EXCELLENCE IN MAGNETICS AND CRYOGENICS

AMI SUPERCONDUCTING MAGNETS

INSTALLATION, OPERATION, AND MAINTENANCE INSTRUCTIONS

American Magnetics, Inc.

PO Box 2509, 112 Flint Road, Oak Ridge, TN 37831-2509, Tel: 865 482-1056, Fax: 865 482-5472

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Introduction

These instructions are written to be generic and apply to most of the various types of magnets supplied by AMI. Some sections and data may or may not apply to the system you have purchased. It is recommended that you carefully read these instructions prior to the installation and operation of your magnet system. If you have purchased a magnet that is permanently installed into a cryostat, these instructions will generally be supplemented by operating instructions provided by the cryostat manufacturer.

Magnet Construction

AMI superconducting magnets are typically wound using conductors comprised of many filaments of a superconducting material embedded in a copper matrix and twisted along its axis to insure optimum performance of the superconductor. Electrical insulation is provided by the insulation on the wire and by the epoxy between each turn. All magnets are wet wound or vacuum impregnated with an epoxy to assure the absence of voids and to prohibit movement of the wire.

The former on which the magnet is wound is constructed of aluminum, brass, stainless steel, or other material as required for a particular magnet. Micarta end flanges are typically used on the magnets to provide a rugged, insulated mounting surface. When required, tapped brass inserts are screwed and epoxied into the end flange for supporting the magnet. Standard mounting holes are tapped for threaded rods or screws. Current lugs, protective diodes, and a persistent switch are typically mounted on one end of the magnet.

AMI magnets are typically over-wrapped with a yellow cord to protect the windings from minor shock. The end flanges are painted dark blue and each magnet is labeled with a unique four digit serial number.

Specifications

A *Magnet Specification Sheet* is provided with each magnet after it has been tested at AMI. All stated currents are nominal and may vary slightly from the cited currents in the final magnet application. The coil constant which specifies the magnetic field produced per ampere of current is supplied with each magnet.

Magnet Protection

All AMI magnets are designed and constructed such that in the unlikely event of a quench at fields up to and including the rated field, damage will not occur to the magnet. Each magnet is warranted against such damage by the standard AMI warranty. AMI magnets are not warranted if operated above the rated field.

Persistent Mode

After it has been energized, a superconducting magnet can be operated in the persistent mode by short circuiting the magnet with a superconductor. This is accomplished by connecting a section of superconducting wire contained in the persistent switch across the terminals of the magnet. This section of superconductor can be heated to drive it into the resistive state so a voltage can be established across the terminals and the magnet can be charged or discharged. After reaching the desired field, the heater is turned off and the magnet is shorted by the switch.

Maintenance

AMI magnets are designed and constructed so as to provide years of useful service and require no maintenance if installed and operated in accordance with these instructions.

Specifications

AMERICAN MAGNETICS, INC.

P.O.Box 2509, 112 Flint Road, Oak Ridge, TN 37831-2509
Phone: (423) 482-1056 Fax: (423) 482-5472
E-mail: amagi@usit.net http://www.usit.net/ami

MAGNET SPECIFICATIONS

AMI JOB# XXXX MAGNET# XXXX
TYPE: Solenoid
MODEL: A6080-3
USER: Dr. XXXXX
FOR: XXXXX
TEST DATE: 11/3/95

Rated Central Field @ 4.2K	150KG
Rated Current	125 Amps
Maximum Test Field @ 4.2K	152 KG
Homogeneity over 1 cm DSV	+/-0.1%
Measured Inductance	50 Henrys
Charging Voltage (Used in test)	3 Volts
Clear Bore	2 inches
Overall Length (Flange to Flange)	10 inches
Maximum Outside Diameter	12 inches
Weight	10 lbs.
Recommended Persistent Switch Heater	30 mAmps
Persistent Switch Heater Nominal Resistance	20 Ohms
Magnet Resistance in Parallel w/Switch	80 Ohms

Mounting Holes: 3 Holes tapped for 10-32 on top flange, equally spaced on an 8 inch B.C.D.

* Magnet not warranted for operation above rated field.
** All resistance measurements made at room temperature.

EXCELLENCE IN MAGNETICS AND CRYOGENICS

The above diagram is an example of a typical *Magnet Specification Sheet*. The specifications for the magnet are mailed to the customer and a copy is included with the magnet shipment.

The following is an explanation of typical magnet specification parameters as they appear on the *Magnet Specification Sheet*. Some specifications are unique to a particular magnet type and the data may not appear on your sheet or additional data may be added as appropriate.

1. **Rated Field @4.2K -** The rated field is the maximum field the magnet is guaranteed to achieve and be protected. The rated field is verified by nuclear

magnetic resonance (NMR) tests at 4.2K or by calculation if NMR checks are not possible.

2. **Rated Current -** The rated current is the magnet current required to achieve the rated field.

3. **Maximum Test Field @4.2K -** The maximum test field is the maximum field achieved during AMI testing. The magnet is not warranted for operation at the maximum test field. AMI performs the test to insure the magnet is of good design and construction and will operate properly at rated field.

Caution

AMI magnets are not warranted for operation above rated field.

4. **Field-to-Current Ratio -** The field-to-current ratio is a number defined to be the magnetic field produced per amp of magnet current. It is specified in units of gauss per amp and is generally determined by NMR measurement techniques.

5. **Homogeneity -** Homogeneity is the maximum field deviation from the rated field specified over a specific length or volume.

6. **Measured Inductance -** The inductance of the magnet is determined during magnet testing using the relationship $L = E(^{dt}/_{dI})$.

7. **Charging Voltage (used in test) -** The charging voltage is the maximum voltage developed across the magnet during testing at AMI.

8. **Clear Bore -** The minimum magnet bore diameter at operating temperature.

9. **Radial Access -** The minimum magnet radial access diameter at operating temperature. (Split coil systems only).

10. **Overall Length (flange to flange) -** The measured overall length of the coil including the end flanges. This dimension excludes the persistent switch and current lugs if applicable.

11. **Maximum Outside Diameter -** Maximum outside diameter of the magnet.

12. **Weight -** Magnet weight.

13. **Recommended Persistent Switch Heater Current -** The recommended persistent switch heater current is the amount of current required to guarantee the persistent switch is in the resistive state.

14. **Persistent Switch Heater Nominal Resistance -** The persistent switch heater nominal resistance is the room temperature resistance of the switch heater.

15. **Magnet Resistance in Parallel with Switch -** Magnet resistance in parallel with switch is the room temperature resistance of the magnet windings and the switch in parallel.

16. **Mounting Holes -** The mounting hole specification is the magnet mounting method and geometry.

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1 Installation

Unpack the magnet

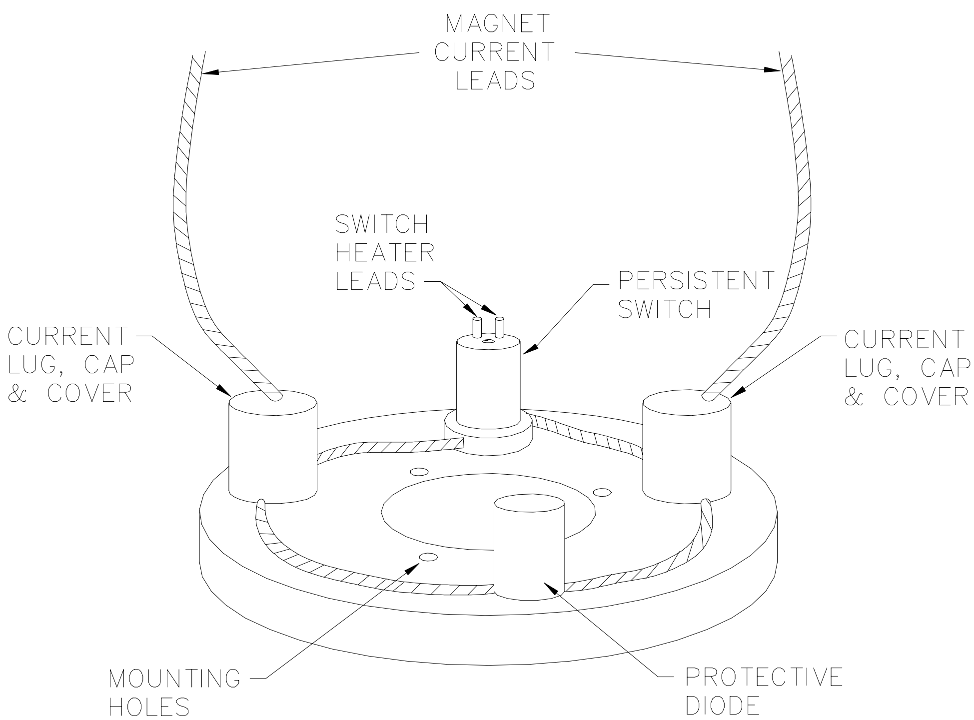
Carefully remove the magnet from the shipping carton and remove all packaging material. Inspect all contents for any damage that may have occurred during shipment.

Note

If there is any shipping damage, save all packing material and contact the shipping representative to file a damage claim. Do not return the magnet to AMI unless prior authorization has been received.

Setup

1. Mount the magnet on the support stand or other device that will support the magnet in the dewar.



Caution

Be careful not to overtighten the mounting screws in the mounting lugs to prevent damage to the threads.

Be careful not to disturb the wiring located on the top of the magnet. Only the magnet current leads are to be bent and/or soldered.

2. Connect the magnet current leads to the superconducting bus bars or vapor-cooled current leads if no bus bars are required. The magnet current lead and bus bar connections are mechanically attached by wrapping the joint region with a small diameter tinned copper wire. Electrical connections are accomplished by soldered the joint region with ordinary eutectic lead-tin or other low melting point solder.

Caution

Exercise care during the soldering process. A heat sink is recommended on the magnet current lead close to the current lug to limit the heating of the lug. Limit the amount of heat applied to the joint to allow the solder to flow between the mating surfaces and not overheat the bus bar or leads. Overheating of the bus bars could lead to delamination of the bus bar.

3. Refer to the persistent switch heater power supply manual and connect the persistent switch heater, if applicable, to the power supply. Generally a top plate connector is used to make this connection.

4. Use nylon cable ties as needed to support all wiring inside the dewar to limit wire movement at very low temperatures.

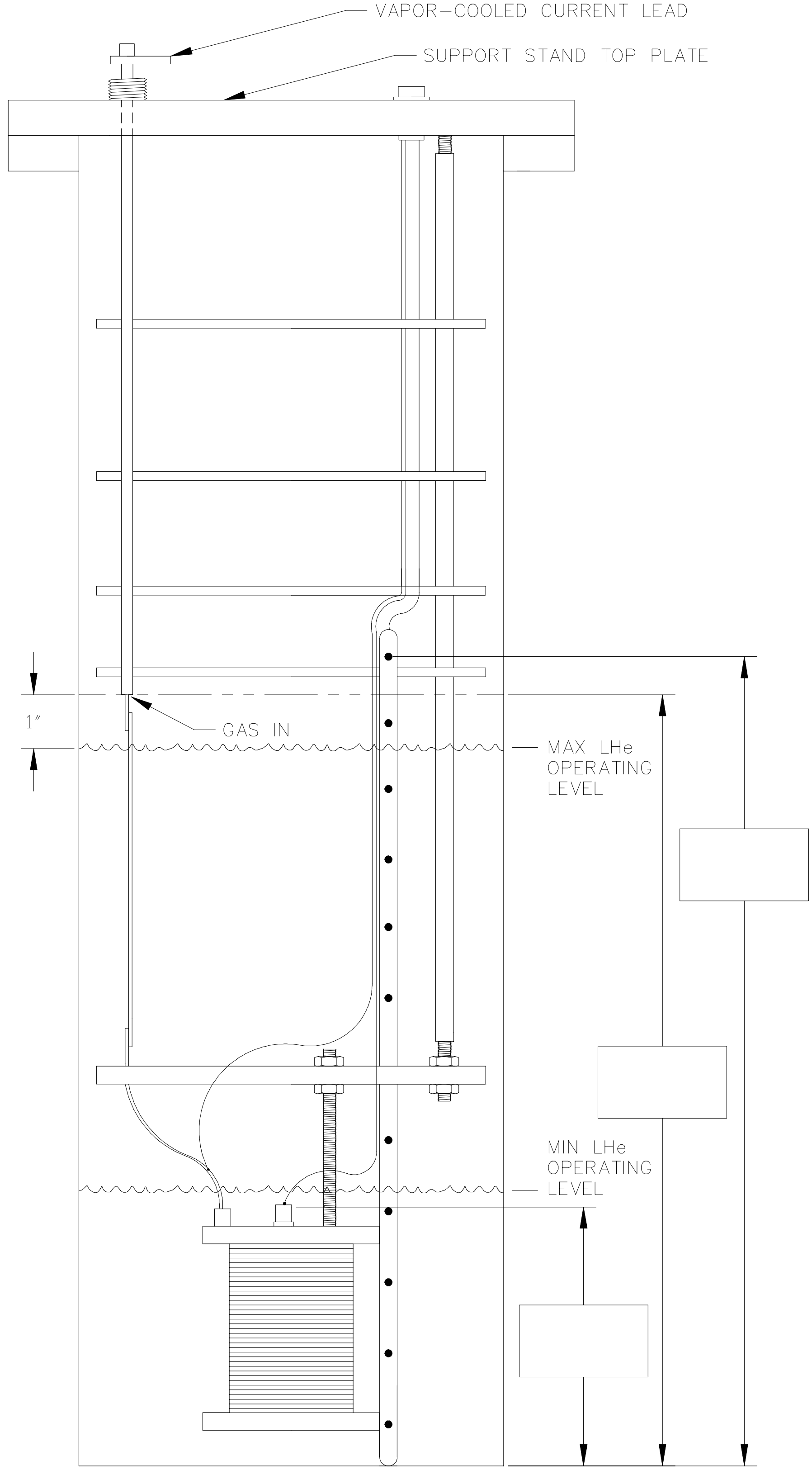
5. Use a resistance meter to check the continuity of all wiring.

6. It is important for the user to know the level of liquid helium on the level sensor when the magnet and switch (if applicable) are just covered. This level will determine the minimum level of liquid helium required for safe magnet operation. For AMI liquid helium level sensors, this distance is measured from the bottom of the sensor to the top of the magnet and switch (if applicable) minus 1/2 in. (1.3 cm). The included figure is provided to record this information.

   It is also important for the user to know the maximum level of liquid helium which will be present in the system. This level is usually one inch (2.5 cm) to two inches (5 cm) below the gas inlet holes at the bottom of the vapor-cooled current leads. The included figure is provided to record this information.

Note

Refer to the operations manual of all system equipment and accessories before connecting to the magnet system...


VAPOR–COOLED CURRENT LEAD
SUPPORT STAND TOP PLATE
1″
GAS IN
MAX LHe OPERATING LEVEL
MIN LHe OPERATING LEVEL

Cooldown

Be sure the magnet and support assembly are free of all moisture and contaminants prior to magnet cooldown.

1. Precooling the magnet to 77K in liquid nitrogen (LN_2) will reduce the amount of liquid helium (LHe) required for cooldown to 4.2K. This can be accomplished several ways.

    a. Immerse the magnet in LN_2 prior to inserting the magnet in the system dewar. Styrofoam cooler containers work well for this process. This process may not be practical for complex magnet systems.

    b. Immerse the magnet in LN_2 while installed in the system dewar. This may be accomplished by adding LN_2 to the LHe chamber to cover the magnet. Once the magnet has cooled to 77K, all LN_2 must be removed from the LHe chamber before helium is transferred.

    c. In a nitrogen-jacketed dewar system where cooldown time is not critical, filling the dewar jacket with LN_2 will slowly cool the magnet and support stand to 77K.

    Note

    If the magnet is precooled in LN_2, it is important that all LN_2 is removed from the magnet assembly and dewar before cooling the magnet and dewar to 4.2K. Residual LN_2 will require an excessive amount of liquid helium (LHe) to freeze the LN_2 and also may adversely affect magnet operation. Removing all residual LN_2 can easily be accomplished by allowing the system to warm-up several degrees above 77K to evaporate any LN_2.

2. Connect a LHe transfer line that will reach to the bottom of the dewar and commence slowly transferring LHe. To make sure there is an efficient transfer of LHe, it is important the transfer tube (or an extension of the transfer tube) introduce the LHe at the very bottom of the dewar below the magnet. This allows the magnet to be efficiently cooled by the cold helium gas as it rises. Transferring LHe should be done slowly until the system is cooled to 4.2K and liquid helium starts to collect in the dewar.

    Caution

    To increase the transfer rate of the LHe, an external pressure source may be used on the LHe storage vessel. Make sure that only dry helium gas is used for this purpose. Air or nitrogen will freeze in liquid helium and contaminate the storage vessel and/or the transfer system and dewar.

3. Vent some of the exhausting helium gas through the vapor-cooled current leads to prevent blocking the gas vent holes with condensing moisture and freezing air.

Note

An 18-24" piece of tubing, connected to the top vent of each lead, and allowed to hang over the side of the dewar is an effective way to create a helium gas trap and minimize the air which enters the leads.

4. It is advisable to monitor the magnet temperature during LHe transfer to make sure proper cooldown is taking place. Cooldown can be simply monitored by measuring the resistance of the magnet. LHe will not collect in the dewar until the dewar and magnet temperature reaches 4.2K. Adjust the storage dewar pressure for the proper transfer rate best indicated by observing the helium gas exiting from the dewar vent. The most efficient transfer rate is one where there is a light flow of vapor from the vessel vent. If the vapor has significant pressure or spits and sputters, the transfer rate is excessive and should be reduced.

Note

A transfer tube with a poor vacuum or thermal short can evaporate all the liquid helium before it reaches the dewar.

5. As soon as the dewar temperature reaches 4.2K and liquid helium begins to collect in the bottom of the dewar, the exhaust gas should decrease noticeably. The transfer rate can be increased at this point without excessive helium loss.

6. Once the desired LHe level is reached, stop LHe transfer, remove the transfer line and cap the transfer port.

Instrumentation and control check

Prior to connecting the power supply cables to the vapor-cooled current leads, the power supply system should be checked for proper control and indication.

1. Setup the power supply system. Refer to the documentation provided with the power supply system.

Caution

Make sure the power supply and magnet controller is installed in accordance with the operating instruction provided with your magnet current programmer.

Caution

Some non-AMI programmer/power supply systems are capable of producing voltages up to 30 volts and more than a 100 amperes. These power supplies can easily exceed the turn-on voltages of protective diodes on superconducting magnets. Furthermore, these power supplies may not always *turn off when a quench occurs in a superconducting magnet. The result is that these power supplies can drive more than 100 amperes through the quench protection diodes on the magnet for an extended period of time causing diode failure. This is especially disastrous if the magnet is welded in a dewar. The dewar must then be cut apart to get the magnet out and replace the protection diodes. AMI programmer/power supply systems are very good at detecting quenches and are designed, in conjuction with an energy absorber, to limit the magnet voltage to less than 5 volts. If you use another vendor's power supply system, AMI cannot assume any liability for the costs associated with cutting the dewar apart and repairing the magnet if AMI determines that the problem was caused by the non-AMI power supply system.*

2. Make sure the magnet power supply is de-energized and short the output leads from the power supply together securely.

   Note

   If an energy absorber is included in the system, short the output leads of the energy absorber instead of the power supply.

3. Check for proper power supply system operation (with the output leads shorted) by ramping the system up and down and adjusting the system current limit to the current level corresponding to the magnet rated central field (i.e. rated current).

   Note

   Refer to the programmer/power supply manuals for the system test procedure.

System setup

1. Upon satisfactory completion of the instrumentation and control checks, de-energize all system components and connect the power leads to the vapor-cooled current leads.

2. Energize the system instrumentation.

3. Verify the liquid helium level in the dewar properly covers the magnet (and persistent switch). This completes the installation and system setup procedures.

2 Operation

Energizing the magnet

1. If the magnet is equipped with a persistent switch, make sure the persistent switch heater power supply is switched on and is supplying the appropriate current to the switch heater. This current value is recorded on the Magnet Specification Sheet provided with the magnet.

Caution

⚠ *Only operate the magnet when completely immersed in liquid helium. Failure to do so may result in magnet and/or system damage.*

2. Adjust all programmer/ power supply system controls in accordance with their respective manuals for system start-up.

3. Set the programmer/ power supply system current limit setpoint to the desired current level but not to exceed the rated current value recorded on the Magnet Specification Sheet. Make sure the programmer ramp controls are in the 'down' position.

4. Energize the programmer/ power supply system.

5. Set the programmer to the appropriate ramp rate.

6. Verify the programmer/ power supply system stabilizes the magnet current at the rated current level.

Caution

⚠ *It is important to always limit the current level of the magnet to never exceed the rated current recorded on the Magnet Specification Sheet. Exceeding the rated current specification may void the magnet warranty and may cause damage to the magnet in the event of a magnet quench.*

Caution

⚠ *During non-persistent magnet operation, the flow through the vapor-cooled current leads should be checked and balanced to achieve approximately equal flow thru each lead. Balancing may be achieved by slightly restricting the flow through the lead with the higher flow. Operation of vapor cooled current leads with inadequate flow could result in lead damage.*

Magnet persistent operation (if applicable)

1. Stabilize the magnet current at the desired current level. Current stability is indicated by zero voltage across the magnet current leads.

2. Record the current level. This is important when returning the magnet to non-persistent mode operation.

3. De-energize the persistent switch heater power supply output. The magnet will commence persistent mode operation after the persistent switch cools.

4. Wait one minute to allow the persistent switch to cool.

5. De-energize the power supply system if desired.

6. Verify persistent mode operation of the magnet by observing the voltage across the magnet when the power supply is de-energized. The voltage should remain at zero.

Returning from persistent operation

1. To return magnet current control back to the programmer/ power supply system, energize the programmer/ power supply system.

2. Match the power supply current to the magnet current recorded when magnet entered persistent mode.

   Note

   The best method to reestablish the power supply current to the level of the persistent magnet is to leave the programmer current limit setting unaltered after switching to the persistent mode.

3. Switch on the persistent switch heater power supply output.

4. Allow 10-15 seconds to allow the switch to transition from the superconducting to the resistive state.

5. A small magnet voltage may be observed as the magnet current and power supply currents equalize. This voltage should quickly decay to zero as the magnet current is controlled by the programmer/ power supply system.

   Caution

   Matching the magnet current to the programmer/ power supply system current is important when returning the magnet from persistent operation. Large *current level differences may cause the programmer/ power supply system to interpret the equalizing voltage as a magnet quench.*

Deenergizing the magnet

Ramp the magnet current to zero using the programmer/ power supply system.

When the current in the magnet and the voltage across the magnet reaches zero, the magnet is de-energized.

System shutdown

1. After the magnet has been de-energized, any desired instrumentation and the programmer/ power supply system may be shutdown.

2. Prior to disconnecting cables from the dewar top plate, make sure the programmer/ power supply system and axillary instrumentation are de-energized.

   Warning

   Superconducting magnets have the capability to store large amounts of energy and can be dangerous and potentially fatal. Make sure the magnet is completely discharged and all electronics are de-energized before performing any disassembly.

   Exercise caution when handling materials which are at cryogenic temperatures. Severe burns could result to unprotected skin.

   Caution

   Use care in handling cold cabling, sensors, etc., since these items usually become very brittle at LHe temperatures and may be damaged if not handled carefully.

3. To minimize condensation internal to the dewar when allowing the magnet to warm-up, close all openings except the outlet of the vapor-cooled current leads (which should have helium gas traps).

4. Warm helium gas may be pumped in to speed up the process. More openings may need to be provided if gas outflow becomes to large.

3 Troubleshooting

The following troubleshooting aids are included to assist he user in identifying and correcting magnet system problems. In the event that the trouble cannot be corrected, please contact an AMI representative for assistance.

Magnet not charging

1. Voltage indicated on power supply; *No* voltage developed across magnet.

    a. Make sure the programmer/ power supply system has been setup and tested in accordance with the respective manuals. Specifically the installation section of this manual which entails operating the power supply system

    b. Check all connections for proper contact and connection. Voltage present with no current flow is indicative of an open circuit.

    c. Make sure the power supply current leads are securely connected to the vapor-cooled current leads with no ice or debris between the contact points.

    d. If using an polarity switching energy absorber in the power supply system, make sure the energy absorber is properly energized.

    e. If the current ramps up and no voltage developed across magnet, make sure the persistent switch heater is properly energized and the proper amount of current is flowing through the persistent heater. The persistent switch heater current specification and the magnet inductance specifications are recorded on the Magnet Specification Sheet. The voltage across the magnet is governed by the equation $E = L * (dI/dt)$. Make sure the proper current is flowing to the persistent switch and the proper connections are made. If the problem continues, investigate a short circuit across the magnet.

    f. If voltage is present at the magnet leads but minimal current flows, the magnet may not be at 4.2K. Make sure the liquid helium level is above the magnet and the helium boil-off has stabilized at the expected level. Also, physical damage to the magnet wires may cause these symptoms. If this magnet damage is a possibility, call AMI and speak with a sales representative.

2. *No* voltage indicated on power supply; *No* voltage developed across magnet.

    a. Make sure the programmer/ power supply system has been setup and tested in accordance with the respective manuals.

b. Make sure the programmer or power supply is not current limiting. Refer to the power supply operating manual to remove front panel control. Refer to the programmer operating manual for operation setup.

Voltage developed across magnet but magnet field less than predicted

1. If the magnet current ramps but the magnetic field increases slowly <u>and the helium boil-off rate is significant</u>, the protective diodes may have turned on and current is flowing thru them. This may occur when the diode is subjected to a voltage which is larger than it's turn on voltage (typically 4-6 volts). The magnet current should be reduced to zero as rapidly as possible. Wait for the current in the magnet to reach zero and the helium boil-off to return to normal. Make sure the ramp rate previously attempted is low enough to keep the inductive voltage of the magnet at or below the voltage listed on the *Magnet Specification Sheet.*

2. If the magnet current ramps but the magnetic field increases slowly and the helium boil-off rate does not increase significantly, one of the protective diodes may be shorted and consequently shunting the magnet current. If these conditions occur, call AMI and speak with a sales representative.

Magnet discharges when attempting to enter persistent mode

Make sure the persistent switch heater is completely de-energized and allowed sufficient cooling time before de-energizing power supply system.

Magnet quenches lower than rated field

1. For typical standard magnets, ramping the magnet fast enough to produce a magnet voltage of approximately five volts has the possibility of turning on the protective diodes. Attempt to reach rated field at a lower charge rate.

2. Verify proper liquid helium level to make sure the magnet and switch are completely covered.

3. Verify rated field and rated current on the Magnet Specification Sheet.

4. If oscillations occurring with the programmer/ power supply system are occurring, refer to the programmer/ power supply documentation.

If the cause of the problem cannot be located, contact an AMI customer service representative for assistance. DO NOT SEND A UNIT BACK TO AMI WITHOUT PRIOR RETURN AUTHORIZATION.

4 Warranty/Return Authorization

All products manufactured by AMI are warranted to be free of defects in materials and workmanship and to perform as specified for a period of one year from date of shipment. In the event of failure occurring during normal use, AMI, at its option, will repair or replace all products or components that fail under warranty, and such repair or replacement shall constitute a fulfillment of all AMI liabilities with respect to its products. Since, however, AMI does not have control over the installation conditions or the use to which its products are put, no warranty can be made of fitness for a particular purpose, and AMI cannot be liable for special or consequential damages. All warranty repairs are F.O.B. Oak Ridge, Tennessee, USA.

Return Authorization

Items to be returned to AMI for repair (warranty or otherwise) require a return authorization number to make sure your order will receive proper attention. Please call an AMI representative at (865) 482-1056 for a return authorization number before shipping any item back to the factory.

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