

5T Magnet and Cryostat

Operator's Handbook

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IMPORTANT

This operating manual is intended to help the user set up and operate an Oxford Instruments Superconducting Magnet and Cryostat.

Before attempting to operate the system, PLEASE READ THE INSTRUCTIONS.

Ensure that any packing bungs (if fitted) are removed from the system before operation - instructions and information are generally stuck to the outside of the cryostat when packing bungs have been fitted - the main exception to this is when an Oxford Instruments installation has been ordered.

This product is guaranteed for 1 year against defective materials and workmanship under the general conditions of sale as detailed in the Company's order acceptance.

The guarantee does not apply to damage caused by failure of the operator to follow the recommended operating instructions. This point should particularly be remembered when dealing with the wiring.

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SECTION 1 SAFETY

1.1 Introduction

A superconducting Magnet System can be operated easily and safely provided the correct procedures are obeyed and certain precautions observed.

This safety section must be read and understood by everyone who comes into contact with a Superconducting Magnet System. They are NOT for the sole information of senior or specialist staff. Proper training procedures must be undertaken to familiarise effectively all persons concerned with such equipment with these requirements. Also since the field from the magnet is 3-dimensional, consideration must be given to floors above and below the magnet as well as the surrounding space on the same level.

The installation and operation of a Superconducting Magnet System presents a number of hazards of which all personnel must be aware. It is essential that:

- Areas in which magnet systems are worked on or used, and their installation generally, are planned with full consideration for safety.
- Such premises and installations are operated in a safe manner and in accordance with proper procedures.
- Adequate training is given to personnel.
- Clear notices are placed and maintained to effectively warn people that they are entering a hazardous area.
- All health and safety procedures are observed.

These notes outline aspects of operation and installation which are of particular importance, however, the recommendations given cannot cover every eventuality and if any doubt arises during the operation of the system the user is strongly advised to contact the supplier.

It is the obligation of Oxford's customers to communicate effectively to their own customers and to users of the equipment the information in this manual regarding safety procedures and hazards associated with magnet systems.

FLOOR LOADING

Professional assistance from a civil or structural engineer should be sought when considering any installation.

1.2 The Magnetic Field

Certain precautions must be taken to ensure that hazards will not exist due to the effect of a magnetic field on magnetic materials or on surgical implants.

Typical of such effects are the following:

Large attractive forces may be exerted on equipment brought near to the magnet. The force may become large enough to move the equipment uncontrollably towards the magnet. Small pieces of equipment may therefore become projectiles, large equipment (e.g. gas bottles, power supplies) could cause bodies or limbs to become trapped between the equipment and the magnet. Either type of object may cause injury or death. The closer to the magnet, the larger the force. The larger the equipment mass, the larger the force.

The operation of medical electronic implants, such as cardiac pacemakers, may be affected either by static or changing magnetic fields. Pacemakers do not all respond in the same way or at the same field level if exposed to fields above 5 gauss.

Other medical implants, such as aneurysm clips, surgical clips or prostheses, may contain ferromagnetic materials and therefore would be subject to strong forces near to the magnet. This could result in injury or death. Additionally, in the vicinity of rapidly changing fields (e.g. pulsed gradient fields), eddy currents may be induced in the implant resulting in heat generation.

The operation of equipment may be directly affected by the presence of large magnetic fields. Items such as watches, tape recorders and cameras may be magnetised and irreparably damaged if exposed to fields above 10 gauss. Information encoded magnetically on credit cards and magnetic tape including computer floppy discs, may be irreversibly corrupted. Electrical transformers may become magnetically saturated in fields above 50 gauss. The safety characteristics of equipment may also be affected.

To prevent situations as described above from occurring, the following general precautions are provided as guidelines. These should be regarded as minimum requirements. Every magnet site location should be reviewed individually to determine precautions to be taken against the above hazards. Also, since the field from the magnet is 3-dimensional, consideration must be given to floors above and below the magnet as well as the surrounding space on the same level.

Before ramping the magnet to field

The following precautions must be taken.

- * Ensure all loose ferromagnetic objects are removed from within 2 meters of the OVC, or 3 metres for high field magnets (> 11 Tesla).
- * At all points of access to the magnet room display warning signs that the magnet is operating.
- * Display warning signs giving notice of the possible presence of magnet fields and of the potential hazards in all areas where the field may exceed 5 gauss.
- * Ensure all electronics and interfacing equipment supplied by Oxford Instruments are placed in areas where the field level is less than 10 gauss.
- * The safe working field level of other equipment must be individually assessed by the system manufacturer.

After ramping the magnet to field

- * Do not bring ferromagnetic objects into the magnet room.
- * Use only non-magnetic cylinders and dewars for storage/transfer of compressed gas or cryogenic liquids. Equipment for transportation of cylinder/dewars must be non-magnetic.

1.3 Fire and Explosion Hazards

In the case of fire evacuate personnel from the area, sound the fire alarm.

Water must not be used on electrical equipment and when sprayed on cryogenic liquids will rapidly freeze. The magnet ventilation may become blocked by ice with subsequent risk of explosion and the release of cryogens from the system.

The surface temperature of containers for liquid nitrogen and helium, if not vacuum insulated, may be sufficiently low to condense oxygen or oxygen enriched air. This liquid in contact with flammable substances can become explosive.

Portable fire fighting equipment must be non-magnetic and should be installed by agreement with the local fire authority.

Local emergency services must be informed of the presence of a magnet operating in their area as this may affect their procedures in dealing with fires or other accidents.

In case of a large cryogen spillage avoid direct contact with the liquid; sound fire alarm and evacuate the area.

Oil mist filters should be fitted to pumps to reduce the emission of toxic oil vapours which pose both health and explosion hazards.

1.4 The Safe Handling of Cryogenic Substances

Cryogenic liquids can be handled easily and safely provided certain precautions are obeyed. The recommendations in this section are by no means exhaustive and when in doubt the user is advised to consult the supplier.

The safe handling of cryogenic liquids requires a knowledge of the properties of these liquids, common sense and sufficient understanding to predict the future behaviour of such liquids under certain physical conditions.

The substances referred to in these recommendations are nitrogen, air and helium.

1 GENERAL SAFETY RULES

Cryogenic liquids, even when kept in insulated storage vessels (dewars), remain at a constant temperature at their respective boiling points and will gradually evaporate. The very large increase in volume accompanying this vaporisation is approximately 700:1 for helium and nitrogen and therefore:

CONTAINERS OF CRYOGENIC LIQUIDS MUST NOT BE COMPLETELY CLOSED AS THIS WOULD RESULT IN A LARGE BUILD UP IN PRESSURE AND THUS PRESENT AN EXPLOSION HAZARD. The nitrogen jackets is always fitted with a non-removable overpressure valve, the OVC is fitted with a combined overpressure / evacuation valve and **the helium bath must have the large black and red quench valve fitted.** (This is normally supplied in the spares kit or left attached to the helium exit port).

In the event of a large spillage operate the fire alarm and evacuate the area.

2 HEALTH HAZARDS

Asphyxia of varying severity will occur if the magnet room is not properly ventilated. (Helium can displace air from the top of a room and cold nitrogen can displace air from lower levels).

Burns. Cryogenic substances in liquid or vapour form or as low temperature gases produce effects on the skin similar to burns (cold burns).

Exposed or insufficiently protected parts of the body coming into contact with uninsulated venting pipes or vessels (see ventilation section) will stick fast and **the flesh will be torn** if removed.

3 FIRST AID

If any of the cryogenic liquids come into contact with eyes or skin, immediately flood the affected area with large quantities of cold or tepid water and then apply cold compresses. Never use hot water or dry heat. **MEDICAL ADVICE SHOULD BE SOUGHT IMMEDIATELY.**

4 PROTECTIVE CLOTHING

Protective clothing must be worn mainly to avoid cold burns and **dry leather or PVC gloves** must be worn when handling or working with cryogenic liquids.

Gloves must be loose fitting so that they can be removed easily in case of liquid spillage. **Eyes must be protected by goggles. Do not wear any metallic objects (e.g. jewellery)** on those parts of the body where they may come into contact with the liquid.

5 HANDLING

Cryogenic liquids must be handled and stored in well ventilated areas.

Do not allow cryogens to come into contact with the body.

Always handle the liquids carefully - boiling and splashing will always occur when filling a warm container or when inserting warm objects into the liquid.

When inserting open ended pipes into the liquid, block off the warm end until the cold end has cooled down (otherwise cold liquid may spurt out of the open end under self-generated pressure). Never direct pipe/piping towards any person.

Beware of liquid splashing and rapid flash-off of helium when lowering equipment at ambient temperature into liquid. This operation must be carried out very slowly.

Use only metal tubing connected by flexible metal hose for transferring liquid nitrogen. For the coupling **DO NOT** use rubber tube, silicon rubber tube (including hospital grade tube - this explodes!) or plastic tubing e.g garden hose and including reinforced tubes e.g. for air lines - this shatters unexpectedly and may cause injury to personnel. It should be noted that polythene and nylon lines are sometimes used however this should not be taken as an implied recommendation, all lines should be tested in safe circumstances or used only after the manufacturer's recommendation.

6 EQUIPMENT

Only use containers specifically designed for use with particular cryogens and constructed of non-magnetic materials.

7 LIQUID NITROGEN

Good ventilation is essential.

Store and use in a well ventilated place. If enough gas evaporates from the liquid in an unventilated place (e.g. overnight in a closed room) the oxygen concentration in the air may become dangerously low. Unconsciousness may result suddenly without previous warning symptoms and may be fatal. For example, the evaporation of 25 litres of liquid nitrogen produces 17,000 litres of nitrogen gas (600 cu.ft.). If this vaporization takes place in a room of 54 m³ (2,000 cu.ft.), i.e. 3 x 6 x 3 metres high (10 x 20 x 10 feet high) it can produce a very dangerous situation if the room is not ventilated. Appropriate multiplication of these parameters will indicate actual site conditions.

Minimise contact with air

Since liquid nitrogen is colder than liquid oxygen, the oxygen of the air will condense into the nitrogen and if allowed to continue for some time, the oxygen concentration may become so high that the liquid may become as dangerous to handle as liquid oxygen. This applies particularly to wide-necked dewars.

Therefore ensure that contact with air is kept to a minimum.

Do not smoke

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

8 LIQUID HELIUM

Liquid helium is the coldest of all cryogenic liquids. It will therefore condense and solidify any other gas (air) coming into contact with it, with the consequent danger that pipes and vents may become blocked.

Liquid helium must be kept in specially designed, storage or transport dewars. Dewars should have a non-return valve fitted in the helium neck at all times in order to avoid air entering the neck and plugging it with ice. Vacuum insulated pipes should be used for liquid transfer; breakdown of the insulation may give rise to condensation of oxygen.

1.5 Ventilation of Exhaust Gases

Gaseous nitrogen and helium exhausted from the cryostat will displace oxygen and if not properly ventilated, the possibility of asphyxiation exists.

Cryogenic substances in liquid, or vapour form, or as low temperature gases, produce effects on the skin similar to burns (cold burns).

Exposed or insufficiently protected parts of the body coming into contact with uninsulated venting pipes or vessels will stick fast and the flesh may be torn if removed.

Exhaust systems are required in order to vent to atmosphere any discharge from the system cryostat as described below.

The static helium evaporation exits from the turret via a non-return valve. The valve prevents ambient air leaking back into the cryostat. The outlet from this valve should be vented out of the room to atmosphere or, if required, to a helium recovery system. In the event of a quench the evaporated helium will be exhausted from the manifold via the pressure relief valve(s). The amount of gas is dependent on the type of system, but for a 500MHz NMR magnet quenching with 100% helium the volume of gas at room temperature will be approximately 50,000 litres. If the system is located in a small room then a system should be provided that is capable of exhausting this gas to atmosphere or to a recovery system.

The static nitrogen evaporation will exit from one (or two) of the nitrogen ports. This gas should be vented out of the room to atmosphere.

1.6 Environmental Safety

It is the responsibility of the user to ensure that all equipment, services, data links or personnel passing through the affected space are adequately protected and that access to the area is controlled. Access doors leading into the affected areas must be capable of being secured against unauthorised entry and fitted with warning signs. It is also recommended that local barriers be erected around the magnet and be fitted with warning signs. Care must be taken to advise personnel who have access (in particular security or cleaning staff who often have their own keys) of all the risks associated with magnetic fields and systems operating with cryogenes.

SECTION 2 DESCRIPTION AND OPERATION OF THE SYSTEM

2.1 General Description

This system comprises a special horizontal field 5T split pair magnet mounted in the tail section of a large capacity, liquid nitrogen shielded, vacuum insulated cryostat. The magnet has a cold split of 100mm x 40mm and a cold bore diameter of approximately 120mm, accessed through aluminium windows. Alternatively room temperature bore tubes may be inserted to allow the magnetic field to be plotted. The vertical split access allows a large cooling power helium-4 insert to be fitted from above. This insert will be described in a separate manual.

The cryogenic efficiency of the cryostat is very high due to the small helium neck diameters and the way in which the exhausting helium gas is used to cool them. The helium can heat load is minimised by the use of a nitrogen cooled shield which will minimise both the conducted and radiated heat to the minimum levels possible.

The current leads are all fixed for high reliability and safe operation.

The magnet is 5T with a homogeneity of better than 1 in 10^{-4} over a length of 20mm and a diameter of 80mm. See the results at the end of the manual for more detailed information. Access is provided through aluminium windows which may be demounted if required for access to the magnet cold bore.

The weight of the system is approx 1000Kg. Appropriate lifting gear must be used to move the cryostat.

This system, when energised to full field has a considerable stray field, extending over many metres, and the system stored energy is approx 0.5MJ. It is therefore VITAL that the safety section is read by ALL personnel coming near the system.

PARTICULAR CARE MUST BE TAKEN TO ENSURE THAT THE SYSTEM IS WELL ANCHORED TO THE FLOOR, AND ANY STEEL OBJECTS IN THE VICINITY ARE SIMILARLY WELL BOLTED TO THE FLOOR.

A detailed description of the system components follows.

2.2 System General Arrangement

Please see Blueprint supplied separately.

Drawing no. ALD0039 4/92.

2.3 Cryostat Description

The cryostat is of a vacuum insulated, all metal construction with intermediate temperature radiation shielding. The outside surfaces of the helium and nitrogen vessels are wrapped with single or multilayer superinsulation to reduce emissivity. The outer vacuum case (OVC) of the dewar will be fitted with an evacuation valve incorporating a pressure relief safety feature that will operate in the event of a cryogen leak to the vacuum space. In addition there is a drop-off plate at the base or side of the dewar.

The syphon entry port has an associated cone located within the cryostat. A tube runs from the cone to the bottom of the cryostat and ensures that all liquid nitrogen can be removed from the helium reservoir after pre-cooling the magnet and that filling with helium is from the bottom.

All cryomagnet service ports should be sealed with the plugs provided when not in use. In all cases the boil-off of cryogens is minimised by taking great care in the design to prevent heat entering from the following main sources:

1). Gaseous conduction. An evacuation / pressure relief valve allows the insulating vacuum space to be evacuated to less than 10^{-4} torr.

2). Metallic conduction. Great care is always taken to use materials of low thermal conductivity combined with mechanical strength to support the cryogens in their vacuum. The supports (usually tubes) are of minimum cross sectional area and maximum effective length within overall size constraints. Neck tubes are thermally anchored with a copper thermal link to the top of the nitrogen vessel and good use is made of the enthalpy of the exhausting gas to minimise incoming conducted heat.

3). Radiation. The radiation load is reduced to reasonable values by the introduction of intermediate temperature radiation shields. These are usually cooled by a reservoir of liquid nitrogen surrounding the helium bath. The enthalpy of the exhausting helium gas is sometimes used to cool a radiation shield inside the nitrogen shield. The emissivity of cold surfaces can also be reduced. This is achieved using many interleaved layers of aluminium and insulation known as superinsulation.

4). Ohmic heating. The principal sources of ohmic heating are the current leads and the superconducting switch. In some systems the current leads are made demountable to minimise the cryogen boil-off with a persistent magnet, the remainder of systems feature carefully designed current leads which do not impose a significant heat load. All systems now feature low-loss switches.

2.4 Evacuating the Cryostat OVC

In order to maintain the thermal isolation of the liquid helium it is necessary that a high vacuum be maintained within the cryostat outer vacuum case (O.V.C.).

IMPORTANT In many cases the thin wall construction of the helium reservoir will not support an external pressure differential of one atmosphere. The helium reservoir must therefore never be evacuated unless the OVC is first evacuated.

The recommended pumping equipment consists of an oil diffusion pump of 50mm (2 inch) diameter or, even better, a turbomolecular pump fitted with a liquid nitrogen cold trap. This pump should be backed by a rotary pump of not less than 12-15 m³/hr pumping speed, fitted with a gas ballast facility. All connecting lines should have an internal diameter of not less than 50mm (2 inch) and be as short as possible. Tubes must NOT have been used previously to carry or pump helium.

- a) Connect the valve on the cryostat top flange to the pumping equipment. Using the rotary pump, evacuate the cryostat slowly (approx half hour) to prevent any possible collapse of internal shielding, until the pressure is less than 0.05 mB.
- b) Switch over to the diffusion pump and evacuate the cryostat to less than 5×10^{-4} mB. Continue pumping at least overnight to ensure the removal of residual gases trapped in the superinsulation.

Inspecting the vacuum:-

If the cryostat is already evacuated and it is desired to inspect the pressure only, the pumping tube should be evacuated and the diffusion pump operating before the O.V.C. valve is opened. If the pressure is greater than 10^{-3} mB with the system warm, the cryostat should be evacuated overnight with the diffusion pump to less than 5×10^{-4} mB. It is recommended that the cryostat is always pumped overnight before use.

Flushing the vacuum space:-

If the vacuum space has been accidentally contaminated with helium gas or moisture evacuation can be improved by flushing the space. **NOTE: Never vent cryostats with helium gas as this will 'stick' in the superinsulation.**

- i) Using a rotary pump, evacuate cryostat to less than 1 mB.
- ii) Admit an atmosphere of DRY nitrogen gas, preferably through a 1mm orifice, and pump out to less than 1 mB.
- iii) Repeat (ii) several times, then pump to less than 0.05 mB.
- iv) Switch over to the diffusion pump as in (b) above.

* Charles Mitchell^v advises with our systems to just put in N_2 until magnet is cold and then flow it out - don't let it sit as these instructions say. SJS 1-May-92

2.5 Precooling The Magnet

Before filling the cryostat with liquid helium, the magnet and system must be cooled to a temperature below 100K, this will save a considerable amount of liquid helium which is much (ten times) more expensive than liquid nitrogen, liquid nitrogen also has a higher latent heat of vaporisation. To perform the precool, fill the liquid helium container with liquid nitrogen, completely above the magnet. Use a length of 9.6 mm (3/8 in.) diameter stainless steel tubing inserted into the transfer tube entry port (this is the 'blow-out' tube supplied with the system). Ensure that the tube is located in the cone fitting below the syphon entry port inside the cryostat, the liquid nitrogen storage dewar should be conveniently positioned and connected to the blow-out tube with flexible plastic tubing (once the transfer has started this should not be moved as it is very brittle and will break easily). Allow the liquid nitrogen to remain for one or two hours and then fill it completely again.

The liquid nitrogen should then be removed. Insert the stainless steel tube into the transfer entry fitting and ensure that it is firmly fitted into the cone on the top of the magnet. Blow out all the liquid nitrogen by pressurising the liquid helium container with helium gas to not more than 0.25 atmospheres overpressure, the blown out liquid nitrogen may then be usefully fed into the nitrogen can, see section 2.6 on page 16. Do not stop this prematurely as removing the remaining nitrogen could cause problems. Use the heaters on the helium can to remove the last few litres of liquid nitrogen that will be left in the helium can.

Monitor the background in the OVC with a leak detector connected to the OVC pumping line to check for low temperature leaks from the main bath to the OVC. It is important that all the liquid nitrogen is removed. Failure to do this properly will make filling with the liquid helium difficult, and may impair the performance of the magnet. When all the nitrogen has been removed, release the pressure in the liquid helium bath and evacuate the liquid helium container using a rotary pump and then fill it with helium gas. If during pump down a pause is seen in the range 70-100 mB, and the pumping line becomes very cold, then liquid nitrogen is still present. Stop pumping immediately and flush out the helium bath with helium gas fed down the blow out tube (which should be located in the cone fitting). Failure to do this will result in solidification of the nitrogen. Repeat this procedure at least two times in order to thoroughly purge the magnet of nitrogen. As an indication that all the liquid nitrogen has been removed, check that it is possible to evacuate the liquid helium container to a pressure less than 10 mB.

2.5.1 Allen-Bradley and Rhodium-Iron Sensor Characteristics

Please note that this sheet is a guide for cooldown monitoring purposes only, and is not a substitute for a full calibration.

Temperature (Kelvin)	Allen-Bradley Resistance / Ω		27 Ω Rhodium Iron sensor Resistance / Ω
	100 Ω sensor	270 Ω sensor	
500	-	-	51.4
475	-	-	48.2
425	-	-	42.8
373	-	-	37.5
323	-	-	32.2
300	100	270	29.8
260	101	276	25.7
220	103	285	21.73
180	105	296	17.66
160	107	304	15.87
140	109	314	13.46
120	112	326	11.38
100	116	343	9.2
90	118	354	8.18
80	122	367	7.19
75	124	375	6.72
70	126	384	6.27
60	131	407	5.43
50	140	435	4.73
40	150	485	4.17
30	170	560	3.75
20	210	730	3.36
16	241	860	3.18
12	300	1120	2.95
10	350	1350	2.81

8	440	1770	2.65
6	625	2700	2.45
4.5	950	4500	2.28
4.2	1050	5000	2.25
4	1150	5500	2.22
3.5	1500	7100	2.16
3	2100	10000	-
2.8	2400	12300	-
2.6	2950	15000	-
2.4	3500	19500	-
2.2	4400	25500	-
2	5650	35000	-
1.9	6800	41000	-
1.8	8000	49000	-
1.7	10000	60000	-
1.6	12400	83000	-
1.55	14000	100000	-

Approximate % error due to magnetic fields:

Sensor	Allen-Bradley Resistor			Rhodium-Iron resistor	
	2.5T	8T	14T	1T	3T
2K	0.5	1.5	4	0.13	0.88
4.2K	0.5	3	6	0.13	0.79
50K	-	-	-	0.14	0.84
77K	0.1	0.5	1.5	-	-

2.6 Filling the Liquid Nitrogen Container.

In the interests of economy it is advisable to precool the magnet before filling the nitrogen can. The procedure for this is described previously and will ensure that the cryogen is most efficiently used.

Connect one of the three filler/vent tubes of the liquid nitrogen container to a storage vessel using flexible polythene pipe. Transfer the liquid nitrogen by pressurising the storage vessel to approximately 0.25 atmospheres above atmospheric pressure. Violent boiling will occur initially until the radiation shield has cooled down. When liquid nitrogen sprays out of the filler tubes release the pressure on the storage vessel to stop the transfer.

The storage vessel can be pressurised using a valve on the outlet. By using an electronically controlled valve, the liquid nitrogen container can be filled and the level maintained using a Liquid Nitrogen Level Controller. Inspect the liquid nitrogen at intervals appropriate to the overall system hold time.

All Oxford Instruments cryostats are fitted with overpressure relief valves which are not customer removable. The problems caused by ice formation in the filling tubes can be reduced by slipping 0.25m (10 in.) lengths of plastic tubing over them. These tubes also prevent any overflow of liquid nitrogen from cooling the top flange and its 'O' ring. This can be important if an autofilling system fails to stop the nitrogen transfer when the tank is full.

2.7 Transfer Tube and Storage Dewar Adapter for Liquid Helium

The transfer tube optionally provided with the system is of a stainless steel construction. It takes the form of a tube surrounded by a second tube with a vacuum of better than 10^{-4} mB maintained between them. The assembly of the two tubes usually takes the form of a large 'n' shape.

For detailed instructions on initial filling and topping-up the reader is referred to sections 2.8 and 2.9 (on pages 19 and 20) respectively.

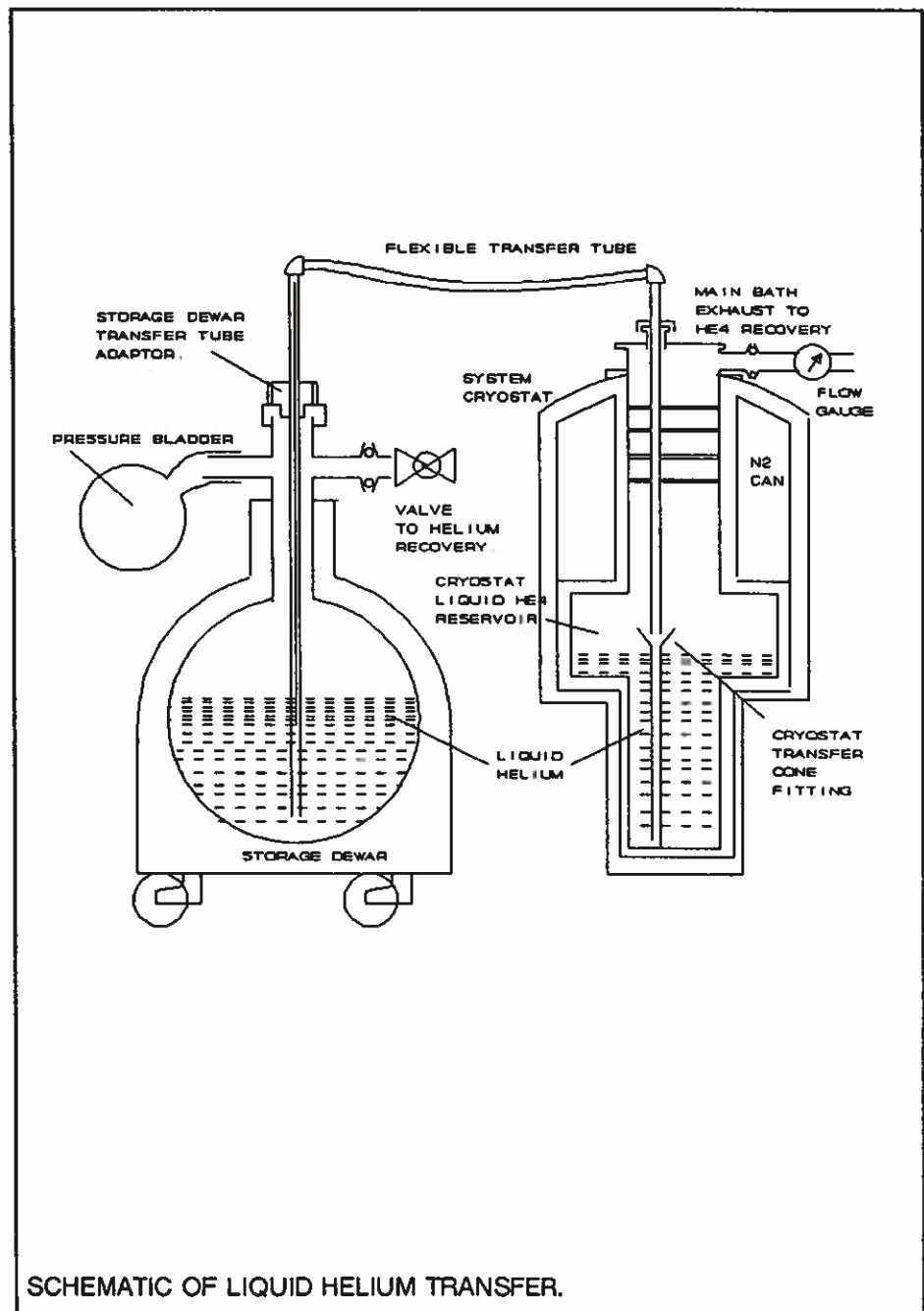
Occasional repumping of the tube will be necessary in service, particularly during the first few months while the materials in the tube are still outgassing.

2.7.1 The ST9 Syphon Evacuation Fitting

The transfer syphons supplied by Oxford Instruments are supplied pre-evacuated, however re-evacuation may become necessary after a period of operation. To evacuate an Oxford Instruments standard syphon, an ST9 fitting is needed to operate the vacuum valve.

- 1 Remove the yellow nylon dust cap from the transfer tube valve. Connect the ST9 fitting to the high vacuum pumping system described in Section 2.4 (page 11).
- 2 Place the ST9 fitting over the transfer tube valve. Evacuate the pumping lines and check the system for leaks.
- 3 Using the red anodized aluminium knob, which is connected to the hexagonal key internally, open the transfer tube valve. Pump out the syphon to 10^{-4} mB or better.
- 4 Close the transfer tube valve using the red knob, isolate the pump and remove the ST9.
- 5 Replace the dust cap.
- 6 Try to avoid getting dirt in the ST9 fitting.

Note: The cryostat overpressure relief valve must be in position and not restricted. If the cryostat is connected to a recovery system any flow meter should be capable of high flow rates and should not introduce a restriction (it may be sensible to fit a bypass flap valve to accommodate the high flows during a possible quench, ensuring that all the helium is recovered).



2.8 Initial Filling with Liquid Helium

Note: See also the instructions for the storage dewar.

- 1). Check that the transfer tube has the correct leg lengths and diameters to be compatible with the cryostat and storage dewar. Connect the cryostat and storage dewar to the helium recovery system or put a oneway valve on the cryostat exhaust port (if the system is large and a one way valve is found too restrictive, it may be replaced by a 2m length of convoluted tubing). Position the liquid helium storage vessel so that the transfer tube can be inserted easily and is close to the cryostat to be filled.
- 2). Remove the plug from the cryostat transfer tube entry port and also from the top of the storage vessel. Insert the transfer tube legs into the cryostat and, slowly, into the storage dewar, allowing it to cool gradually. Ensure that the end of the transfer tube in the cryostat is fitted into the cone on top of the magnet. In this way, cold gas and then liquid is introduced at the bottom of the magnet which is then cooled by the enthalpy of the gas as well as by the latent heat of evaporation.
- 3). Start transferring the liquid helium by pressurising the storage vessel. (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 about 10 litres of liquid per hour. This rate can be increased as the magnet cools and the boil-off reduces. Typically the cool-down from 77K to 4.2K will take between 10 and 60 litres depending on the system size and the care taken in the transfer.

By monitoring the Allen-Bradley sensors, when the magnet temperature falls below 10 Kelvin, the transfer rate can be further increased in order to fill the liquid helium container. This should occur when a further 10 to 50 litres of liquid have been transferred, depending on the size of magnet and dewar.

- 4). 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 plug. Inspect the liquid helium level at appropriate intervals.

2.8.1 Volumes of Liquid Helium required for Cooldown.

The **typical** volumes of cryogenics required for cooldown are given in the results section.

2.9 Refilling with Liquid Helium

The cryostat should be refilled before the level reaches the 10% mark (if a helium level meter is in use). In refilling, care should be taken not to evaporate the liquid in the cryostat with the hot gas which initially comes through the transfer tube. (N.B. Failure to take care can cause the magnet to quench).

With Oxford Instruments syphons a 'phase separator' is supplied. This is a small brass cylinder approximately 25mm long x 10mm diameter with an internal screw thread at one end and two angled cuts in the curved surface, it does not have a hole right through. The phase separator may be screwed to the end of the syphon leg which enters the cryostat, the liquid / gas passing through the transfer line is then separated as it is thrown upwards by the angled slots and the liquid simply falls back under gravity to collect in the base of the helium can. The phase separator is particularly useful when the refilling is intermittent (eg with autofilling systems, or transfer lines left permanently in the cryostat) as liquid in the transfer line may have vaporised and this is then not passed through the colder liquid in the cryostat, which would cause it to boil off. The phase separator should not be used for initial cooling of the system.

The correct procedure is as follows:

- 1) Insert one leg of the transfer tube into the storage vessel, but leave the other one outside of the cryostat. The cryostat syphon entry fittings (the O-ring, washer and the knurled ring) should be undone and slid onto the transfer leg to go into the cryostat, reseal the cryostat entry with the bung provided, the syphon may now be precooled without warm gas entering the cryostat. Pressurise the transport dewar in the normal way, as if transferring helium. After about a minute liquid will issue from the transfer tube, indicated by a blue tongue of vapour. (Prior to this a white vapour plume will have been seen for about 20 seconds).
- 2) Quickly release the pressure in the transport dewar and insert the open end of the transfer tube into the cryostat.
- 3) Lower the transfer tube until it reaches the bottom of the necktube. DO NOT push the tube into the cone on top of the magnet, or on the magnet support structure. Transfer liquid helium in the usual way.

If the helium level has fallen below 5% and the magnet is still energised there are two courses of action open:

- (i) If the level is below 0% or if the user is not certain that a careful transfer can be done DE-ENERGISE THE MAGNET, refill and then re-energise the magnet.
- (ii) Refill the dewar, but be careful as the syphon is introduced and as the transfer starts.

The cryogen boil-off test results are given in the results section.

2.10 Cooldown Fault Diagnosis

Helium level meter has erratic display whilst refilling.	Rotate helium level probe to prevent splashes of liquid helium entering the small breather holes in the probe.
Helium level probe has continual erratic display.	If demountable, remove probe and warm up to remove ice. If probe is not demountable warm system and pump out helium can for 24 hours.
During helium filling magnet temperature does not drop and helium will not collect.	There is liquid nitrogen from the precooling (which may have now frozen) in the helium can. Allow system to warm slightly and then repump the helium can. Check base pressure is less than 10 mB. Poor OVC vacuum - does the outside or the cryostat feel cold or has ice formed on the outside? - Repump and/or check for leaks.
Allen-Bradley resistances do not appear to correlate with calibration given (particularly at low temperatures).	Are you looking at the right calibration (100 Ω or 270 Ω)? If sensor is 100 Ω a high impedance meter is required otherwise resistance will appear to be less than it really is.
Liquid helium transfer tube (a) has ice spots on the exterior (b) has ice all over exterior	(a) Internal capillary is touching outer tube, continue to use if feasible, replace or return to factory for repair. (b) Loss of internal vacuum, repump as described on page 17, if supplied by Oxford.
Lack of vacuum in outer vacuum container of cryostat.	Leak on pumping system, isolate cryostat and check pumping system base pressure. Leak on dewar, use mass spectrometer to identify source of leak, check all 'o' rings for cleanliness (eg a human hair). Excessive moisture in the OVC - pump and flush with dry nitrogen gas several times then repump thoroughly - preferably 24 hours.

2.11 Superconducting Magnet

The magnet consists of a number of concentric solenoid sections together with compensating coils including shimming coils (when required to achieve the specified level of homogeneity). Each section is wound from multifilamentary superconducting wire formed from Niobium Titanium (NbTi) filaments surrounded by a stabilizing matrix of copper. High field magnets i.e. those with maximum fields of greater than 11 Tesla will be fitted with inner coil sections of Niobium Tin (Nb_3Sn). All sections are constructed to the MAGNABOND system, an integration of proprietary techniques, developed by Oxford Instruments, to give a structure which is both physically and cryogenically stable under the considerable Lorentz forces generated during operation. All the constituent sections of the magnet are connected to allow series energisation except when independently excited shims are fitted.

2.11.1 The Superconducting Switch

A superconducting switch is used to establish 'persistent mode operation', this is the temporary connection of a superconducting short circuit across the magnet leads when the magnet has the desired current flowing within. In this way the magnet may be set (persistently) at a given field, and the current in the supply leads reduced to zero. This will save a considerable amount of liquid helium due to the ohmic heating in the current leads.

The switch consists of a length of superconducting wire non-inductively wound with an electrical heater. The superconducting switch, as supplied, has this length of superconductor wired in parallel with the entire magnet. The superconducting wire is made resistive by raising its temperature using the heater. The switch is then in its open state and current, due to a voltage across the magnet terminals, will flow in the superconducting magnet windings in preference to the resistive switch element. The switch is in its closed state when the heater is turned off and the switch element becomes superconductive again. The process of establishing persistent mode operation of the magnet consists of energising the magnet to give the required field with the switch in the open state, closing the switch and then reducing the current flowing through the magnet current leads to zero, leaving the magnet in its previously energised state. The current flowing in the magnet windings remains constant as the magnet lead current is reduced, the current flowing in the closed switch then being the difference between the magnet and lead currents.

Magnets are specifically constructed for fast sweep applications may not be fitted with a switch, the advantages of this are a reduction of the boil-off whilst sweeping as switch heater current is not required, and, secondly, all the power supply current is forced through the magnet and is not shunted by the switch.

This shunt current would otherwise lead to non-linearity between the power supply current and the field, which may be undesirable for some applications.

2.11.2 Magnet Quench Protection

Protection resistors, and diodes if appropriate, are provided for all magnet sections, restricting the development of potentially high voltages in the event of a magnet quench (rapid conversion from the superconducting to the normal resistive state). The resistors also dissipate some of the energy stored in the magnet during a quench thereby reducing the energy dissipation within the magnet windings. The resistors are mounted on baffles attached to the magnet support structure or on plates above the magnet itself and hard wired or coupled to the magnet via an electrical connector. The connector will also incorporate the wiring for the superconducting switch heater, making it impossible to run the magnet without the protection circuit attached.

If barrier diodes are used in the protection circuit then, under limited voltage conditions, e.g. energisation or de-energisation of field and when the field is static, all the current passes through the magnet and ensures proportionality between energisation current and magnetic field. As no current is flowing through the protection circuit the heat load from the protection resistors and hence system boil off are reduced.

Under quench conditions, the barrier voltage is exceeded and the protection circuit shunts a proportion of the current away from the magnet windings.

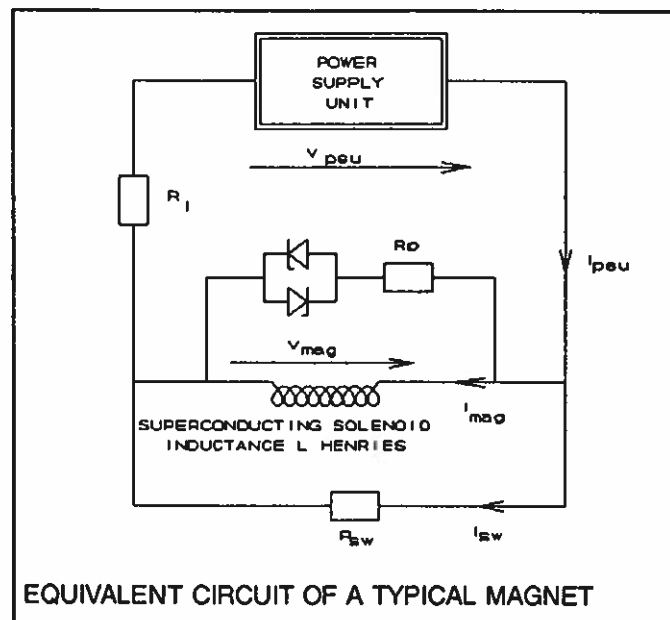
2.11.3 Equivalent Circuit of a Superconducting Magnet.

A Superconducting magnet can be considered to be a pure inductor, however connections from the power supply to the magnet will of course be resistive and a small voltage will be dropped along the length of the leads (typically < 0.7 volts for 5 metre leads at 120A) and along the leads inside the cryostat (typically 0.15 volts at 120A). This voltage will be roughly proportional to the current in the leads. It is a good idea to check these voltages and the cryostat boil-off, with the switch heater off (ie magnet not energised) and full current in the leads, after commissioning and any subsequent disassembly.

The switch will shunt a small amount of the magnet current whilst there is a voltage across the magnet i.e. when the field is changing. This current is minimised by running the magnet up slowly and using a high resistance (100 Ω) switch, a worst case may be energisation at 10 Volts (the maximum output voltage from a PS120-10) through 100 Ω i.e. 0.1A. For experiments requiring an extremely linear field versus current ratio, such as VSM measurements, a switch

may not be fitted.

The protection circuitry is generally fitted with special diodes and will not pass current until a certain voltage is exceeded. This is generally 4 Volts, however some special magnets and those designed for fast ramping may have a "protection voltage" of 10 Volts (or more if a special power supply is used, such as the PS120-20). Some small magnets and magnets designed for very infrequent running up and down may have no diodes. In this case the protection circuit will dissipate power whenever a voltage is present across the magnet terminals.



To run the magnet up to field a voltage must be applied to the magnet leads to overcome the inductance of the coil. The magnitude of this voltage will govern the speed at which the magnet will run-up, this is defined by the equation:

$$V_{mag} = -L \cdot \frac{dI_{mag}}{dt}$$

Where:

$$V_{mag} = V_{psu} - (I_{psu} \cdot R_{leads})$$

L is the magnet inductance given in the specification section.

For magnetic circuits with no iron (i.e. they are linear) the magnetic field at any point is proportional to the magnet current i.e.:

$$B = \frac{I_{mag}}{k}$$

k is the current to magnetic field ratio given in the specifications section.

2.12 Operating the Magnet

Check that the quench valve is in position on the outlet from the main bath, this is VITAL as a magnet quench liberates hundreds or thousands of litres of helium and any restriction on the recovery line or exhaust port could cause an explosion.

After cooling down the system and collecting liquid helium in the helium can the magnet is ready for energisation.

A magnet power supply is needed to energise the magnet. Typically an Oxford Instruments PS120-10, PS120-3 or PS120-10HS power supply would be used, however any power supply with the necessary current rating to achieve the full field of the magnet, and a voltage suitable to allow field sweeping at the desired rates may be used. The following instructions are general. Read the relevant Power Supply Unit (PSU) handbook for specific information. The magnet field strength is determined by the current available (the Tesla/Amp ratio is given in the specifications), while the voltage determines the rate of change of field (the inductance is also given in the specifications).

The magnet can be operated manually or under control of a computer. Three modes of magnet energisation exist namely:

Current control mode with voltage trip. This allows the solenoid to be swept to a set current or zero current at a constant rate of change of current, which with resistor-diode protection allows a constant rate of energisation. If the maximum output voltage of the power supply is not capable of energising the magnet at the set rate due to the sum of the inductive back EMF and the lead drop, the power supply will trip and go into the 'Hold' state ie energisation halts and can be restarted by the user at a lower sweep rate. All recent power supplies manufactured by Oxford Instruments work in this mode.

Current control mode with voltage limit. This is a similar mode to voltage trip constant current sweep rate but in the event of the voltage limit being reached, if the rate of energisation demands more voltage at the power supply than it is allowable, then the power supply will limit at that voltage but will continue to sweep to the set current.

Constant voltage. This allows the solenoid to be swept to a set current or zero at a rate dictated by a constant voltage at the power supply terminals, the voltage drop in the current leads and the inductance of the solenoid. This will not give a constant rate of energisation with increment of time and is therefore not of any interest for VSM experiments. It is mentioned here for historical reasons only and is now rarely used.

IMPORTANT Before initial use, and if the system has not been used for sometime the following measurements should be made, and compared with the quoted values.

1. Magnet continuity.
2. Magnet / cryostat, switch heater / cryostat, and magnet / switch heater isolation.
3. Switch heater resistance.

Suggested sweep rates are described in the specification section of this manual.

2.12.1 Running the magnet with a PS120-10, PS120-3 or PS120-10 HS Power supply.

The following instructions assume that an OXFORD INSTRUMENTS PSxxx-yytype magnet power supply is being used. (xxx defines the maximum current, yy defines the maximum output voltage).

The instructions that follow are sufficient to cover the basics of running a magnet. For more detailed instructions and description, consult the power supply instruction manual.

The PSxxx-yy allows operation of the magnet either manually or under control of a computer (using the RS232 link, or IEEE488 interface if the optional converter is fitted).

IMPORTANT: Before initial use, and if the system has not been used for some time the following measurements should be made, and compared with the quoted values.

- 1) Magnet resistance
 - 2) Magnet to cryostat isolation
 - 3) Switch heater resistance
 - 4) Switch heater to cryostat isolation
 - 5) Magnet to switch heater isolation
1. Before connecting the PSxxx-yy to the electricity supply, check the rating plate on the rear of the unit corresponds with the supply voltage being used. Now connect the magnet current leads and the persistent mode switch heater lead to the terminals inside the rear cover of the power supply.
 2. Connect the leads to the cryostat magnet terminals and the appropriate

ten pin seal. Check for electrical isolation from the cryostat.

3. Switch on the magnet power supply. The power supply will indicate successful initialisation by displaying the firmware version eg 'PS2.04', then 0.00.
4. Select the mode of display required, this can be in Amps or Tesla by pressing the button labelled CURRENT/FIELD (the ratio of these is set in the software for a given magnet).

Set the current or magnetic field to which the magnet is to be energised by pressing the RAISE and LOWER buttons on the ADJUST panel while depressing the SET POINT button on the DISPLAY panel. Set the rate of change in a similar way by pressing RAISE and LOWER while depressing the SET RATE button. Please consult the results section of this manual for advised energisation limits.

5. If the magnet is equipped with a persistent mode switch, press the HEATER ON button on the SWITCH HEATER panel. The button should be pressed, the indicator light will come on. Wait 30 seconds to allow the switch to heat up before proceeding.
6. The magnet energisation can now be started by pressing the SET POINT button on the SWEEP CONTROL panel. The current or field will be seen to increase on the digital display and the output voltage will have been seen to kick over to the voltage needed to overcome the magnet impedance on the analogue meter (if fitted, ie not the PS120-3).
7. When the set point has been reached, the switch heater can be turned off by pressing the HEATER ON button again. After waiting about 30 seconds for the switch to become superconducting, press the ZERO button on the SWEEP CONTROL panel. The current in the magnet leads will decrease to zero leaving the magnet, still energised, in persistent mode. The rate at which the leads alone can be swept is faster than the magnet and leads, this is automatically taken into account in the power supply firmware.
8. The magnet can be taken out of persistent mode by using the following procedure:-
Pressing the SET POINT button on the SWEEP CONTROL panel (the

switch heater is left 'off'). The current leads will be swept at a fast rate to the Set Point value. Turn the switch heater current 'on' by pressing the HEATER ON button. Wait 30 seconds for the switch to warm up. Press the ZERO button on the SWEEP CONTROL panel and the magnet will start to de-energise. The Set Rate can be increased during the sweep without stopping.

If it is desired to change the value of magnetic field, sweep the current leads to the present current or field of the magnet, press HOLD, open the switch by turning on the heater. Press the SET POINT button and RAISE and LOWER to change the Set Point to the new desired value. Make changes to the Set Rate of sweep in a similar manner. Press the SET POINT button on the SWEEP CONTROL panel and the magnet will either energise or de-energise to the new field.

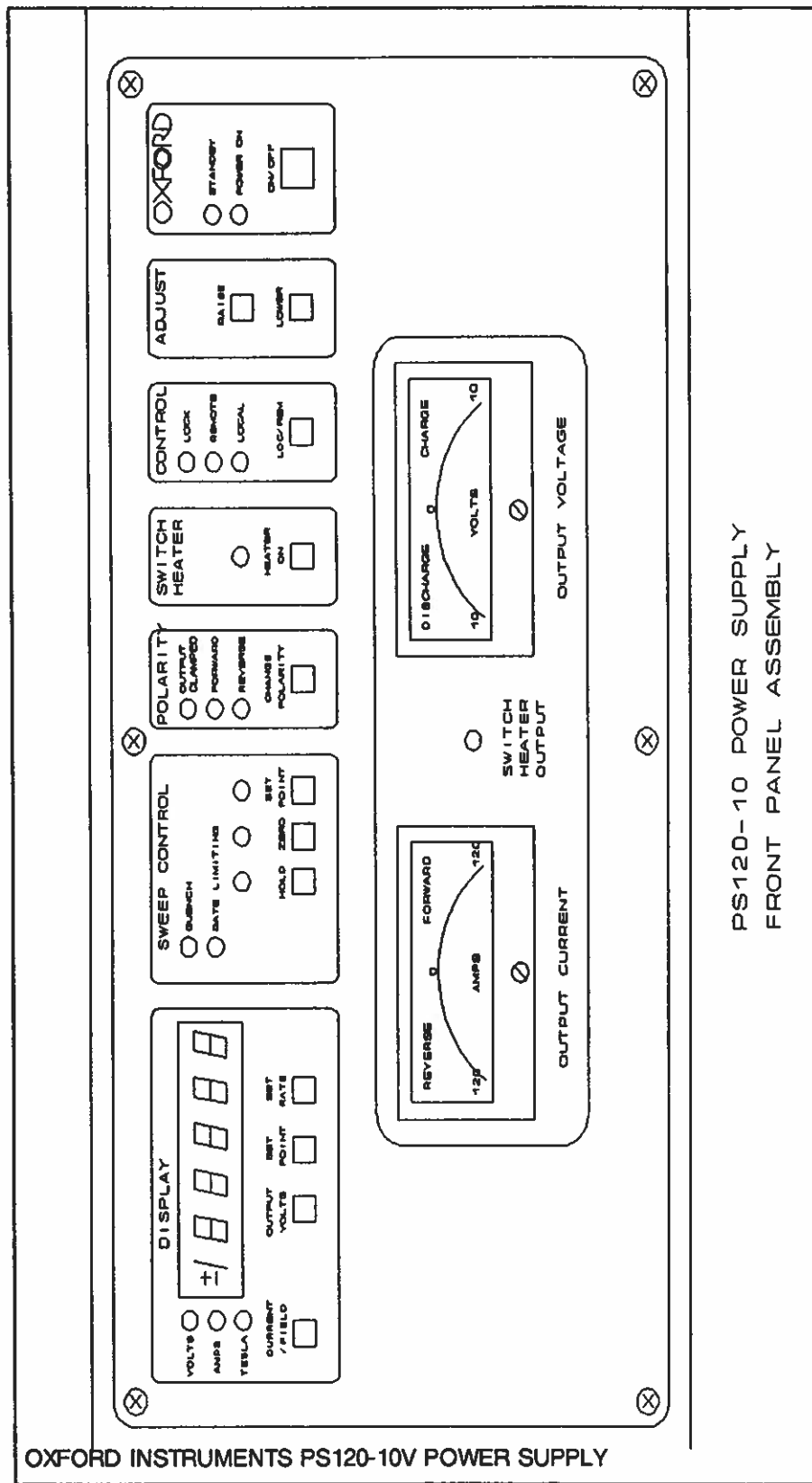


If the voltage needed to drive the magnet at a given rate is such that the maximum voltage of the power supply will be exceeded, the power supply will trip into the 'Hold' mode, and the HOLD light will illuminate, on the SWEEP CONTROL panel. The sweep can continue, after a slower rate has been selected, and the SET POINT button has been depressed.

In the event of a magnet quench, the power supply will trip to zero amps and the **QUENCH** light will illuminate.

A diagram of the front panel layout is shown in the diagram on page 31.

Useful facilities on the PSxxx-yy power supplies include automatic running down of the magnet (whatever state it is in) if the helium level falls below a threshold value. Please see the power supply manual (See Autorundown section).



OXFORD INSTRUMENTS PS120-10V POWER SUPPLY

PS120-10 POWER SUPPLY
FRONT PANEL ASSEMBLY

2.12.2 Current control mode with voltage limit or trip

NOTE; This mode is **not** used with Oxford Instruments power supplies and is included for information only.

1. Connect the magnet leads and persistent mode switch heater leads. Check for electrical isolation from the cryostat.
2. Switch on the magnet power supply, then set the power supply to constant current mode, with voltage limiting or trip.
3. Set the output voltage limits to the required level on the power supply.
4. Set the current for the required field on the power supply and the current sweep rate. (N.B. this may change several times during a sweep, the actual sweep rates are defined in the specifications section).
5. Turn the switch heater ON wait 30 seconds. Start the sweep to field by allowing the current output of the power supply to start sweeping on the power supply.

6. When the magnet has reached field and the voltage at the power supply has died away to the voltage drop in the current leads, turn the switch heater OFF. Wait 30 seconds, then sweep the current from the power supply back down. The sweep rate is not critical. This will cause the leads to run down leaving the magnet in persistent mode.

If the ramp rate is too high the voltage across the magnet will exceed the set positive voltage. This will either cause the power supply to continue energisation but at a rate dictated by the set voltage, or trip and allow the magnet current to decay at a rate dictated by the negative set voltage. The mode in which the power supply is set will dictate which of these two cases will apply.

To take the magnet out of persistent mode:

- 1) With the switch heater OFF, run the leads to the set current.
- 2) Turn the switch heater ON and wait 30 seconds.
- 3) Re-set the current sweep rate required for de-energisation and allow the power supply current to sweep down. The magnet will sweep to zero amps at the prescribed rate providing it is less than that allowed by the negative voltage setting.

IMPORTANT: If the magnet has been left in persistent mode and the power supply disconnected, briefly short circuit the output current terminals of the power supply before re-connecting.

Extreme care must be taken to ensure that the current leads are re-connected with the correct polarity. If any doubt exists as to the correct polarity, it is preferable to use the emergency de-energisation procedure, rather than attempt to de-energise the magnet in the conventional manner.

2.12.3 Constant voltage mode

NOTE; This mode is not used with Oxford Instruments power supplies and is included for information only.

1. Connect the magnet leads and persistent mode switch heater leads. Check for electrical isolation from the cryostat.
2. Switch on the magnet power supply.
3. With the switch heater off, sweep the power supply to the current required. The sweep rate used is not critical. When the required current is reached measure the voltage at the power supply output terminals. This is the resistive voltage drop in the magnet leads and should be noted.
4. Sweep the power supply back to zero amps. This will sweep the leads down to zero amps.
5. Turn the persistent mode switch heater on, wait 30 seconds for the switch to open.
6. Turn the positive voltage setting to a value that is the resistive voltage drop plus the required magnet charging voltage. Allow the power supply to sweep the magnet to field.
7. Turn the switch heater off and wait 30 seconds.
8. Turn the negative voltage setting on the power supply to 0.5V and allow the power supply to sweep down. This will cause the leads to run down, leaving the magnet in persistent mode.

To take the magnet out of persistent mode:

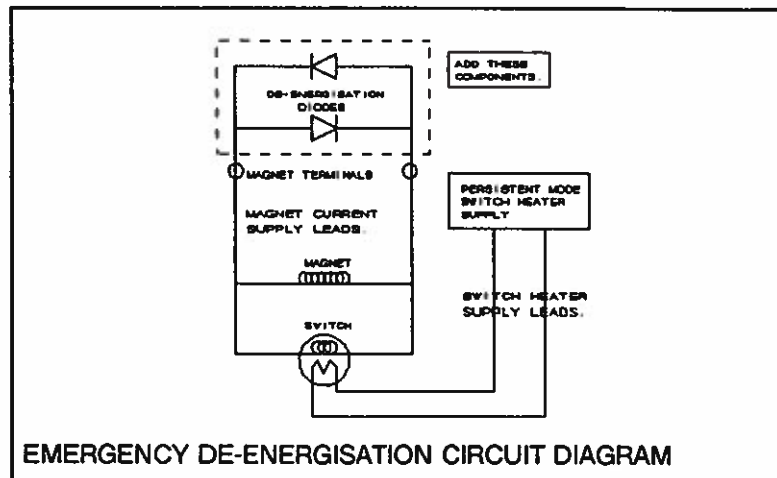
1. With the switch heater OFF sweep the leads to the previously set current.
2. Turn the switch heater ON, wait 30 seconds.
3. Sweep the power supply back to zero amps. The sweep rate is not critical. The magnet will then sweep down to zero current. Turn the switch heater off to conserve helium.

2.13 Emergency De-Energisation Procedure

IMPORTANT: AT NO TIME SHOULD THE MAGNET TERMINALS OF A PERSISTENT MAGNET BE HELD, BECAUSE IN THE EVENT OF THE MAGNET QUENCHING HIGH VOLTAGES COULD BE DEVELOPED. EXERCISE GREAT CARE IN THIS PROCEDURE.

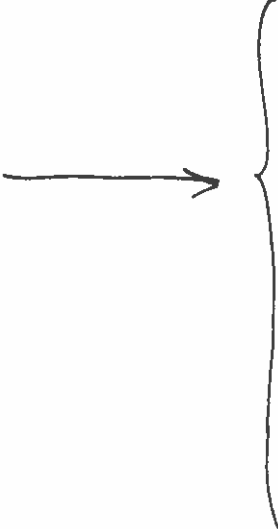
In an emergency, for instance when the polarity of the current leads is unknown the magnet may be safely run down to zero with an Oxford Instruments PSxxx-yy (except the PS120-3) simply by switching off the power supply, switching it back on again (it will now be in 'output clamped' mode) and then activating the switch heater. The magnet will run down slowly at a rate governed by the lead resistance and the magnet inductance.

If no Oxford Instruments PSxxx-yy power supply is available the magnet may be de-energised by carefully connecting a pair of diodes across the terminals as shown in the figures following. Activate the switch heater using either the (switch) power supply or from a separate 6 volt battery. The switch heater current required is given in the magnet specifications. The magnet will de-energised at a rate determined by the forward voltage drop of the diode. The de-energisation will be slow, eg about 100 minutes using silicon diodes. Care should be taken not to disconnect the diodes before de-energisation is complete. **The diodes must be capable of carrying the full operating current of the magnet and must be fixed to an adequate heatsink.** De-energisation is complete when the voltage across the diodes drops to zero. Instead of using diodes the current leads may simply be connected together, however this should only be used as a last resort. It is very difficult to know when the current in the magnet has fallen to zero, and to break this short circuit with current flowing would be very dangerous. The decay rate is very slow indeed and may take several hours to reach zero depending on the lead resistance and the magnet inductance.



2.14 Magnet and Power Supply Problem Diagnosis

<p>Magnet quenches once or twice</p>	<p>Minor settling in transit sometimes requires a magnet to be partially retrained during installation. Check energisation rates are as recommended. Top-up with liquid helium and rerun.</p>
<p>Magnet persistently quenches</p>	<p>It is possible that frozen nitrogen is trapped round the magnet introducing high stresses to the superconductor. Either warm up the system, recool, and rerun, or remove the liquid helium allow helium can to warm to $> 77K$ and repump, check base pressure for indications of the presence of LN^2. Are there any nearby ($< 1m$ away) large ferromagnetic objects - including mild steel optical benches and floor reinforcing rods?</p>
<p><u>Switch quenching</u> The symptoms for this are that when the leads are run down to zero with the magnet persistent the display will flash, change value, and then go into the hold mode, this is alarming but not dangerous.</p>	<p>The power supply is programmed so that any unexpected voltages across the leads when the magnet is persistent (perhaps due to switch quenching) will cause the power supply to try to 'catch' the magnet as it de-energises, this it will do before going into the stable 'hold' state. The magnet must now be rerun to field, put persistent again and the leads run to zero again. If this problem persists it can sometimes help to slow down the rate at which the leads are run down. See power supply manual.</p>
<p>Switch heater light will not come on when the button is pressed.</p>	<p>The power supply keeps track of the field at which the magnet is set, even when the leads have been run down to zero with the magnet persistent. If the leads are run to a current which does not correspond to the current at which the power supply 'thinks' the magnet is energised then the switch heater operation will be inhibited. The display of the digital meter will briefly show the assumed current / field as the switch is depressed. Override occurs if the switch is held down for more than 4 seconds.</p>



2.15 Magnet Electrical Access

Single current terminals or coaxial pairs are provided on the cryostat for attachment of room temperature current leads. Internally the current leads take the form of brass tubes shunted at their lower end by superconducting wire and 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

IMPORTANT On no occasion should the current leads inside the cryostat be modified or any electrical connectors be unscrewed or removed. Serious damage to the magnet may result.

The magnet temperature and lambda point refrigerator performance (if fitted) are generally monitored with Allen-Bradley carbon resistors. An appropriate ten pin electrical seal is provided on the cryostat OVC, service neck or magnet support plate.

The superconducting switch heater will also be wired to a ten pin electrical seal.

2.16 Independent Shims and Current Settings.

The independent shim set is provided on the magnet to achieve a higher level of field homogeneity than is possible by using only series connected shims (generally it is used to achieve 1 part in 10^6 homogeneity over 10mm dsv from a basic magnet with a nominal homogeneity of 1 part in 10^5). If the experiment being performed is based on NMR signals then it will be possible for on-site shimming to be performed which would further optimise the field homogeneity eliminating any small variations caused by nearby pumps, structural steel etc.

Basic magnet homogeneity;

Plotted over line / volume	Homogeneity
± 10 mm on axis	~ 1 in 10^4
40 mm radial	< 2 in 10^4
Total variation over \sim mm dsv	—

Shimmed magnet homogeneity;

At ± 5.25 T.

Plotted over line / volume	Homogeneity
± 10 mm on axis	1 in 10^5
40 mm radial	1 in 10^4
Total variation over \sim mm dsv	—

The independently energised superconducting shims should be set to the following currents using the 20 amp SPS10 shim power supply.

These nominal settings were found to be satisfactory on testing of the magnet system in the factory. Slight enhancements in the on site homogeneity may be possible by altering some of the currents slightly to eliminate the effects of the local ferromagnetic environment. This will be only possible if there is a suitable NMR signal available.

Field strength (Tesla)	Independent Shim Currents								
	Z0	Z1	Z2	X	Y	ZX	ZY	X ² -Y ²	XY
5.25T	-	-16A ^(*)	-10A ^(**)	-	-	-	-	-	-
-5.25T	-	+16A	+10A	-	-	-	-	-	-

Please see shim power supply instructions for details of operation.

(*) in the case tests change to -0.25A = -25A

(**) -11- -12A

Note: The shims are series coupled
There are ??

2.17 Independent Shim Wiring Diagrams

See ALD0023 Supplied separately.

2.18 System Closedown

Temporary Closedown

If the system is to be left unattended for any length of time (eg over a weekend period) it is preferable, but not absolutely necessary to de-energise the magnet. However, the following precautions **MUST** be taken to ensure system safety.

- 1 Ensure that the cryostat contains sufficient helium to last for the required period.

- 2 Ensure that the nitrogen reservoir is full, and arrangements have been made to ensure topping up if necessary.

- 3 Ensure that there is no chance of the helium or nitrogen exhaust ports becoming blocked or iced up. The helium exhaust should be connected to a helium recovery system or vented through a one-way valve.

In order to minimise helium consumption the lambda point fridge needle valve should be firmly closed and the fridge evacuated (if a lambda fridge is fitted).

Warming the system

Before warming the system, it is imperative that there is no trapped volume of gas or liquid within the cryostat. In particular the lambda point fridge exhaust port needle valves should be opened and linked to the main bath exhaust. (Alternatively the valve can be closed off and the fridge pumped out continually during the warming procedure).

Having adopted the above precautions, and with the magnet de-energised the system can simply be allowed to run out of liquid helium and nitrogen, and left to warm up. If a rapid warm up is desired either transfer the helium out of the cryostat into a transport dewar or insert the blowing out tube into the transfer tube entry port and gently pass DRY helium gas through it. This will boil-off the remaining liquid. Remove the liquid nitrogen by passing a stainless steel tube through one of the filler tubes and blocking off the other two fillers. This will pressurise the container and blow out the liquid.

Having removed all the cryogenic liquids the system can be warmed by softening the vacuum. Leave for 1 hour to let the magnet warm towards 77K.

Slowly allow 1 bladder full of DRY nitrogen gas into the OVC or admit it until approximately 10 millibar is reached, close off the evacuation valve.

Non preferred method: With the vacuum valve closed, blow some helium gas into the pipe attached to the valve. Place a rubber bung on the end of the pipe, then open the valve and close it again. This technique ensures that only a small amount of helium gas enters the vacuum space, so that the warming up process is not too violent. Ensure that the relief valve is unobstructed. This technique is very effective, but afterwards great care must be taken to flush the helium out of the superinsulation. Do not under any circumstances attempt this method with vapour shielded dewars as they contain very large quantities of superinsulation making flushing difficult.

2.19 Typical Installation Requirements

The requirements below include items that may be purchased with Oxford Instruments spares kits.

PHYSICAL.

Hoist or Crane	1000kg minimum safe working load to allow lifting height of 3 metres.
Lifting sling and shackles	To suit eye bolts.
Trolley with wheels	Necessary if lifting equipment is not in laboratory. The system must be removable from the trolley for magnet running.
Wooden platform	Strong enough to stand the system on. It should be 25 cm high and is needed if it is suspected that the floor has steel reinforcing.
Personnel protection	Hazard warning signs, barriers and controlled entry systems as applicable to the environment.
Electricity supply	Single phase, several sockets needed.

TOOLS.

Spanners	Open ended. Metric.
Allen Keys	Metric set.
Screw Drivers	Various sizes.
Roll of Mylar Adhesive Tape	
Roll of Aluminium Adhesive Tape	
Tube of Vacuum Grease	
Pair of Cotton Gloves	
Boxes of Tissues	
Indium Wire	1 mm diameter (about 2 metres)
Rubber Bladders	2 needed.
Hot Air Gun / Electrical Soldering Iron - 75 Watts / Digital Multimeter	
Rubber and Plastic Tubing	0.375 ins (9.6 mm) bore diameter. 10 metres required.

VACUUM DEVICES.

Oil mist filters	Fitted to all pump exhausts to eliminate possible carcinogenic vapours.
High Vacuum Pump	Ideally fitted with penning gauge, capable of evacuating to less than 10^{-6} mB. (Can be diffusion pump fitted with Nitrogen cold trap, or turbomolecular pump). Pumping port should be 50mm diameter minimum.
Leak Detector	For checking indium joints.

CRYOGENIC VESSELS AND FITTINGS.

Liquid Nitrogen	In self pressurising dewar. (300 litres typically)
Liquid Helium	In self pressurising dewar. (300 litres typically)
Helium gas	For flushing system. Can use gas for storage dewar or from a gas cylinder.
Helium Transfer Tube	Oxford Instruments standard diameter is 0.375 ins (9.6 mm).
Laboratory Clamps	To suit rubber tube.

Vacuum Fittings :-

NW10 Clamps, "O" Ring Carriers, Christmas tree fitting,
NW25 Valves (Edwards Speedivac recommended),
NW25 Clamps, "O" Ring Carriers, Tees, Elbow, Christmas Tree fitting,
NW25/10 Adaptor
NW40 Clamp, "O" Ring Carrier, NW40/25 Adaptor
Pumping Lines NW25 each end, 2.5 metres long, 20 mm bore.

2.20 Assembling and Dismantling the System

Initial assembly will be done by an Oxford Instruments technician. It is important that the system is treated with respect, this is particularly important when moving the system.

Moving the system any appreciable distances ie to a new laboratory on a different floor of the building or to a new building should be done with the transit packing in position. It is highly recommended that this is done by an Oxford Instruments technician.

Brief Initial assembly (installation).

1. The cryostat will arrive at the customer's site with internal packing to prevent transit damage to the delicate internal tubes etc. The first job is to remove the internal packing, support the cryostat top plate, on a crane using the lifting eyes on the top flange, unscrew the bolts holding the magnet OVC tail in position, carefully remove the OVC tail, taking care as it is heavy.
2. The same should now be done with the tail radiation shield, packing pieces (usually marked red) will be found between the helium can and the nitrogen shield and between the nitrogen shield and the OVC. All these packing pieces should now be removed so that there is no connections visible between the OVC, nitrogen shield or helium can.
3. The tails are now refitted, care must be taken to ensure that the radiation shields do not touch the magnet can or OVC. Radial and axial location is provided with the screws provided.

Disassembly.

1. With the cryostat at room temperature fill the sample spaces with dry nitrogen gas or dry air, then fill the O.V.C. (outer vacuum can) with the same gas, slowly.
2. Disconnect all wiring from the top of the cryostat.
3. Disassembly is now the reverse of the procedure for assembly above.

If any problems are encountered please telephone the Oxford Instruments Agent's service department or Oxford Instruments directly.

2.21 System Wiring Diagram

See ALD0023 Supplied Separately.

SECTION 3- TEST RESULTS

3.1 Magnet Test Results

Magnet performance specifications		Specified	Achieved	
Maximum central magnetic field at 4.2 Kelvin		5.1 T	5.25 T	
Current for specified field at 4.2 Kelvin		76.06 A	78.30 A	
Field / current ratio (Tesla/Amp)			0.06705	
Homogeneity (in 10mm dev) 20mm x 80mm ϕ		1 in 10^4	1 in 10^4	
Other homogeneity requirements		-	-	
Switch heater current				
Current decay in persistent mode		< 1 in 10^6 / hr	< 6 in 10^7 *	
Clear bore diameter			~ 110mm	
Clear split access and dimensions			40mm x 100mm	
Magnetic field centreline from base of magnet / system			On optical c/L **	
Nominal inductance			71 H	
Superconductor type			NbTi	
Superconducting switch resistance			100 Ω	
Resistance specifications		300K	77K	4.2K
Magnet resistance; Start - finish **		51.6 Ω		
Superconducting switch heater resistance		112 Ω		104 Ω
Isolation at 500V	Magnet windings - ground	> 2.3 M Ω		3 M Ω
	Magnet windings - Switch heater	∞		∞
	Switch heater - ground	∞		∞

** Magnet start - end resistance is measured with the magnet in its system cryostat, where provided, with its protection circuit and switch (if fitted) connected in parallel with it. In general the switch resistance will be much lower than the resistance of the magnet windings and so will dominate this reading.

* Decay after only 2 hours. This would be expected to improve with increased time.

** when cold.

Oxford Instruments Description of Work

7 Oct 92

The magnet cryostat was unpacked and assembled, leak checked and then cooled.

The magnet was run to 5.1 T (using only Z₂ switch heater).

The magnet was run 4 more times at a maximum rate of 4 Am².

The magnet and Z₁/Z₂ shims were put persistent and left over night.

The SPS20 heater output was increased and the magnet swept to 5.1 T with all heaters on.

The cryostat boil off was: 3.23 lmi³ He gas @ 48%
5.6 lmi³ N₂ gas @ 95%.

The magnetometer was calibrated with a span of 5.1 T

The temperature indicator was recalibrated

The magnet problem was caused by the Z₂ shim switch not opening when all the switch heaters were on. Therefore the Z₂ shim would couple with

the magnet as it was swept. The current induced was enough to quench the Z₂ shim, giving voltage kicks and high boil off from the cryostat.

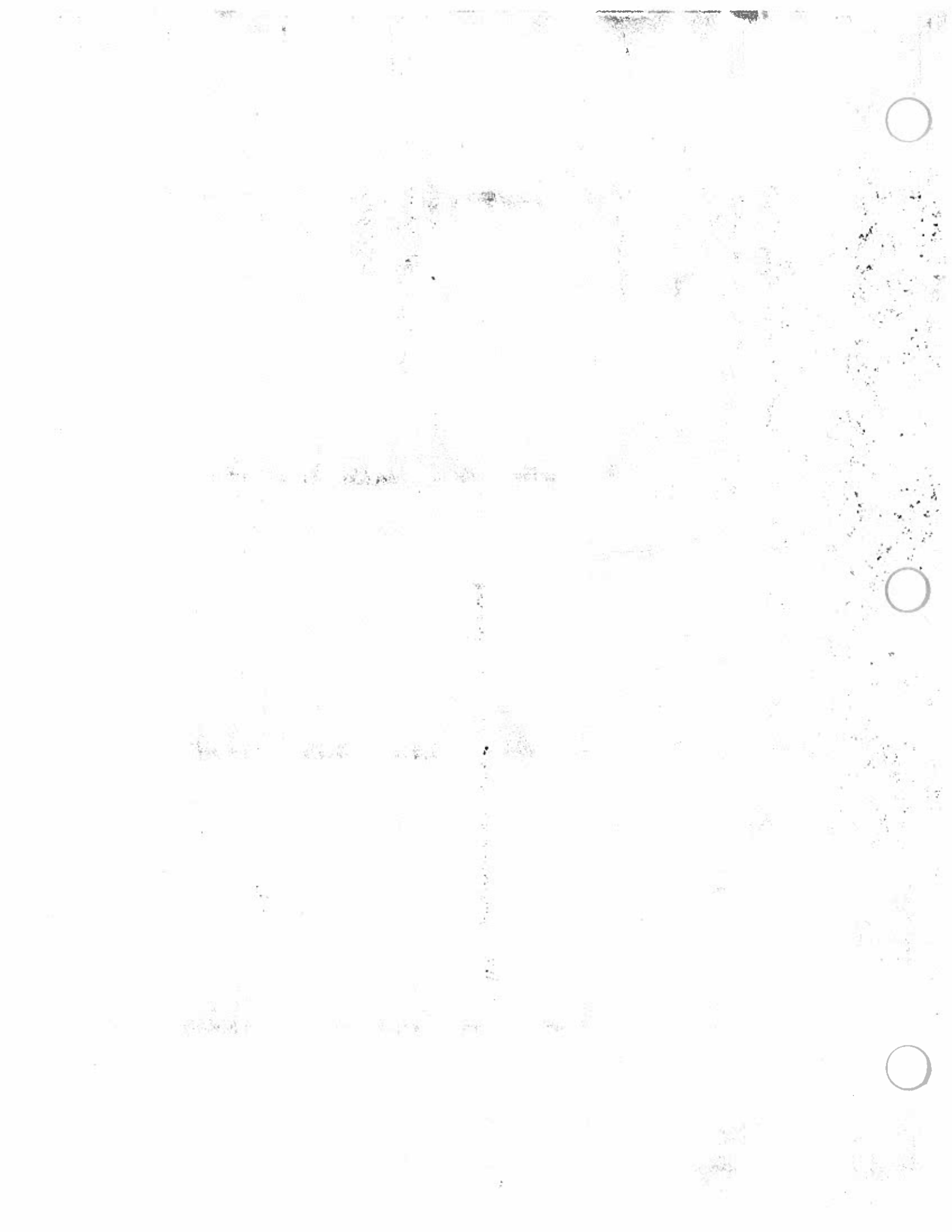
By changing the SPS20 voltage to 220V the heater output has increased from 32 to 36 mA with all the heaters on (36 → 41 mA with just the Z₂).

Now the magnet can be swept with either all heaters on or just the Z₂ heater on.

7 Oct - 92

Seppo Penttila
SEPP0 PENTTILA

CW Mitchell



ELECTRICAL CHECK.

PENTILA

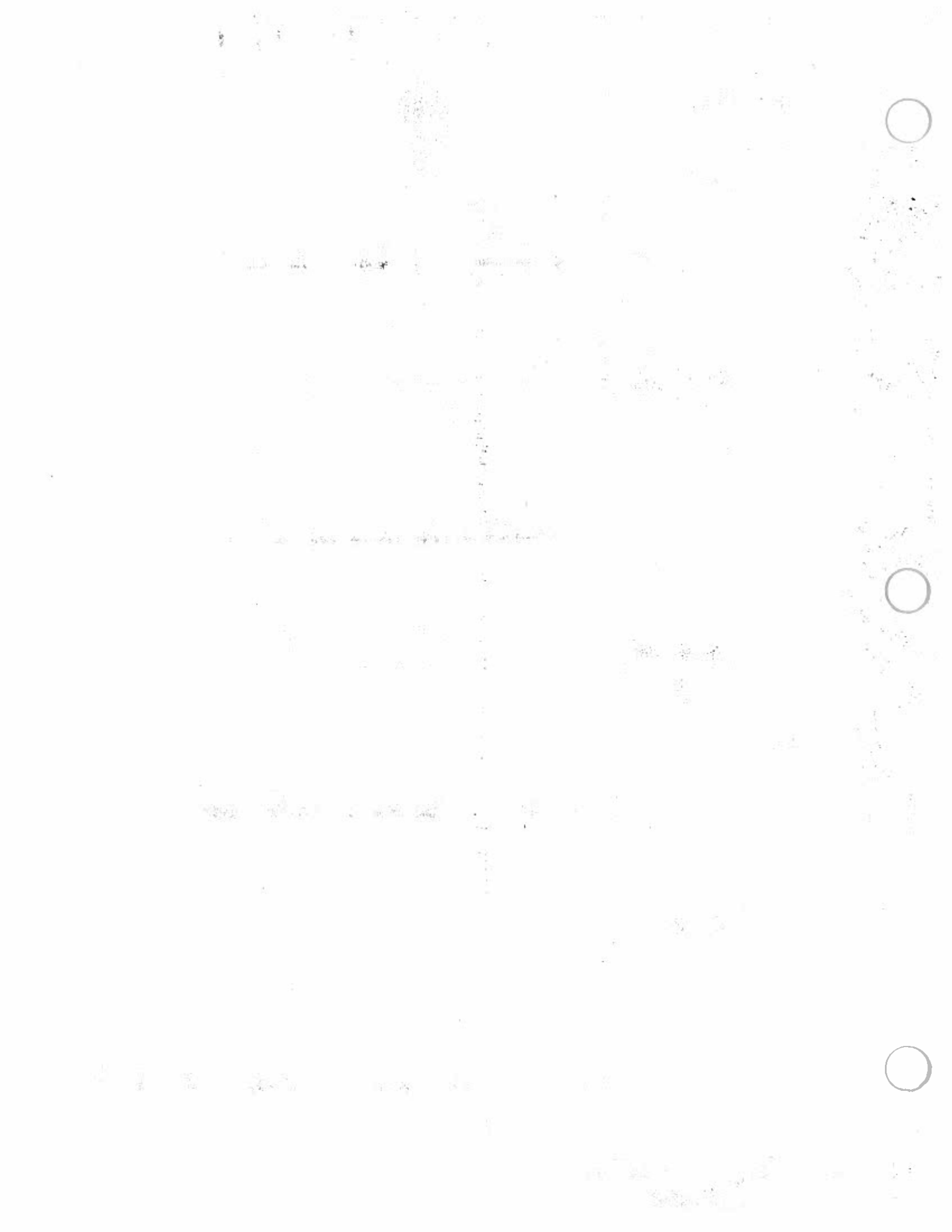
6/5/92

MEASUREMENT	VALUE	VALUE	VALUE	VALUE
MAGNET S-E	51.8Ω @ RT	41.4Ω @ 77K	0	@ 4.2K
S-grnd	>20M	>20M	>20M	
WITH HEATERS 10B-1A	112.3Ω	110.9	104	
-3A	110.6	109.3	100	
-4A	111.3	109.4	100	
-5A	111.5	109.6	100	
-6A	111.0	109.1	101	
-9B	113.7	112.4	105	
10B-grnd	>20M	>20M	>20M	
-may	>20M	>20M	>20M	
1,2B - 4,5B	27.7Ω	9.0Ω	0	
1B - grnd	>20M	>20M	>20M	
1B - 10B	>20M	>20M	>20M	
WLEN 1 3c-4c	310Ω	342Ω	365	4.88 KΩ
RADLETS 2 -5c	320.9	396	385	4.91
3 -6c	347.0	415	414	4.97
4 -7c	343	421	418	5.01
-grnd	>20M	>20M	>20M	>20M
5 3D-4D	353	419	419	
6 -5D	357	433	444	
*7 -6D	351	391	407	
*8 -7D	389	447	432	
*9 -8D	325	397	390	
*10 -9D	351	414	404	
-grnd	>20M	>20M	>20M	
LN ₂ HEATERS 1E-2E	35Ω	34		
3E-2E	35	33		
HALL 7E-8E	2.5	2.1		
PROBE -9E	2.5	2.1		
-10E	2.5	2.2		
-grnd	>20M			

* Note new positions

3.92
5.61
4.78
5.71

New Values
7 Oct 1992
CWM.



C, D

SENSORS.

PENTTILA

6/5/92

- | | | |
|----|--|----------------------------------|
| 1 | Top He ₄ can | |
| 2 | Bottom He ₄ can | |
| 3 | Top magnet | |
| 4 | Bottom magnet | |
| 5 | Heater block on side with blowout tube | |
| 6 | " " " " without " " | |
| 7 | Bottom N₂ tail | N ₂ jacket |
| 8 | By window on N₂ tail | N ₂ jacket |
| 9 | N₂ jacket | By window on N ₂ Tail |
| 10 | N₂ jacket | Bottom of N ₂ tail. |

7 Oct '92

E N₂ Heaters to remove precool N₂ from magnet.

- 1-2 side with blow out tube
 2-3 " without " " "

~1A.

Pass 30V through pins 2-3, watch the temperature change on sensor 6, and the boil off of N₂ gas from the cryostat (~10.5 lmi) when the liquid N₂ has been boiled off the sensor will show a sharp increase in temperature and the flow rate will drop. This will take about 3 hours.

drawings



Allen-Bradley sensor resistances.

Position of Allen-Bradley Sensor	Connector / pins	Resistance at 300K	Resistance at 77K	Resistance at 4.2K
1 He Can Top.	C C-D	313 Ω	342 Ω	4.88k Ω
2 He Can Bottom.	C C-E	323 Ω	396 Ω	4.91k Ω
3 Magnet top.	C C-F	349 Ω	420 Ω	4.97k Ω
4 Magnet bottom	C C-H	344 Ω	418 Ω	5.01k Ω
5 LN ₂ heater block	D C-D	370 Ω	378 Ω	4.1k Ω
6 LN ₂ heater block	D C-E	362 Ω	439 Ω	4.4k Ω
7 LN ₂ tail bottom	D C-F	342 Ω	355 Ω	(383 Ω)
8 LN ₂ bore tube end	D C-H	369 Ω	379 Ω	(409 Ω)
9 LN ₂ Jacket.	D C-J	347 Ω	396 Ω	(412 Ω)
10 LN ₂ Jacket.	D C-K	332 Ω	381 Ω	(398 Ω)

Heater blocks are in the connectors:

E
E 1-2
2-3

* {

Values in brackets when system at 4.2k not the sensor.

Magnet energisation

When the magnet and cryostat have been cooled to 4.2 Kelvin the energisation procedure can begin (see section describing magnet energisation for details).

Current in leads (Switch heater not energised)	Voltage across leads (at cryostat)	Voltage across leads (at power supply)	System boil-off
78A	0.182V.	2.92V	8 l/min flow gauge 7 l/min CHAL gauge

(stable after 8 minutes).

* These heater-block sensors are to assist with the energisation of the heaters on the helium can used to remove the liquid nitrogen. They should be monitored when the heaters are energised, when the sensed temperature starts to rise the nitrogen has been removed.

The first run refers to runs after initial commissioning and runs from warm. The second runs are when the magnet is being re-energised after having been kept cold.

Current / Amps		Energisation rate / Amps min ⁻¹	Approximate time / minutes	
1st run	2nd Run		1st Run	2nd Run
		12		
	0-76.06	5		15.2
0-59		2.4	24.6	
59-71		1.2	10	
71-74		0.6	5	
74-76.06		0.24	8.3	
		Total	~ 50	15.2

(9V at PSU).

Absolute maximum energisation voltage across cryostat terminals.	10 Volts
Rate at which magnet leads may be run down (magnet persistent).	200 Amps/min
Leads may be run up again at the same rate.	
Maximum rate at which magnet may be run down.	5 Amps/min

Test Engineer... MJ / ATB Date... 27-3-92

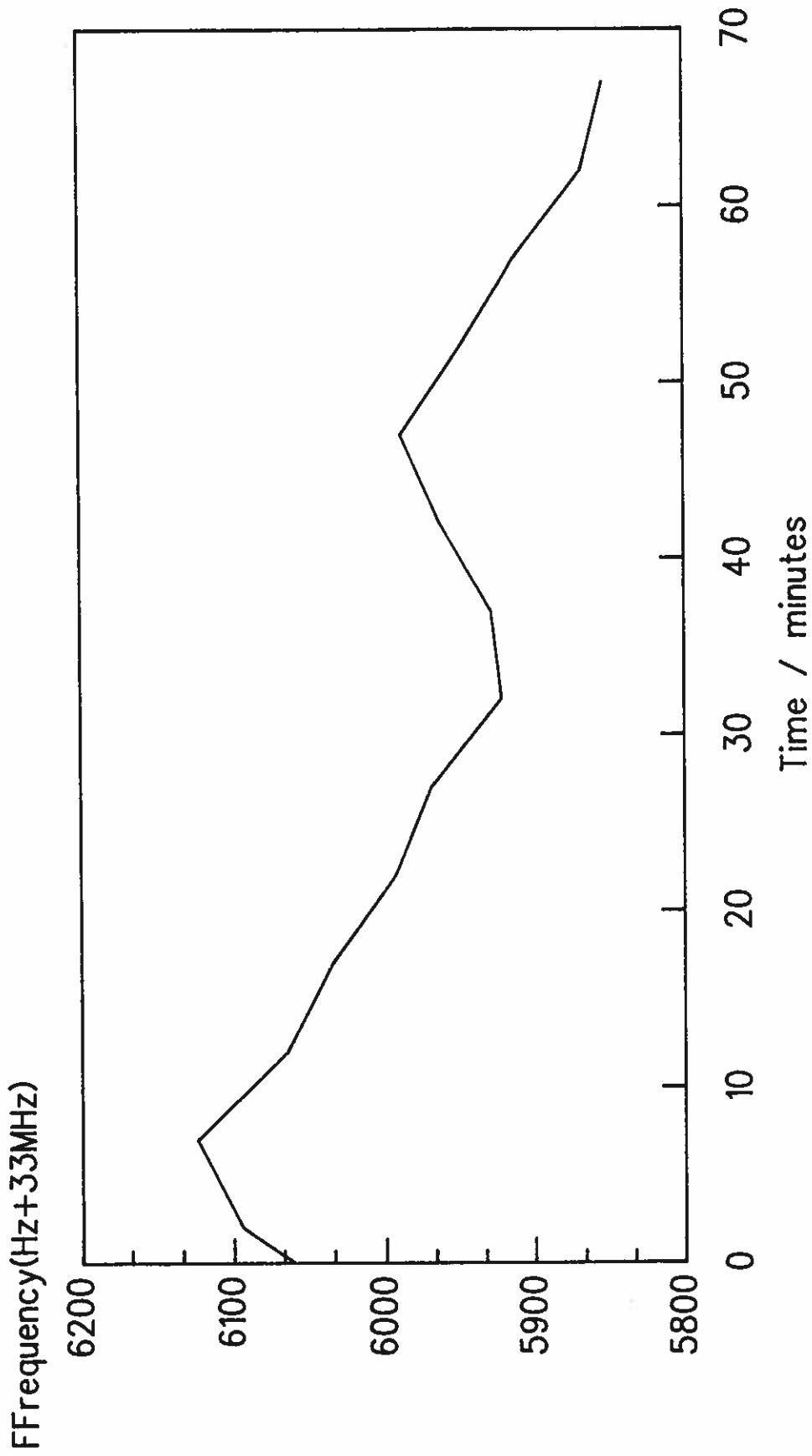
Field Modulation

Field may be modulated at full field by $\pm 1\%$ at 5 A/min.

PSU stability

The power supply was found to be stable.

Power Supply Stability Trial (NMR)
PS120-10HS - P/N 35092 - Dr Penttila



Water had been running for 2 hours.
Current had been flowing for 30 minutes

3.2 Cryostat Test Results

CRYTEST.FRM

Cryostat performance specifications	Specified value	Value achieved
Liquid helium boil-off (static)		< 400 cc/hr
Liquid helium boil-off (full current in leads)		< 650 cc/hr
Liquid nitrogen boil-off		600 cc/hr.
Liquid helium hold time (Static)		~ 250 hrs.
Liquid nitrogen hold time		~ 150 hrs.

Cryogen Cooldown Volumes Required During Testing in the Factory.

Cryogen	Volume (Approx)
Liquid Helium	200 - 300 litres.
Liquid Nitrogen	300 litres.

CRYOSTAT VACUUM AND LEAKRATE.

(System only pumped for 12 hours before cooldown).

Vacuum : 1×10^{-5} mB and falling.

Leakrate : $< 10^{-7}$ mB L/sec.

3.3 Field Profile

The magnet field to current ratio was measured with a Hall probe in a test cryostat which contains a set of room temperature insert tails. The Hall probe is calibrated against an NMR probe in an NMR magnet to ensure the accuracy of the measurements (an NMR probe being accurate to at least 1×10^{-6} while the Hall probe is only accurate to at best 1×10^{-4}). (Magnets $\leq 1 \times 10^{-5}$ homogeneity in a 10mm dsv are plotted exclusively by NMR probe).

The predicted field plots obtained are shown overleaf. It should be noted that the 'distance along the axis' is relative to the test cryostat not the magnet, the actual field centre is given on the magnet specification page.

3.4 Field Plots

Plotting frequency = 33.447 MHz.

Data points are in Hz.

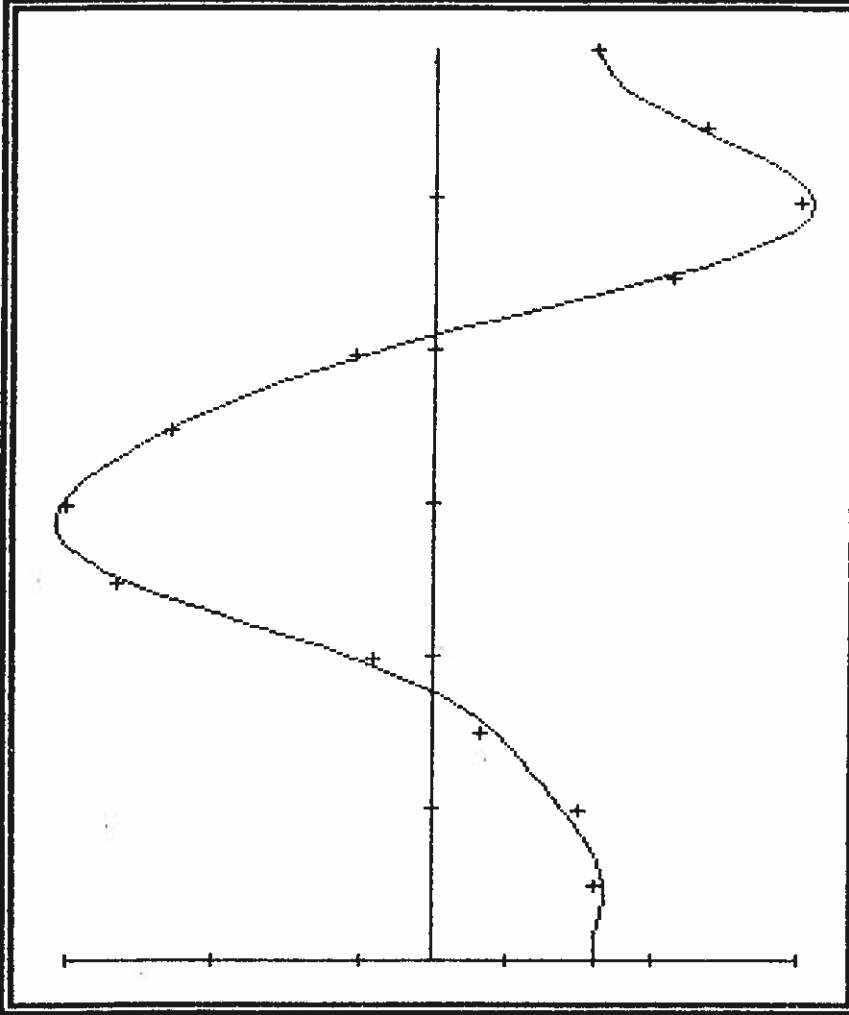
Circular planes plotted at 47.1cm, 48.1cm, 49.1cm.

ie. -1, 0, +1 cm relative to C/L.

Filename: rounds.rna 47.1

03-26-1992 17:37:57

Angle	Data	-Mean	Res
0	2000.00	-259.17	-0.91
30	2000.00	-259.17	-15.57
60	2030.00	-229.17	28.99
90	2220.00	-39.17	-35.76
120	2420.00	160.83	34.07
150	2900.00	640.83	-24.36
180	3000.00	740.83	9.24
210	2800.00	540.83	7.24
240	2460.00	200.83	-20.66
270	1860.00	-399.17	27.43
300	1620.00	-639.17	-25.73
330	1800.00	-459.17	16.02
360	2000.00	-259.17	-0.91



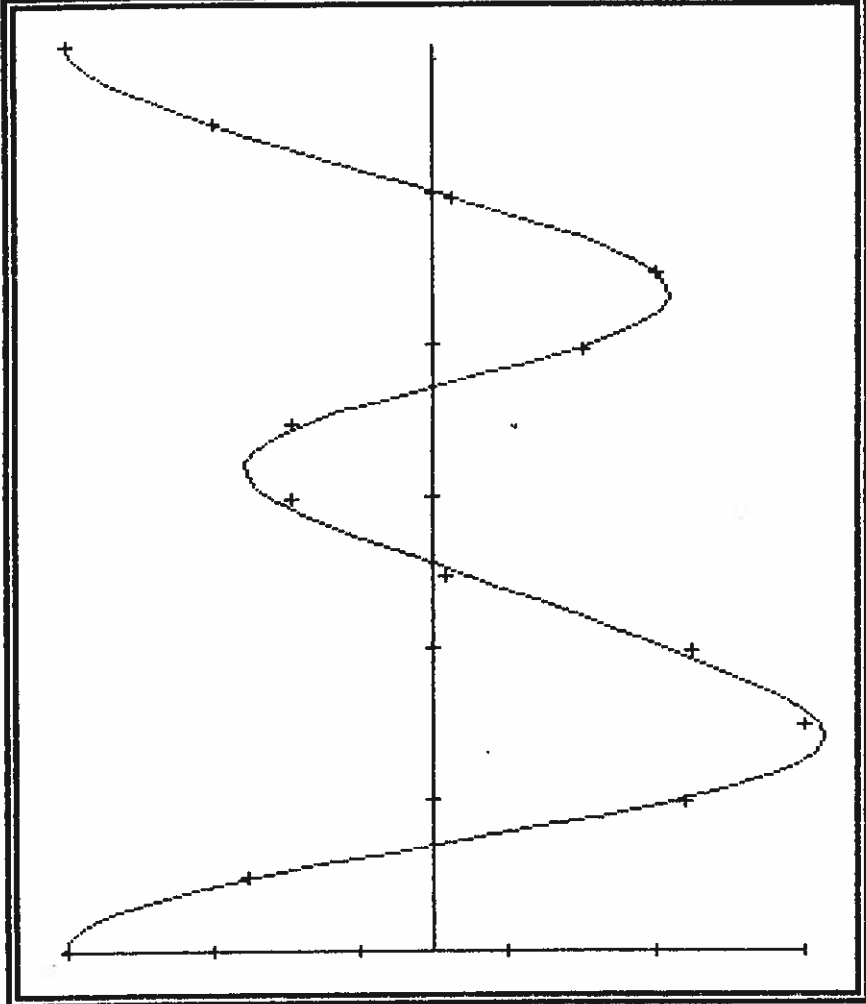
Mean : 2259.17
 Drift: 0.00
 $\sqrt{(\Sigma \text{Res}^2)}$: 79.7068

Order	Magnitude	Direction
10	1121.517	165.71
20	494.515	9.36
30	79.232	355.13
40	103.334	340.53

Filename: rounds.rnu 4Y.1

03-26-1992 17:45:46

Angle	Data	-Mean	Res
0	5200.00	525.83	0.68
30	4950.00	275.83	-7.96
60	4360.00	-314.17	16.46
90	4200.00	-474.17	-23.90
120	4350.00	-324.17	28.28
150	4680.00	5.83	-28.43
180	4890.00	215.83	24.32
210	4890.00	215.83	-17.04
240	4500.00	-174.17	8.54
270	4400.00	-274.17	-1.10
300	4670.00	-4.17	-3.28
330	5000.00	325.83	3.43
360	5200.00	525.83	0.68



Mean : 4674.17
 Drift: 0.00
 $\sqrt{(\Sigma \text{Res}^2)}$: 59.0984

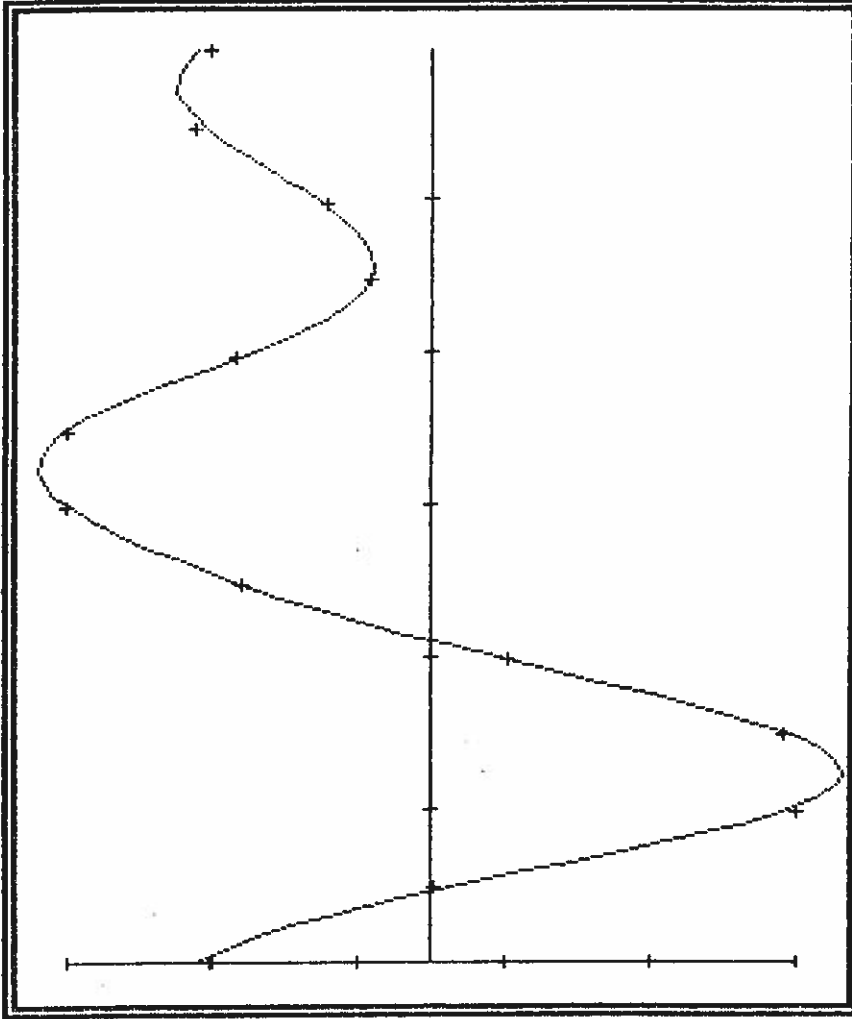
Order	Magnitude	Direction
10	343.528	315.03
20	770.000	180.00
30	47.726	351.74
40	92.437	23.02

Filename: rounds.rvm

49

03-26-1992 17:50:29

Angle	Data	-Mean	Res
0	3400.00	320.83	27.74
30	2900.00	-183.33	-33.05
60	2100.00	-987.50	24.07
90	2130.00	-961.67	-18.77
120	2750.00	-345.83	3.00
150	3350.00	250.00	3.45
180	3750.00	645.83	-14.41
210	3750.00	641.67	11.39
240	3380.00	267.50	-10.74
270	3080.00	-36.67	-2.90
300	3180.00	59.17	10.34
330	3480.00	355.00	-25.12
360	3450.00	320.83	27.74



Mean : 3104.17
 Drift: 50.00

$\sqrt{(\Sigma \text{Res}^2)}$: 69.1636

Order	Magnitude	Direction
10	1047.855	244.09
20	1013.920	355.25
30	175.008	359.82
40	85.136	25.90



MAGNET & CRYOSTAT	1
HIGH-COOLING POWER REFRIGERATOR	2
MAGNET POWER SUPPLY	3
SYSTEM CONTROLLER	4
10-CHANNEL TEMPERATURE MONITOR ITM 10	5
- ITM SERVICING	6
	7
	8
HALL MAGNETOMETER	9
HELIUM LEVEL METER	10
NITROGEN LEVEL METER	11
	12
	13
	14
	15

