③

200/400

28143

MAGNET

HORIZONTAL SUPERCONDUCTING MAGNET SYSTEM: 200/400

③

~200/400

Project Number 28143

MAGNET

+1 978 369 9933
Kevin Loneagon
ext. 103

Talked to:
Paul Brody

for any add'l ?'s

Oxford

how big is bore?
120 A - 10 V power supply

Call Ref. #: 170-722
181-641 archived at factory: file

Ramp rates
field/current ratio

IMPORTANT

Please read the manual before commissioning the system. It is possible to damage the cryostat and magnet if the correct procedures are not followed.

Oxford Instruments cannot accept responsibility for damage to the system caused by failure to observe the correct procedures laid down in the instruction manual.

Quote the above project number in any communication with Oxford Instruments Limited.

If problems are experienced with the magnet and/or cryostat, complete the questionnaire at the back of this manual and return it to Oxford Instruments Limited.

WARNING	The warning sign denotes a hazard. It calls attention to a procedure, practice, condition or the like, which, if not correctly performed or adhered to, could result in injury or death to personnel.
CAUTION	The caution sign denotes a hazard, it calls attention to an operating procedure, practice, condition or the like, which, if not correctly performed or adhered to, could result in damage to or destruction of part or all of the product.
NOTE:	The note sign denotes important information. It calls attention to an operating procedure, practice, condition or the like which is essential to highlight.

SUPERCONDUCTING MAGNET SYSTEM

PAGE

PART 1 - UNPACKING AND RE-ASSEMBLY INSTRUCTIONS

SECTION 1

1.1 Removal of Shipping Fixtures 2
1.2 Assembly of Cryostat 4
1.3 Assembly of Top Hat Services 5

PART II - SHORT FORM INSTRUCTIONS - for quick reference only

SECTION 1

1.1 Magnet Specifications, Operating Data and Test Results 7
1.2 Cryogenic Short Form Instructions 9
1.3 Magnet Short Form Instructions 11
1.4 Shimming with Superconducting Correction Coils 12
1.5 Shimming with Room Temperature Bore Correction Coils. 13
1.6 General Precautions 16
1.7 General Maintenance 17

PART III - DETAIL INSTRUCTIONS

SECTION 1 General Principles of Operation

1.1 Magnet 21
1.2 Cryostat 22
1.3 Cryostat Services 22
1.4 Cryogen Level Sensors 22
1.5 Demountable Current Leads 25

PAGE

SECTION 2 Cryogenic Fluids and Cooldown Procedure

2.1 Liquid Helium and Liquid Nitrogen 26
2.2 Evacuating the Outer Vacuum Case 27
2.3 Filling the Liquid Nitrogen Container 28
2.4 Precooling the Magnet 28
2.5 Initial Filling with Liquid Helium 29
2.6 Refilling with Liquid Helium 29
2.7 Closing Down and Warming Up 30
2.8 Helium Gas Recovery 31
2.9 Over-pressure Relief Valve 31

SECTION 3 Magnet Operation

3.1 Insertion of Leads 32
3.2 Energising the Magnet 32
3.3 Persistent Mode Operation 34
3.4 Shimming the Magnet 35
3.5 Discharging the Magnet 37
3.6 Emergency Discharge 37

SECTION 4 Trouble Shooting

4.1 Cryogenic Operation 38
4.2 Magnet Operation 39

Problem/Return Form 41

PART I - UNPACKING AND REASSEMBLY INSTRUCTIONS

9.10.86
Issue 1

FITTING ELECTRICALLY OPERATED SORBS

Mounting of Sorbs

Two sorbs should be fitted, one at either end of the helium can. Each is held onto the helium can by a copper bracket which is bolted under the GCS anti-twist plate on the top of the helium can and flanges. The sorb is then bolted to the copper spacer (see figure 1).

The wiring internal to each sorb is as shown in figure 2.

Thermal Anchoring of Leads

First connect the copper leads to the sorb (red to red and black to black) and anchor the leads to the helium vessel using aluminium tape. The leads should be run between the helium and nitrogen vessels by winding loosely along a glass-fibre support rod and holding in position using the tie wraps. There should be at least 1.5 metres of sleeved wire between the two vessels.

The thermal connection to the nitrogen can is made by sandwiching unsleeved copper wire in cigarette paper and sticking down with varnish.

Apply a thin coat of varnish to the nitrogen can (approx 2cm x 13cm) and apply the paper. Each paper will provide the top and bottom covering, the existing fold marking the boundary. Strip off the sleeve from that part of the wire that is to be thermally anchored (10cm minimum), and position on top of the first layer of paper holding the wire in position using aluminium tape. Apply a second coat of varnish and stick down the paper layer. The wire sleeving should extend into the paper to ensure electrical insulation.

The leads should be brought through the insulation to the pumping port ensuring that there is a minimum of 1 metre of wire between the nitrogen vessel and the OVC. The wires should then be brought through the pumping port and terminated as shown figure 3 using the pumping port extension with the 10-pin seal.

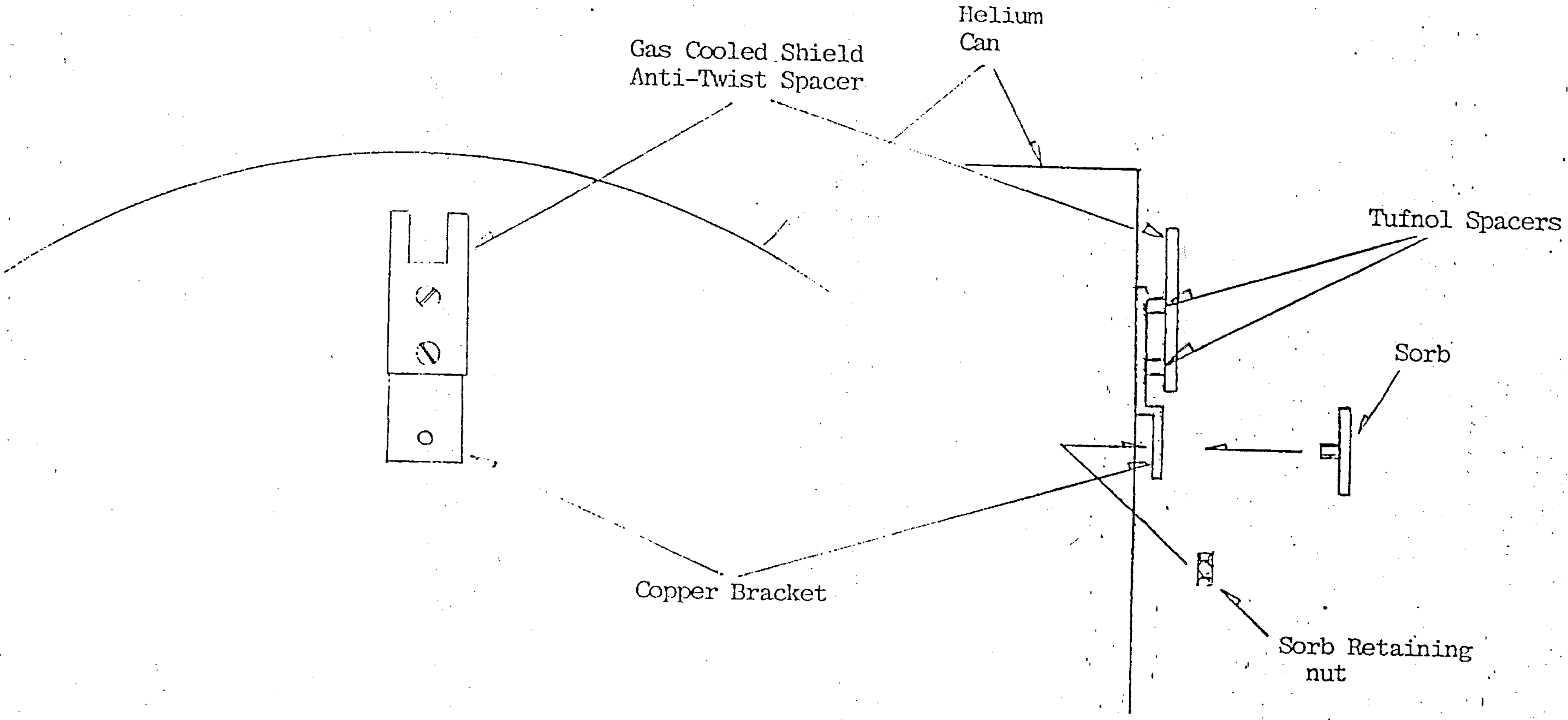

Gas Cooled Shield
Anti-Twist Spacer
Helium
Can
Tufnol Spacers
Sorb
Copper Bracket
Sorb Retaining
nut

FIGURE 1

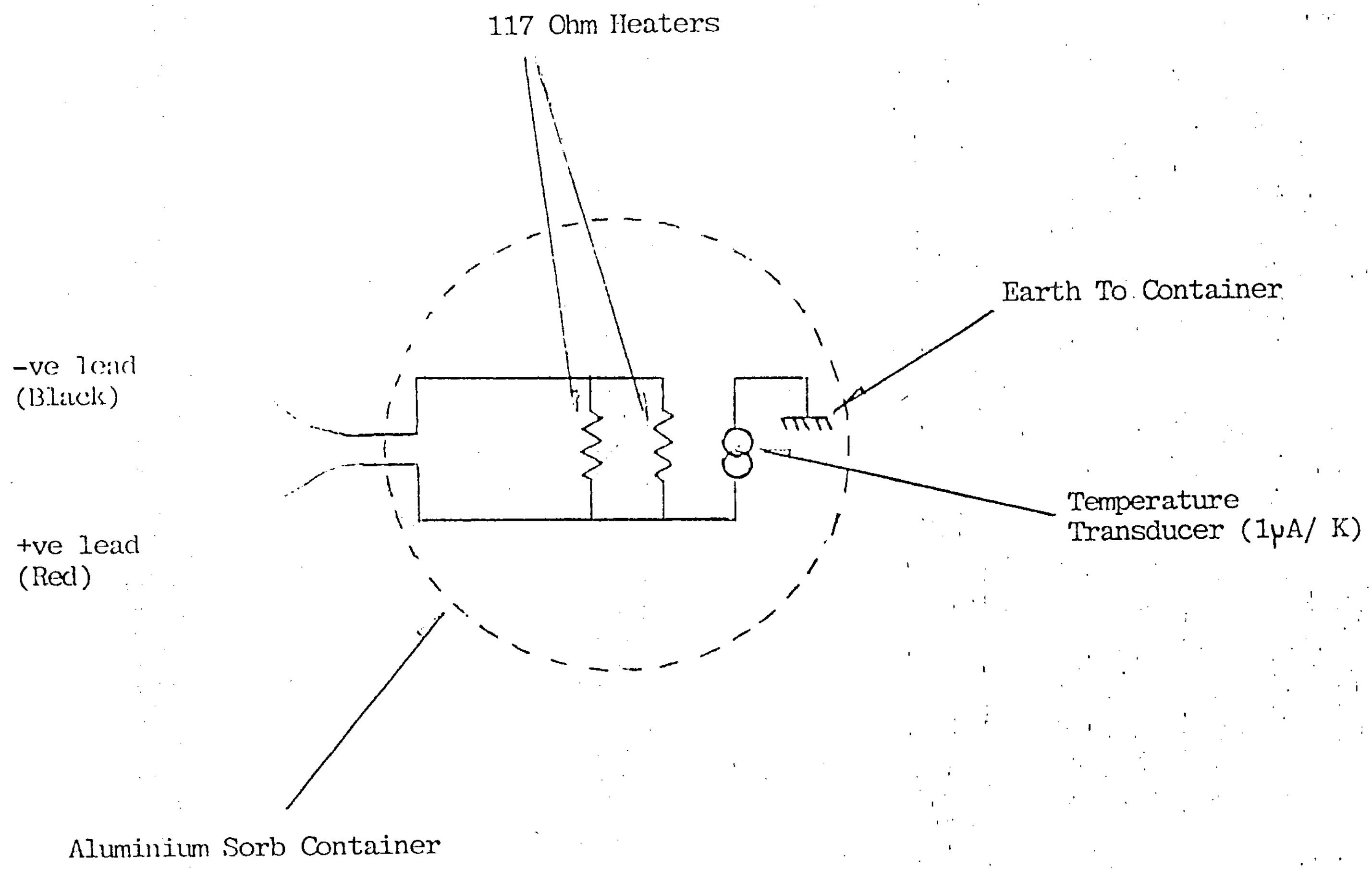
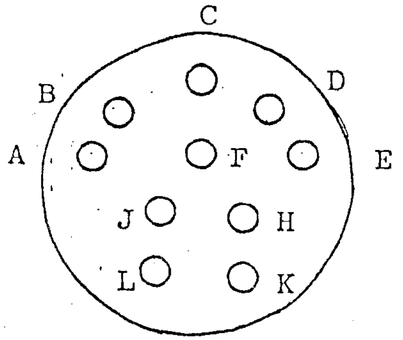

117 Ohm Heaters
Earth To Container
-ve lead
(Black)
+ve lead
(Red)
Temperature
Transducer (1μA/ K)
Aluminium Sorb Container

FIGURE 2

Labelling Of Pins

(View on male connector pins)



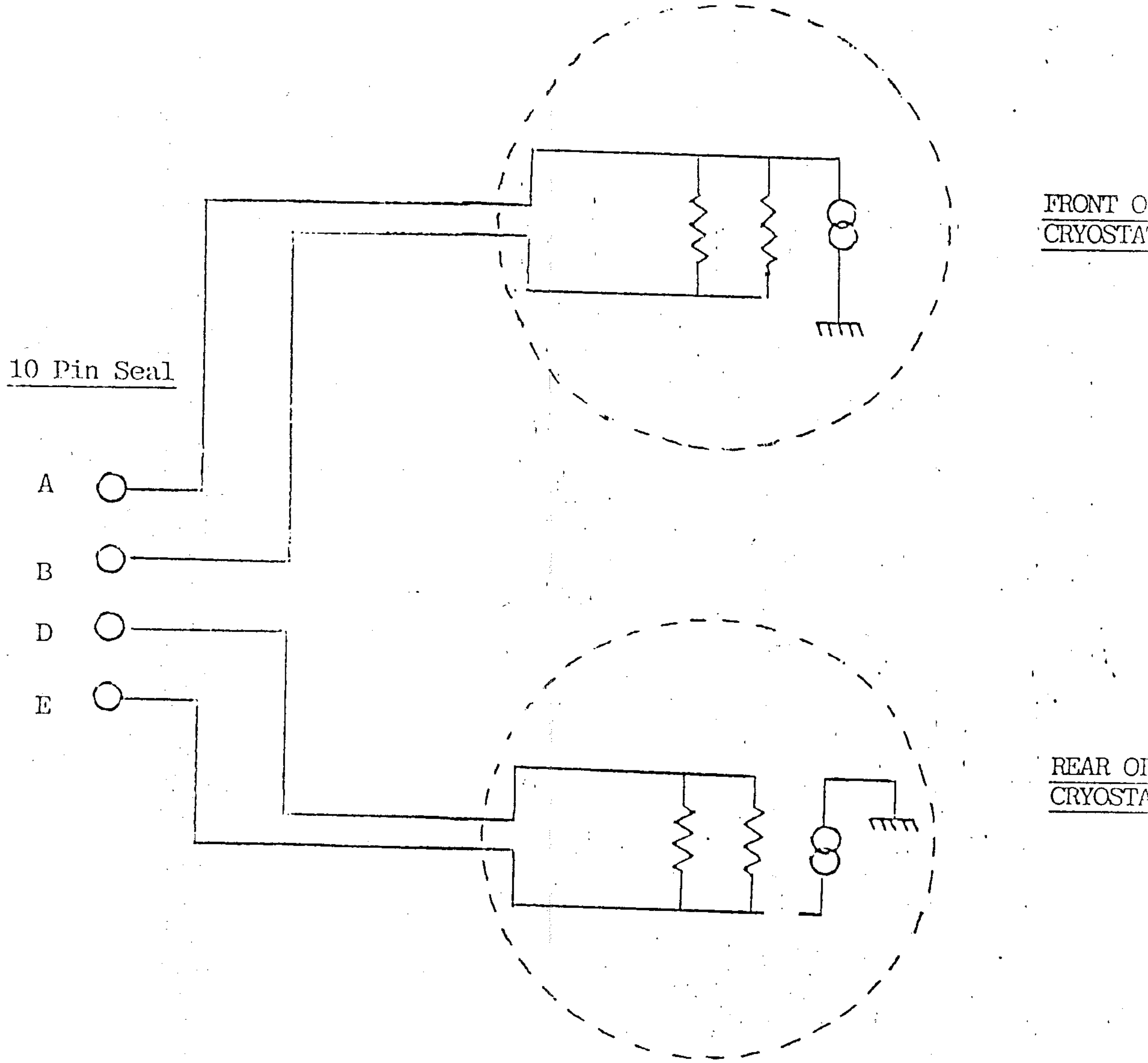


FIGURE 3

29th October 1986

Issue 3

OPERATION INSTRUCTIONS FOR ELECTRICALLY ACTIVATED SORBS

Two sorbs have been fitted to the cryostat, one at either end of the helium can. The internal wiring of a sorb is shown in figure 1.

The leads from the sorb exit from the cryostat at the pumping port and are wired to a 10-pin seal mounted on a T piece at the port. The wiring of the two sorbs to the 10-pin seal is shown in figure 2.

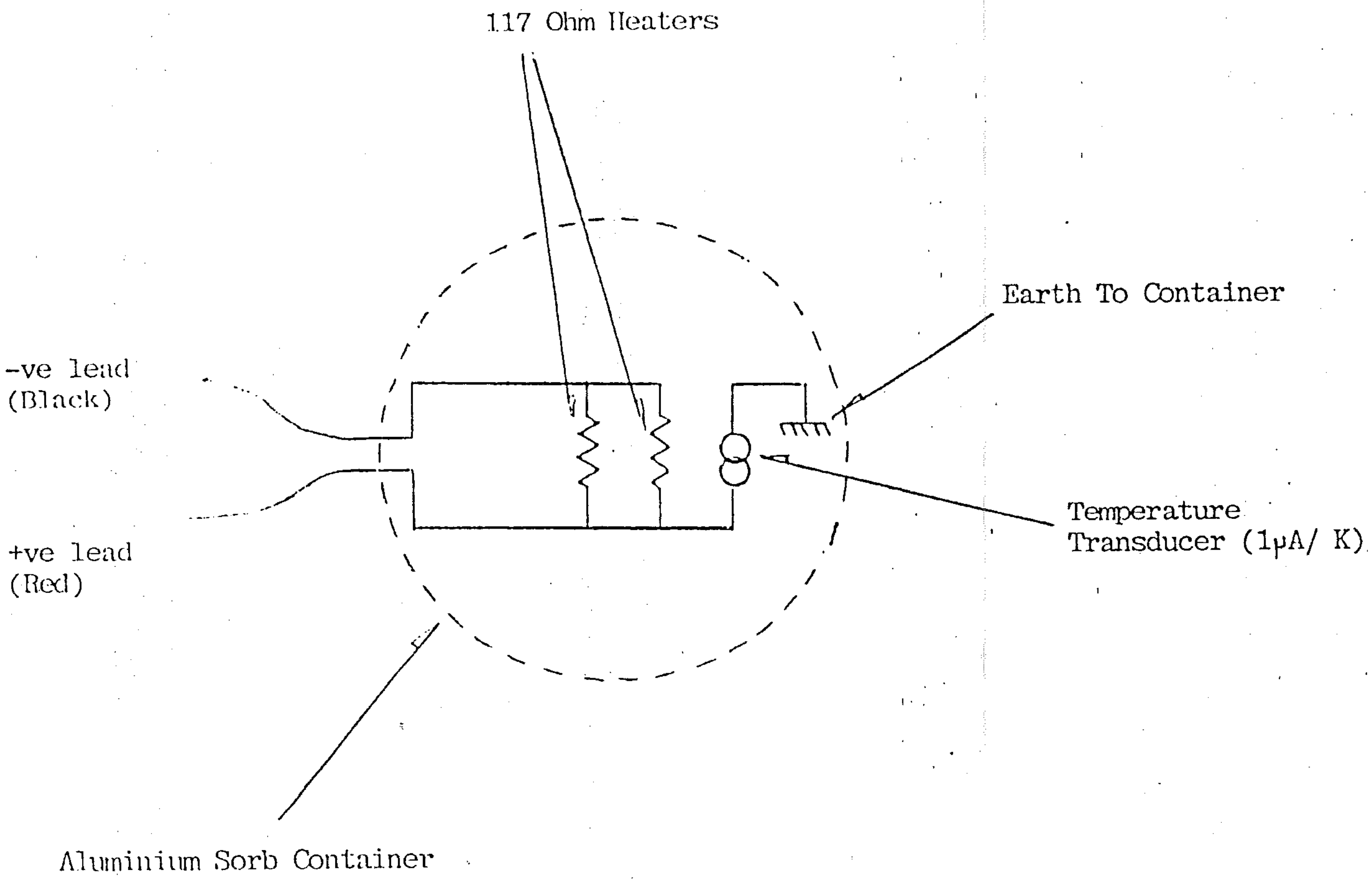
Operation

While the cyrostat is at room-temperature and being pumped the sorb should be activated by connecting a 30 volt/1 amp power supply as shown in figure 3. The power to each sorb should be approximately 15 watts.

To monitor the temperature of the sorb the heating circuit should be disconnected and the temperature monitoring circuit shown in figure 3 connected with the 0 volt terminal earthed to the cryostat. The transducers will allow a current to pass of 1 micro v/^{o}K (valid between -55^{o}C and +150^{o}C only). So by measuring the voltage across the 1 K ohm resistors (the DVM will read 1 micro v/^{o}K) it is possible to measure the sorb temperature.

The temperature should rise to approximately 80^{o}C (353 K). The temperature should be held at this for 15 minutes while the pumping continues.

The sorbs should also be activated while the cryostat is being leak tested.


117 Ohm Heaters
Earth To Container
-ve lead
(Black)
+ve lead
(Red)
Temperature
Transducer (1μA/ K)
Aluminium Sorb Container

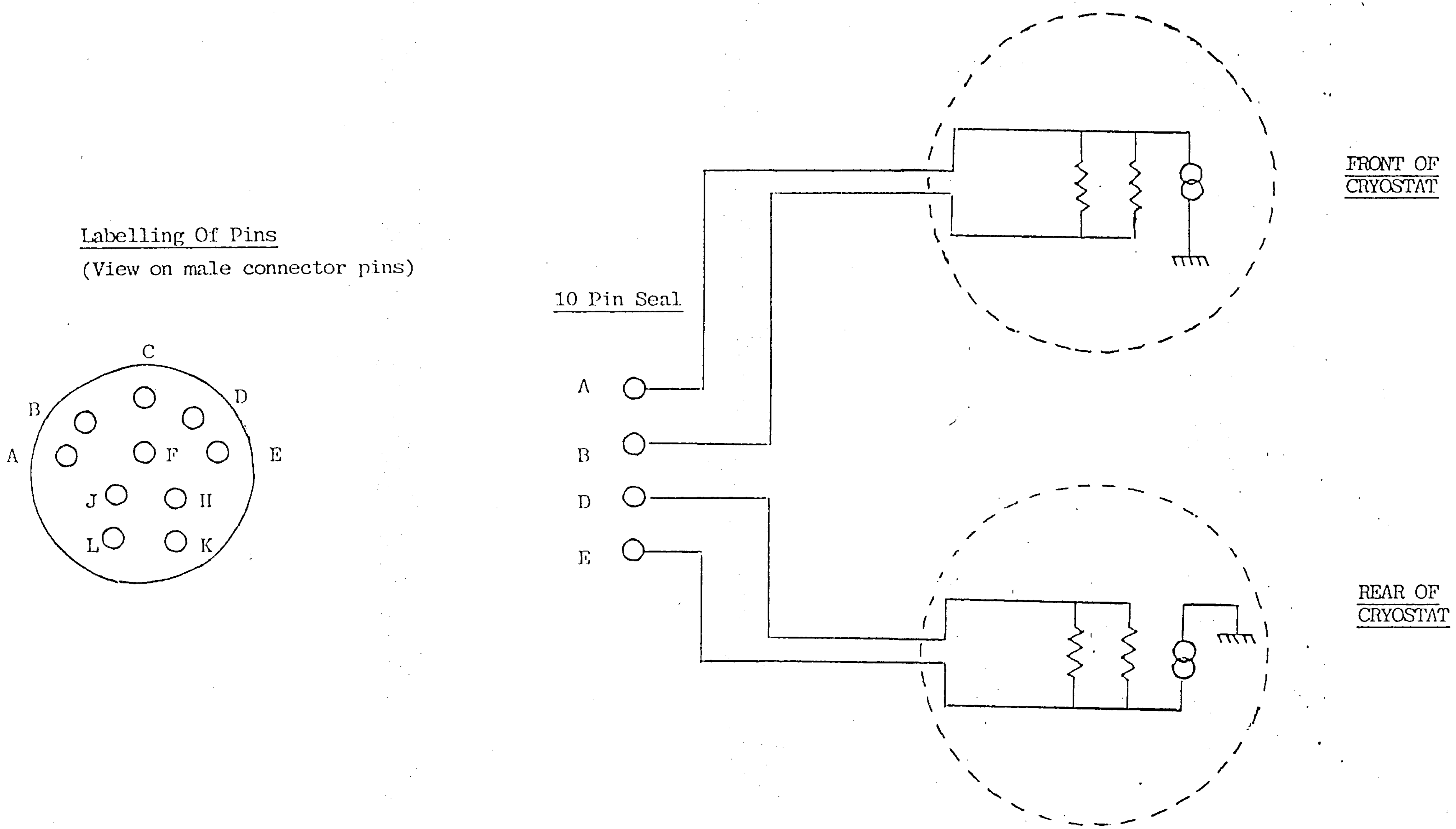

Labelling Of Pins
(View on male connector pins)

FIGURE 2

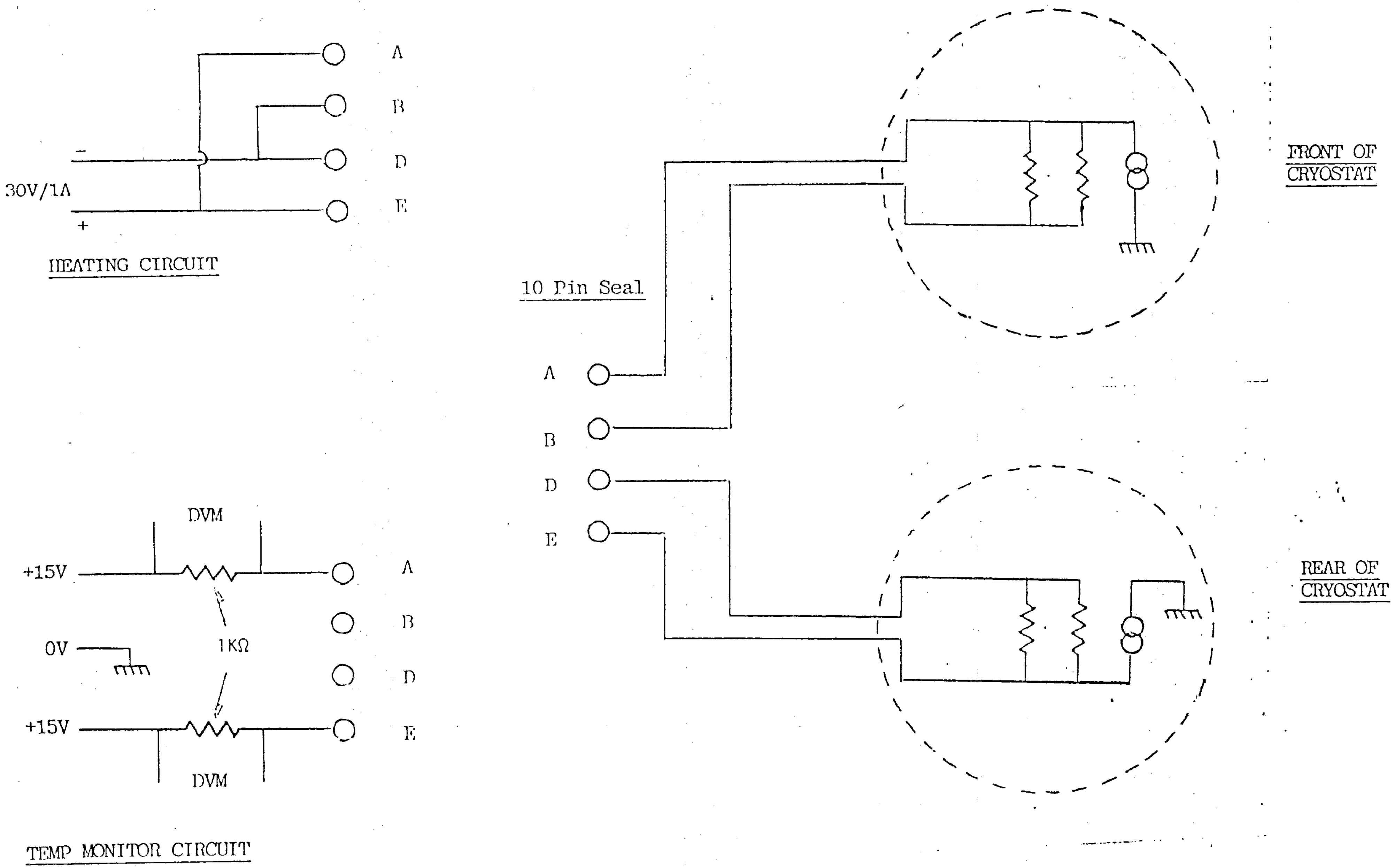

A
B
D
E
−
30V/1A
+
HEATING CIRCUIT
DVM
+15V
1KΩ
0V
+15V
DVM
A
B
D
E
TEMP MONITOR CIRCUIT
10 Pin Seal
A
B
D
E
FRONT OF CRYOSTAT
REAR OF CRYOSTAT

FIGURE 3

1.1 Removal of Shipping Fixtures

NOTE: It is strongly recommended that final assembly be done where the magnet is to operate. Movement of the cryostat after assembly can cause deterioration of performance.

Transportation brackets are fitted to support the inner vessels to the outer vacuum case during transportation.

Brackets are fitted at three positions at each end of the cryostat. Each bracket is held in place with bolts tightened to given torque values, and locked. Details of unpacking and packing are given below.

When the cryostat is to be re-packed for further shipment, the transportation brackets should be fitted in accordance with these instructions. A wire locking tool is provided for this purpose.

The cryostat is shipped under vacuum, before any work commences it should be let up with dry nitrogen gas.

Unpacking the cryostat

1 Remove the end flanges from the cryostat.

2 Remove all the bore tubes, nitrogen flanges and gas cooled shield flanges.

3 The transportation brackets are arranged as shown schematically in figure 1. Bolts for the helium vessel and nitrogen vessel are locked in position using a wire locking mechanism. Before removing the bolts, break the wires with wire cutters at position indicated in figure 2 (d), and remove wire from each bolt.

4 Loosen and remove bolts to helium vessel, nitrogen vessel and OVC bracket.

Remove the sections of the transportation brackets which were bolted to nitrogen and helium vessels and the OVC bracket.

The sections of the transportation brackets bolted to the OVC are fixed in position by welds on the cap of each bolt, and are not to be removed from the cryostat.

Re-packing the cryostat

(a) Locate each section of transportation bracket to helium and nitrogen vessel, matching the number on each to the numbers on the sections left in place on the OVC.

(b) Insert and turn up each bolt. Tighten to the torque values shown on each transportation bracket.

Typical torque values are as follows:-

Bolt type	Torque for bolt to helium vessel and OVC bracket	Torque for bolt to nitrogen vessel
M8	21-25 lbf. ft (28-34 N.m)	14-16 lbf. ft (19-22 N.m)
M10	35-40 lbf. ft (47-54 N.m)	23-27 lbf. ft (31-37 N.m)

(c) (i) Thread wire through holes in the head of each bolt, as shown in figure 2 (a)

(ii) Clasp ends of wire in jaws of wire locking tool, as shown in figure 2 (b)

(iii) Lock tool as shown in figure 2 (c)

(iv) Twist wire by pulling nut as shown in figure 2 (d).

AMENDMENT TO CRYOSTAT ASSEMBLY PROCEDURE

In order to improve the nitrogen boil-off the super-insulation technique has been modified. The super-insulation is now supplied on the nitrogen can, on the room temperature bore tube, as a series of overlapping blankets, and as blankets to fit over support rod end brackets.

The super-insulation should be prepared as follows:

NOTE : <u>Clean cotton gloves should be worn when handling super-insulation.</u>

1 The small blankets should be applied, as shown in figure (i), to cover the end brackets. The blankets should be held in place using mylar tape.

2 The insulation on the nitrogen can should be folded down and interleaved with the bore tube insulation on a 10:1 basis (approximately). At each stage the layers can be held in place using mylar tape, see figure (ii) for details.

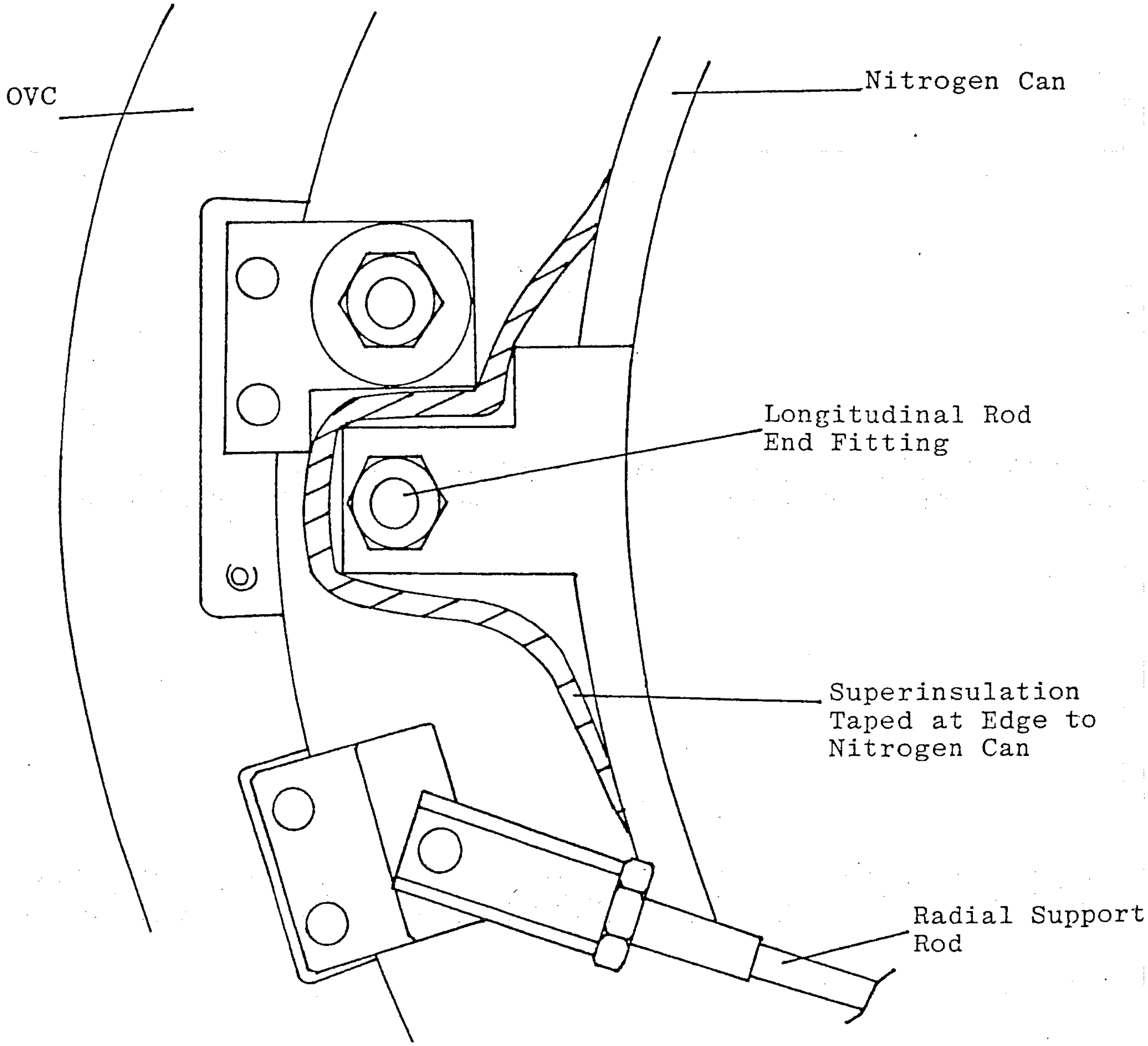
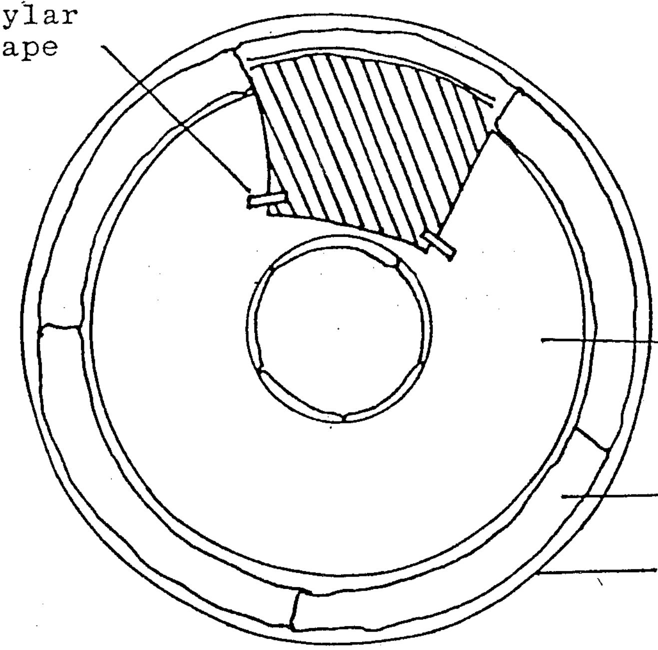
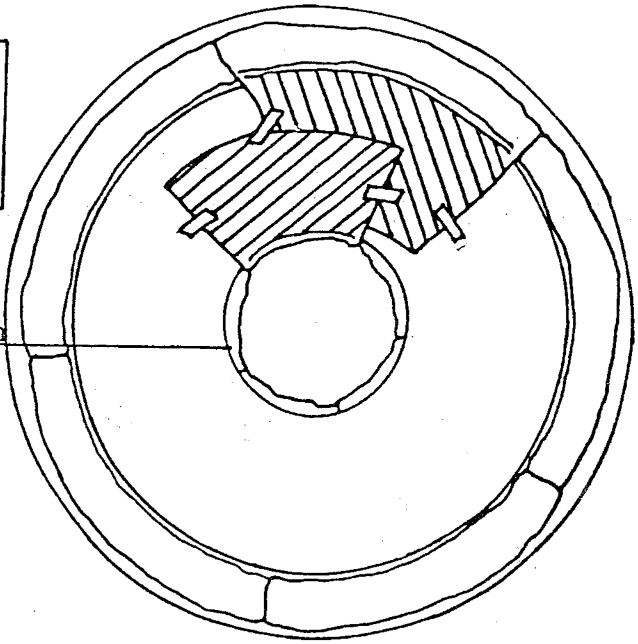


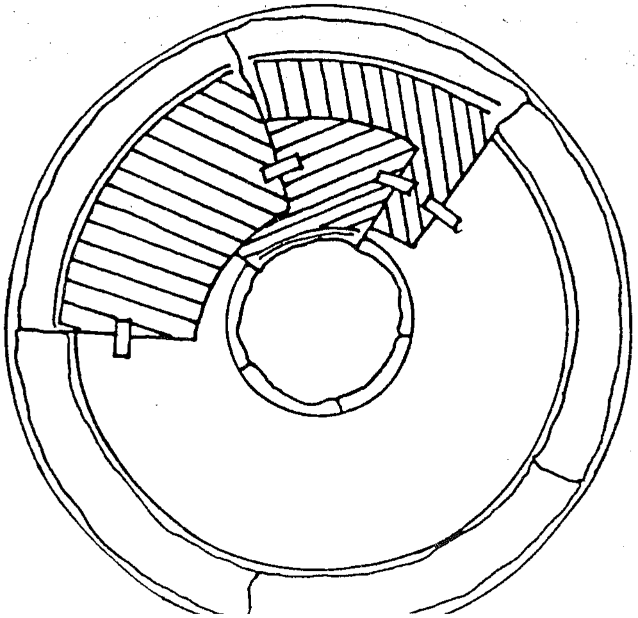
FIGURE (i) Superinsulation Around Support Rod Brackets

STEP 1
Fold down 10 layers of superinsulation, tape to nitrogen can end flange as shown.



STEP 2
Fold up 1 layer of bore tube superinsulation, tape as shown.





Repeat steps 1 and 2 working round in circles until all the superinsulation is interleaved.

FIGURE (ii) Interleaving of Superinsulation

1.2 Assembly of the Cryostat

The following equipment should be made available before assembly is started:-

1) Assorted metric allen keys, screwdriver and sharp knife.
2) Silicone vacuum grease.
3) Acetone or similar solvent.
4) Clean cotton gloves and soft cloths for cleaning bore tubes.
5) Aluminised mylar tape.

Clean all the bore tubes and end flanges using a solvent; polish any areas that have dulled since leaving the factory. Avoid greasy finger marks by wearing clean cotton gloves, and finally buff the components with dry cloths. All end flanges are stamped, the identification marks corresponding to one end of the cryostat, these should be observed throughout the assembly procedure.

1. Replace the gas cooled shield cover plates, these are used where the packing straps come through the shield to the helium can. The plates are stamped for identification. Bolt the gas cooled shield spacers into place. Cover the hole in the base of the gas cooled shield with aluminium tape.

2. Fix the gas cooled shield flanges to the cryostat. Slide in the bore tube and fix this with the clamping rings.

3. Fix the nitrogen can flanges to the cryostat. Slide in the bore tube and fix this with the clamping rings.

4. Slide in the room temperature bore tube. Slide the superinsulation pads over the bore tube, one at each end. Tape the pads with mylar tape to the outer diameter of the nitrogen can at, approximately, six inch intervals around the periphery. Interleave the pads with the superinsulation already around the nitrogen reservoir. Make sure that the superinsulation does not foul the room temperature bore and trim back where necessary so that the outermost layers are shorter than the innermost. This minimises the inner layers receiving conducted heat from the outermost layers.

5. Clean all 'O' rings thoroughly and lightly grease them also ensure that all 'O' ring seals are clean.

6. Remove the blanks and clamping rings from the OVC flange.

7. Bolt one end flange to the cryostat, matching identification marks. When this is done and all bolts are fully tightened pull the room temperature bore tube towards the flange so that the lip on the bore tube mates with that on the flange.

8. Bolt the other end flange to the cryostat, repositioning the bore tube if necessary.

9. Finally, secure the bore tube with the clamping rings.

1.3 Assembly of Top Hat Services

All services to the cryostat are accessed via a top hat which is located inside the cryostat turret. These services must be located and connected before operation of the system can begin.

Insert the service top hat into the turret, ensuring that the demountable lead access and socket are aligned. The top hat is held in place with '0' rings, which must be cleaned and greased, and a split clamping ring. Before fixing into place insert the insertion tool through the syphon entry and slightly rotate it to align the locating on the 20-way connector with its socket. Push the tool firmly into the socket. Put the 2 pin magnet demountable lead in. Now tighten the split clamping ring. Remove the magnet demountable lead and then unscrew the insertion tool and withdraw it carefully.

The nitrogen meter assembly plugs onto the 10-pin socket on the nitrogen port. This is held in place with a PTFE seal and an NW25 clamping ring. The nitrogen filler tube fitting fits on either of the other two ports.

Finally, connect the leads for the helium level meter and emergency discharge to the 10 pin seals, as given in part III.

CAUTION: Before operation the tape covering the over pressure relief valve must be removed.

PART II - SHORT FORM INSTRUCTIONS - For Quick Reference Only

z -366
Z2 - 723
x - 439

y - 439
xy - 512
x^2-y^2 - 490

Zx - 502
Zy - 504
Z3 - .

ST. +VE.

DEC 99

Run To 244.55 Amps <u>ST. -VE</u>

200.45 MHZ.

Z1 +4.170
Z2 - 3.213
Z3 + 3.317

Zy +0.145
xy -0.537
x^2-y^2 -0.472.

x + 1.403
y + 0.687
zx 0.00

J. DAVIDSON

O.I.N.M.R.

SECTION 1

1.1 Magnet Specifications and Operating Data

200/400 Magnet Type

Central field : 4.7 Tesla (200 MHz proton)
Expected current for central field : 240 Amps
Superconductor type : multi filamentary Niobium Titanium
Room temp bore diameter : 400 mm minimum
Inductance : 116 Henries nominal
Switch "open" resistance : 100 ohms
Shim switch "open" resistance : 10 ohms
Switch heater resistance (all heaters) : 100 ohms
Switch heater current (all switches) : 60m Amps
Recommended power supply trip voltage : 4 Volts
Axial shims fitted : Z_1, Z_2, Z_3
Transverse shims fitted : X and Y; ZX and ZY; XY and X^2-Y^2
Overfield value : 900 mA

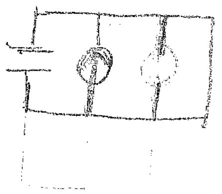
Mode	V at P.S.U	V at magnet	From (Amps)	To (Amps)
Max charge rate constant volts	④	3.15 (~~200~~)	0	170
	3.5	2.68	170	180
	3	0.68	180	190
	2.5	0.59	190	214
	2		214	FIELD
Max discharge rate constant volts	0		Field	190
	-2		190	0

1.7/A/MIN

Charge and discharge current leads by hand when no sweep generator is available.

$$\text{Enduced} = -L \frac{dI}{\Delta t}$$

$$3.15 = -116 \frac{\Delta I}{\Delta t}$$



$$\frac{\Delta I}{\Delta t} = 0.027 \frac{Amp}{sec} = \frac{1.629\ Amp}{min}$$

if $100\ \Omega$

$0.67\ \Omega/min$

$$\frac{243\ Amp}{4.7} = \underline{51.7\ Amp}$$

1st May 1987

Magnet Run to field 243.5 Amps
.9 overfield

S/C shim settings

Z^1	310	
Z2	728	
Z^3	330	
X.	441	
Y	442	
ZX	~~511~~	489
ZY	~~499~~	481
XY	~~5[illegible]9~~	511
X^2-Y2	—	499

17th JUNE 1987
Change value of Z^2
Z^2 — 668

20TH JULY 1988

D.VOLTS	.61
A.VOLTS	.48
TOP HAT	.46
D AMPS	243.6
ACT.AMPS	243.5

23 July 1988

Z^1 —	335	-2.68	-3.216
Z^2 —	723	+4.46	+4.377
Z^3 —	330	-3.40	-3.440
X —	430	-1.40	-1.333
Y —	439	-1.22	-1.313
ZX —	502	0.00	0.00
ZY —	504	0.00	0.00
XY —	512	+0.24	0.24
X^2Y^2	491	+0.18	0.18

727

1.1

System Test Summary

Date 29/ 1 /87

Project No. ____

Magnet No. 93252

Cryostat No. DLH0048

Field current for 4.7 Tesla (200.04 MHz) : 243.7 Amps

Field/current ratio : 0.0193 Tesla/Amp

Distance of Z_1 centre from OVC flange : 760 mm

Homogeneity:-

peak-peak without room temperature shims

140 mm dsv : ____ ppm

100 mm dsv : ____ ppm

peak-peak with room temperature shims

140 mm dsv : ____ ppm

100 mm dsv : ____ ppm

Shim currents:-

Figures show shim power supply helipot readings, where 500 is zero.

Z_1	701 310	X	556 440	ZX	512 490	XY	480 570
Z_2	273 728	Y	540 440	ZY	519 480	X^2-Y^2	496 500
Z_3	670 330						

NOTE:- All switch heaters on the magnet have a resistance of 100 ohms and require approximately 60 mA current to operate the switch.

The shim currents given above are those used during tests at Oxford Instruments. These currents may need to be changed slightly, depending on the siting of the cryostat and the new ferromagnetic environment in which the magnet is operated. Therefore the figures given are only a guide to intial shimming, and final figures should also be recorded.

Persistence:-

Final rate of decay : 1.0 Hz/hr i.e. 0.005 ppm/hr

Nitrogen boil off : 450 ml/hr 10.8 l/day

Helium boil off : 135 ml/hr = 3.24 l/day

Other Problems/Remarks

1.2 Cryogenic Short Form Instructions

NOTE: Use this section as a quick reference procedure/check list, if there is any doubt at all then refer to PART III.

1.2.1 Commissioning cryostat (at room temperature)

It is assumed that the cryostat has been unpacked, the bore tubes inserted and the helium gas recovery system is ready for connection.

1) Evacuate the outer vacuum case (O.V.C) to better than 5×10^{-5} torr. Use a fast rotary pump and diffusion pump.

2) Ensure that O.V.C valve is closed and cover the pumping orifice.

3) Insert demountable current lead.

4) Flush and pump the liquid helium tank several times with dry helium gas. The tank should quickly reach a pressure of 1 torr using a 50 l/min rotary pump. **(N.B O.V.C must be at vacuum.)**

1.2.2 Cooling to 4.2K

1) Fill the helium tank and nitrogen tank up to the neck tube, until full with liquid nitrogen (LN_2). Leave overnight.

2) Refill the helium reservoir and leave one more night to precool. In the morning pump on the nitrogen in the helium can to 110 torr and then blow out the nitrogen with dry helium gas via a tube inserted through the syphon entry into the cone. When no more nitrogen is seen leave overnight.

3) Blow out the remaining nitrogen with dry helium gas.

4) Connect a capsule gauge, rotary pump and source of dry helium gas to helium tank.

5) Pump out and watch for a pause in the pressure in the range 80 to 100 torr, indicating liquid nitrogen.

6) Flush and pump out, at least twice, until certain that no LN_2 remains (less than 5 torr). Then fill with helium gas and connect to recovery system.

7) Insert helium transfer syphon ensuring that it is firmly located in the cone inside the cryostat.

8) Gently transfer until liquid collects (approximately 4 hours and 450 litres)

9) (a) If the magnet is to be energised and shimming performed transfer until the cryostat is completely full.

   (b) If the magnet is to be energised at a later time remove the demountable lead and insert the gas plug.

10) Check that all air passages into the helium tank, except the recovery system, are blocked.

11) The final boil-off figure for the liquid heium will not be known until about a week after initial filling. This is a result of the long thermal time constant of the gas cooled shield.

1.2.3 Refilling with liquid helium

1) Insert the helium transfer syphon into the transport dewar (NOT into cryostat) which has been placed close to the cryostat.

2) Pressurise transport dewar and wait until liquid comes out of the syphon.

3) Insert syphon into cryostat, but stop when its end is about 50mm above cone.

4) Transfer liquid.

5) Reduce pressure on transfer dewar and remove syphon.

6) Ensure that all air passages are closed.

1.2.4 Warming up the cryostat

1) Insert transfer syphon into cone, close off recovery system and transfer as much liquid as possible to a transport dewar by pressurising the helium tank with dry, compressed helium gas. (Tank pressure < 0.5 Atm.)

CAUTION DO NOT overpressurise.

2) Circulation of dry warm helium gas round the magnet will accelerate the warm up.

3) For fast warm up soften the O.V.C with dry nitrogen gas and warm the outside using a 1 kW fan heater.

NOTE: 4) If the cryostat temperature rises above 77K then the O.V.C MUST be repumped to better than 5×10^{-5} torr.

5) The cryostat end flanges should not be removed until the cryostat is fully warm.

1.3 Magnet Short Form Instructions

(If in doubt refer to Part III)

1.3.1 Running the magnet up from zero

1) Check that the helium and nitrogen levels are adequate.

2) Insert the 2 pin demountable current lead, and the 20 way lead for shims and heaters.

3) Check for continuity of current lead.

4) The gas exhaust port on the 2 pin lead should remain open while there is positive pressure in the dewar, this provides the necessarry cooling for the lead.

5) Connect power supply and set current to zero.

6) Decide upon final magnet current and add the over-field value recommended in Section 1.1.

7) Follow instructions for energising, as given in section III.

8) Check that main current is initially zero.

9)) Activate switch heater, accessed via the 10 pin seals at the top of 20 pin demountable lead.

10) Begin to increase the current.

11) Dump any induced currents in the other shim coils (i.e. open and close their switches), at approximately 20 minute intervals.

12) When over-field is reached leave current flowing for about 15 minutes.

13) Reduce field to final value; wait 10 minutes.

14) Close all magnet switches and wait 2 minutes.

15) Reduce main power supply current to zero.

16) Dump any currents in all other shims.

17) Insert NMR probe and adjust shim currents for best line.

NOTE: 18) RECORD MAGNET MAIN CURRENT AND POLARITY plus shim current values.

19) Remove leads and replace with the gas plugs and baffles.

WARNING SHORT THE MAGNET TERMINALS BEFORE DISCONNECTING THE MAIN LEADS OR BEFORE SWITCHING THE POWER SUPPLY OFF.

1.3.2 Running down an energised magnet

1) Look up the operating current and polarity. If there is any doubt about these, follow the emergency discharge procedure.

2) Insert current leads and connect to power supply.

WARNING: SHORT THE MAIN POWER SUPPLY TERMINALS BEFORE CONNECTING TO MAGNET.

3) Remove the short circuit.

4) Turn main current up to operating value.

5) Open the superconducting switches in the following order:

Z_1 and Main Coil

6) Set current to run down at the recommended rate.

7) When discharged switch off all heater currents and remove leads.

1.4 Shimming with Superconducting Correction Coils

NOTE: DO NOT operate the main coil heater during this procedure.

1) Set all potentiometers to 500 (zero current) and operate all shim heaters.

2) If magnet centre has been found move the probe about the approximate centre to a position where the resonance is independant of the Z_1 current. (At a later stage of shimming it may be better to go to the centre of the ZX and ZY shims.)

3) If room temperature bore shims are present set all their currents to zero.

4) Adjust Z_1 shim for best line.

5) Adjust all superconducting shims, in turn, to give maximum signal height. Finally adjust to give best line shape (or longest ringing on a medium sweep rate). Note all currents.

6) Remove leads and close the entry port.

1.5 Shimming with Room Temperature Bore Correction Coils

Axial Shims

1. Do an axial plot over a region, say 12 cm.
2. Analyse the plot to find the axial gradients remaining after shimming with superconducting shims. Using the shim coil strengths as given in the shim and gradient manual it will be possible to calculate the current required in the shims and thus cancel the remaining gradients.
3. Input the currents and repeat the axial plot to check.

Transverse Shims

1. Locate the X-axis of the shims. Set 0° on the x-axis.
2. Plot the magnet on 7 cm radius at +7, +3.5, 0, -3.5, -7 cm axially. Analyse the results.
3. Using the results and the shim strengths, from the manual, calculate the current required in the Z(XY) and Z (X^2-y^2) shims.
4. Input currents. Repeat plot and analysis.
5. Calculate currents for Z^2X and Z^2Y.
6. As (4).
7. Calculate currents for X^2-Y^2 and XY.
8. As (4).
9. Calculate currents for ZX and ZY.
10. As (4).
11. Calculate currents for X and Y.
12. As (4).
13. Repeat plot and check results.
14. Plot axially and check axial shim currents.

1.6 General Precautions

1.6.1 Magnet

NOTE: 1) Ensure that the 10- pin seals 'A' and 'B' are connected to the correct cables.

WARNING: 2) Magnet Demountable Lead removal & replacement

Removing the demountable lead is a potentially hazardous operation; at full field the magnet has a high stored energy which in the event of the switch breaking open and the protection circuit failing would see itself as a very high voltage at the terminals of the lead, although this situation is extremely unlikely it cannot be dismissed. To avoid this voltage build-up the lead must remain connected to the power supply and shorted between the terminals. Maintain this situation when re-inserting the lead.

3) Do not attempt to insert the demountable lead or refill the cryostat with liquid helium when the magnet is energised with less than 10% (on meter) of helium without first contacting Oxford Instruments.

1.6.2 Cryostat

NOTE: Removal of precooling nitrogen

It is important to ensure that **ALL** liquid nitrogen is removed from the helium can after the precooling stage, any traces left will severely impair the speed of transferring helium and may prevent the magnet operating, due to the presence of frozen nitrogen.

The recommended procedure is as follows:-

(a) Pump on the nitrogen in the helium can to 110 torr.Blow liquid nitrogen out using pure helium gas. Ensure that the nitrogen blow-out tube is firmly located in the cone (max pressure 8 p.s.i.g.).

(b) After the liquid stops issuing from the tube leave overnight.

(c) Re-start blowing helium gas until no liquid appears.

(d) Continue blowing helium gas for five minutes after the nitrogen stops.

(e) Pump and flush the helium can at **LEAST TWICE** before attempting to transfer liquid helium. With a capsule type vacuum gauge fitted any pause in pressure between 80 to 100 torr indicates the presence of liquid nitrogen.

CAUTION Warming up the cryostat

It is important never to open the vacuum valve to air while the system is cold, even if all cryogens have been removed. Condensed water vapour will extend the pump out time considerably and will severely contaminate the superinsulation, eventually destroying the aluminised reflecting surfaces of the superinsulation and polished aluminium internals.

Always soften the cryostat with dry nitrogen gas to part or full atmospheric pressure and close the valve.

Always store the cryostat under vacuum.

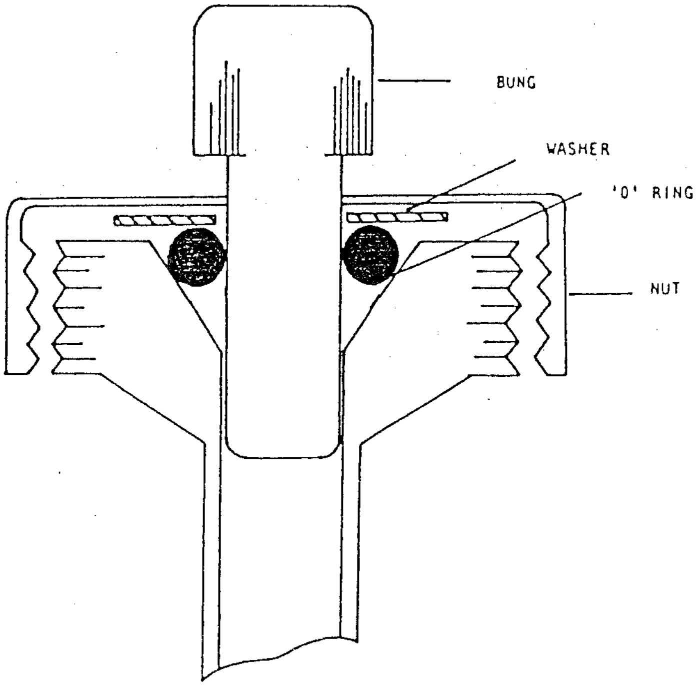
Dry nitrogen

The simplest method of obtaining dry nitrogen gas is to immerse a tube into a liquid nitrogen storage dewar below the surface of the liquid, connect and seal the tube to the vacuum valve using suitable fittings. On slowly opening the vac valve, liquid will be forced into the cryostat where it will immediately vaporise to form dry gas - having not had the opportunity to be contaminated with moisture.

1.6.3 Safety procedures

CAUTION The following procedures must always be followed to ensure efficient and safe operation of the cryogenic system.

1) Assemble the syphon bung correctly, that is the rubber 'O' ring should be below the washer, see below. The demountable lead entry fitting should be sealed in the same way. Ensure 'O' rings are fitted to the 10 pin connectors alongside the syphon entry fitting, and ensure all manifold 'O' rings are fitted and the clamps tightened, otherwise icing up will occur in the neck.



2) Icing up

It is important to ensure that the helium and nitrogen necks do not ice up by air migration, particularly where boil-off rates are low. Total blockages may occur and lead to pressurised reservoirs and if this goes unnoticed the pressure may rise to a point where it ruptures the wall of the can, allowing liquid to spray out and gasify rapidly, causing considerable damage to virtually every component in the cryostat.

3) Periodically check the helium level, excessive boil-off could indicate a leak into the vacuum space which may require running down the magnet and warming the cryostat before a cure can be effected.

4) Do not let the level of liquid nitrogen fall below about 20%.

If in doubt contact your local Oxford Instruments Agent.

1.7 General Maintenance

1.7.1 Cryostat

The cryostat once assembled and cooled should require little maintenance apart from the periodic topping up of the cryogen liquid levels.

There are several routine checks and procedures which should be observed to ensure trouble free long term operation.

i) Proper assembly of 'O' rings.

This applies particularly to the 'O' rings around the turret Incorrectly assembled 'O' rings may lead not only to the leaking of valuable helium to the atmosphere, but over a period of time will allow air into the cryostat where it will freeze and cause constriction. If allowed to continue unchecked this could result in the complete blocking of exit ports for the exhausting gas and the consequent increase in pressure in the helium can. In the worst case explosion of the helium can could result.

Syphon and demountable lead entry ports.

The 'O' ring should be assembled below the washer so that on tightening the nut the 'O' ring is compressed against the tube or plug.

ii) Boil off check valve

If the system is not supplied with a low pressure (approximately 0.5 psi) check valve or bursting disc, on the exhaust then a simple bunsen valve can be very effective. A bunsen valve is made from a 6 inch piece of rubber tube, typically $\frac{1}{2}$" O.D. and 1/16 inch wall. One end is blocked off with a bung and a split is made in the tube. This valve when placed over the exhaust port will act as a non-return valve.

Some form of non-return valve <u>must</u> be fitted to the cryostat if it is not exhausting to a helium recovery system. When atmospheric pressure changes it is possible for a negative differential pressure to exist between atmosphere and the helium can, air will then enter the helium can and this must be prevented.

iii) Periodically, every few days, check that some boil off is occurring. An apparent zero boil off could imply a blockage which must be attended to at once. A steadily increasing boil off over a period of time could indicate a small leak into the vacuum space and consequent deterioration of the vacuum. The vacuum space cannot be pumped while liquid helium is in the helium can unless special precautions are taken such as a liquid nitrogen trap on the diffusion pump to prevent the cryostat from cryopumping the diffusion pump oil.

iv) Precooling the syphon

The phase separator must be used with the syphon while topping up liquid helium. During topping up of the liquid helium it is important to pre-cool the syphon before attempting to introduce liquid into the cryostat. This is done by inserting the syphon leg into the transport dewar and pressurising it so that gas escapes through the syphon to air. After five minutes or so the escaping gas will get colder as the syphon cools. Eventually a dense blue plume of cold gas will be seen, at this stage the syphon can be gradually introduced into the cryostat while still transferring. The syphon should be lowered to within 2 inches of the syphon cone over a period of five minutes. Do not push down completely.

Failure to pre-cool properly could result in the superconducting switch opening and the magnet discharging through the protection circuit or, in a severe case, quenching.

v) During topping up of liquid helium the increased flow of cold helium can supercool the liquid nitrogen and stop it boiling. During this period there is a possibility that ice will form in the nitrogen exhaust ports. Check the nitrogen ports regularly.

1.7.2 Magnet

i) Once the magnet is run to field and shimmed some small changes in field and homogeneity may occur over the first month. These changes may continue at a very low level for a longer period. The homogeneity changes will be gradients of low order and can easily be corrected by use of the room temperature shims.

On changing from one probe to another different room temperature shim settings will be required. This is quite normal and is due to the small differences in geometry of different probes disturbing the field profile by different amounts. You should note the room temperature shim settings for each probe as this will speed up the shimming process after changing probes.

ii) If for any reason the magnet should begin to discharge e.g. by attempting to transfer helium without pre-cooling the syphon. The magnet should be left to discharge completely before any action can be taken, this will take approximately 2 minutes. It is advised that Oxford Instruments be contacted as soon as possible.

iii) Magnet quench

Under normal operating conditions it is extremely rare for a quench to occur. Generally a slightly increased risk of quenching occurs on running the magnet to field (training quench) or on topping up the liquid helium level where the syphon has not been pre-cooled and/or a very low helium level exists in the helium can.

A quench is a result of part of the superconductor temporarily becoming a normal resistive metal, heat is generated and propagates through the whole magnet. The result is that all the stored energy of the magnetic field is converted to heat which rapidly boils off the remaining liquid.

A quench can be alarming but not dangerous. Keep clear of the cold exhausting gas, and if in a small unventilated room open doors and windows to allow fresh air into the room as the helium gas may displace the oxygen in the room.

After a quench when the cold gas has stopped issuing from the cryostat liquid helium can be re-introduced into the helium can and the magnet run back to field. Contact your service engineer to do this.

iv) Re-shimming

As already mentioned some small changes in homogeneity and field are expected in the first few months of operation. This is due to the re-distribution of the magnetic flux within the superconducting wire itself to the most energentically favourable distribution. Normally these changes will cause the room temperature shim settings to drift to a new position not far from the initial positions. Occasionally a room temperature shim may drift to its maximum (or minimum) value. In this case the superconducting shims need to be re-adjusted. This must be done by a qualified engineer.

PART III - DETAIL INSTRUCTIONS

1. General Principles of Operation

1.1 The Magnet

The magnet is wound from superconducting wire which is NbTi alloy in a protective matrix of copper. It consists of a number of short solenoid sections with a set of superconducting shims. All the solenoid sections are connected in series and a superconducting switch is put in parallel with the whole assembly.

(A superconducting switch consists of a length of superconducting wire thermally isolated from the liquid helium bath. By raising its temperature, using an inbuilt electrical heater, it is made resistive. It is then in its "Open" state and current from the power supply will flow through the superconducting magnet rather than through the resistive switch element. When the heater is turned off, the switch element becomes superconductive again and the switch is closed. At this point the current is circulating through the magnet and power supply only. As the current from the power supply is reduced the magnet current remains constant and the difference current flows through the switch. Eventually all the magnet current is going through the switch and full persistent mode has been reached.)

Residual field gradients, caused by winding inhomogeneities etc, and the axial gradients which result from the finite length fo the solenoid sections are cancelled by the set of shim coils carrying currents specified in Part II. These currents may vary depending on the ferromagnetic environment in which the magnet is operated.

The circuit diagram, figure 3, shows the arrangement of the various coils and switches.

The protection consists of low value resistors across sections of the magnet. In the event of the magnet quenching (becoming resistive) these resistors prevent the development of high voltages which could cause insulation break down. They also dissipate some energy during the quench and thus reduce the energy dissipated in the magnet windings.

1.2 The Cryostat

The magnet is operated at a constant temperature of 4.2K, obtained by immersing it in a bath of liquid helium-4 which is boiling at normal atmospheric pressure.

The liquid helium is held in the cryostat which is shown schematically in figure 4. The helium vessel containing the magnet is suspended by a neck tube which also provides service access. Lateral support is given by radial struts at the ends of the helium tank. The helium vessel is surrounded by a gas cooled shield and then by a liquid nitrogen tank and shield, which is in turn enclosed by the outer vacuum case. The helium tank, gas cooled shield and nitrogen tank are all superinsulated.

1.3 Cryostat Services

The arrangement of the fittings on the top of the cryostat is shown in figure 4. The neck tube, which projects above the top of the main cryostat body, carries the inlets for the liquid helium transfer tube, the demountable current leads and three fill/vent tubes for liquid nitrogen.

The electrical contacts to the magnet are made via the two demountable leads, the two pin lead is used for energising the magnet, all shims and heaters are accessed via the twenty pin lead. Both leads have plugs which mate with a socket thus allowing repeated insertion and removal. The wiring details are shown in figure 5. The helium level probes and quench heaters are accessed via the three 10 pin seals as shown in figure 6.

The cryostat also has a valve for evacuating the OVC and an over pressure relief valve.

1.4 Cryogen Level Sensors

1.4.1 Helium level sensor

In order to monitor the level of helium around the magnet, three independent level sensors are mounted inside the helium can. Two are of the pulsed superconductor type; one is monitored continuously by the HLM2 meter, the other remains as a standby, should the first one fail for any reason. In the extremely unlikely event that both should fail, a third method of monitoring is available, consisting of a series of carbon sensors, these will indicate whether they are immersed in liquid or gas and can be monitored by custom built electronics supplied by Oxford Instruments upon request.

Superconducting type The level sensors do not monitor the full depth of the helium can only the major part of the useable volume. The following table relates the HLM2 meter reading to the actual volume of helium:-

He Boil off ≈ 3.24 l/day
Refill ~ every 2 months

HLM2 meter reading	Litres	
Max vol	466	
100%	460	
90%	408	
80%	362	
70%	332	
60%	304	
50%	276	
40%	254	← Recommended refill level
30%	234	
20%	209	
10%	186	
0%	158	

Minimum operating level 5%

See separate operating manual for further information

If the level falls to 0% on the meter refilling is still possible but there is danger of quenching the magnet; it is recommended that the magnet be de-energised in the standard manner before refilling. Insert the leads VERY CAREFULLY with power supply connected. Contact Oxford Instruments if in doubt.

Carbon resistor type There are three carbon sensors mounted around the periphery of the magnet end flange and are positioned to relate to the following volumes:-

1st carbon sensor	:	460 litres
2nd carbon sensor	:	234 litres
3rd carbon sensor	:	140 litres

Each sensor is a standard Allen Bradley resistor with most of the insulation removed - this greatly improves its response time and it can detect the difference between liquid and cold gas.

Use a constant current source set at 2mA and connect to each resistor separately (see figure 5). Measure the voltage across the same resistor; there should be approx 100mV difference between liquid and cold gas.

1.4.2 Nitrogen level sensor This is of the capacitive type, monitoring the full volume of the nitrogen can (288 litres). The associated probe electronics are mounted on the cryostat above one nitrogen fill/vent tube to eliminate capacitive effects of a long lead. The small tube spacing the electronics away from the vent prevents them suffering icing and condensation problems. The nitrogen is monitored continuously by the NLM2 meter and relates to the following volumes:-

NLM 2 meter reading	Litres
100%	288
90%	268
80%	243
70%	206
60%	176
50%	144
40%	115
30%	82
20%	49
10%	22
0%	0

Recommended refill level 35% ← ~ at 100 l

refill every 2.5 weeks

See separate operating manual for further information

In general, refill N_2 every 2 weeks.
" " He " 2 months.

1.5 Demountable Current Leads

The magnet start and end are accessed using the two pin demountable lead. All shims and heaters are acessed via the twenty pin demountable lead. Both leads are interfaced to the internal wiring by sockets which are rigidly and permanently sited at the bottom of the helium neck tube, and positioned so that exhausting helium gas is allowed to escape vertically through the neck tube and demountable lead tube, thus using the available enthalpy of the gas to cool both tubes and copper current leads, intercepting the conducted heat to the helium can. The main current lead also has forced gas cooling facility which should be used when energising or de-energising the magnet, this is shown in figure 7.

The object is to remove the leads once the magnet is energised and shimmed, thus removing a large potential heat leak from room temperature to liquid helium temperature and thereby considerably extending the hold time of the helium reservoir.

At the top of the demountable lead are the various connectors for interfacing to the main and shim power supplies. Bolt connectors are used on two pin lead for carrying the main current to the magnet (approximately 240 Amps). Connection should also be made to the top of the connectors for volt sensing at the top of the lead. The shim lead has 2 x 10 pin connectors which provide a means of supplying current to all the switch heaters and shims. See table 2 for the correct wiring of these connectors to the shim power supply.

2. Cryogenic Fluids and Cooldown Procedure

2.1 Liquid helium and liquid nitrogen

The cryogenic fluids used with this system are liquid helium and liquid nitrogen. The relevant properties of these liquids are in table 4.

(a) Liquid nitrogen is a colourless liquid obtained from the liquefaction of air. It is generally stored in vacuum insulated containers but its relatively high latent heat of evaporation permits short term storage in foamed plastic vessels. It may be transferred from one container to another by pouring, or by the use of a rubber or plastic tube. The following safety precautions should be observed.

i) Flexible materials become brittle when cooled to liquid nitrogen temperature. Rubber tubes used for transferring liquid nitrogen will break easily if strained.

ii) Open vessels containing liquid nitrogen should be kept covered to prevent frost formation by the condensation of water vapour from the atmosphere and also to prevent oxygen enrichment by condensation from the air. This can present a fire risk.

iii) Vessels containing liquid nitrogen should not be sealed so that evaporating gas can escape and prevent a pressure build-up.

iv) Liquid nitrogen spilled on vacuum or cryogenic equipment will freeze 'O' rings and cause loss of vacuum. Care should be taken when pouring to prevent excessive spillage.

v) Liquid nitrogen spilled on the body will cause tissue damage, similar to a severe burn. Rubber gloves and boots should be worn where necessary.

(b) Liquid helium is a colourless liquid produced from the naturally occuring gas deposits in the earth. The density of the gas is so low that the concentration in the atmosphere is minute. Where possible evaporated gas should be recovered and re-liquefied, both to economise in operating costs and to conserve the earth's resources.

Liquid helium is stored in vacuum insulated containers which also include some form of radiation shield to intercept thermal radiation from the room temperature environment. It is transferred between storage vessels, or from a storage vessel to a cryostat by means of a vacuum insulated transfer tube (sometimes called a syphon).

2.2 Evacuating the outer vacuum case

It is not recommended that this be done if the cryostat is below room temperature.

CAUTION NEVER PUMP HELIUM CAN WITHOUT A VACUUM IN THE O.V.C (Failure to observe this rule will result in collapse of the helium reservoir.)

In order to maintain the thermal isolation of the liquid helium it is necessary that a high vacuum be obtained in the outer case of the cryostat (O.V.C). Traces of air will be condensed when the cryostat is filled with liquid helium, but helium gas will spoil the vacuum. Over a long period of time helium gas may percolate past 'O' rings from the atmosphere. The OVC should not need pumping if the cryostat contains liquid helium.

A slow increase in the boil-off rate of liquid helium indicates that the dewar is going soft (helium has entered the O.V.C.).

If the O.V.C goes soft, de-energise the magnet (Part II), warm up the cryostat and try to locate the leak. Assuming that the problem was helium gas diffusion, pump out the O.V.C and follow the usual commissioning procedures.

The pumping equipment should consist of an oil diffusion pump of 50mm (2 in.) diameter fitted with a liquid nitrogen cold trap. The diffusion pump should be backed by a rotary pump of speed not less than 25 l/min. The rotary pump should have a gas ballast facility. If plastic or rubber link tubes are used these must NOT have been used previously to carry or pump helium.

(a) Connect the valve on the cryostat to the pumping equipment using a short tube of not less than 15mm (¾ in.) internal diameter. Using the rotary pump evacuate the cryostat (O.V.C) until the pressure is less than 1 torr then admit an atmosphere of DRY nitrogen gas and pump out again - repeat several times. Finally pump to less than 0.05 torr.

(b) Switch over to the diffusion pump and evacuate the cryostat to less than 5 x 10^{-5} torr and continue pumping for at least 24 hours (preferably at least 48 hours) before sealing the O.V.C valve. This ensures that residual gas trapped in the superinsulation is removed and cannot impair the reflecting properties of the superinsulation. (On filling the cryostat with cryogenic liquids, the pressure should fall to less than 10^{-6} torr.) Place a dust cap over the pumping port.

It has been assumed that the evacuation procedure started from atmospheric pressure. If the cryostat is already evacuated and it is desired to inspect the pressure only, the pumping tube should be already evacuated and the diffusion pump operating before the O.V.C valve is opened.

The recommended equipment for evacuating the outer case is shown in figure 7.

2.3 Filling the liquid nitrogen container

Connect the fill tube of the liquid nitrogen container to a storage vessel using flexible plastic pipe. Transfer the liquid nitrogen by pressurising the storage vessel to approximately 0.25 atm. (4 p.s.i.g.) Violent boiling will occur initially until the radiation shield has cooled down. When liquid nitrogen sprays out of the fill tubes release the pressure on the storage vessel to stop the transfer.

The storage vessel can be pressurised using a high-pressure gas cylinder fitted with a reducing valve. By using an electrically operated valve between the gas cylinder and the storage vessel, the liquid nitrogen container can be filled and the level maintained using a Liquid Nitrogen Level Controller.

Inspect the liquid nitrogen level daily.

2.4 Precooling the magnet

Before filling the cryostat with liquid helium the magnet must be cooled to a temperature below 100K. To do this completely fill the liquid helium container with liquid nitrogen. Use a length of 10mm (3/8 in.) diameter stainless steel tubing inserted into the transfer tube entry port, but not pushed fully down into the cone. Leave this overnight and then refill. Leave the system one more night to fully pre-cool and then remove the nitrogen as follows.

Pump on the nitrogen in the helium can to 110 torr. Blow the nitrogen out using dry helium gas and when no more nitrogen appears leave overnight. The next day blow out the remaining nitrogen with dry helium gas.

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. Evacuate the liquid helium container using a rotary pump, (if during pump down a pause is seen in the range 80 - 100 torr then liquid nitrogen is still present) and then fill it with helium gas. 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 torr.

The recommended equipment for performing this operation is shown in figure 8.

2.5 Initial filling with liquid helium

Connect the cryostat to the helium recovery system or put a one-way valve on the cryostat exhaust tube. Position the liquid helium storage vessel so that the transfer tube can be inserted easily. Ensure that the transfer tube is not blocked by blowing helium gas through it.

Remove the plug from the cryostat tube entry port and also from the top of the storage vessel. Insert the transfer tube slowly, allowing it to cool gradually. Ensure that the end of the transfer tube is fitted into the cone above the magnet. In this way, 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.

Start transferring the liquid helium by pressurising the storage vessel. (This is generally done by gently squeezing a rubber bladder attached to the vessel). The transfer rate should be such that the vent pipe is frozen for not more than 2m (6 ft) of its length. The initial transfer rate should be quite slow approximately 20 litres of liquid per hour but this rate can be increased as the magnet cools.

When the magnet resistance drops to zero the transfer rate can be further increased in order to fill the liquid helium container. This should occur when 400 to 500 litres of liquid have been transferred, further liquid is then required to fill the cryostat.

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 least daily.

2.6 Refilling with liquid helium

The cryostat should be refilled when the level reaches the 40% mark. If refilling care should be taken not to evaporate the liquid in the cryostat with the hot gas which initially comes through the transfer tube.

NOTE: Failure to take care can cause the magnet to quench.

The correct procedure is as follows:-

(a) Insert one leg of the transfer tube into the storage vessel, but leave the other one outside 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.)

(b) Quickly release the pressure in the transport dewar and insert the open end of the transfer tube into the cryostat.

(c) Lower the transfer tube until it reaches the bottom of the neck tube. DO NOT push the tube into the cone above the magnet. Transfer helium in the usual way.

If the helium level has fallen below 10% and the magnet is still energised there are two courses of action open.

i) If the demountable lead has not been removed, then DE-ENERGISE THE MAGNET, refill and then re-energise the magnet.

ii) If the magnet is to remain energised the cryostat may be topped up but take care as the syphon is introduced and as the transfer starts. Use the gas/liquid deflector supplied with the transfer tube to direct the helium away from the magnet.

2.7 Closing down and warming up the cryostat

Having de-energised the magnet 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 the straight filler tube and seal the joint with a piece of rubber hose, pressurise the container through the other filler tube and blow-out the liquid into a storage dewar.

Having removed all the cryogenic liquids the system can be warmed up by softening the vacuum. Leave for 1 hour to let the magnet warm towards 77K. Slowly allow DRY nitrogen gas into the O.V.C until 1 atmosphere is reached - close the valve to prevent any moisture contaminating the superinsulation. The nitrogen gas can be obtained from the neck of a container of quickly boiling liquid nitrogen. 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.

CAUTION Never open the valve to air when the cryostat is cold-condensed water vapour will eventually destroy the silvering of the superinsulation.

2.8 Helium Gas Recovery

The use of a gas recovery system is desirable for four reasons.

i) Financial saving.

ii) Conservation of the earth's supply of helium.

iii) Prevention of the cryostat becoming contaminated with ice and air.

iv) Prevention of the air becoming contaminated with helium gas to the detriment of vacuum seals.

A typical recovery system consists of low-pressure gas storage, in the form of a gas-holder, or gas-bag, connected to the cryostat vent; a compressor; and high-pressure gas storage. The compressor should be specifically made for helium because of the large amount of heat produced when compressing this gas.

NOTE: To prevent air entering the cryostat the recovery system should be maintained slightly above atmospheric pressure. A pressure of a few centimetres of water is sufficient.

Failure to observe this precaution may lead to ice and solid air forming on the connectors for the demountable leads preventing reinsertion of the leads.

2.9 Over-Pressure Relief Valve

This device is intended to protect cryostats against a large increase in pressure which could arise should a superconducting magnet quench. When used as a relief valve it forms a positive seal preventing the flow of gas in either direction unless the internal pressure exceeds approximately 2 p.s.i.

3 Magnet Operation

3.1 Insertion of leads

Remove the plug in each of the the current lead entry ports by slackening the knurled nut. *Insert the current leads and lower them gently, allowing adequate time for them to cool down, until the lower end is felt to enter the conical socket. The 20 pin lead has a location pin on it, but in order to avoid damaging pins extra location is provided by a key on the plug. Rotate the lead until the key allows it to be pushed gently into the socket. The two pin lead should be pushed gently into place.Care should be taken to avoid bending the pins. Tighten the knurled nut to ensure a gas tight seal. Check that the resistance between the two main leads is less than 0.1 ohm, and test for continuity and short circuits. Connect the flexible leads to the current supply, observing the polarity and ensuring that all connections are tightly clamped.

NOTE: Note the polarity in the system log-book.

(*If connectors are "iced-up" so that the leads can not be inserted, see part III 4.2).

3.2 Energising the magnet

Constant voltage mode

When using an Oxford Instruments, or similar, power supply to run the magnet up from zero field the supply is used in constant voltage mode. This provides a smooth charging rate which decreases at higher currents as the voltage drop down the leads subtracts from the set voltage level on the supply. Operating current and charging voltages are given in Part II. Set all the supply controls to zero.

(a) With the main superconducting switch closed adjust the VOLT LIMIT control to the desired setting. Set the CURRENT DEMAND to zero.

(b) Open the switch heater, put the power supply on HOLD and then adjust the SET CURRENT controls to the desired level. De-select HOLD to start the power supply running up.

(c) When the output current reaches the set level, use the SET CURRENT control to achieve the correct field. Record the final current for future reference.

(d) Close the switch heater and then wait a few minutes before running the leads down, by selecting RUN TO ZERO.

Refer to power supply manual for detailed instructions and explain of controls

WARNING Short the terminals on top of the demountable current lead and disconnect the flexible leads from the power supply.

Constant current mode

In this mode the power supply current is changed by external means - either manually or using a sweep generator. The magnet will only charge at the programmed rate if the "set voltage" level (at the output terminals of the supply) is large enough to overcome the back e.m.f. of the magnet. Set all the controls to zero. (It is assumed that an external sweep unit is used.)

(a) With the main superconducting switch closed set the sweep unit output to maximum. Set the positive voltage limit to maximum, then increase the power supply control until the full current is flowing in the leads. Lock the control in this position.

(b) Reduce the sweep unit output to zero and check that the main current falls to zero. Wait one minute.

(c) Open the superconducting switches on the main magnet and wait 30 seconds.

(d) Set the sweep rate to the value shown in Part II and begin the sweep. Change the sweep rate at the specified current values.

(e) Stop the sweep at the full over-field current and wait for a few minutes. Reduce the current to the operating value (either by hand or on the slow sweep rate) and wait for several minutes. Then close the superconducting switch.

NOTE: NOTE THE POLARITY AND FINAL CURRENT IN THE LOG-BOOK.

(f) Wait for a few more minutes and then smoothly reduce the power supply current to zero.

WARNING Short the terminals on the demountable current lead and disconnect the flexible leads from the power supply.

After an hour the magnet may be shimmed to within 10 times the specified homogeneity. There may be significant field and homogeneity changes over the next two days (or longer if the over-field value was not correct - see Part II) so that the final shimming should be delayed until the magnet has settled to its final field value. If room temperature bore shims are used on the magnet then they can accommodate any changes unless the overfield value was grossly incorrect.

3.3 Persistent mode operation

Although a superconducting magnet in persistent mode produces great long-term field stability the superconducting screening currents associated with superconductors take a considerable time to settle to their final distribution and values. During this time, about one week, the field will drift by about a gauss. This effect can be reduced so that the drift is almost eliminated by the following technique.

If the final value of the field is being approached from below (i.e. charging the magnet), increase the current above its final value by the overfield value given in part II. Then reduce the current to its final value. These operations are done manually using the SET CURRENT control, taking care to operate the control smoothly. Before proceeding further wait several minutes to ensure that current sharing between the magnet and the protection resistors has ceased, then close the superconducting switch by turning the heater "OFF". Wait for another minute then decrease the current supply output smoothly to zero. When the current reaches zero turn the voltage control to zero.

WARNING Short the main terminals, together to avoid transients (which could possibly cause the switch to open) and disconnect the power supply.

NOTE: NOTE THE POLARITY IN THE LOG-BOOK.

3.4 Shimming the Magnet

General comments

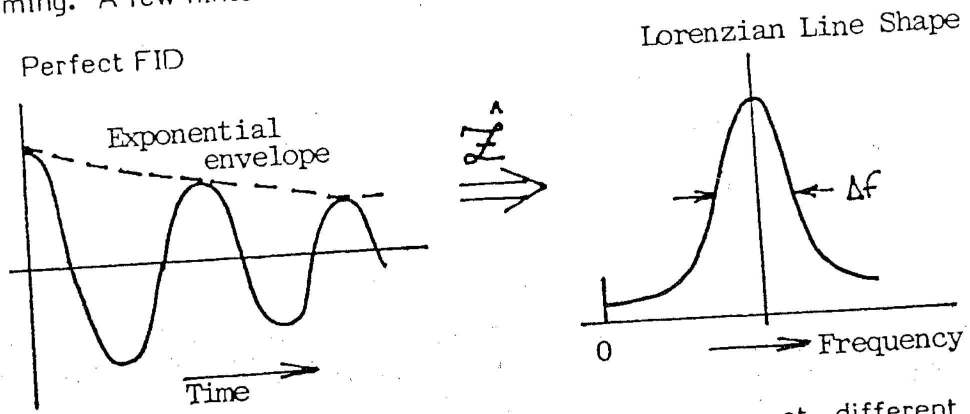
To obtain the best field homogeneity it is necessary to observe an NMR signal from a nuclear species which has a line width significantly less than the expected magnet line width. It will be assumed that the line is observed in the pulsed transmitter mode using a moderately fast repetition rate and an unsaturated signal.

All the shims have low stored energy so that no special precautions need to be taken in their operation.

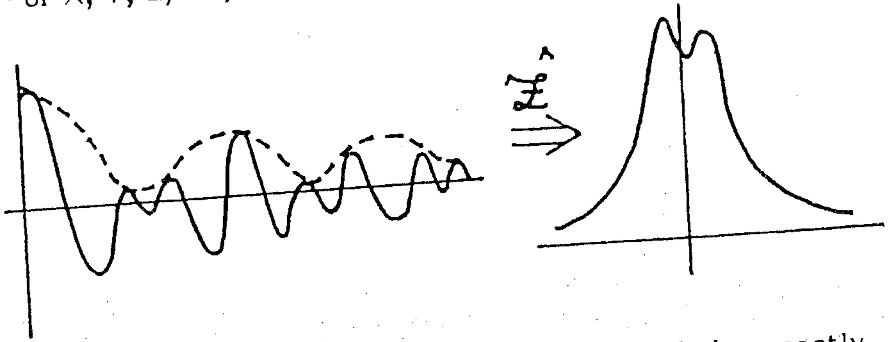
Shimming is done by altering the currents in the shim coils to make the free induction decay (FID) last as long as possible.

Each user will develop his own style of FID interpretation whilst shimming. A few hints are outlined below.

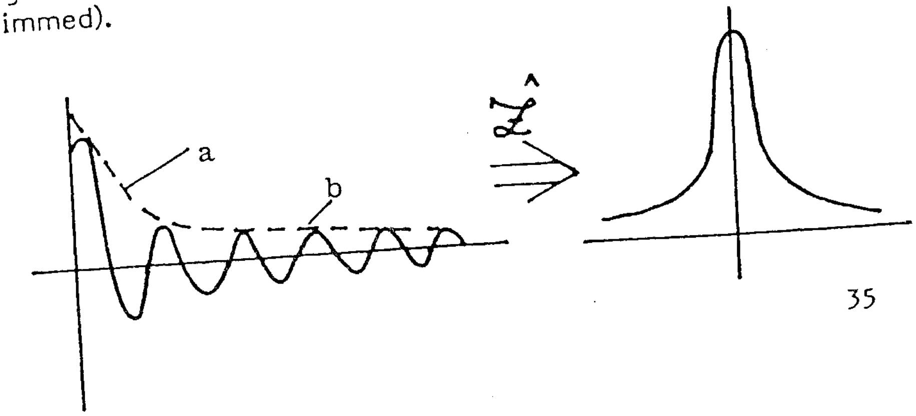
i) Perfect FID



ii) Possible "split field" giving double resonances at different frequencies. Typically caused by wrong balance between Z^1, Z^2, Z^3, Z^4 or X, Y, Z, ZX, ZY.



iii) High order gradients wrong (i.e. outside of sample is incorrectly shimmed).



When first starting to shim the FID is likely to resemble (iii). It is recommended that one first tries to minimize region (a) before concentrating in the final stages on region (b).

(a) Turn all shim switch heaters "ON" for about 30 seconds then switch them "OFF".

(From here it is assumed that the switch heaters are operated when required and no explicit instruction will be given.)

(b) Adjust the NMR probe height until the centre of the Z_1 shim is located. (i.e. the line position does not move with Z_1.) It is recommended that the shims be adjusted in the following order:

(c) Z_1, Z_2, X, Y - go round twice or more.

(d) ZX, ZY then return to Z_1, X, Y - repeat until best signal is found.

(e) XY, $X^2 - Y^2$.

(f) Repeat (d) and (e) as often as required.

(g) Sometimes the centre of the ZX and ZY shims does not coincide with the Z_1 centre, this is true if the Z_1 shim couples to the magnet. With large magnets this is quite common. In the final stages of shimming it helps to move the probe to the centre of the ZX and ZY shims. This movement will not exceed ±5 mm.

The Z_3 shim is usually set by plotting and calculating the current required. this should be done prior to adjusting the Z_1, Z_2 etc.

NOTE: It should be remembered that, at these levels of field homogeneity, the susceptibility of the construction materials of the NMR probe can cause problems. This is especially true if the symmetry of the probe construction is low, since then the inhomogeneities cannot be removed using only first and second order shims.

3.5 Discharging the Magnet

Turn all the controls of the main power supply to zero and switch on. Short the output terminals.

Insert the demountable current lead into the cryostat and connect to the electronics. TAKE CARE that all switch heaters are OFF.

Remove the short circuit from the output terminals.

CAUTION EXTREME CARE must be taken to ensure that the main current leads are connected with the correct polarity. If any doubt exists as to the correct polarity it is preferable to operate the emergency discharge mechanism rather than attempt to discharge the magnet in the conventional manner (Section 3.6.).

Set a suitable voltage limit on the current supply and sweep up the current to exactly the value of the operating current.

Open the main superconducting switch.

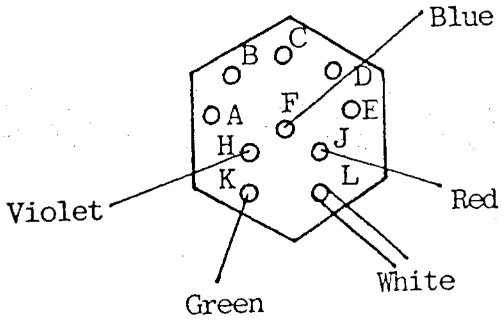
Discharge the main solenoid by running down its current at the rate specified in Part II. This can be done in constant voltage or constant current mode. Wait until the power supply terminal voltage falls to zero before disconnecting the leads.

Discharge all the shims by opening their switches.

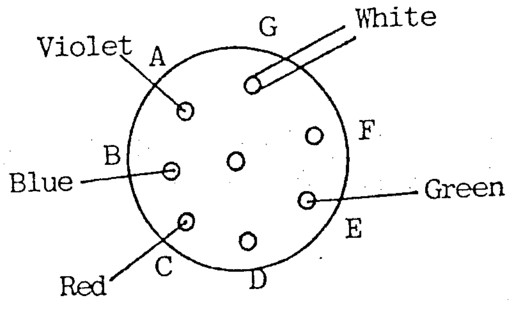
Disconnect all power supplies.

3.6 Emergency Discharge

The system is provided with a facility to allow immediate quench of the magnet in the event of an emergency. The facility consists of four heaters on the magnet wired in series and accessed via the 10 pin seal, as shown in figure 6. The wiring details to the quench unit are given below.



Soldering view of a 10-pin Seal Socket



8-way connector

4 Trouble Shooting

4.1 Cryogenic operation

High impedance pumping line	shorten line or use large bore tubing.
Defective pump	rectify or replace.
Condensable vapours in vacuum space	pump on gas ballast until clear. Warming the outer case may help.
Leak into vacuum space	prove and locate leak by connecting helium mass spectrometer leak detector to the vacuum valve. Leak located in nitrogen or helium vessels by evacuating the vessel in question, when leak rate should diminish and then filling with helium gas when leak rate will increase.
Leak in outer case	inspect 'O' rings and replace as necessary or consult Oxford Instruments Company.
Leak in nitrogen or helium vessels	consult Oxford Instruments Company.

Vacuum case pressure does not decrease on filling with liquid nitrogen

Leak into vacuum space	see above.

Vacuum case pressure does not decrease on filling with liquid helium

Diffusion pump back streaming	disconnect pump.
Leak into vacuum space	see above.

Magnet does not pre-cool

Nitrogen vessel empty	fill.

Difficulty in transferring liquid helium

Magnet not adequately pre-cooled	see part III 2.4.
Transfer tube blocked	remove, allow to warm up and blow helium gas through it.
Storage vessel empty	replace.
Transfer rate too high	recovery pipes excessively frosted. Frost for 1m indicates adequate transfer rate.

4.2 Magnet operation

Leads cannot be inserted

Entry ports blocked with ice	-	see "syphon entry port blocked with ice", above.
Connectors blocked with ice or solid air	-	with the liquid helium level at approx. 50% insert a 10 mm diameter stainless steel tube into the leads entry port. (The blowing out tube provided can be used.) The tube should be connected to a supply of helium gas before inserting it, and should be sealed with a bored-out rubber stopper to prevent further ingress of air. Lower the tube until its lower end reaches the connector on the terminal plate and then play a jet of helium gas over it. This will vaporise the solid air condensed on the plate. Remove the tube and try to insert the leads again.
Probe not central	-	check and adjust.
Magnetic materials present	-	check and remove.

Magnet discharges spontaneously

Helium level low	-	refill and re-energise.
Helium level indicator faulty	-	disconnect and check. (Applies when level indicator is interlocked to switch heater unit.)

Magnet quenches

Helium level low	-	refill, check magnet and safety mechanisms.
Leads replaced with incorrect polarity	-	refill, and check magnet.

Excessive heat leak	-	see "excessive evaporation rate" below.
Thermal oscillations in helium vessel neck	-	Place ear to top of cryostat-oscillations can sometimes be heard. Move transfer tube up or down until oscillations disappear.
Syphon does not reach to the bottom of magnet	-	when cooling the magnet down to 4.2K it is essential to transfer liquid to below the magnet so that the enthalpy of the gas is used for cooling. Ensure that the transfer tube is inserted into the extension socket on top of the magnet.

Excessive liquid helium evaporation rate

Leak into vacuum space	-	indicated by condensation of water vapour or frost on the cryostat's outer wall.
Helium vessel touching	-	indicated by reduction in radiation shield evaporation rate. Consult Oxford Instruments Company.
Radiation shield insufficiently cold	-	either the liquid nitrogen vessel is empty - refill, or the radiation shield is touching the outer case indicated by a cold spot on the outer case - constult Oxford Instruments Company.

N.B Normal liquid helium evaporation rate is given in Part II. This is with the magnet in persistent mode and the leads removed. The evaporation rate will be higher than this immediately after transferring.

Syphon entry port blocked with ice

Remove the top cap from chimney and cover the aperture. Warm and dry the cap.

SYSTEM PROBLEM/RETURN FORM

If any difficulty is experienced in operating the system, the following details should be given to the Project Manager, Magnet Systems Group or his appointed representative. In the event that the system is returned to the works for repair, then this written form should be completed and addressed to:- Magnet Systems Manager, Oxford Instruments Ltd., Osney Mead, Oxford. OX2 0DX England. Telephone (0865) 41456.

System Type ....

System Project No. ....

Magnet No. ....

Cryostat No. ....

Date first received ....

Who commissioned the system ....

Briefly describe the problems/symptoms experienced with the system.

If other equipment such as power supply, sweep generator, temperature controller etc. is faulty, please give details:-

Equipment ....

Model ....

Serial No. ....

Date first received ....

Customer .... Date ....

Address ....

....

....

SEAL 1

				Ohms (approx)	
Helium Level Probe :	A	-	B	1.3	5.3
	A	-	D	145	155
	A	-	E	152	160
	B	-	D	145	156
	B	-	E	152	160
	D	-	E	15.3	22
	A	-	ground	00	∞

SEAL 2

Helium Level Probe 2 :	A	-	B	1.3	5.8
	A	-	D	145	155 - 15
	A	-	E	152	158
	B	-	D	145	155
	B	-	E	152	155
	D	-	E	15.3	20
	A	-	ground	00	
Allen Bradley Resistors :	H	-	ground	00	
	H	-	J	101	
	H	-	K	103	
	H	-	L	102	
	J	-	K	204	
	J	-	L	204	
	K	-	L	205	

SEAL 3

Emergency Discharge Heaters :	F	-	ground	00	
	F	-	H	10	-13
	F	-	J	10	-13
	F	-	K	10	-13
	H	-	J	20	19
	H	-	K	20	19
	J	-	K	20	24

Table 1 HELIUM LEVEL SENSOR CHECK

STATUS AT MAGNET	21 PIN NO	TOP OF DEMOUNTABLE LEAD	(2-14-2008) Ω
Shims (positive)	1	B1/B2	0.3/0.3
X Heater	2	A5 ✓	0.7
Y Heater	3	A6 ✓	0.7
ZX Heater	4	A7 ✓	0.6
ZY Heater	5	A8 ✓	0.6
XY Heater	6	A9 ✓	0.6
X^2-Y^2 Heater	7	A10 ✓	0.6
Shims (negative)	8	B4/B5	0.3/0.3
Heater Common	12	B10 ✓	0.7
Main Heater	13	A1 ✓	0.6
Spare Main Heater	14	A2	0.7
Z_1 Heater	15	A3 ✓	0.7
Z_2 Heater	16	A4 ✓	0.7
Z_3 Heater	17	B9	0.7

TABLE 2 SHIM DEMOUNTABLE
LEAD WIRING

TABLE 3

MAGNET WIRING AND CHECKING

				Ohms (approx)
B10	-	A1	Main heater	100 - 105
B10	-	A2	Spare main heater	100 - 104
B10	-	A3	Z_1 heater	100 106
B10	-	A4	Z_2 heater	100 106
B10	-	B9	Z_3 heater	100 106
B10	-	A5	X heater	100 105
B10	-	A6	Y heater	100 104
B10	-	A7	ZX heater	100 105
B10	-	A8	ZY heater	100 105
B10	-	A9	XY heater	100 105
B10	-	A10	$X^2 - Y^2$ heater	100 104
B1/B2	-	B4/B5	All shims	50 81

B10	-	ground	Heater isolation	00
B10	-	B1/B2	Heater - shim isolation	00
B1/B2	-	ground	Shim isolation	00

Cryogen	Normal Boiling Point (K)	Latent Heat (Joules/g)	Amount of Liquid Evaporated by 1 Watt (L/hour)	Liquid Density (g/ml)	Gas Density at NTP (g/ml)	Liquid to NTP Gas Volume Ratio	Enthalpy Change (gas) B.P to 77K (J/gm)	Enthalpy Change (gas) 77 to 300 (J/gm)
Liquid Helium	4.2	20.9	1.38	0.125	1.79×10^{-4}	1 : 700	384	1157
Liquid Hydrogen	20.39	443	0.115	0.071	8.99×10^{-5}	1 : 790	590	2900
Liquid Nitrogen	77.55	198	0.023	0.808	1.25×10^{-3}	1 : 650	-	234
Liquid Oxygen	90.19	212.5	0.015	1.14	1.43×10^{-3}	1 : 797	-	From BP 193

TABLE 4 Properties of Cryogenic Liquids

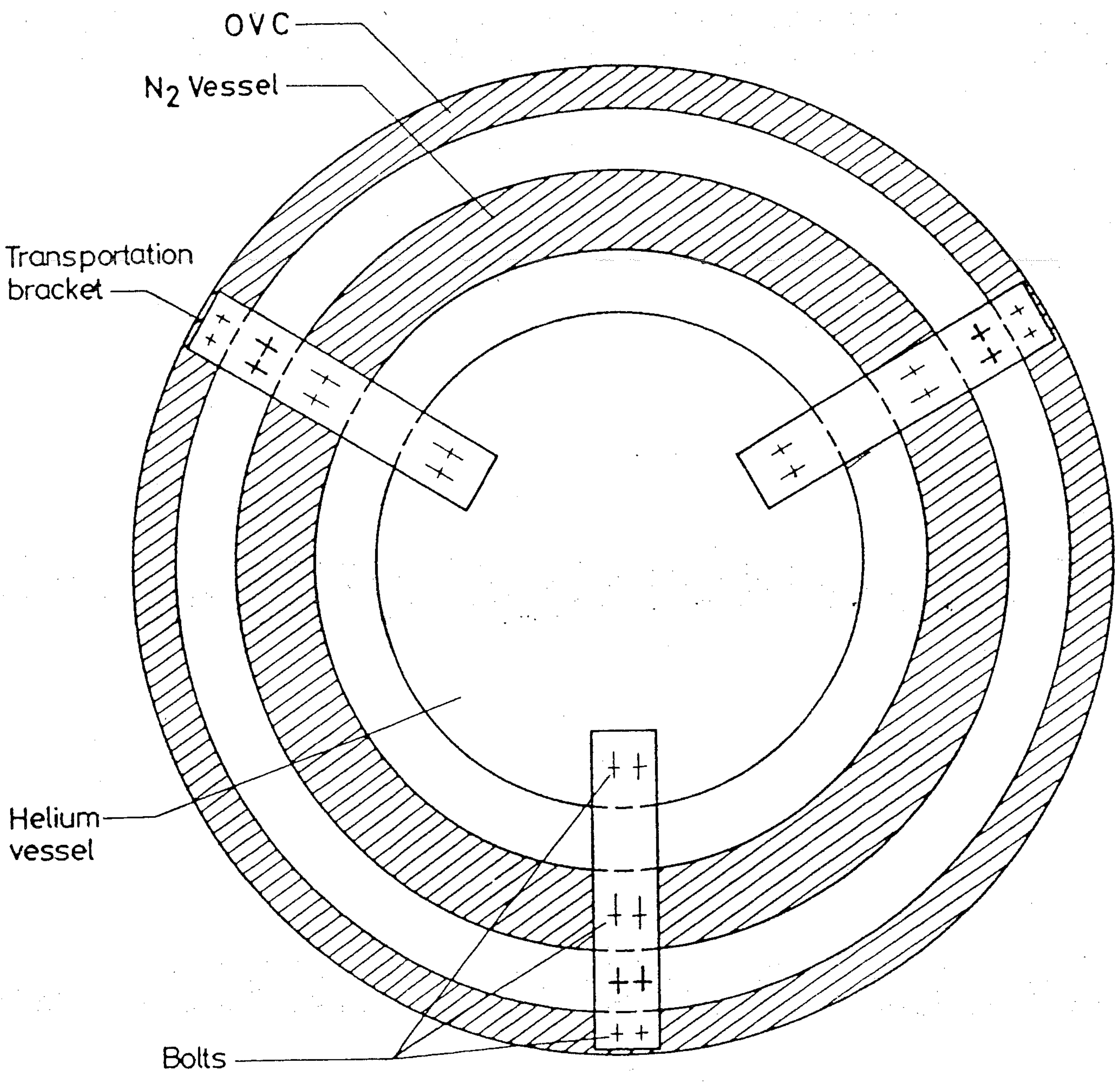


Figure 1 Schematic layout of Transportation brackets

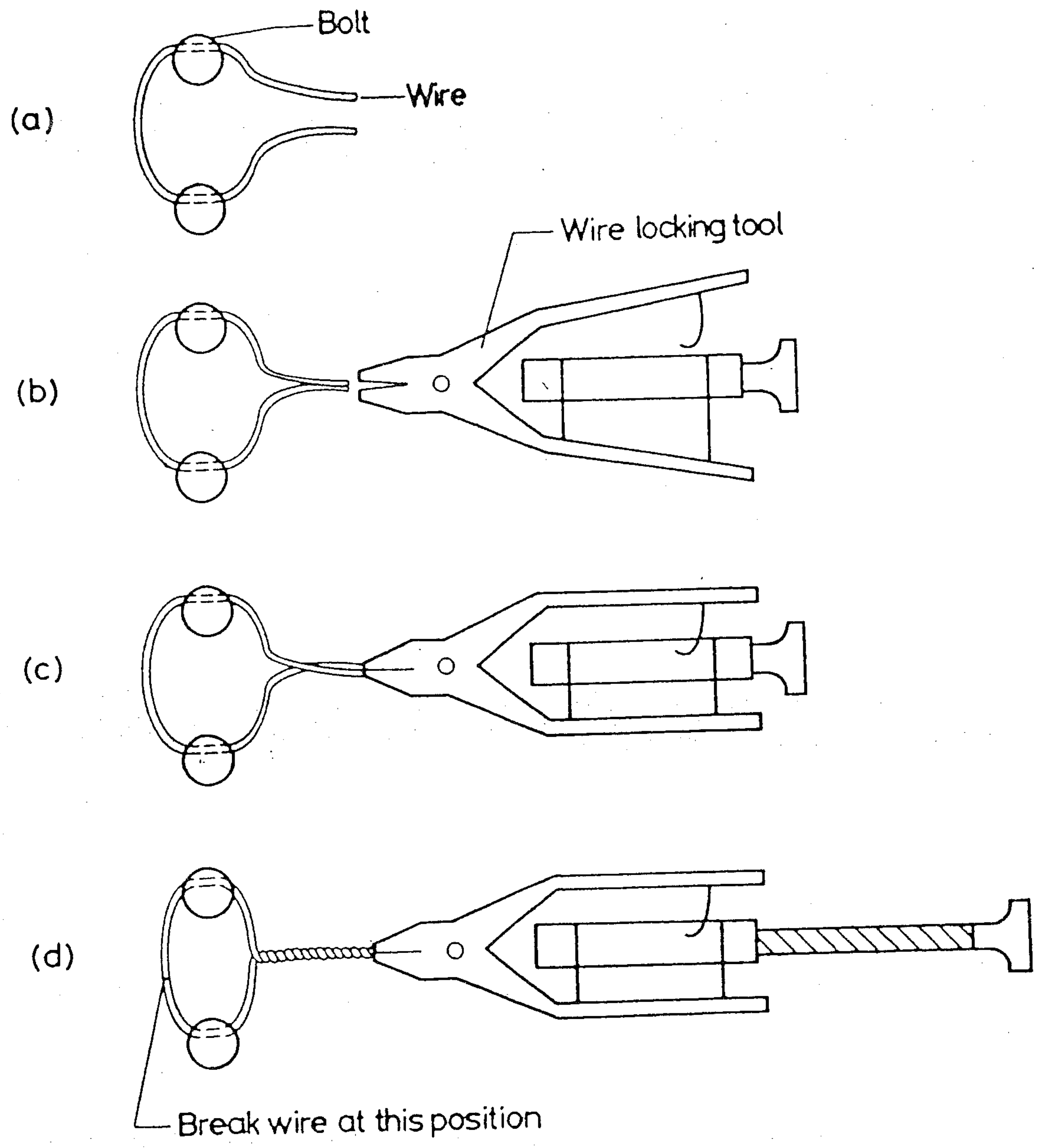

Bolt
Wire
(a)
Wire locking tool
(b)
(c)
(d)
Break wire at this position

Figure 2

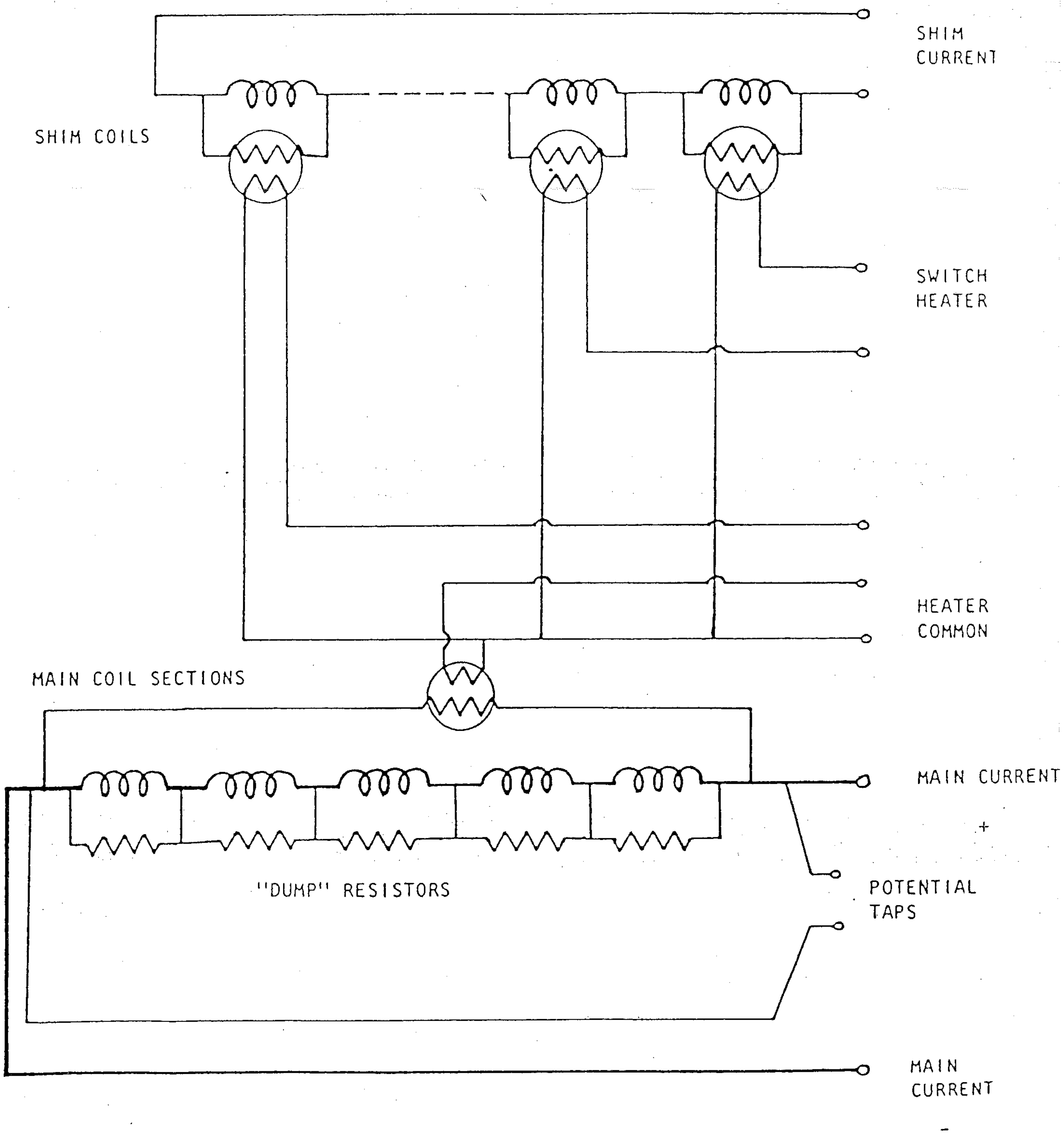


FIGURE 3 MAGNET CIRCUIT SCHEMATIC

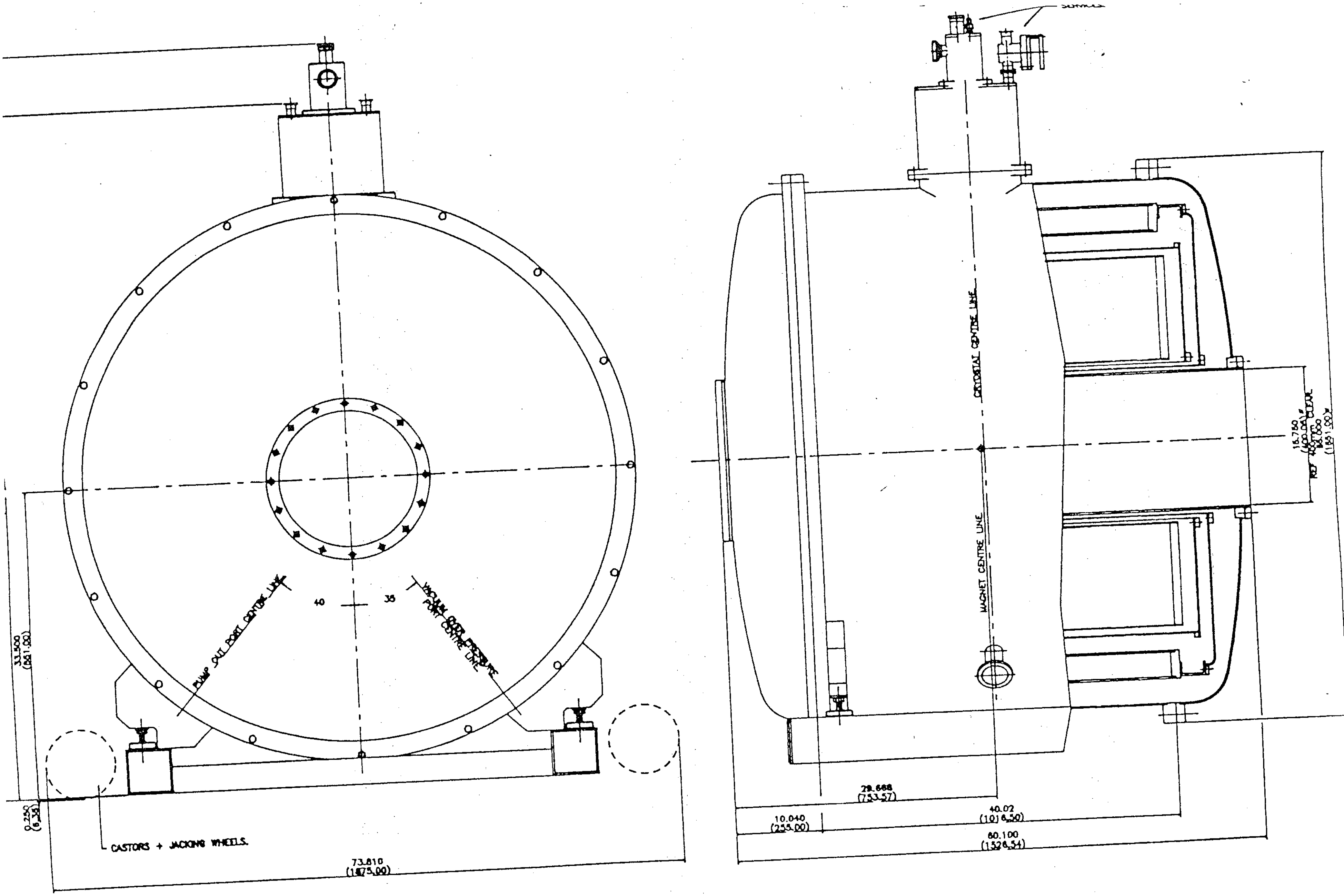


Figure 4 - Cryostat Schematic

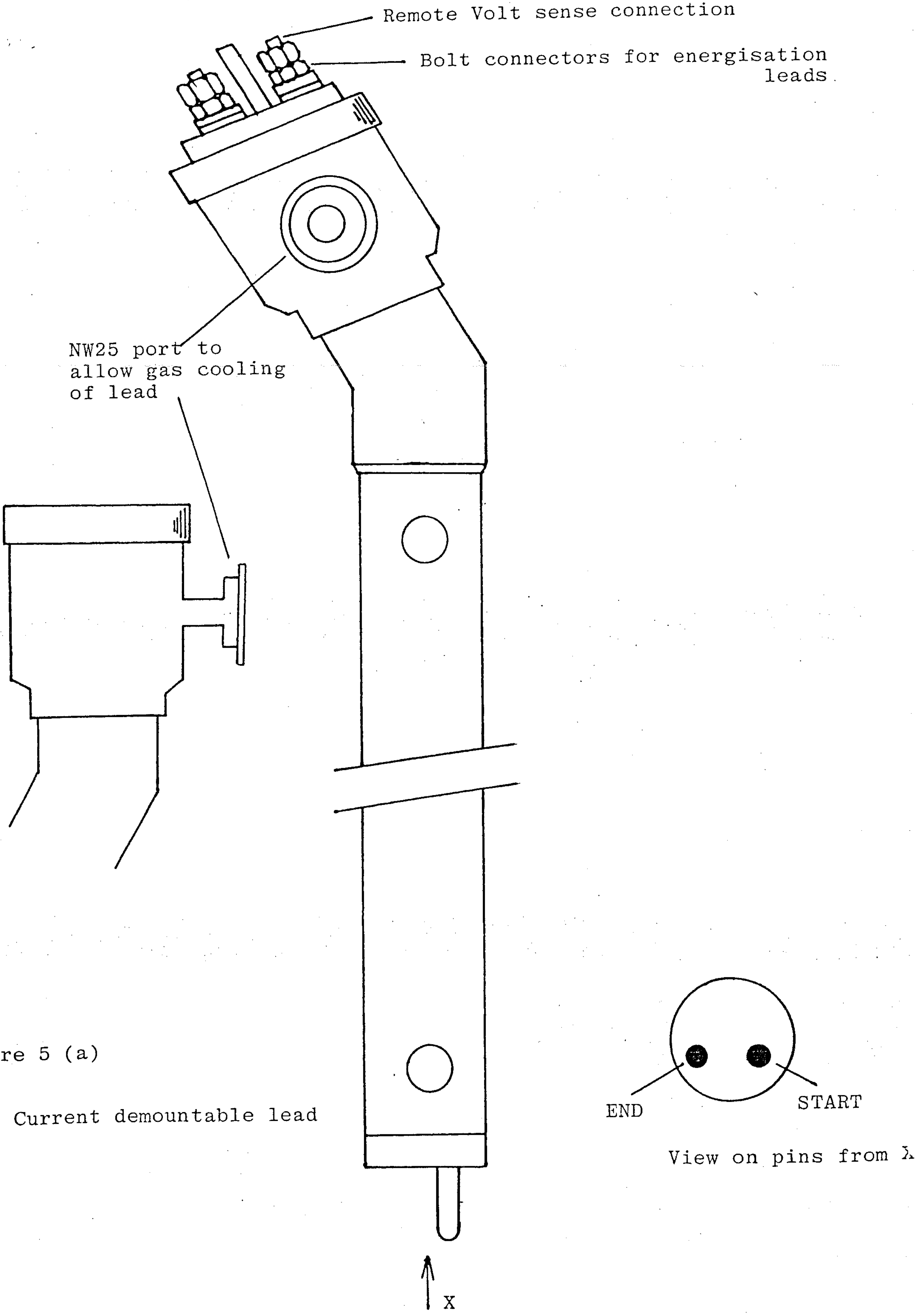


Figure 5 (a)

Main Current demountable lead

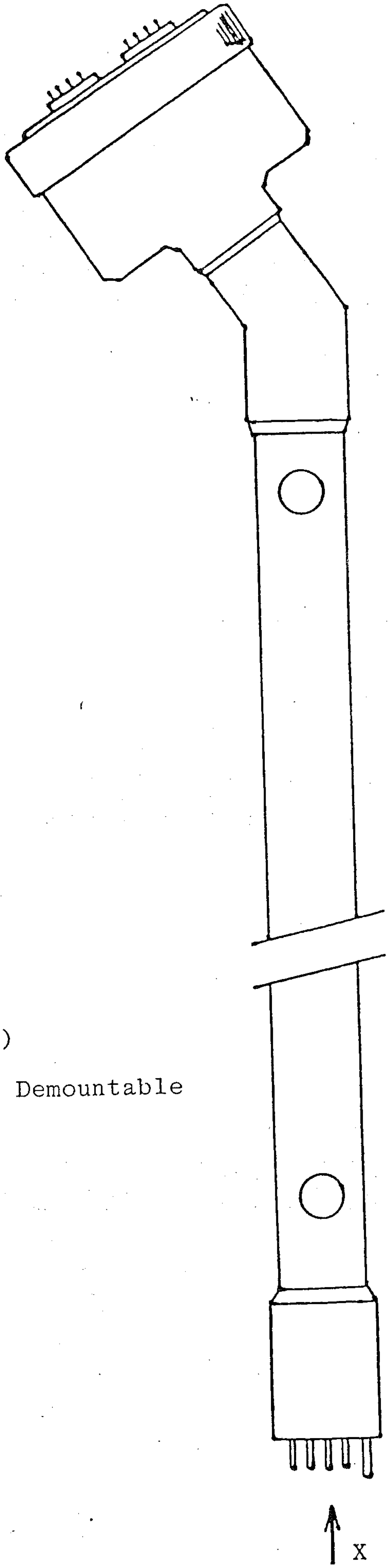
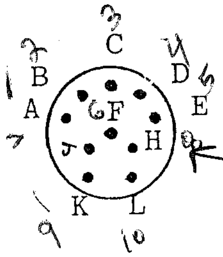
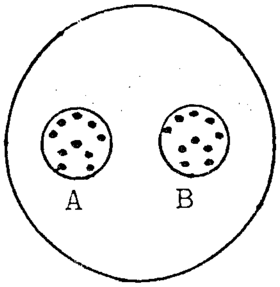


Figure 5 (b)

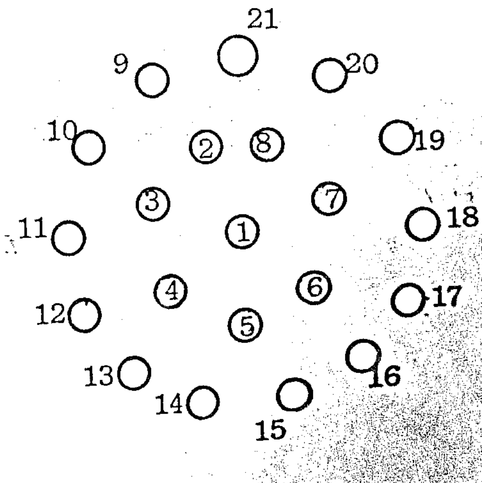
21 pin Shim Demountable Lead



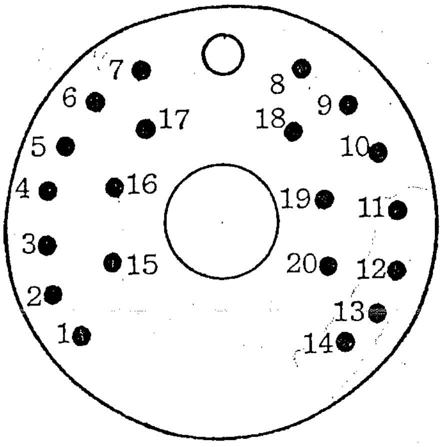
switch H & J (see next page)



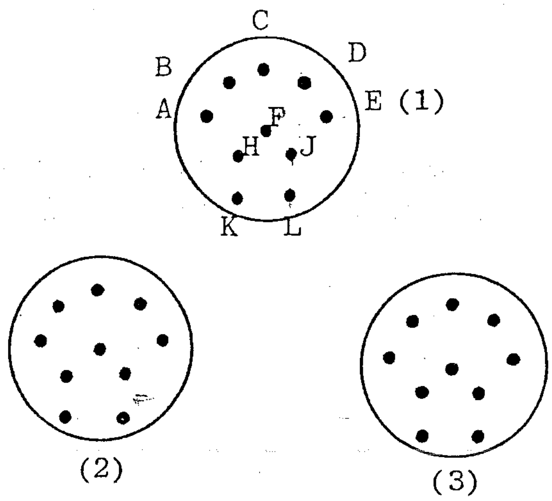
View at top of lead



View on pins from X



View onto socket looking into Cryostat



View onto 3-10 pin Seals on Cryostat.

		20 pin socket	10 pin seal
Helium level probe (1)	(I+	1	1A
	(V+	2	1B
	(V-	3	1D
	(I-	4	1E
Helium level probe (2)	(I+	6	2A
	(V+	7	2B
	(V-	8	2D
	(I-	9	2E
Allen Bradley Resistors	(Common	11	2H
	(1st	12	2J
	(2nd	13	2K
	(3rd	14	2L
Quench heaters	(Common	15	3F
	(1st	16	3H
	(2nd	17	3J
	(3rd	18	3K
	(4th	19	3L

Firgure 6 Helium Sensor and Emergency Discharge Wiring

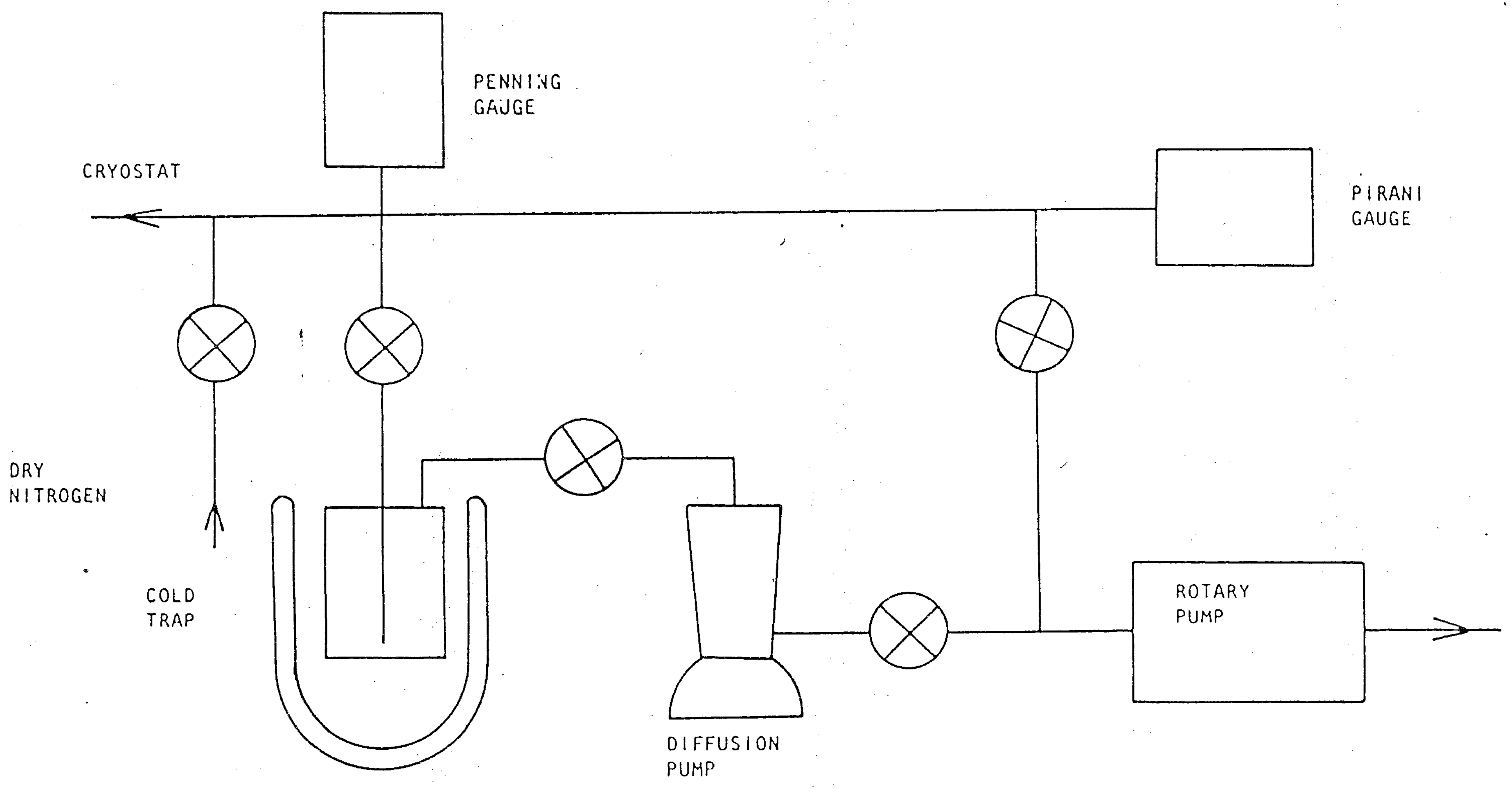

PENNING GAUGE
CRYOSTAT
PIRANI GAUGE
DRY NITROGEN
COLD TRAP
DIFFUSION PUMP
ROTARY PUMP

FIGURE 7

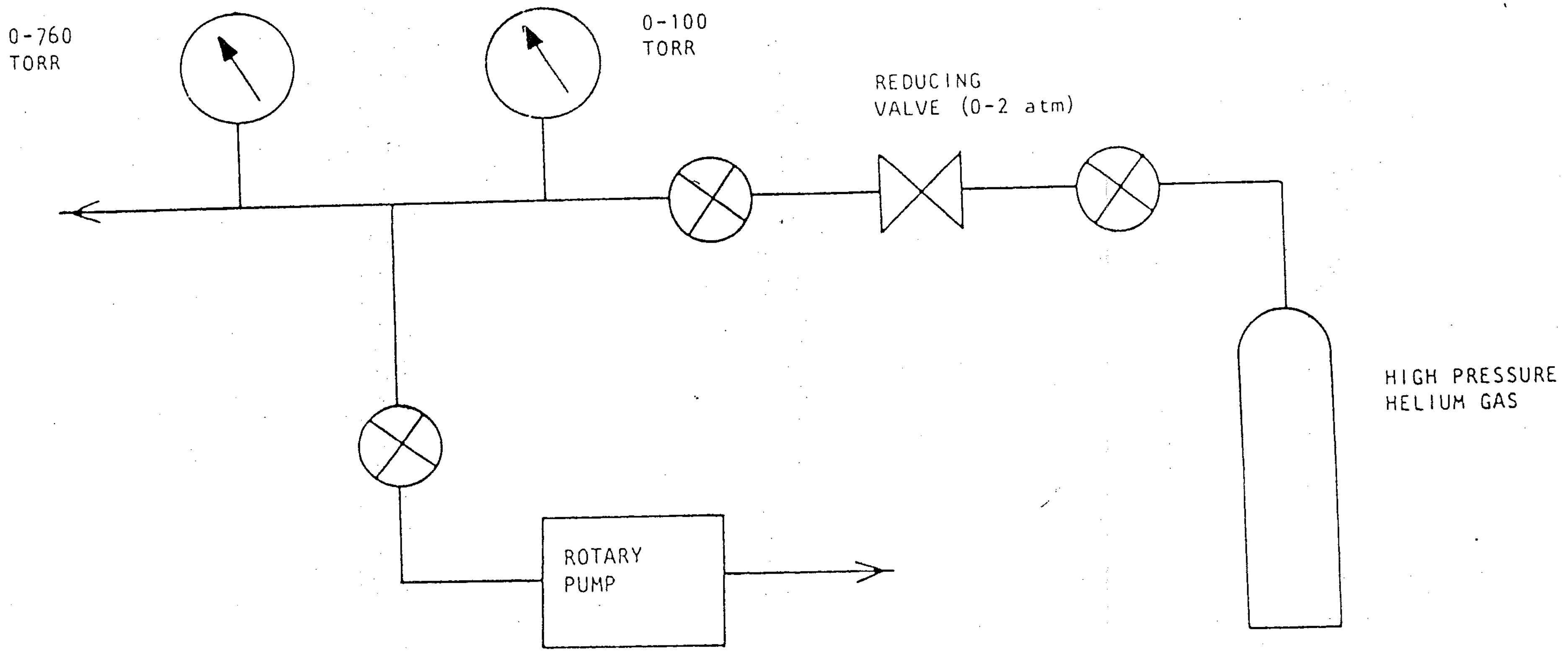

0-760
TORR
0-100
TORR
REDUCING
VALVE (0-2 atm)
HIGH PRESSURE
HELIUM GAS
ROTARY
PUMP

FIGURE 8

7/30/2014 Oxford Magnet Al Tobias

---

20 ft / 0 AWG $0.096\,\Omega/1000\text{ft} \rightarrow 0.00192\,\Omega$

---

100 ft / 000 AWG $0.063\,\Omega/1000\text{ft} \rightarrow 0.0063\,\Omega$

---

100 ft / 6 AWG in parallel w/ 1 AWG

$0.4028\,\Omega/1000\text{ft}$ $0.1264\,\Omega/1000\text{ft}$

$\underbrace{0.04028\,\Omega \quad 0.01264\,\Omega}_{\rightarrow\ 0.009620922\,\Omega}$

Assume $\tau = \frac{L}{R}$ $\frac{116\,H}{R}$

$$I = I_0 e^{-\frac{t}{\tau}}$$

$0.00192 + 0.0063 + 0.04028$

$R_{TOTAL\_i} \simeq 0.017841\,\Omega$ $R_{TOTAL\_f} \simeq 0.0485\,\Omega$

$V = IR_i \Rightarrow (200\,A)(0.017841) = 3.5682\,V$ $\tau = 1.81$ hrs

$I_1 = I_0\, e^{-\frac{t}{\tau} \leftarrow 1} = 73.6\,A$ (one time constant)

$I_2 = I_0\, e^{-2} = 27.1\,A$ (two time constants)

$V = IR_f \Rightarrow (27.1A)(0.0485\,\Omega) = 1.31435\,V$ $\tau \simeq 40$ mins

$I_1 = I_0 e^{-1} = 9.97A$ $I_2 = I_0 e^{-2} = 3.67A$ $I_3 = I_0 e^{-3} = 1.35\,A$

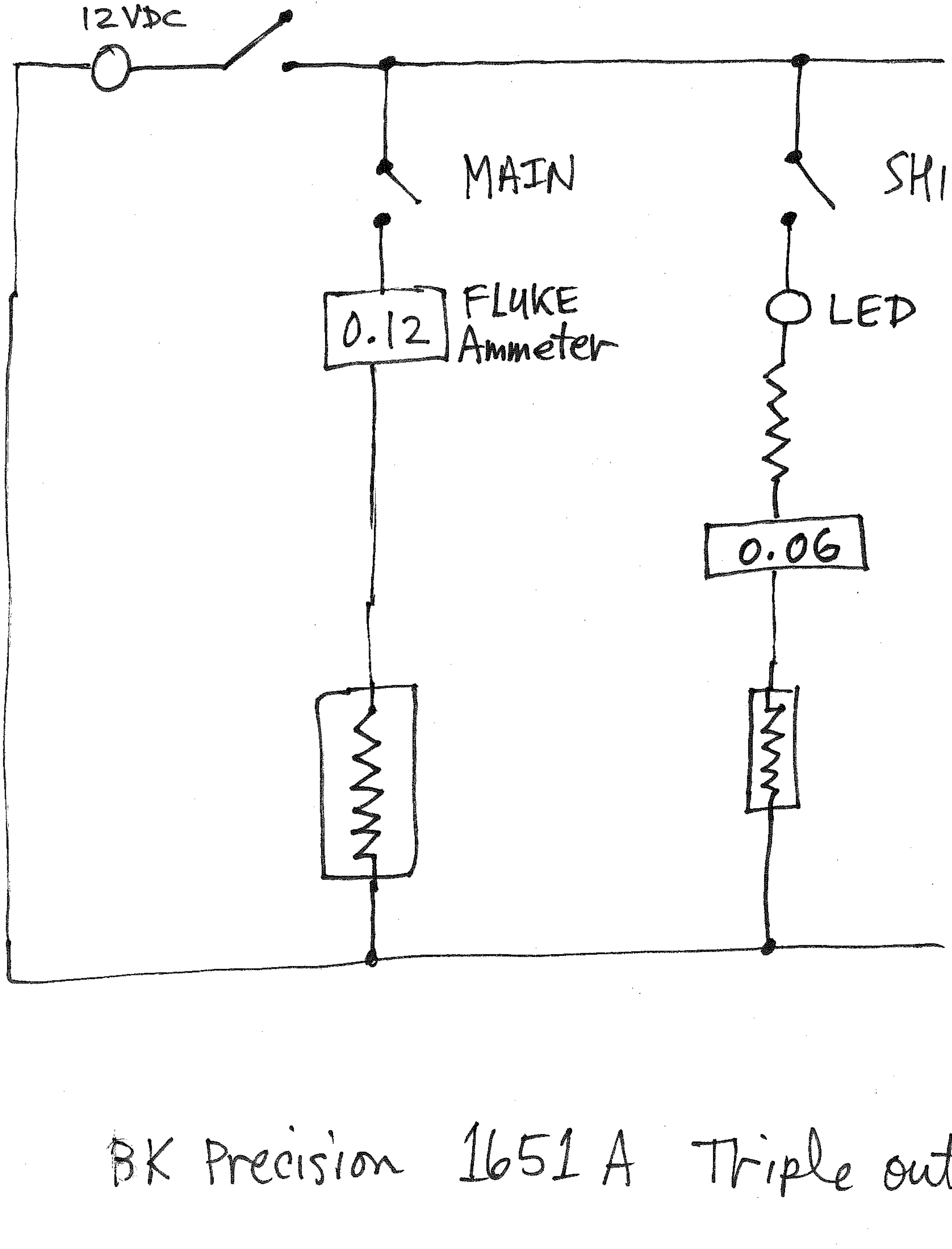
Eck Supply (434) 977-2990
1150 Rose Hill Drive

7/30/2014

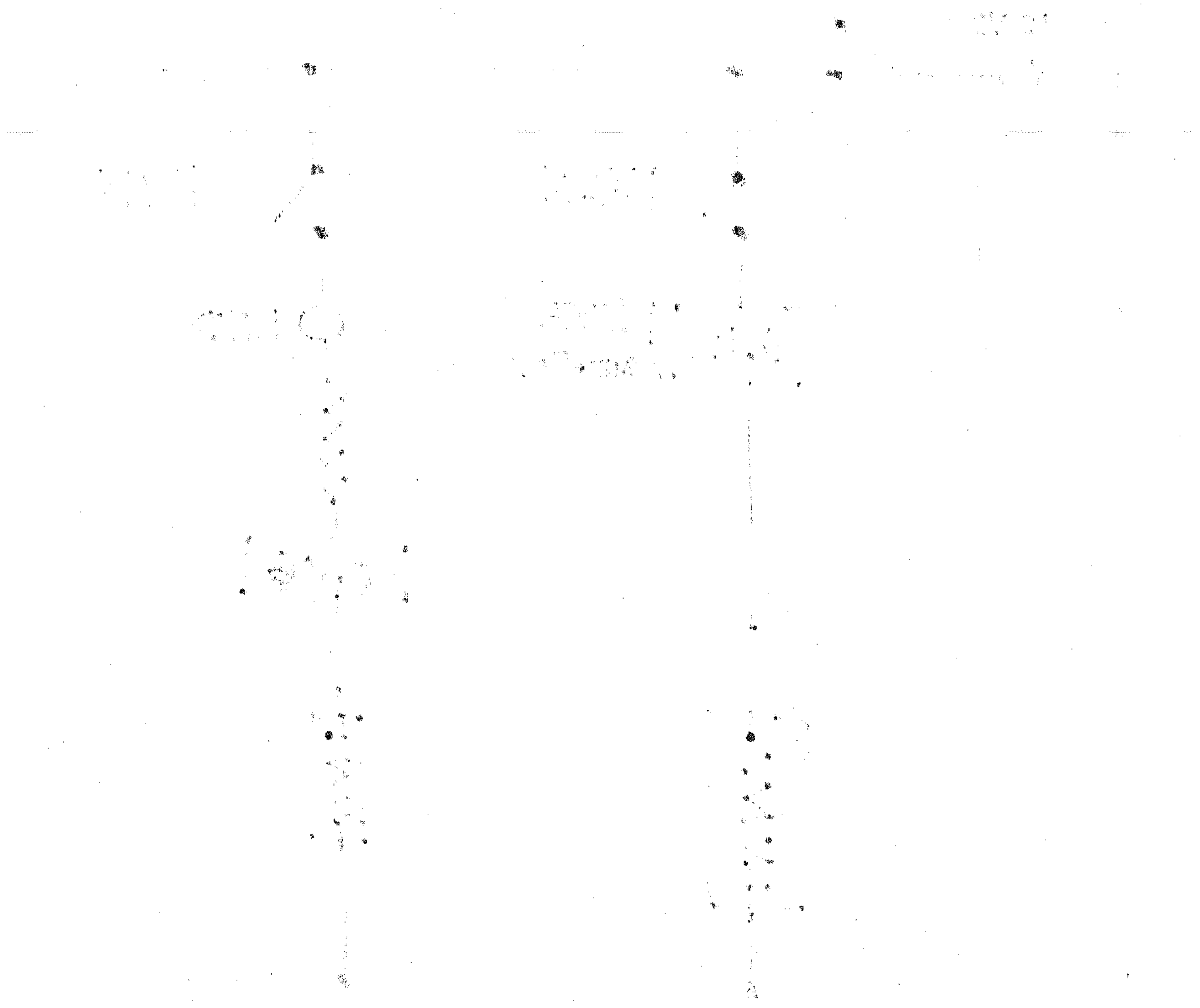
Main Switch Heater A=120mA w/ 100Ω load

~12 VDC use FLUKE to meas. current

Switch Heater for Shims A=60mA w/ 100Ω



BK Precision 1651 A Triple output



7/30/2014

4.7 T , 240 A , multifilamentary Ni Ti

Bore 400mm dia , I = 116H , Switch = 100 Ω

shim = 10 Ω

↑

switch (not heater)

Switch Heater = 100 Ω

P.S. Trip = 4 V

Overfield Value = 900mA

☐ What are the ramp down voltage parameters?