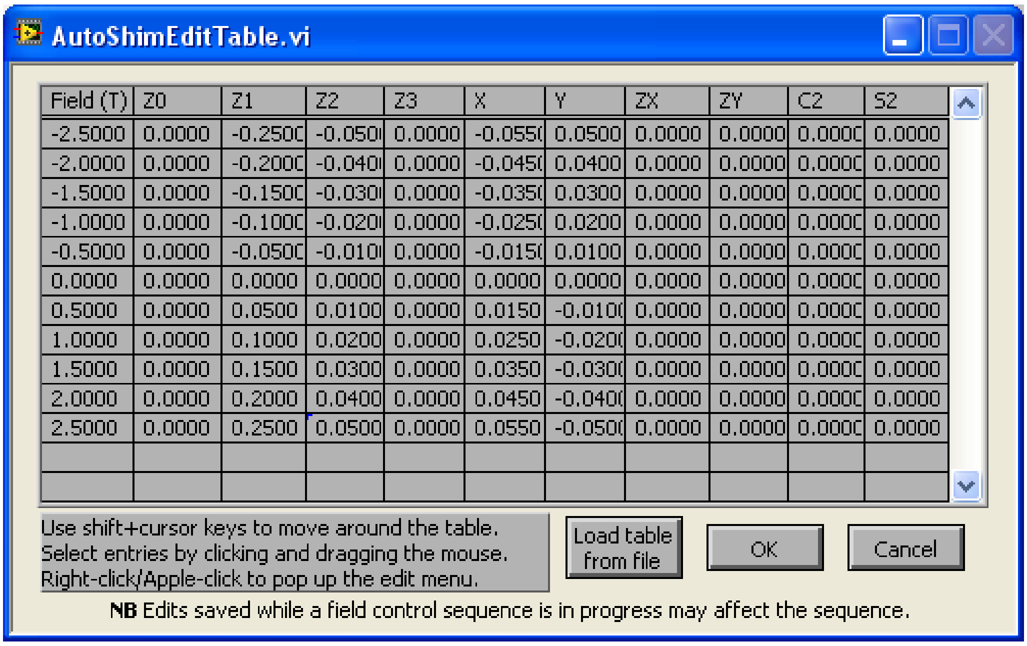
The advanced page shown below contains various buttons which in most cases show the various virtual instrument front panels. In the case of the upper panel buttons these display confirmation dialogs for the mode selected.



The following screen-shots show the instrument VI's as they are displayed

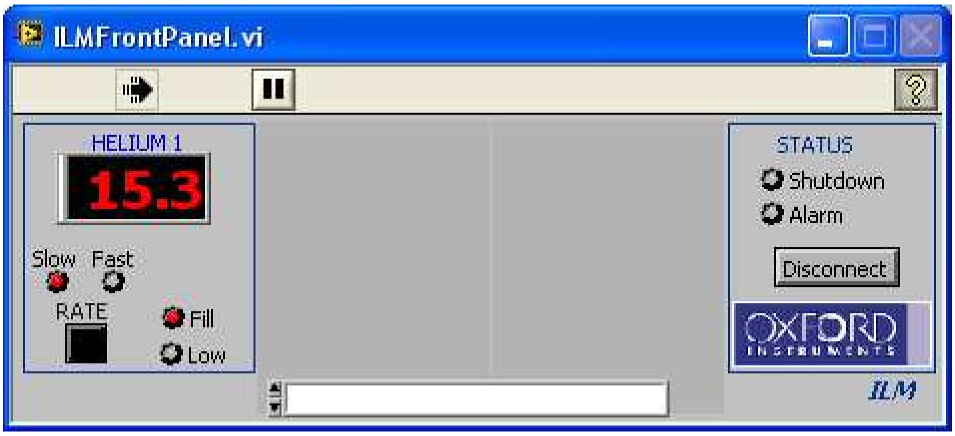


The ISS10 front panel VI

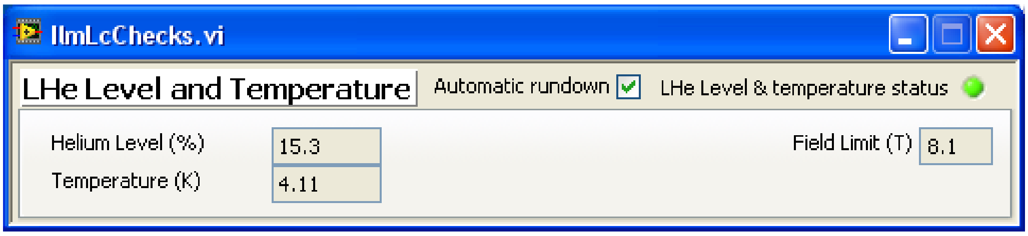


Field (T)	Z0	Z1	Z2	Z3	X	Y	ZX	ZY	C2	S2
-2.5000	0.0000	-0.250	-0.050	0.0000	-0.055	0.0500	0.0000	0.0000	0.000	0.0000
-2.0000	0.0000	-0.200	-0.040	0.0000	-0.045	0.0400	0.0000	0.0000	0.000	0.0000
-1.5000	0.0000	-0.150	-0.030	0.0000	-0.035	0.0300	0.0000	0.0000	0.000	0.0000
-1.0000	0.0000	-0.100	-0.020	0.0000	-0.025	0.0200	0.0000	0.0000	0.000	0.0000
-0.5000	0.0000	-0.050	-0.010	0.0000	-0.015	0.0100	0.0000	0.0000	0.000	0.0000
0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.000	0.0000
0.5000	0.0000	0.0500	0.0100	0.0000	0.0150	-0.010	0.0000	0.0000	0.000	0.0000
1.0000	0.0000	0.1000	0.0200	0.0000	0.0250	-0.020	0.0000	0.0000	0.000	0.0000
1.5000	0.0000	0.1500	0.0300	0.0000	0.0350	-0.030	0.0000	0.0000	0.000	0.0000
2.0000	0.0000	0.2000	0.0400	0.0000	0.0450	-0.040	0.0000	0.0000	0.000	0.0000
2.5000	0.0000	0.2500	0.0500	0.0000	0.0550	-0.050	0.0000	0.0000	0.000	0.0000

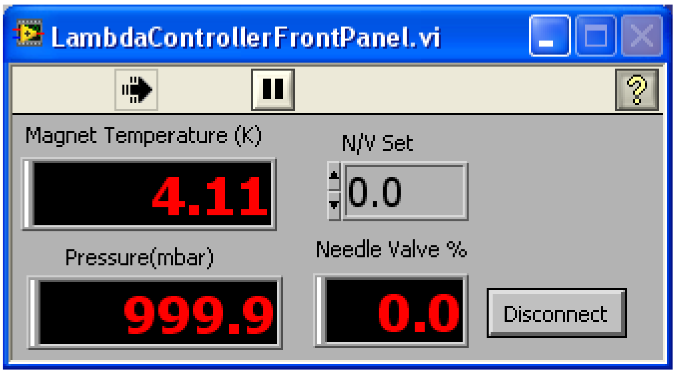
The Shim current edit table VI. Note the load table from file button which allows an externally prepared file in the correct (tab delimited) format to be imported.



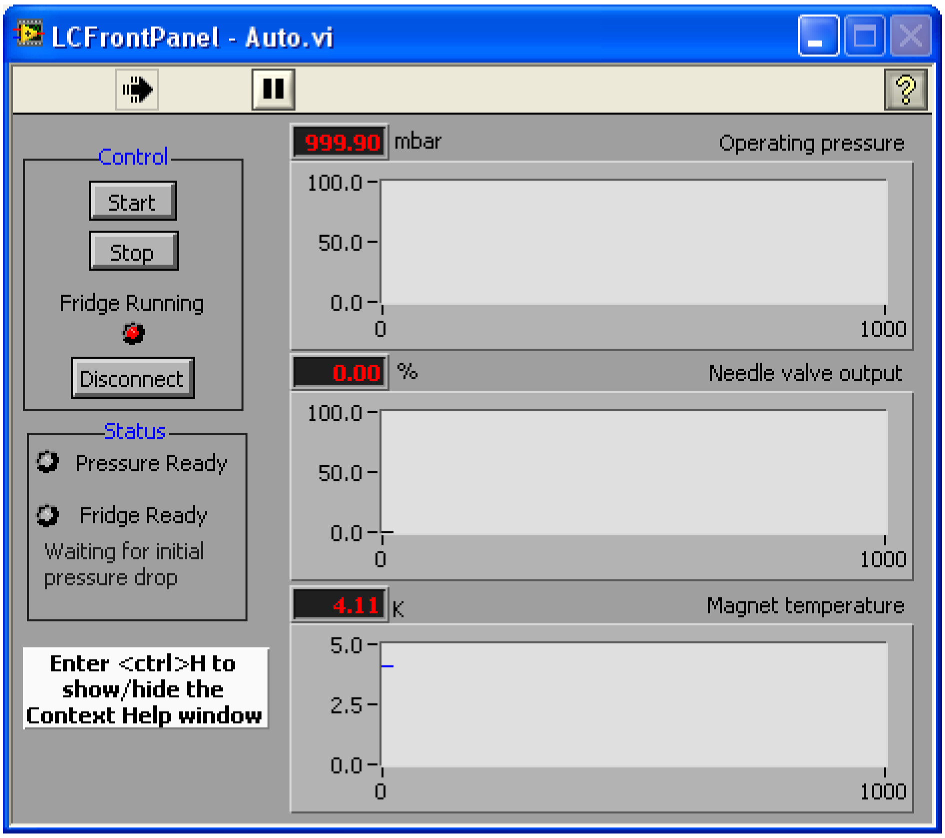
The ILM front panel VI



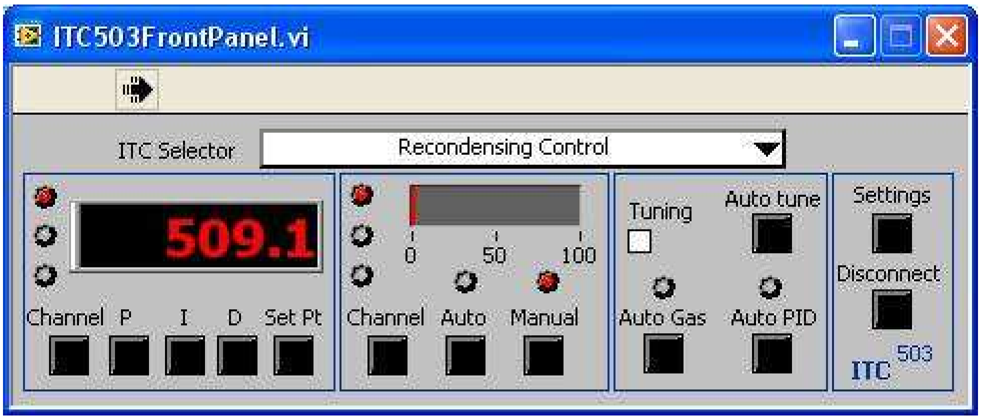
The Helium level and temperature VI. For setting the auto run-down helium level and temperature for reduced temperature / enhanced flux density operation together with the maximum 4.2 K flux density. Note that if the Automatic run-down box is unchecked the automatic run-down feature in the software will not operate however a dialog issuing a warning will be displayed. The hardwired auto run-down feature will still however operate providing the correct interconnections are used.



The manual lambda point refrigerator control VI. The automatic lambda point refrigerator control should be used as part of the automatic control process. This VI is included only to allow remote closing of the needle valve at the end of 2.2 K operation.



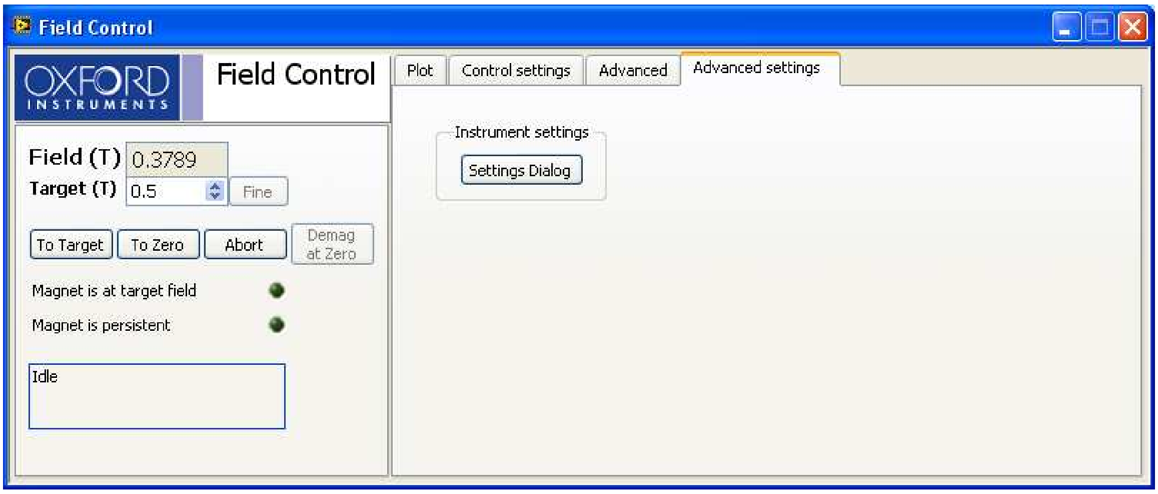
The automatic lambda point refrigerator control VI.



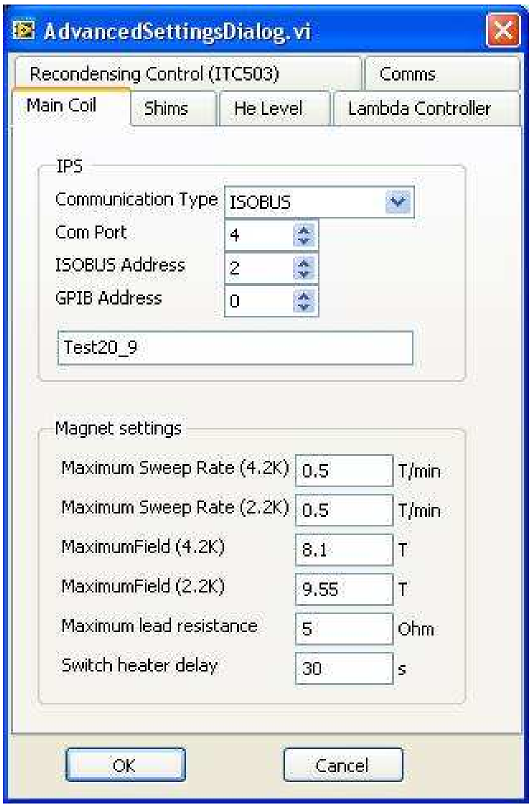
The Recondensing controller VI

6.2.2.4. The Advanced settings page

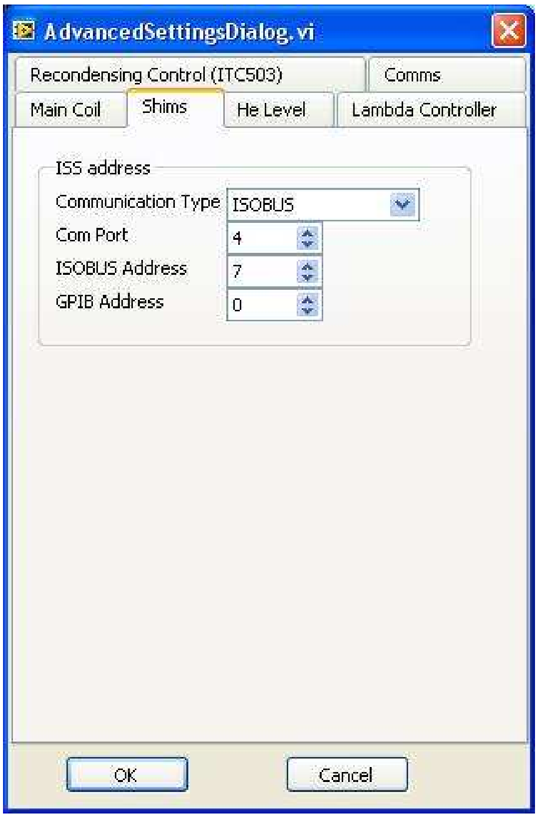
The advanced settings page is shown below and contains a single button which opens a tabbed page dialog for entering data related to various instrument and operating parameters.



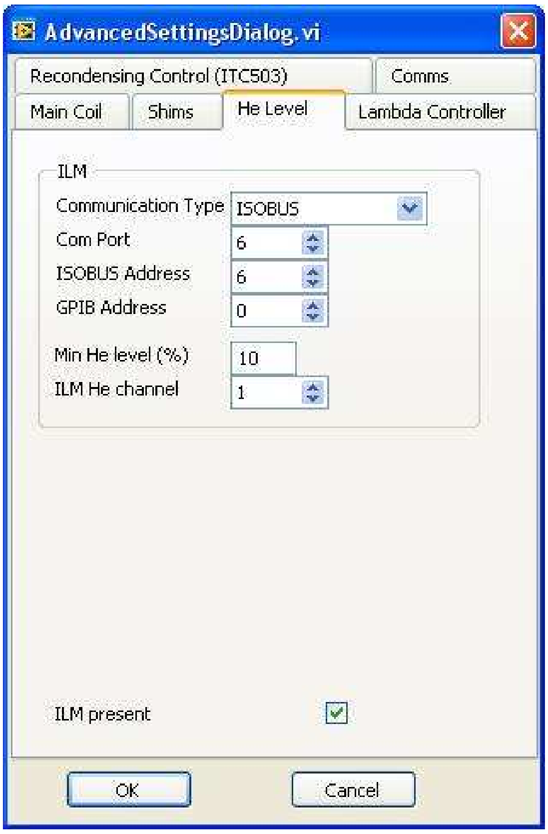
The screen shots below show the various tab pages that are available within this control.



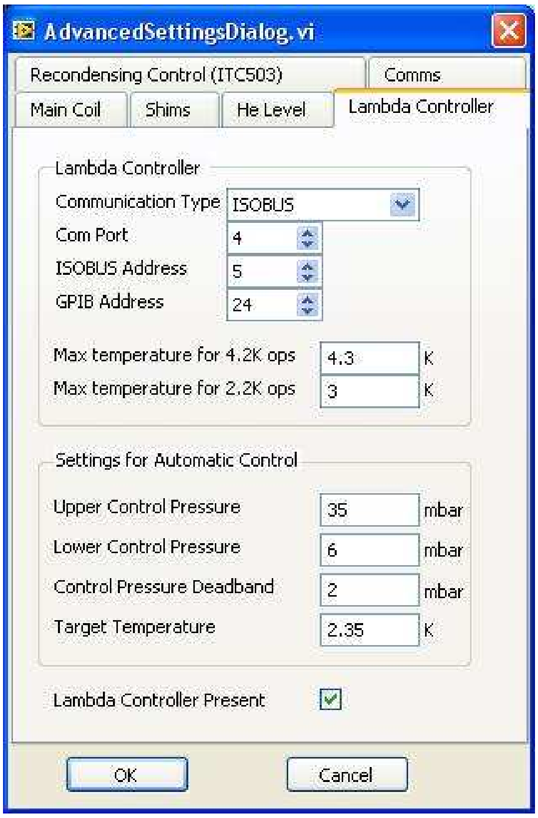
The Main Coil advanced settings page. This page is used to set the magnet operating limits and to configure the communications to the IPS120-10



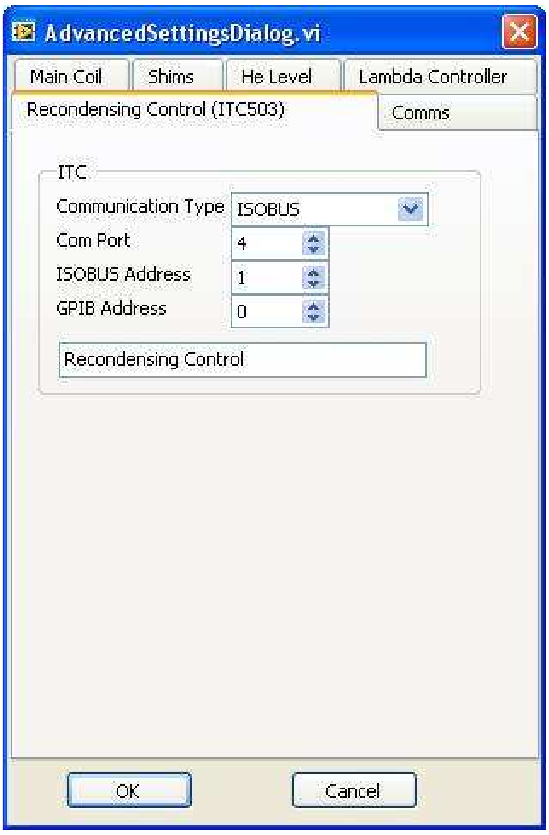
The Shims settings page. This page is used to configure the communications to the ISS10.



The He level meter settings page. This page is used to set up the minimum helium level (for the auto run-down function) and to configure the communications to the ILM210



The lambda point refrigerator page. This page is used to set the control parameters and configure the communications to the lambda point refrigerator controller.



The Recondensing controller (ITC503) page. This page is used to configure the communications to the recondensing controller

The Communications page. This page is used to run the search for and set up of instrument addresses.

6.2.3. Checking the system before operation

Before you run the magnet you should make the following electrical checks.

- Magnet and shim coil resistances
- Magnet and shim coil to cryostat isolation
- Switch heater resistances
- Switch heaters to cryostat isolation
- Magnet and shim coils to switch heaters isolation

Compare resistance values with the quoted values in the wiring section of the manual. Isolation values should typically be > 1 MΩ unless otherwise stated.

6.2.4. Preparing to run the magnet under automated control

Connect up the system as shown in the diagram on A11430 sheet 4 noting that the main switch heater supply from the IPS120-10 is routed to the system via the shim coil lead from the ISS10. This output is floating (isolated from ground) in order that it may be connected to the heater common connection from the ISS10.

Ground the cryostat effectively using the leads supplied (ground from the marked connection on the cryostat top plate to the earth studs on the power supplies) so that it cannot accidentally reach a dangerously high voltage in the event of a failure in the insulation if the magnet quenches

Warning: **Before you run the magnet make sure that you have taken the necessary steps to ensure your own safety and the safety of other people working around you. Refer to the booklet *Safety Matters*, which is included in the Safety section of this manual.**

Warning: **Do not disconnect the power supply from the magnet while it is at field unless your system is fitted with special demountable current leads. You may be putting your life at risk (because of the chance of an electric shock) and you may damage the magnet.**

Switch on the IPS120-10 and ISS10 power supplies and ensure that the software is communicating correctly (see the relavant sections in the software guide)

6.2.5. Running the magnet in automatic mode

6.2.5.1. Running the magnet to a required flux density

To run the magnet to a set point from zero or from any current value of flux density simply enter the target value into the appropriate field and click on the 'To target' button. The software will take all the steps required i.e. open the main switch, set the shim coil power supply into 'dump' mode, sweep to the set point, set the magnet into persistent mode using the demagnetisation parameters set then set and cycle the shim coils currents using data interpolated from the stored table.

6.2.5.2. Running the magnet to zero flux density

The magnet may be run to zero either by setting zero as the target value and click on the 'To target' button or simply click on the 'To zero' button.

6.2.5.3. Aborting a magnet sweep

If during a magnet sweep it is required to stop the operation simply click on the 'Abort' button. To set another flux density value or run to zero repeat the steps in 6.2.5.1 or 6.2.5.3. The software is able to determine the current conditions and start a new sweep when requested with minimum operations.

6.2.5.4. Fine flux density control

The magnet must be in persistent mode before the fine control mode may be used. This mode is entered by simply clicking on the 'Fine' button on the main' Field control' VI positioned next to the 'Target' field. A confirmation dialog is then displayed before then there is a delay as the magnet current is matched and the switch opened. The flux density may then be adjusted within the available range with the slider control shown (see section 6.2.2.1). Closing the control window sets the magnet in persistent mode at the newly adjusted flux density value with the 'Target' and 'Field' values updated.

6.2.5.5. Demagnetisation at zero flux density

This control is only available when the magnet is at zero flux density. Clicking on the 'Demag at Zero' button runs the sequence using the parameters set in the appropriate set-up dialog (see Control settings section 6.2.2.2)

6.2.6. Running the magnet in manual mode

Note: **Due to the complex nature of the control and interconnections of the power supplies used with this system manual control from either the instruments front panels or their virtual instruments is not recommended.**

6.3. Running the magnet at 2.2 K using a lambda point refrigerator

Warning: **Before you attempt to run the magnet to a higher field at a temperature below 4.2 K, check the specifications / test results to make sure that it was designed for this type of operation. If these results do not specify a current for a 2.2 K field and you expect to be able to run it to higher fields please contact Oxford Instruments for clarification before you proceed.**

6.3.1. Preparing the lambda point refrigerator

Connect the pumping system as shown in the assembly section of this manual (drawing A11477). As this system operates in recondensing mode the exhaust gas from the pump is circulated via filters and a cold trap to the top of the refrigerator neck which is in turn connected to the main reservoir exhaust manifold. The main exhaust is fitted with aball valve with a low pressure bypass valve in parallel. During the initial phases of the cool-down from 4.2 to 2.2 K the ball valve should be open to provide a low impedance pathway for the exhausting gas

6.3.2. Preparing the magnet

The operation of the lambda point refrigerator will be most efficient if the magnet is run to its 4.2 K field and put into persistent mode as described in "Running the magnet at 4.2 K". If the magnet is in this state the heat load on the helium reservoir is minimised.

6.3.3. Running the lambda point refrigerator manually

Note: **Operation in this mode is not recommended.**

6.3.4. Running the lambda point refrigerator automatically

The Automatic Lambda controller shown in section 6.2.2.3 above helps you to monitor and control the lambda point refrigerator economically and automatically. The operating parameters are set via the main VI under 'Advanced settings' on the 'lambda point refrigerator page'. The automatic control system will check the helium level and ensure that the magnet is cold enough to operate at the required field. If necessary it will sweep the magnet down to a safe field automatically.

As the system is intended to be recondensing when the magnet is in static mode (persistent) it is important to keep the lambda point refrigerator throughput low enough for complete recondensation of all evolving gas to take place. To ensure that this condition is met the target control temperature is set to > 2.2 K (typically 2.35 K) as this reduces the required throughput. The thermal margin of the magnet is large so a higher than normal temperature may be used. In fact the margin is such that the magnet operates satisfactorily during sweeping in this mode when the temperature rises to > 3 K.

6.3.5. Running the magnet to its 2.2 K field

When the magnet is at a stable temperature and you are confident that you understand the operation of the lambda point refrigerator you can run it above its 4.2 K field.

Operation of the magnet in this mode is exactly the same as at 4.2 K as described in section 6.2.5.

When the magnet is in persistent mode the ball valve in the exhaust path from the main reservoir should be closed to help maintain a clean environment. As the helium throughput falls the recondensing power available will tend to reduce the pressure in the reservoir and the recondensing controller will try to maintain a positive pressure by imputing heat via the control heaters. The control pressure, under normal static conditions, will be below the setting of the relief valve in parallel with the ball valve. In this mode the system is effectively closed with all the evaporating and lambda point refrigerator gas being recondensed to liquid.

6.3.6. Closing down the lambda point refrigerator

When you have finished running the magnet above its 4.2 K field, (and if you do not intend to run it above this field again for a long time), you can close down the lambda point refrigerator by closing the needle valve. This operation can only be performed by running the manual lambda point refrigerator control VI and setting the needle valve to zero. The magnet is likely to stay below 4.2 K for a long time (perhaps one or two days for a large system). This does not affect normal operation up to the 4.2 K field.

6.4. Leaving the system unattended

6.4.1. Running the system unattended

If you plan to leave the system to run unattended you must take the following precautions. Remember that it is your responsibility to make sure that no one is put into danger by the system. Read and learn the contents of the Safety section of this manual and take appropriate actions.

- Erect suitable warning signs to prevent tampering by other people
- Try to make sure that only competent people have access to the system
- Make sure that there are sufficient cryogens in the system
- Arrange for the cryogens to be re-filled if necessary
- Connect the exhaust of the helium reservoir to a recovery system or fit an appropriate one way valve to prevent air or moisture from entering
- Make sure that the system can vent safely, even if it is accidentally warmed up or pumps stop running unexpectedly
- Leave a telephone number so that you can be contacted in an emergency
- Make sure that there is sufficient ventilation in the laboratory to avoid a potential asphyxiation hazard when you return

If there are any closed volumes that are pumped during normal operation make sure that they are free to vent either into the cryostat reservoirs or through the pumping line. If there are valves in the pumping line and on the inlet to these volumes make sure that you do not leave them both closed.

6.4.2. Leaving the system static

If you are not using the system for a few days (for example over the weekend) it is often possible to close it down and leave it in a static condition. This could save liquid helium or reduce some of the potential hazards associated with the system. To leave a typical system in static mode:

- De-energise the superconducting magnet
- Close down the lambda point refrigerator (if one is fitted) and vent it safely
- Close down any variable temperature insert, Heliox insert or Kelvinox insert

In this system the recondensing function ensures that the system can remain in static operation indefinitely .

6.5. Re-filling the liquid helium

When the liquid helium level drops close to the minimum working level you should carefully re-fill it. When you refill the liquid helium you should take care to pre-cool the transfer tube thoroughly before you put it into the system. Otherwise the warm gas passing through the tube will evaporate liquid in the helium reservoir. The booklet *Practical Cryogenics* contains a list of practical solutions to the problems commonly encountered in liquid helium transfers.

Important Note: This describes the easiest method of transferring liquid into a cold system for beginners. However, some laboratories have strict rules about recovering all helium gas. If you have a helium recovery system ask the administrator to show you the preferred method of transferring helium.

Caution: If your system contains a superconducting magnet:

- Make sure that the liquid helium level does not drop below the minimum level shown on the drawing while it is energised.
- Run down the magnet, if in doubt
- Beware of the stray magnetic field while you are working close to the cryostat.

Some transfer tubes are supplied with special fittings for refilling the liquid helium. These fittings are screwed onto the end of the transfer tube and divert the gas and liquid from the transfer tube up and away from the liquid surface. The gas passes out of the cryostat and the heavier liquid falls into the reservoir.

Important Note: **Before starting a refill procedure ensure that the recondensing control is operating correctly and that a positive pressure exists within the helium reservoir.**

6.5.1. Pre-cooling the transfer tube (or siphon)

Prepare the storage dewar and transfer tube as described in the section about "Cooling systems to 4.2K". Insert one leg of the transfer tube into the helium storage vessel, but leave the other leg outside the cryostat. Unscrew the cryostat 'siphon entry' fittings (the O-ring and the knurled nut) and slide it onto the leg of the transfer tube which will go into the cryostat. Put the bung loosely in the transfer tube entry port on the system to prevent gross contamination with air. Pressurise the transport dewar slightly, in the normal way. After about 20 seconds you should hear oscillations in the tube, gradually increasing in frequency and intensity. When these stop you should see white vapour and when liquid starts to emerge you may see a white cone (like a gas flame).

6.5.2. Transferring the liquid helium

If you have a rigid transfer tube quickly release the pressure in the transport dewar, lift the transfer tube and insert the open end into the cryostat. If you have a transfer tube with a flexible section it is easy to do this without releasing the pressure or moving the leg in the storage dewar.

Push the transfer tube into the system to approximately the maximum helium level. Do not push it to the bottom of the helium reservoir or into the siphon cone (if there is one on your system).

Caution: Do not push the transfer tube below the maximum helium level if you have a superconducting magnet in the system. You may quench the magnet.

Quickly increase the pressure in the storage dewar again. It is most efficient to transfer the liquid quickly to reduce the losses in the transfer tube. However, 200 mbar is usually sufficient pressure to do this.

Note: The reading on the helium level probe may be affected when using the siphon entry on the cryostat to top up with helium. For best results use the siphon entry on the insert (if fitted)

Note: Make sure that pressure readings of the pressure control system are sensible as the gauge may give false readings (usually off scale) when overcooled during fast He transfer. At this stage of the system operation it is recommended to adjust the pressure control set point to -50 mbarg or to put the control system into manual mode with 0V heater output and to open the ball valve to accommodate the high gas flow rate at the start of the refilling process.

7. Warming up the system

7.1. Preparations

Before you start to warm up the system you must make sure that it is safe. The Safety section of this manual gives some guidelines.

Make sure that there are no trapped volumes of liquid, gas or condensed solids inside the system. You may not know that they are there if they have accidentally been condensed into the system while it has been cold. Therefore you must make sure that all closed volumes are free to vent or that they are pumped continuously as the system warms up.

Close down any other parts of the system. In particular if your system contains any of the following items prepare them properly.

- Superconducting magnets must be de-energised
- Pulse tube refrigerator must be stopped (refer to manufacturer's instructions)
- Lambda point refrigerators must be closed down and pumped out (and pumped continuously during warm-up) or vented to the main helium reservoir
- Variable temperature inserts, Heliox inserts or Kelvinox inserts must be closed down and vented (or pumped continuously during warm-up)

7.2. Allowing the system to warm naturally

When you have prepared the system you can leave it to warm up naturally. When the cryogens have all evaporated the system will warm slowly to room temperature. If you do not need to use it again soon this is the easiest way to warm the system up.

7.3. Warming the system quickly

If you want to warm up the system more quickly you have to blow out the cryogens and break the insulating vacuum in the outer vacuum chamber.

The liquid helium can be blown out of the system either into a storage vessel for use elsewhere or into a helium gas recovery system. The system will then begin to warm up.

8. Background information

8.1. Making indium seals

Oxford Instruments uses two main types of indium seal, as illustrated in the diagram below. They both use 1mm diameter wire, retained

- Either in a groove by a flat surface
- Or in a corner between two flanges

In both cases, the indium wire is overlapped by bending one end of the wire sharply outwards and laying the other end across the corner of the bend. The wire is so soft that the joint will be compressed into a cold weld.

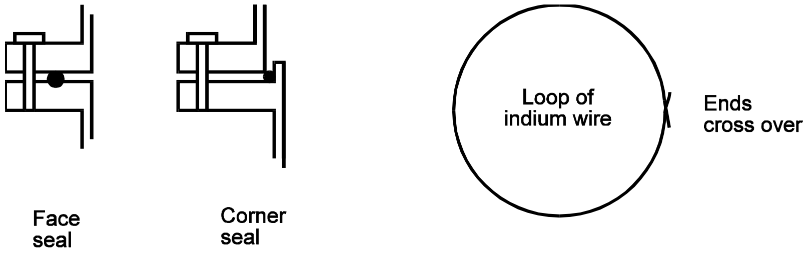


Figure 3 Indium seals

8.1.1. Preparations

Before you make the seal ensure that the groove and the mating surfaces are clean. Thoroughly remove any old indium wire from the seal faces. If necessary a solvent can be used for cleaning. Some people like to grease the metal surfaces with silicone vacuum grease to make it easier to remove the wire later, but this is not necessary.

8.1.2. Making the seal

Lay a new piece of indium wire in the groove or round the male spigot on one of the flanges and overlap it as shown on the diagram. There are usually alignment marks on the flanges to indicate the correct orientation. Carefully bring the two flanges together and hold them loosely in place with two bolts while you put the other bolts into the flanges and tighten them by finger only. Slowly and evenly tighten all of the bolts with a small spanner (wrench) or Allen key. Do not tighten them too much. There is no need to use an extension on the tool to give extra leverage. On large seals (typically > 50mm diameter) it is then best to leave them for about an hour. The indium flows slightly during this period so it is often possible to tighten the bolts slightly more.

8.1.3. Separating indium seal flanges

It is often difficult to separate indium seal flanges because the indium metal seems to glue them together. Most large indium seals made by Oxford Instruments have two or more threaded holes in one of the flanges for 'jacking screws'.

Remove the bolts that hold the indium seal together (leaving two of the bolts loosely in place so that the flanges do not fall apart when they separate). Use another two of these bolts to jack the flanges apart by screwing them evenly into the jacking screw holes from the same side of the flange. This will push the flanges apart.

If there are no jacking screw holes (as often happens on small diameter indium seals), the flanges can be separated by inserting a sharp blade between the flanges. Make sure that the blade does not slip and cut you as the flanges separate.

8.2. Emergency run down procedure for magnets

If it is not possible to run the magnet down conventionally using the magnet power supply it is possible to do it safely by dumping the energy into a pair of high power diodes. This might be necessary:

- If you cannot remember the polarity of the current in the magnet when it is in persistent mode
- If you cannot remember the current in the magnet when it is in persistent mode
- If no power supply is available

Warning: Never touch the current lead terminals while the magnet is at field. The protection circuit is built to prevent the development of high voltages in the event of a magnet quench, but it is not good practice to rely on it.

Choose a pair of high power diodes capable of carrying the full operating current of the magnet and fix them to an adequate heat sink. Remember that the magnet stores a very large amount of energy so the heat sink must be well cooled. Connect a pair of diodes across the terminals as shown in the figures below. Activate the switch heater using either the power supply or a separate 6 volt battery. The switch heater current required is given in the test results section of this manual. The magnet will run down at a rate determined by the forward voltage drop of one of the diodes. The de-energisation will be slow, (for example, typically about 100 minutes using silicon diodes). Do not disconnect the diodes before the magnet is completely de-energised.

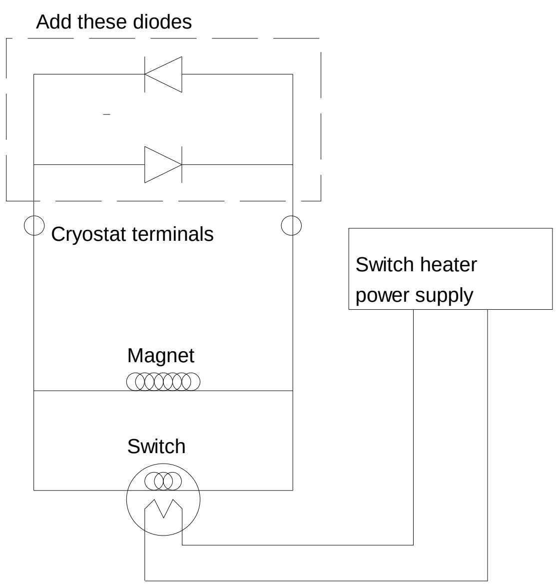


Figure 4 Emergency de-energisation circuit diagram

8.3. Cryostat fault finding

Symptom	Possible cause	Solutions
Poor vacuum in OVC	Leak on pumping system	Close the cryostat OVC valve and check pumping system base pressure.
	Leak on cryostat	Obtain a mass spectrometer leak detector and identify the source of the leak. The booklet *Practical Cryogenics* gives advice on this subject.
	Excessive moisture in OVC	Pump and flush the OVC with dry nitrogen several times, then pump to high vacuum again.
High helium boil off	Poor vacuum in OVC	See above.
	Refrigerator not working correctly	Check that the compressor is still running and that the gas pressure is correct (>20 bar high pressure). If the compressor pressure is low contact Oxford Instruments to replenish the gas charge (99.999% helium only to be used).
	Compressor is not running and its gas pressure is below normal	Contact Oxford Instruments to replenish the gas charge before restarting.
	Compressor is not running, and its gas pressure is normal	Check that the mains supply to the compressor is present and correct
		Check that the water supply (if needed) to the compressor is flowing at an adequate rate, and that the inlet temperature is suitable.
		Switch off the compressor. Check that the compressor system cut outs are reset. Switch on the compressor. If the compressor does not start contact Oxford Instruments.
	If the compressor runs for a short period and then cuts out.	Contact Oxford Instruments.

Symptom	Possible cause	Solutions
High helium boil off (cont'd)	Compressor running at the correct pressures, but the system boil off does not come within specification	Contact Oxford Instruments.
	Helium gas leak on turret/manifold, faulty 1 p.s.i. valve or leak through quench valve.	Investigate and restore leak tightness.
Condensation or frost on the OVC when the system is cooled down	Poor vacuum in the OVC	Pump the OVC again. Check with a mass spectrometer leak detector for leaks including leaks from the helium reservoir.
Transfer tube gets frosty	Poor transfer tube vacuum	Pump its vacuum space to high vacuum again.
Transfer tube shows ice "spots"	Internal capillary touches outer tube	If the transfer tube is still under warranty and it has not been damaged contact us for a replacement. Otherwise consider replacing the transfer tube if the liquid helium consumption is unacceptably high.
Difficulties transferring liquid helium into the system.		See the chapter on this subject in the booklet *Practical Cryogenics.*

8.4. Preventive maintenance and background information for refrigeration system

8.4.1. Helium vessel pressure

Regularly check the pressure reading indicated on the recondensing controller and the heater output voltage. If low pressure is indicated and/or if the heater is at a full power, the venting should be inspected for a leak. However, it should be noted that under certain atmospheric pressure conditions the pressure within the helium vessel will drop.

8.4.2. Compressor pressure

Record the refrigeration compressor pressure and check that it is stable from week to week. If a drop of more than 2 bar is seen, contact Oxford Instruments. However it should be noted that the low gas volumes in the compressor/cold head mean that the pressure is significantly affected by the ambient temperature. The quoted nominal fill pressures are all based on an ambient temperature of 20°C, but any deviation from this can produce large variations.

This potentially large deviation should be remembered when investigating any sudden reduction in pressure which could also be interpreted as a gas leak in the system. Also if it is anticipated that the ambient temperature will rise above 20°C the pressure should be adjusted accordingly to ensure that the recommended pressures are maintained and the maximum pressure is not exceeded.

8.4.3. Refrigerator maintenance

The refrigerator cold head and compressor require regular maintenance as detailed in the manufacturers operating guide. Refrigerator maintenance must be carried out by Oxford and refrigerator trained personnel only. The system warranty will be invalidated by unauthorised adjustment.

8.5. Helium recovery systems

Helium gas recovery systems are often used to collect the exhaust gas from cryostats. They are useful for the following reasons:

- To allow the gas to be liquefied and recycled
- To collect gas for other uses (for example vacuum leak detection)
- To prevent air from entering and contaminating the cryostat
- To conserve the Earth's helium supply.

A typical recovery system consists of a low pressure gas collector, a compressor and high pressure gas cylinders to store the gas. Many different cryostats are usually connected to a central low pressure gas collector. The recovery system typically has non-return valves at strategic points to make sure that the cryostats do not interact, and the system operates slightly above atmospheric pressure to reduce the risk of contaminating the gas if there is an air leak. The compressor should be specifically chosen for use with helium because a large amount of heat is generated when it is compressed.

Many factors affect the financial implications of building and using a helium recovery system. In particular it is important to consider:

- The cost of liquid helium in your laboratory
- The cost of installing and running a recovery system and liquefier

If you do use a recovery system you should take precautions to make sure that you recover as much gas as possible and avoid contaminating the gas with air or other substances.

8.6. Useful reference books

The following books may be found useful as background reading.

Experimental Techniques in Low Temperature Physics,
by G.K.White, Oxford University Press, ISBN 0-19-851381-X

Experimental Principles and Methods below 1 K,
by O.V.Lounasmaa, Academic Press, ISBN 0-12-455950-6

Low Temperature Laboratory Techniques,
by A.C.Rose-Innes,
London: English Universities Press, ISBN 0-34004778-X
(Probably out of print, but worth looking in the library).

Properties of Materials at Low Temperature, A Compendium.
General Editor Victor J. Johnson, National Bureau of Standards.
Pergamon Press, 1961.

Vacuum Technology its Foundations Formulae and Tables
Leybold Heraeus GMBH.

Superconducting Magnets
Martin N. Wilson,
Clarendon Press, Oxford, 1983, ISBN 0-19-854805-2.

Eleménts de Cryogénie,
R.R. Conte (in French).
Masson & Co, Paris, 1970. (Probably out of print, but very useful).

Experimental Techniques in Condensed Matter Physics at Low Temperatures.
Robert C Richardson and Eric N Smith,
Addison Wesley Publishing Company Inc, 1988, ISBN 0-201-15002-6

Matter and Methods at Low Temperatures
Frank Pobell,
Springer Verlag, 1992, ISBN 0 540 53751 1 and 0 387 53751-1

Practical Cryogenics
An Introduction to Laboratory Cryogenics.
N.H.Balshaw, Oxford Instruments Ltd, 1996.

Introduction to Thermometry below 1 K
(A review of the available techniques)
Oxford Instruments Ltd., Ultra Low Temperature Group, 1990.

9. Drawings

The following drawings are included. Some of these drawings have been folded so that you can see them while you are reading text elsewhere in the manual.

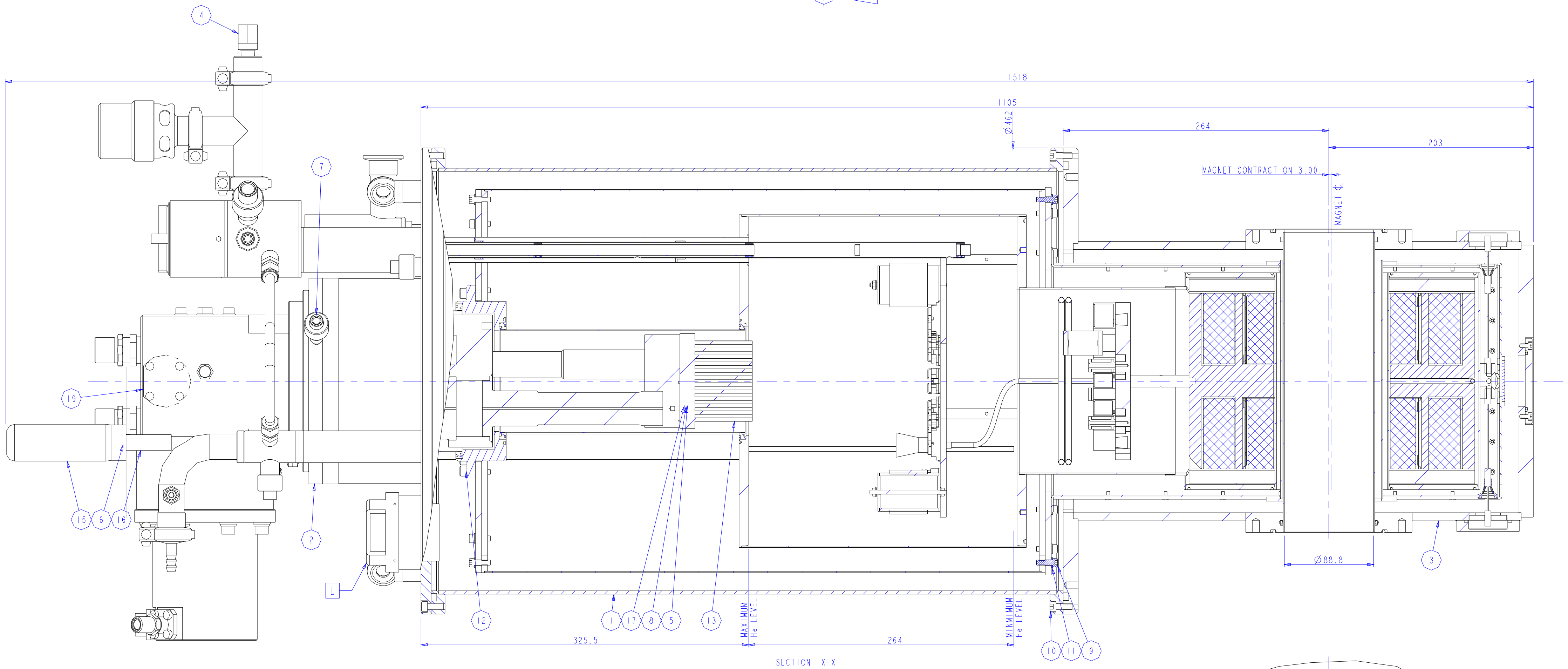
General assembly drawing of the system	A11430
Lambda point refrigerator pumping and re-condensing circuit	A11477
Transit fitting	P13015
Magnet protection circuit	No user serviceable parts

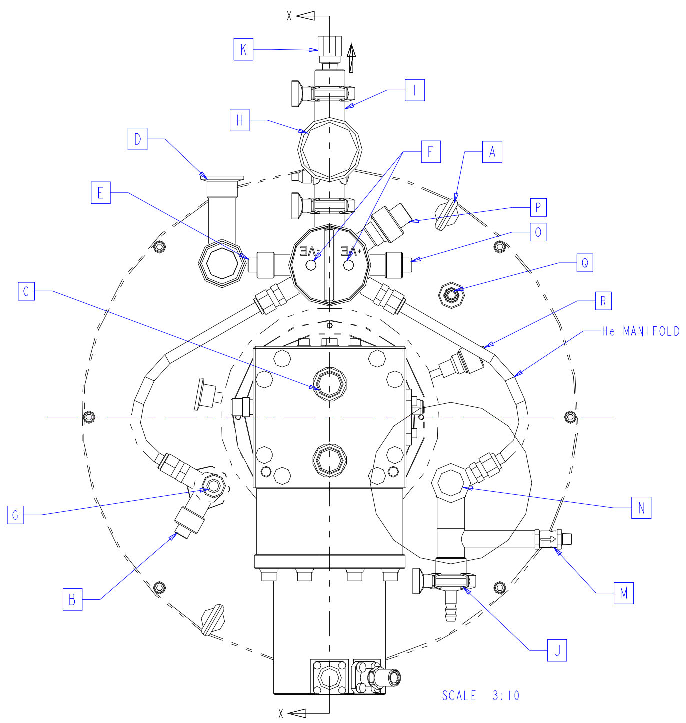
In-Field Failure Form (IFF) (for use if you have to return any equipment to the factory).

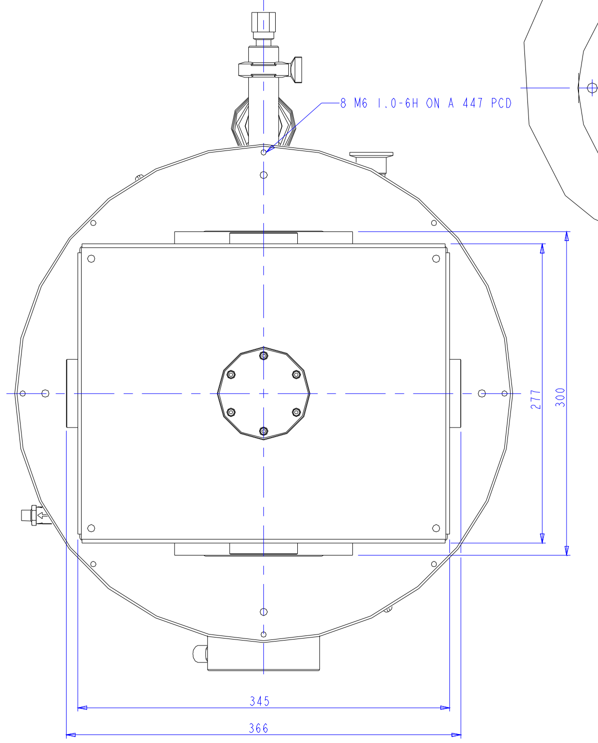
A1 ORIGINAL SIZE

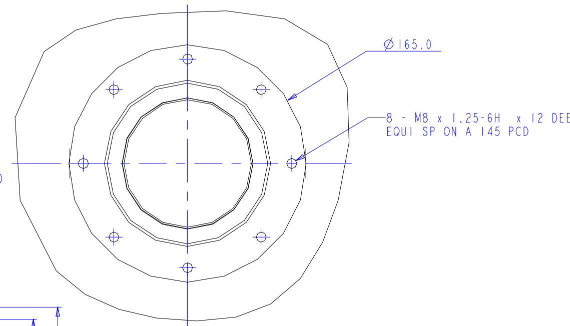
THIRD ANGLE PROJECTION

Model Version 0+









HELIUM LEVEL PROBE WIRING B		
PIN	WIRE	FUNCTION
1	41 swg CU	PROBE I+
2	41 swg CU	PROBE V+
3	41 swg CU	PROBE V-
4	41 swg CU	PROBE I-

NEEDLE VALVE WIRING Q		
PIN	WIRE	FUNCTION
1		
2		
3		
4		
5		
6		
7		
8		
9	36 swg CU	68ohm N/V HEATER
10	36 swg CU	68ohm N/V HEATER

MAGNET WIRING E		
PIN	WIRE	FUNCTION
1	36 swg CONST	LINK TO PIN 3
2	36 swg CONST	LINK TO PIN 6
3	36 swg CONST	COMMON
4	36 swg CONST	A/B 10cm ABOVE LPF
5	36 swg CONST	A/B ON LPF
6	36 swg CONST	A/B ON MAG TOP
7	36 swg CONST	A/B ON MAG BOTTOM
8	28 swg CONST	SWITCH HEATER SPARE
9	28 swg CONST	SWITCH HEATER MAIN
10	28 swg CONST	SWITCH HEATER COMMON

	SPECTROMAG LEGEND	SIZE
A	CRYOSTAT LIFTING EYE BOLTS - 2 OFF	M12
B	WIRING FOR HELIUM LEVEL PROBE	4 PIN
C	SUMITOMO COLD HEAD	
D	OVC VACUUM PUMPING PORT	NW 25
E	MAGNET SWITCH & A/B WIRING	10 PIN
F	120amp CO-AX CURRENT LEAD	
G	SYPHON ENTRY	Ø9.5
H	QUENCH VALVE	NW 25
I	HELIUM RECOVERY PORT	NW 25
J	LPF PUMPING LINE	
K	ONE WAY VALVE	NW 25
L	OVC OVER PRESSURE VALVE	
M	LPF RELIEF VALVE	
N	LPF AUTO NEEDLE VALVE	7 PIN
O	SHIM CURRENT LEADS 105 FISCHER (RED)	10 PIN
P	SHIM SWITCHES 103 FISCHER (GREEN)	10 PIN
Q	NEEDLE VALVE HEATER	10 PIN
R	COLD HEAD 2ND STAGE SENSOR	10 PIN

VESSEL VOLUMES	
OUTER VACUUM CAN	41L
HELIUM CAN (4He)	26L
USEFUL LIQUID HELIUM	22L

LIQUID HELIUM LEVEL PROBE LENGTHS	
OVERALL	732mm
ACTIVE	261mm

TRANSFER TUBE DELIVERY LEG LENGTH	
OVERALL	800mm

MAGNET SPECIFICATION	
1st FIELD (4.2K)	8.0T AT 4.2K
2nd FIELD (2.2K)	9.5T AT 2.2K
COLD BORE COLD SPLIT	Ø 116
HOMOGENEITY	0.1 mT OVER Ø 10mm x 4mm Lng
PERSISTANCE	0.01 mT / HOUR
CURRENT (AMPS)	100 AMPS

HEIGHT REQUIREMENTS	
MINIMUM HEIGHT REQUIRED TO REMOVE SERVICES FROM CRYOSTAT EXCLUDING WINCH:	
TRANSFER TUBE	2.4m

DRAWING APPROVAL	
PROJECT NUMBER	39370
PROJECT NAME	SCHEUERMANN
CUSTOMER SIGNATURE	N/A
DATE	N/A

APPROX WEIGHT OF SYSTEM EXCLUDING CRYOGENS : 250KG

Item	Part No	Description	Length	Qty.	REMARKS
21	Z10291	PLOTTING JIG PARTS		1	
20	Z10290	JIGS 39370 SCHEURMAN		1	
19	VPZ0432	SUMITOMO PT-RP-082B + COMP 400V		1	
18	RZS0049_B	AUSTRAIN AERO BLNKET ROLL 1.5M		1	
17	PRZ0005	270OHM X 0.125W A/B TEMP SENSOR		1	
16	PRP23332	NEEDLE VALVE SUPP SLEEVE		1	
15	PRA0598	AUTO NEEDLE VALVE ASSEMBLY		1	
14	P13046	LPF SUPPORT BRACKET		1	
13	P12894	2ND STAGE HEAT EXCHANGER		1	
12	FSW0005	WASHER ST M06.0		16	
11	FSW0004	WASHER ST M05.0		16	
10	FSS0020	SCREW A4ST CAP M06.0 X 016 SET		24	
9	FSS0015	SCREW A4ST CAP M05.0 X 016		16	
8	FBS0089	SCREW BR CHSE M03.0 X 006 SET		1	
7	EPF3110	FISCHER 10 PIN DBEE1031Z		2	
6	DCZ0164	NEEDLE VALVE MK2 TOP ASSY		1	
5	DCZ0007	ALLEN BRADLEY CLAMP (L)		1	
4	A80731	NW25 FLG - R/VALVE 1PSI ASSY		1	
3	A11475	RECON TAIL SET (MD20)		1	
2	A11474	FISCHER TOP RING		1	
1	A11435	RECON MD20 ASSY TOP		1	

DO NOT SCALE IF IN DOUBT ASK

REMOVE ALL BURRS AND SHARP EDGES

TOLERANCES UNLESS STATED FOR:	
MACHINING	ASSEMBLY
X ± 0.5mm X.X ± 0.3mm X.XX ± 0.1mm ANGLE ± 0°15′	LINEAR ± 1mm ANGULAR ± 1°

SURFACE FINISH - UNLESS STATED
mm UNLESS STATED

DESCRIPTION: **SYSTEM GA 39370 SCHEUERMANN**

SCALE	DATE	DRAWN	RELEASE LEVEL		DRAWING NUMBER	REV
2:5	12-May-10	M.Wilkinson	Production	ONLY MANUFACTURE DRAWINGS WHEN RELEASE LEVEL IS SET TO "PRODUCTION"	A11430	01

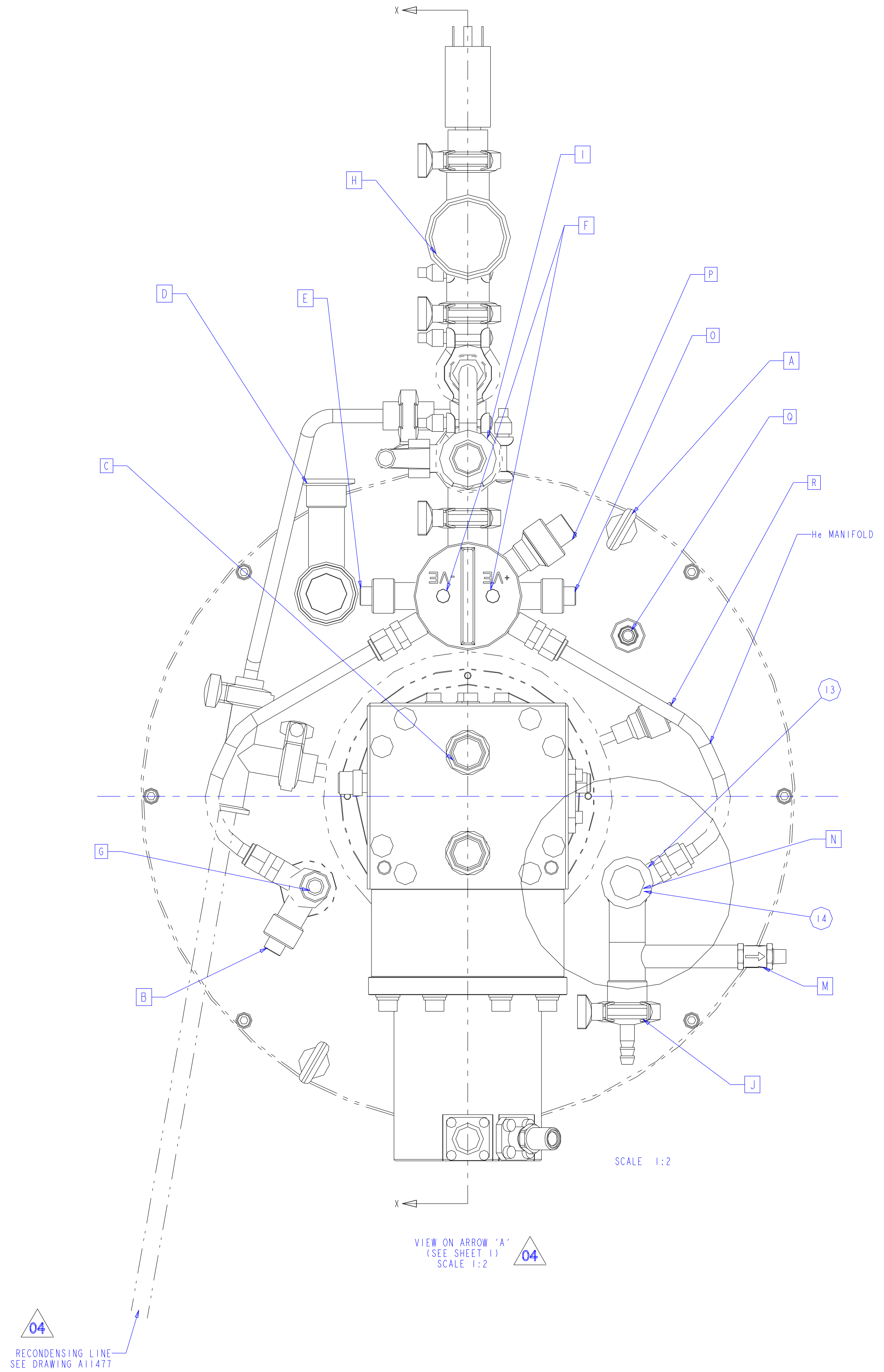
SHEET 1 OF 3

OXFORD INSTRUMENTS

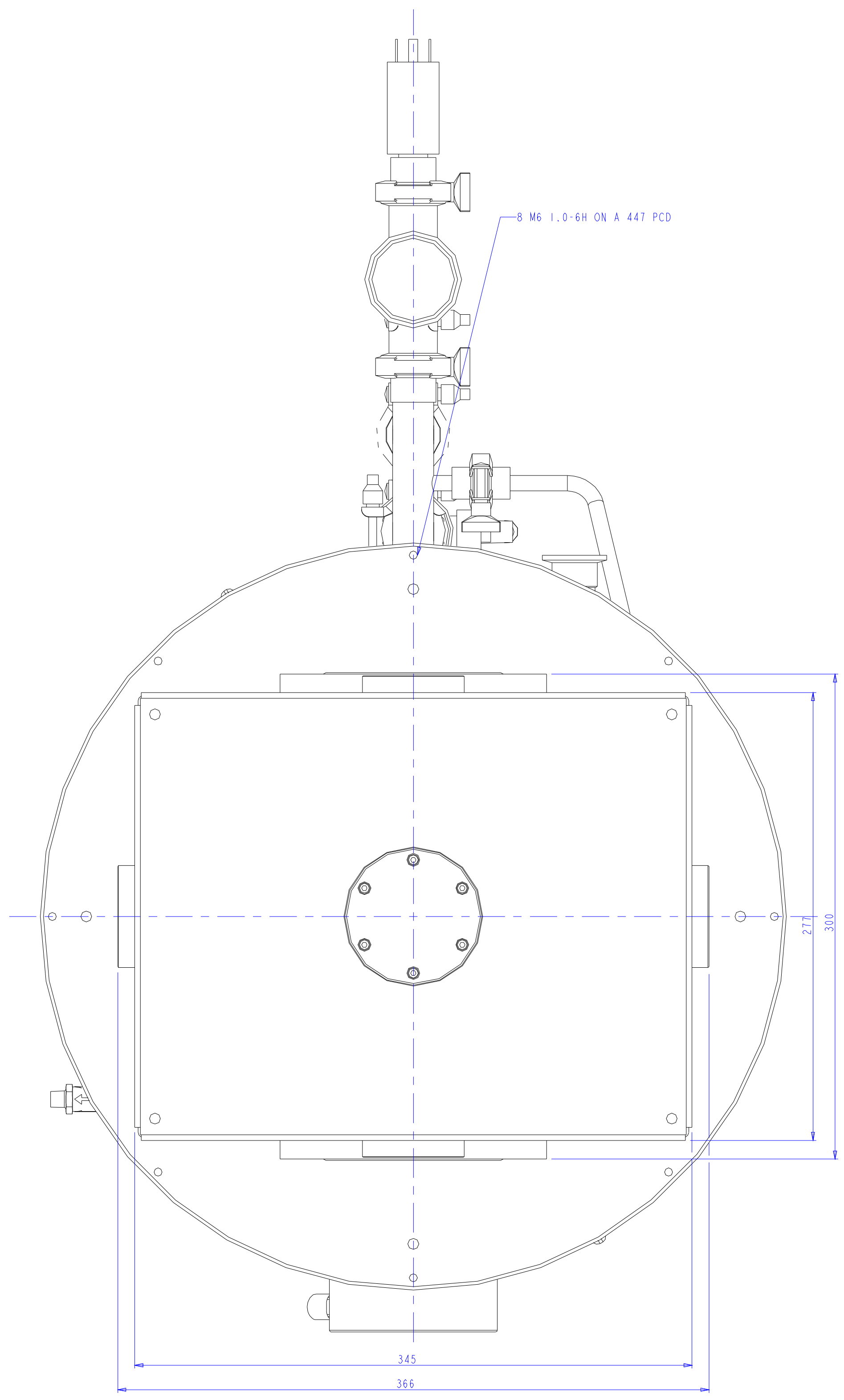
A1 ORIGINAL SIZE

THIRD ANGLE PROJECTION

Model Version 6*



VIEW ON ARROW 'A'
(SEE SHEET 1)
SCALE 1:2
04



VIEW ON ARROW 'B'
(SEE SHEET 1)
SCALE 1:2
04

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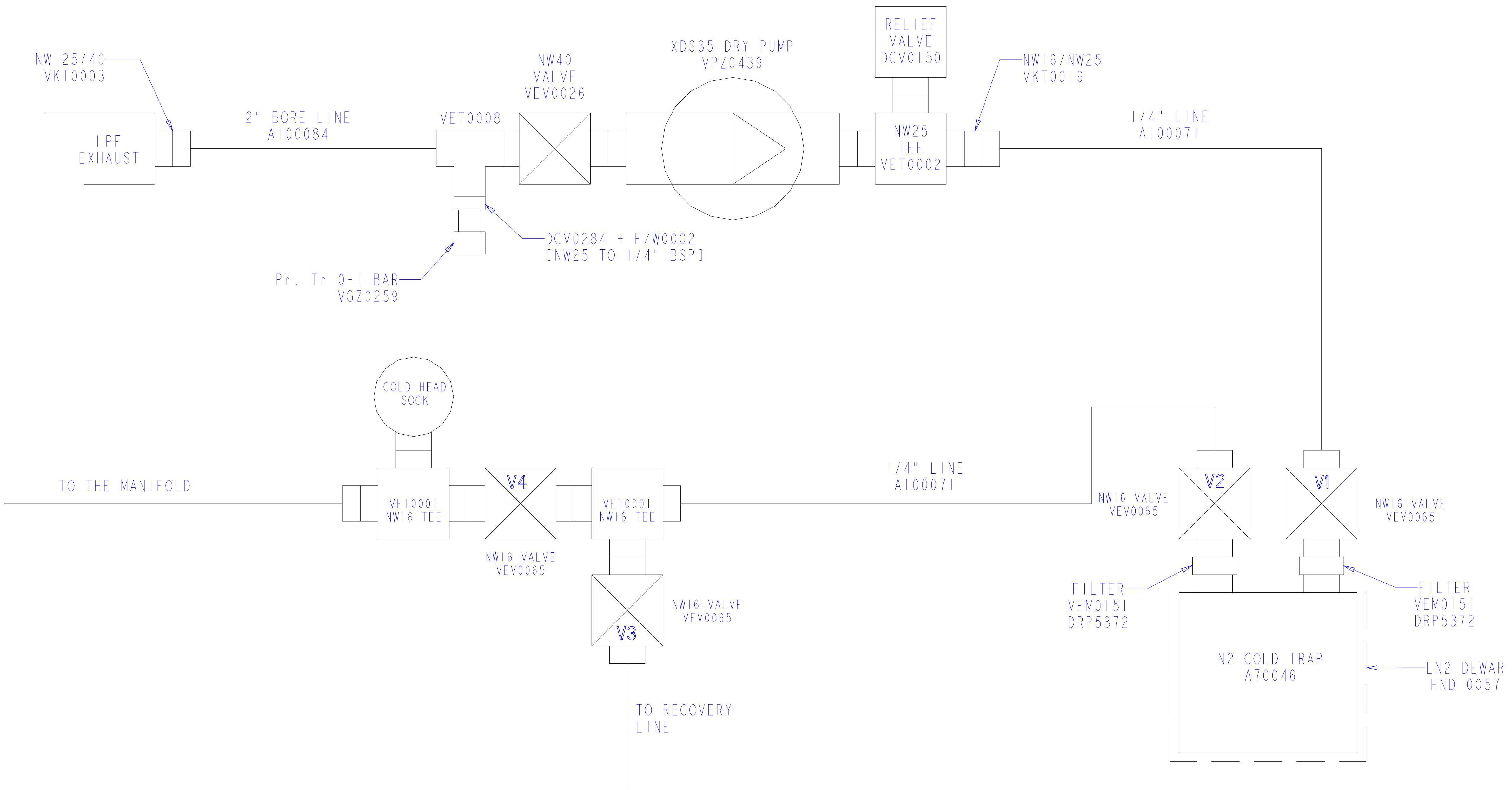
RELEASE LEVEL		DRAWING NUMBER	REV
Production	ONLY MANUFACTURE DRAWINGS WHEN RELEASE LEVEL IS SET TO "PRODUCTION"	A11430	04
		SHEET 2 OF 4	

OXFORD INSTRUMENTS

A3 ORIGINAL SIZE

Model Version 0

THIRD ANGLE PROJECTION



Item	Part No	Description	Length	Qty.	REMARKS
21	Z30117	NW40 EDWARDS CARRIER AND CLAMP		4	
20	Z30116	NW25 EDWARDS CARRIER AND CLAMP		5	
19	Z30115	NW16 EDWARDS CARRIER AND CLAMP		11	
18	VPZ0439_B	PUMP XDS 351 DRY VACUUM EDWARD		1	
17	VKT0019	ADAPTOR NW25/16 ALUM		1	
16	VKT0003	ADAPTOR NW40/NW25 AL.AL		1	
15	VGZ0259	LPF PRESSURE TRANSDUCER		1	
14	VEV0065	NW16 SPEEDI VALVE C332-05-000		4	
13	VEV0026_B	VALVE SPEEDI SP40K		1	
12	VET0008	TEE NW40 AL.AL		1	
11	VET0002	TEE NW25 AL		1	
10	VET0001	TEE NW10 EQ AL		2	
9	VEM0151	NW10 CENTRING RING + FILTER		2	
8	HND0057	NITROGEN DEWAR IC-38RX-CTI		1	
7	FZW0002	SHOULDERED RUBBER WASHER		1	
6	DRP5372	NW10/16 FILTER CENTER RING (L)		2	
5	DCV0284	NW25 FLANGE - 1/4" BSP ST		1	
4	DCV0150	RELIEF VALVE DUAL SPR NW25		1	
3	A70046	COLD TRAP ASSY MKIII		1	
2	AI00084	P/LINE 2.00x3.5xNW40xNW40		1	
1	AI00071	P/LINE 0.25x2.5xNW16xNW16		2	

DO NOT SCALE
IF IN DOUBT ASK

REMOVE ALL BURRS
AND SHARP EDGES

TOLERANCES UNLESS STATED FOR:

MACHINING	ASSEMBLY
X ± 0.5mm X.X ± 0.3mm X.XX ± 0.1mm ANGLE ± 0°15'	LINEAR ± 1mm ANGULAR ± 1°

SURFACE FINISH
UNLESS STATED
mm
UNLESS STATED

DESCRIPTION
RECON LPF KIT

SCALE	DATE	DRAWN	RELEASE LEVEL	DRAWING NUMBER	REV
1:10	07-Dec-10	M.Wilkinson	Production	A11477	01

ONLY MANUFACTURE DRAWINGS WHEN RELEASE LEVEL IS SET TO "PRODUCTION"

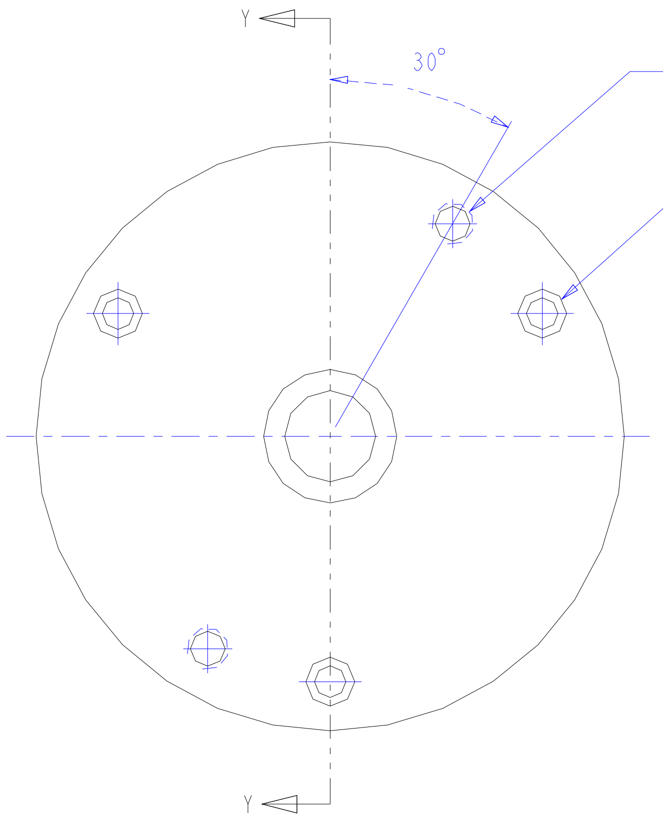
OXFORD INSTRUMENTS

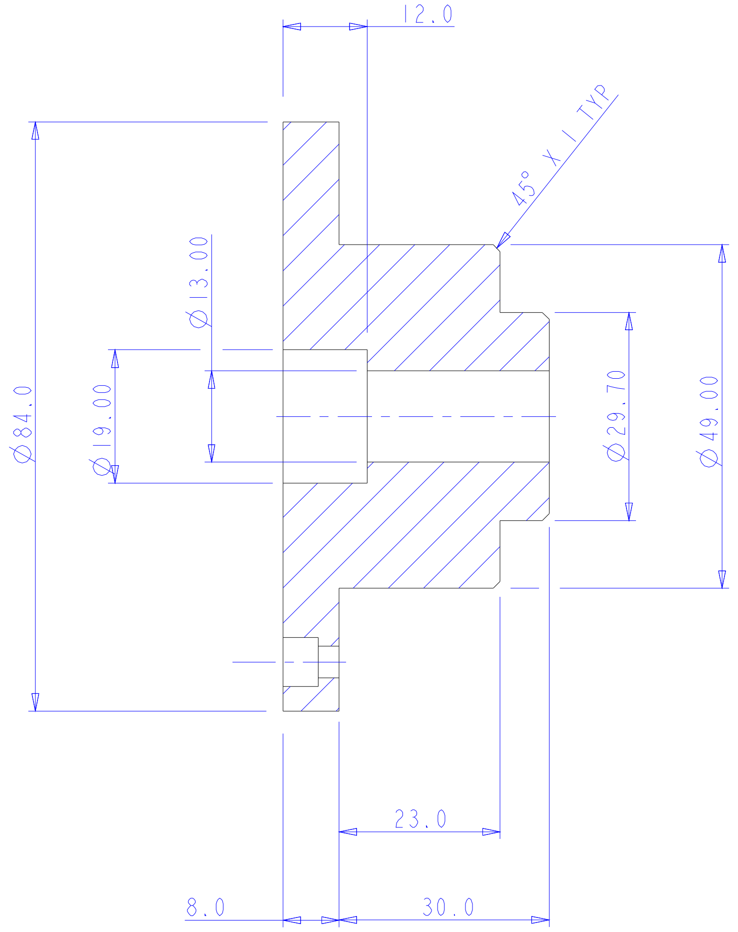
SHEET 1 OF 1

A3 ORIGINAL SIZE

Model Version 0

THIRD ANGLE PROJECTION





SECTION Y-Y

MATERIAL SPEC.	ALUMINIUM EN AW-6082(T6)
FORM	ROD
FINISH SPEC.	CLEAN
COLOUR	-

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OXFORD INSTRUMENTS
TUBNEY WOODS
ABINGDON, OXON, OX13 5QX, ENGLAND

A3P REVISION : 10

DO NOT SCALE
IF IN DOUBT ASK

REMOVE ALL BURRS
AND SHARP EDGES

TOLERANCES UNLESS STATED
X ± 0.5mm
X.X ± 0.3mm
X.XX ± 0.1mm
ANGLE ± 0° 15′

SURFACE FINISH 1.6 UNLESS STATED

mm UNLESS STATED

DESCRIPTION
RECON OVC SHIPPING BUNG

SCALE	DATE	DRAWN	RELEASE LEVEL		DRAWING NUMBER	REV
1.000	07-Apr-10	M.Wilkinson	Production	ONLY MANUFACTURE DRAWINGS WHEN RELEASE LEVEL IS SET TO "PRODUCTION"	P13015	01

OXFORD INSTRUMENTS

SHEET 1 OF 1

10. Specifications, wiring and test results

10.1. Magnet services - control wiring

10.1.1. Earthing the cryostat

Before you run the magnet you must make sure that the cryostat is firmly earthed using a low resistance cable. During normal operation the magnet and its protection circuit are electrically isolated from the cryostat so there is little danger of the cryostat reaching a high voltage. However, if the magnet quenches and the electrical insulation fails at any point the cryostat could reach a dangerously high voltage, causing a hazard.

10.1.2. Magnet current leads

Single current terminals or coaxial pairs are provided for the magnet current leads. Attach the room temperature current leads to these and fit the rubber boot over the leads to make sure that you cannot accidentally touch the exposed terminals. The current leads are optimised to give the best possible electrical and thermal performance, and they are cooled by helium gas from the main reservoir of liquid helium.

Current terminal pairs are wired as follows:

Centre or red terminal = +ve = start of magnet
Outer or black terminal = -ve = end of magnet

Warning: **Do not modify the wiring in any way.**

Do not disconnect the power supply from the magnet while it is at field. On most systems the power supply must be connected to guarantee that the voltages at the magnet terminals are kept at a safe level.

10.1.3. Protection circuit

Warning: **A superconducting magnet must always be fitted with a protection circuit, otherwise the magnet may be permanently damaged.**

If the magnet is supplied as part of a complete system this protection circuit will have been installed on the magnet support system and it is only necessary to connect it when you assemble the system. Magnets supplied independently have to be protected as specified in the protection circuit diagram. Magnets which are welded into cryostats have had their protection circuits fitted in the factory and no access is possible.

10.2. 4,10 and 12 way Fischer connector pin labels

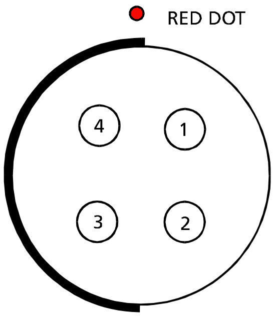


Figure 5 Pin numbers on a 4 way hermetically sealed Fischer connector viewed onto pins from the outside of the cryostat. Fischer part number 103 Z053 (DBEE). (Mating connector Fischer part number SE103 Z053)

Tip The connector on the cryostat is a plug and the pins are accessible.

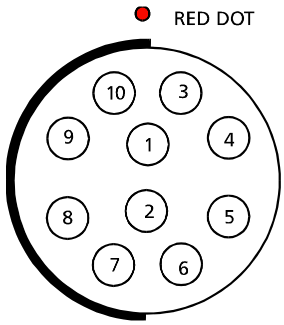


Figure 6 Pin numbers on a 10 way hermetically sealed Fischer connector viewed onto pins from the outside of the cryostat. Fischer part number 1031 Z010 (DBEE). (Mating connector Fischer part number SE1031 Z010)

Tip The connector on the cryostat is a plug and the pins are accessible.

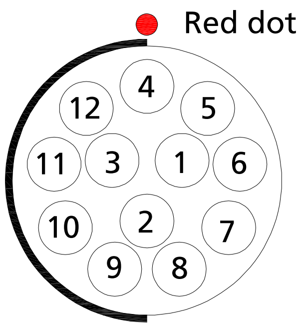


Figure 8 Pin numbers on a 12 way hermetically sealed Fischer connector viewed onto pins from the outside of the cryostat. Fischer part number 1031 Z012 (DBEE). (Mating connector Fischer part number SE1031 Z012)

Tip The connector on the cryostat is a plug and the pins are accessible.

10.3. Fischer connectors for magnet systems

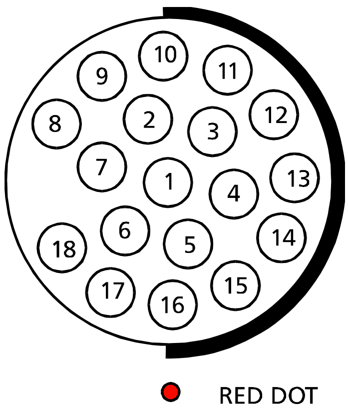


Figure 7 Pin numbers on an 18 way hermetically sealed Fischer connector viewed onto pins from the outside of the cryostat. Fischer part number.105 Z038 (DBEE). (Mating connector Fischer part number SE105 Z038)

Tip The connector on the cryostat is a plug and the pins are accessible.

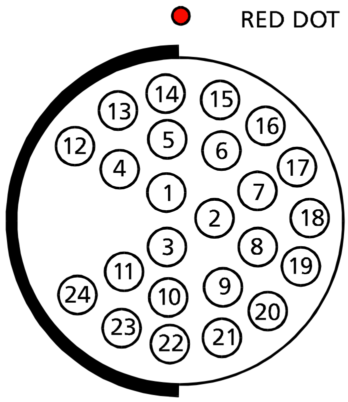


Figure 8 Pin numbers on a 24 way hermetically sealed Fischer connector viewed onto pins from the outside of the cryostat. Fischer part number 105 Z093 (DBEE). (Mating connector Fischer part number SE105 Z093)

Tip The connector on the cryostat is a plug and the pins are accessible.

10.4. Flying leads for Fischer connectors

Leads attached to Fischer connectors by Oxford Instruments are colour coded according to the following convention.

1	Red		11	Turquoise		21	Blue/Black
2	Blue		12	Grey		22	Orange/Blue
3	Green		13	Red/Blue		23	Yellow/Green
4	Yellow		14	Green/Red		24	White/Green
5	White		15	Yellow/Red			
6	Black		16	White/Red			
7	Brown		17	Red/Black			
8	Violet		18	Red/Brown			
9	Orange		19	Yellow/Blue			
10	Pink		20	White/Blue		Body	Screen

Note: That leads with less than 24 wires are colour coded in the same way. If you have a 10 way lead you should simply ignore the information given for pins 11 to 24.

10.5. Magnet Test results

The system test results are given after this page.

10.5.1. Description and overall specifications

Magnet type.. P8/9.5/110/15

Persistent mode switch fitted..Yes

Type of protection .... Resistor Diode

Specifications and measured values for the magnet are combined in the following tables.

Guaranteed maximum central magnetic flux density at 4.2 K	8.0	tesla
Guaranteed maximum central magnetic flux density at 2.2 K	9.5	tesla
Current for 9.5 tesla	99.489	amp
Current / flux density ratio	10.4725	amp/tesla
Homogeneity (over 10 mm dia x 4 mm long cylinder) (see homogeneity plots)	0.1	mT
Flux density integral on axis	1.38	TM
Shim coils fitted	Z1, Z2, X & Y	(Z2 not used)
Shim coil currents (see table of test values)	<20	amp
Inductance	53.2	henry

Energisation rate	0.5 Tesla min^{-1}
Flux density temporal stability	<0.01 mT $hour^{-1}$ < 0.1 mT over the first 12 hours in persistent mode
Magnet clear bore diameter at ambient temperature	88.9 mm
Magnet ambient temperature bore length	300 mm
Magnetic and physical axes alignment	< 5 mRad

10.5.2. Shim strengths and orientations

Shim	Strength	Orientation
Z1	0.01 mT/A/mm	Horizontal, parallel with magnet axis
X	0.0024 mT/A/mm	Vertical, transverse to magnet axis
Y	0.0024 mT/A/mm	Horizontal, transverse to magnet axis

10.5.3. System test shim currents

The following shim currents were obtained from a series of optimisation runs. During the optimisation process, which was performed with the ISS10 power supply in manual mode, a shim cycle was performed after each change in individual coil currents.

Because of the limited winding positions available to the shim coils the Z_2 couples significantly with the main magnet and is of relatively low strength. For these reasons the main winding geometry has been adjusted to remove the requirement for this shim. This is however still part of the shim circuit but is set to zero current.

The values in the table were obtained following energisation to 8 tesla. Due to magnetisation of the single core superconductor, the use of which is mandatory to obtain superconducting joints within the shim circuit, there is some difference in optimium shim currents when the magnet polarity is reversed or when flux densities of < 6 T are set from zero. This effect is shown in the NMR homogeneity plot data presented below which were collected using the automatic system with a data table constructed from best linear fits through zero for each of the shim currents

The shim currents found during test at Oxford should only be regarded as a guide as there is always some degree of environmental influence on the homogeneity.

B - tesla	Iz - amp	Ix - amp	Iy - amp
1.2	2.2	0.6	-2.5
2.6	3.83	0.9	-4.7
5.085	7.9	2.65	-10
6.8	9.9	2	-12.73
8	12.85	2.9	-15.2
9.5	14.8	4	-18.7

10.5.4. Energisation rates

Energisation From	Current (A) To	Energisation Rate (amps/min)	(tesla/min)
0	83.78 at 4.2 K	5.24	0.5
83.78	99.489 at 2.2 K	2.62	0.25

The flux density may be swept up or down and in either direction at these rates.

10.5.5. Persistent mode

Maximum rate of change of current in the magnet leads with the magnet in persistent mode (switch heater off) — 120 amps/minute

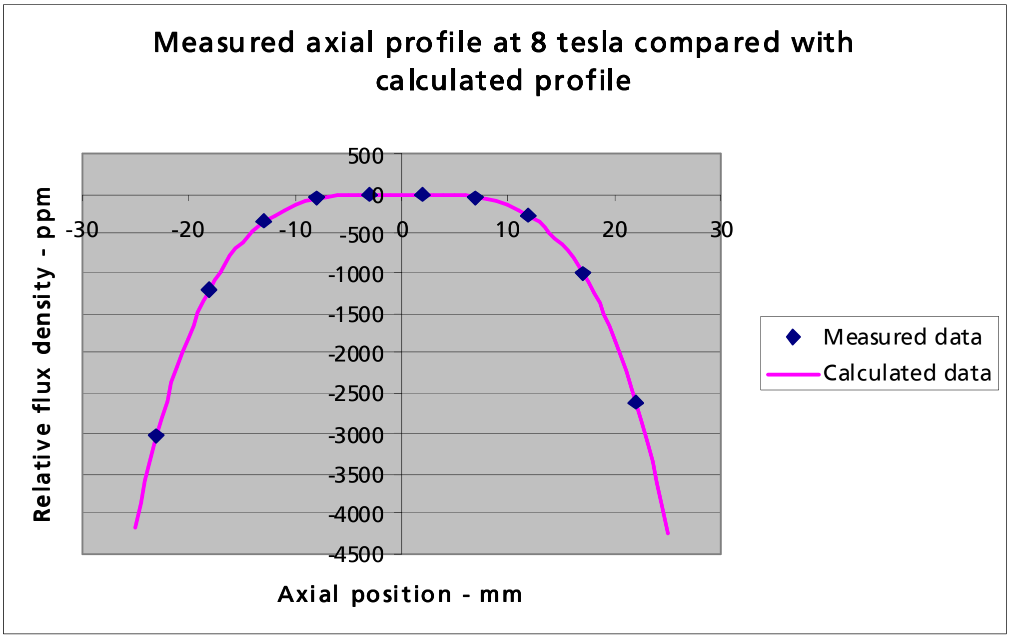
Oxford Instruments power supplies have a default rate of 240 amps/minute

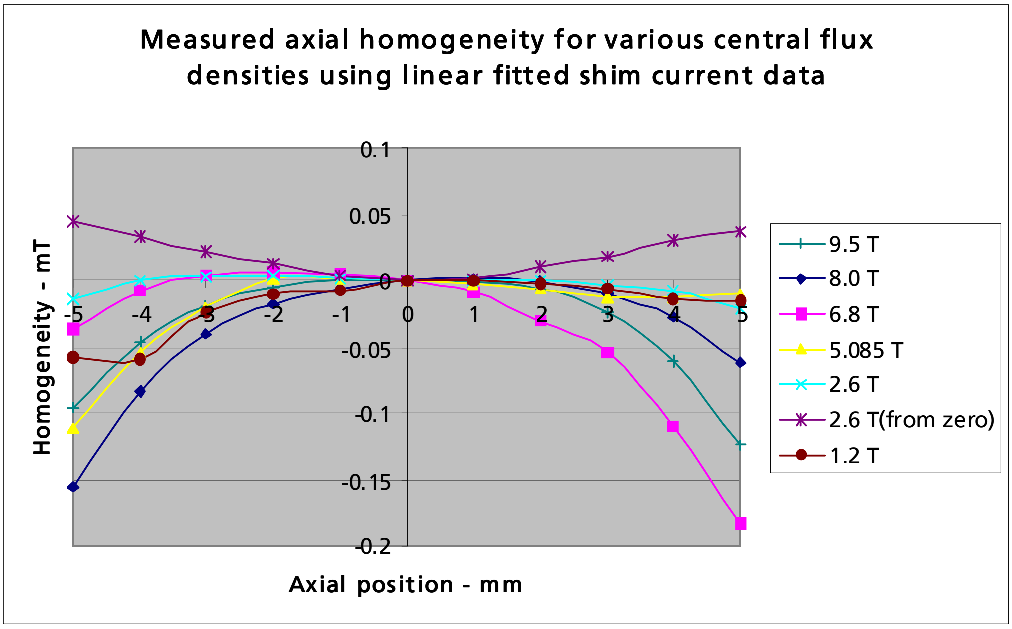
10.5.6. Measured magnet resistance values (ohms)

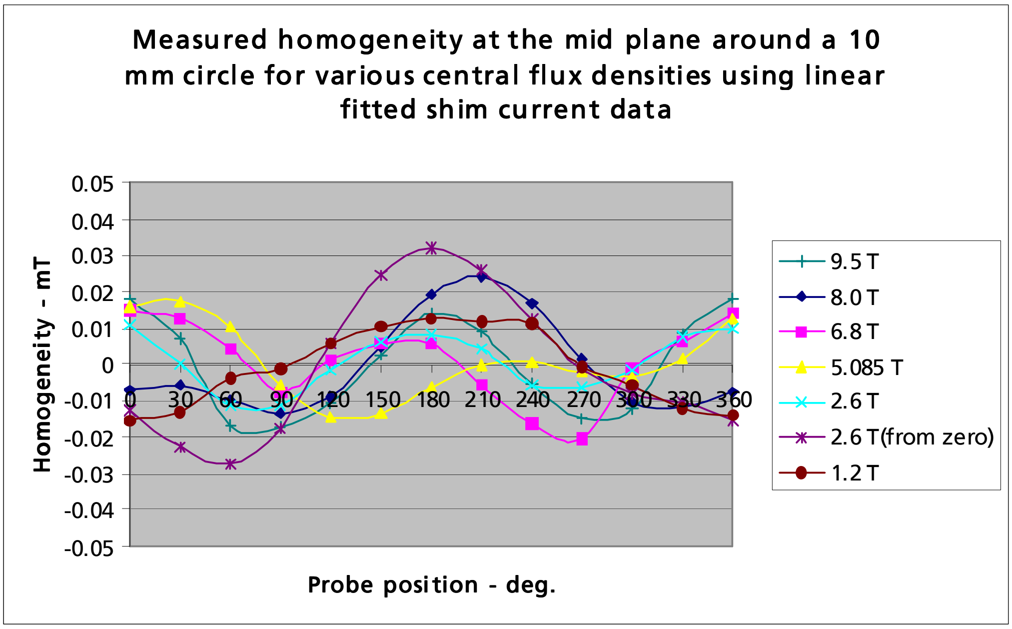
Temperature	**Room temperature**	**77 K**	**4.2 K**
Main magnet resistance Start-End (switch connected)	49.2	42.5	0.9
Main Switch heater resistance	111	109.6	101.7
Spare main switch heater resistance	111.4	110.1	102.7
Main switch heater(s) to cryostat isolation	> 20 M	>20 M	>20 M
Magnet to cryostat isolation	>20 M	>20 M	>20 M
Main magnet to switch heaters isolation	>20 M	>20 M	>20 M
Shim coil resistance Start to End	25.8	11.5	0.4
Z1 shim switch heater	111	109.9	101.2
Z2 shim switch heater	109.3	108.3	99.5
X shim switch heater	109.7	108.7	100
Y shim switch heater	109.1	108.2	99.4
Shim coils to switch heater isolation	>20 M	>20 M	>20 M
Shim coils to main magnet isolation	>20 M	>20 M	>20 M

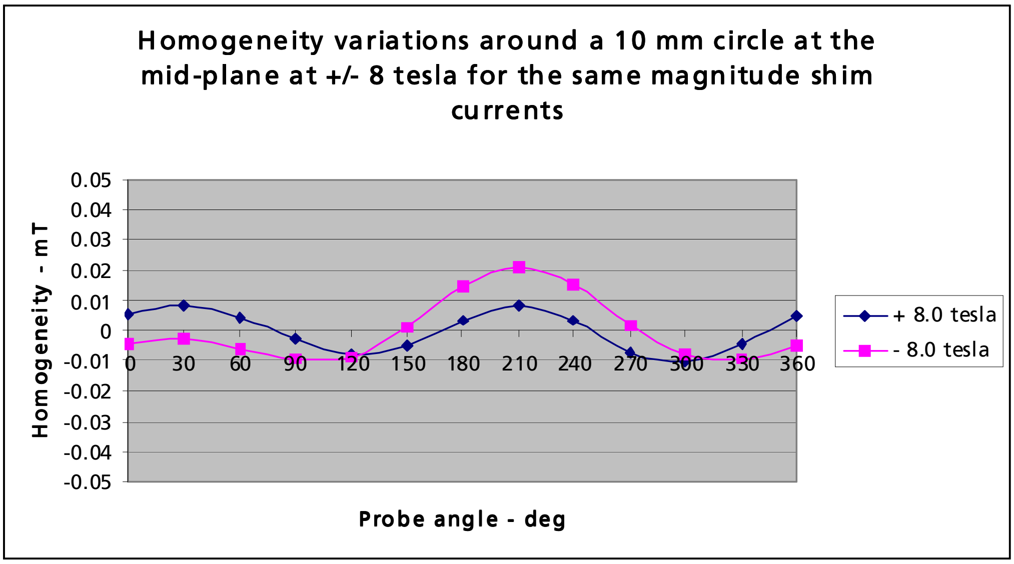
10.5.7. Flux density homogeneity plots

The magnet was plotted with a Hall probe along the axis over the central region to confirm the calculated flux density profile. The magnet was also plotted at various flux densities with an NMR probe both along the axis and around a circle at the mid-plane. The plotted results shown below are with shim currents taken from a linearised table fitted to the actual optimised currents.

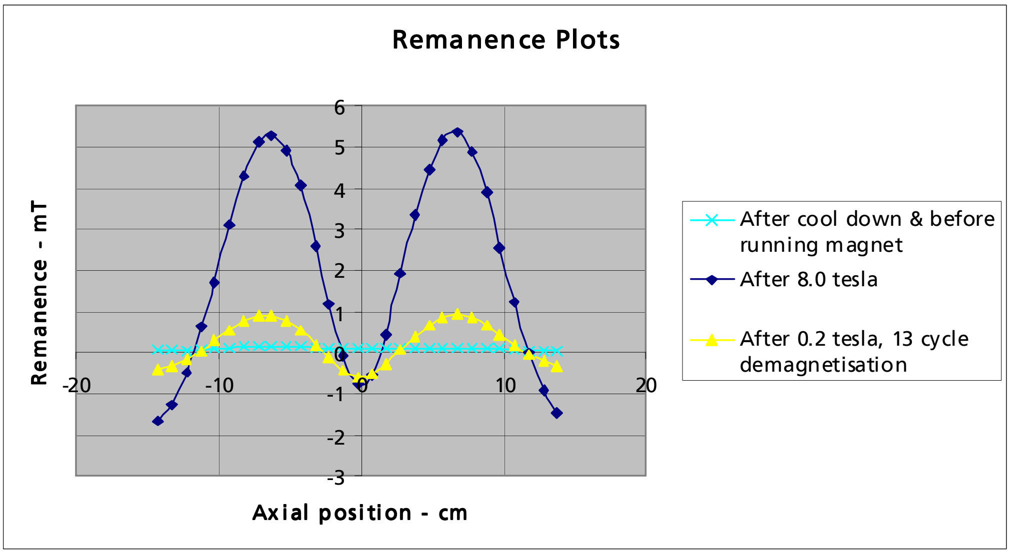





Measured homogeneity at the mid plane around a 10 mm circle for various central flux densities using linear fitted shim current data
Homogeneity - mT
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
0
30
60
90
120
150
180
210
240
270
300
330
360
Probe position - deg.
9.5 T
8.0 T
6.8 T
5.085 T
2.6 T
2.6 T(from zero)
1.2 T

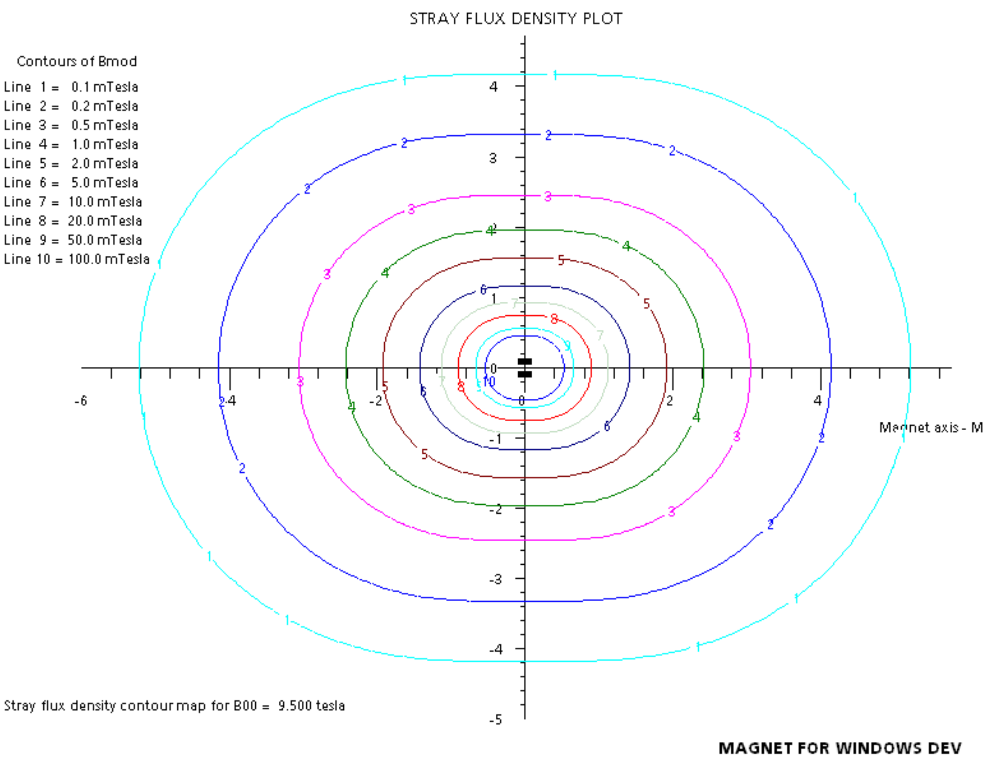

Homogeneity variations around a 10 mm circle at the mid-plane at +/- 8 tesla for the same magnitude shim currents
Homogeneity - mT
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
0
30
60
90
120
150
180
210
240
270
300
330
360
Probe angle - deg
+ 8.0 tesla
- 8.0 tesla

10.5.8. Measured magnetic hysteresis

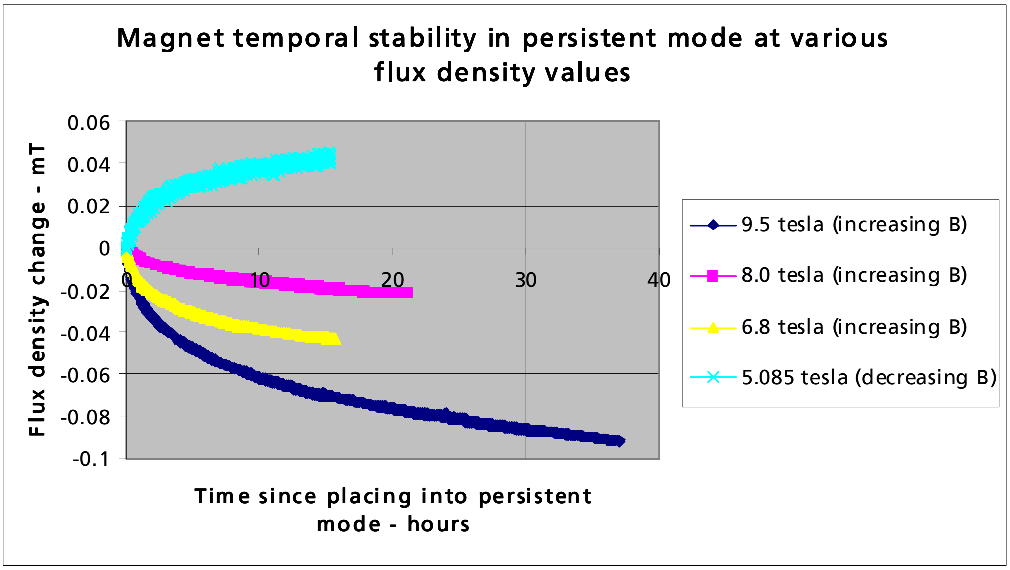


10.5.9. Stray flux density plot

The following plots show the calculated stray flux density profiles for the magnet at 9.5 tesla



10.5.10. Measured flux density temporal stability



The plots above were obtained under different starting conditions as indicated in the legend. The demagnetisation overshoot parameter was scaled at each flux density from 0.01 tesla at 8.0 tesla and a three step procedure with 180 second delay at each step employed.

10.6. Cryostat test results

10.6.1. Specifications (static conditions)

Cryostat type .... recondensing MD20

Liquid helium capacity ....22 litre

Liquid helium reservoir evaporation rate ....Zero in recondensing mode

10.6.2. Recondensing controller

Type of temperature controller ITC503

Serial number of temperature controller C37100009

Heater voltage limit ....7.5 V

Auto needle valve limit ....N/A %

Auto needle valve set up (C1, C2, C3, C4, C5, C6) 0, 0, 99.9, 10, 10, 0

10.6.3. Thermometer information

Temperature controller channel	ITC range name	Serial number and calibration number	Resistance at 300 K	Position of sensor
1	N/A	N/A	N/A	N/A
2	Custom	X68404	78Ω	PTR stage 2
3	Pr20a.	N/A	N/A	M/B Pressure

10.6.4. Pressure control parameters

Proportional band (%)	20
Integral time constant (minutes)	0.1
Derivative time constant (minutes)	0

10.6.5. Cryostat test results

Useful liquid helium volume	22 litres
Liquid helium evaporation rate (static)	0 cm^3/h
Pressure control heater power (static)	380 mW
Total helium loss ramping from zero to 8 tesla and back to zero	0.6 L

10.6.6. Main magnet current lead test results

The cryogenic and electrical performances of the current leads were ascertained during a test where the maximum current was passed through the leads and the closed superconducting switch on the magnet. The recondensing refrigerator was operating so the reported evaporation rates in the table are those in excess of the refrigerator capacity.

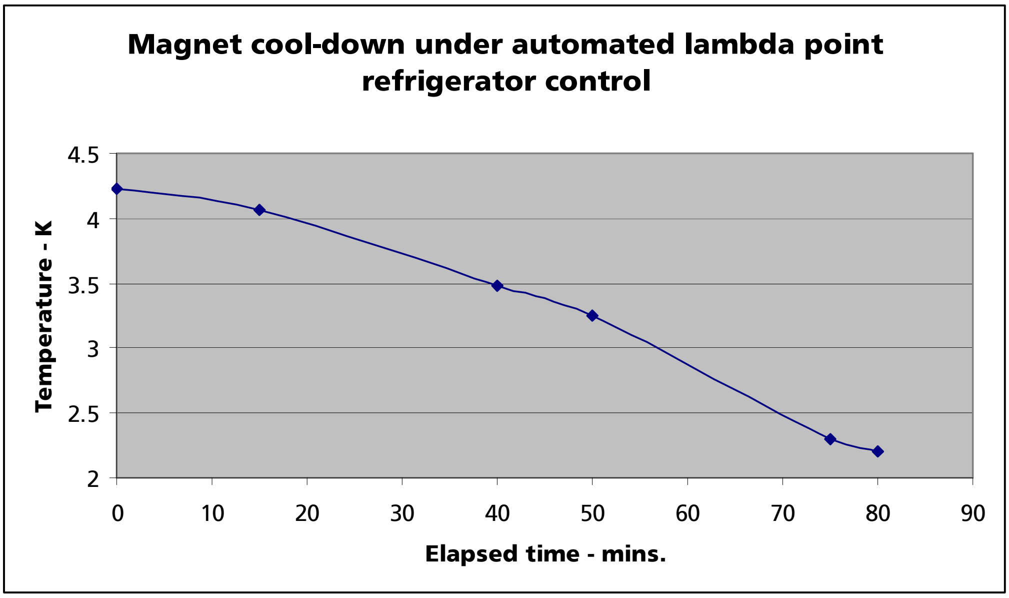
Time	**Evaporation rate - l/m He4gas**	**Voltage at cryostat - Volt**	**Voltage at PS - Volt**	**Current Amp**	**He_4 Level - %**
start	0	0.190	1.16	99.5	80.6
+ 5 min	1.18	0.198	1.20	99.5	80.6
+10 min	1.37	0.198	1.21	99.5	80.6
+15 min	1.58	0.198	1.22	99.5	80.4
+ 20 min	1.69	0.198	1.22	99.5	80.4

10.6.7. Lambda point refrigerator test results

The lambda point refrigerator was tested using the automated system provided with operating parameters set as in the table below.

Control pressure – mB	Temperature limit for low flow control - K	Proportional, integral and derivative terms Plus needle valve setting etc.
6.0	3.05	Standard – see software set up parameters

The magnet cooldown from 4.2 to 2.2 K under automated control gave the following results.



During cool-down the magnet was in persistent mode at 8.0 tesla. After temperature stability was achieved the magnet was taken out of persistent mode and energised to 9.5 tesla at 0.25 tesla min^{-1}. During this time the magnet temperature indicated increases to > 3 K however due to the large operating temperature margin the magnet does not quench. To minimise temperature rise during energisation at low temperature a lower energisation rate of 0.1 tesla min^{-1} should be employed.

Total liquid helium throughput during cool-down .... 1.2 L

Total liquid helium throughput during energisation .... 0.8 L

10.6.8. Helium level probe calibration

Active length 261 mm

ILM Level Meter Reading (%)	Volume (litres)
0	0.0
5	1.1
10	2.2
15	3.3
20	4.4
25	5.5
30	6.6
35	7.7
40	8.8
45	9.9
50	11
55	12.1
60	13.2
65	14.3
70	15.4
75	16.5
80	17.6
85	18.7
90	19.8
95	20.9
100	22

10.6.9. Weight and dimensions of the system

Approximate weight of the system 250 kg

Minimum ceiling height requirement for helium transfer 2.5 M