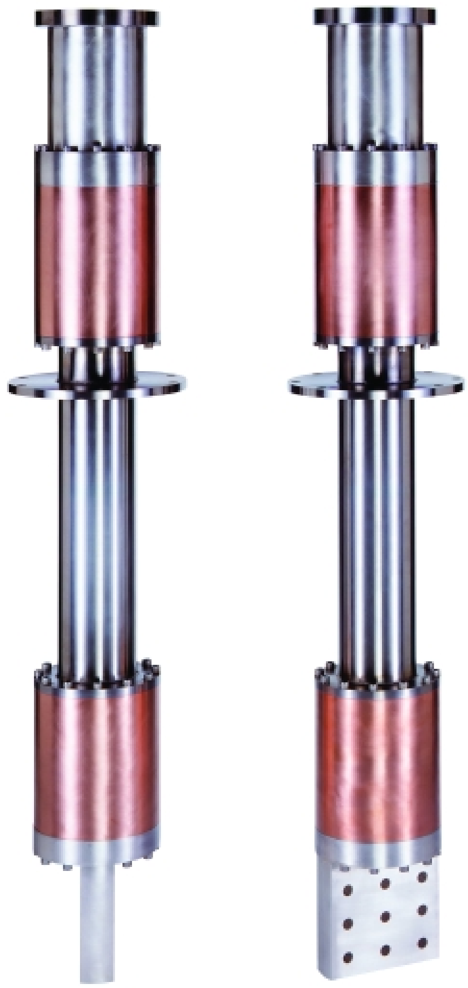
American Magnetics

Information Brief

Excellence in Magnetics and Cryogenics

Current Leads for Cryogenic Systems

American Magnetics Inc.'s (AMI) Vapor Cooled Current Leads provide reliable and consistent electrical current transfer from room temperature (300K) to a Liquid Helium environment (4.2K). These high efficiency heat exchangers use the heat capacity of cold helium vapor to counterflow the incoming conductive and resistive heat, thereby minimizing the liquid helium consumption. The thermal input of the leads is carefully designed to insure that just enough helium gas is generated to provide adequate cooling across the full range of operating currents. AMI offers a wide range of current lead designs from small current requirements to over 100,000 Ampere leads.



FEATURES	BENEFITS OF OWNERSHIP
Ultra hi-efficiency heat transfer	Minimize helium usage and operating costs
Custom designs up to 100,000 Amps	Application flexibility
Conventional Copper Leads	Proven reliability
Brass Leads	Lower helium usage in "standby" mode without intervention
Hybrid HTS Leads	Lowest helium usage available in a fixed lead configuration
Break-Away Leads	Ultimate Minimum helium usage in "standby" mode

APPLICATIONS

- *MRI or NMR*
- *Magnetic Energy Storage (SMES)*
- *Fusion Energy*
- *Accelerators and Colliders*
- *Conductor Testing & Characterization*

HELIUM USAGE

Standard AMI vapor cooled current leads (VCCL) have been shown to evaporate approximately 2.8 x 10^{-3} liters/(hour • amp • pair) when operated at the rated design current. These leads are expected to provide this performance under normal operating conditions. However, a more conservative value of 3.2 x 10^{-3} liters/(hour • amp • pair) is recommended for system design calculations. Helium consumption at zero current is approximately 60% of rated current consumption.

Consumption rates assume the use of AMI superconducting bus bars and fixed current leads with soldered connections. These specifications do not apply for breakaway current leads which have a lower consumption rate in standby mode. The use of water-cooled power cables, resistive cold end bus bars, improperly sized bus bars, or high contact resistance joints may cause consumption rates to be higher than those stated above.

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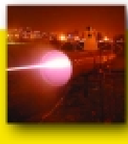
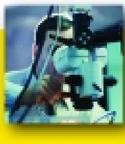
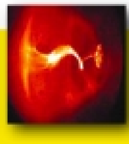




APPLICATION CONSIDERATIONS

VOLTAGE DIFFERENTIAL

AMI leads operate with a voltage differential of less than 100 mV as measured from the top of the lead to the bottom, or 200 mV measured between the leads on the warm end. Upon request, voltage tap attachment points can be provided on all lead sizes. The measurement of this value can be a useful tool for detecting insufficient gas flow or an overcurrent condition. System trigger points can be established to take corrective action or shut down the system prior to overheating of the leads for whatever reason.

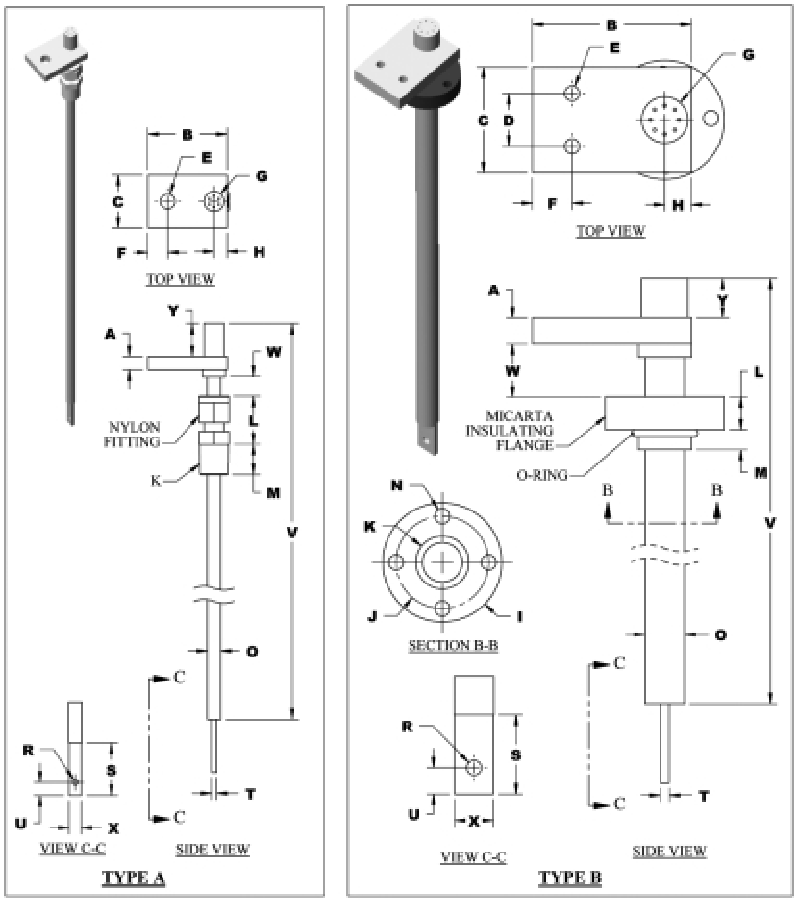


Figure 1: *Dimensional References for Standard Vapor Cooled Leads Up to 10,000 Amperes*

PRESSURE DIFFERENTIAL

A typical pressure differential of approximately 2 mm mercury (0.03 psi) is developed through the leads when operating at their maximum rated current for standard lead lengths.

ICING & FROSTING

Depending upon the operating conditions of the cryogenic system, frosting or icing on or around the top of the current lead may be observed. This may be caused by forcing more cold gas through the leads than is necessary. A common example of this occurs when the background dewar boil-off gas is vented through the leads while in standby mode. Although small amounts of icing or moisture do not generally present a problem, AMI can provide electrical heaters to keep the exposed lead above the freezing point. Special construction techniques are also available to prevent O-rings from freezing on the cryostat mounting flanges.

CUSTOM INTERFACES

A number of different style interface points are available on current leads. The standard horizontal upper end tab can be rotated to the vertical 'Flag' position in cases where the leads must be mounted very close together. The warm end connection for power cables can be configured with special bolt patterns, large surface area mounting surfaces for low contact resistance, or designed for a circular clamping type connection. Cold end connections are also highly adaptable to suit specific requirements.

Model Number		L-50	L-75	L-100	L-150	L-200	L-250	L-500	L-1000	L-2000	L-3000	L-5000	L-10000
Amperes		50	75	100	150	200	250	500	1000	2000	3000	5000	10000
Approx. Helium Consumption, Liters/Hr. (pair of leads)		0.16	0.24	0.32	0.48	0.64	0.8	1.6	3.2	6.4	9.6	16.0	32.0
Type		A	A	A	A	A	A	A	B	B	B	B	B
DIMENSIONS IN INCHES	A	1/4	1/4	1/4	1/4	3/8	3/8	1/2	1/2	1/2	1/2	3/4	3/4
	B	1-1/2	1-1/2	1-1/2	1-1/2	2	2	3	3	3	3-3/4	4-1/2	7
	C	1	1	1	1	1-1/4	1-1/4	1-1/2	2	2-1/2	3	3	3-1/2
	D	--	--	--	--	--	--	--	1	1	1-1/2	1-1/2	2
	E	9/32	9/32	9/32	9/32	9/32	9/32	9/16	9/32	7/16	7/16	7/16	7/16
	F	3/8	3/8	3/8	3/8	1/2	1/2	3/4	3/4	3/4	1	1	1 & 3
	G	3/8	3/8	3/8	3/8	1/2	1/2	1/2	7/8	1-1/8	1-1/4	1-1/2	2-1/2
	H	1/4	1/4	1/4	1/4	3/8	3/8	1/2	1/2	3/4	1	1	1-3/4
	I	--	--	--	--	--	--	--	2-1/4	2-1/2	2-5/8	3	3-3/4
	J	--	--	--	--	--	--	--	1-3/4	2	2-1/8	2-1/4	3-1/4
	K	1/4 NPT	1/4 NPT	1/4 NPT	1/4 NPT	3/8 NPT	3/8 NPT	1/2 NPT	1	1-1/4	1-3/8	1-5/8	--
	L	7/8	7/8	7/8	7/8	1	1	1-3/16	5/8	5/8	5/8	5/8	3/8
	M	9/16	9/16	9/16	9/16	9/16	9/16	3/4	3/8	3/8	3/8	3/8	--
	N	--	--	--	--	--	--	--	9/32	9/32	9/32	9/32	9/32
	O	1/4	1/4	1/4	1/4	3/8	3/8	1/2	3/4	1	1-1/8	1-3/8	2-1/8
	R	--	--	--	--	0.201	0.201	0.201	9/32	13/32	17/32	17/32	3/8
	S	1	1	1	1	1	1	1	1-1/2	1-1/2	1-1/2	1-1/2	4
	T	1/16	1/16	1/16	1/16	1/8	1/8	1/8	1/4	1/4	1/4	1/4	3/8
	U	--	--	--	--	1/4	1/4	1/4	1/2	1/2	1/2	1/2	1 & 2-1/2
	V	16-5/8	16-5/8	16-5/8	16-5/8	16-5/8	16-5/8	17-1/2	19-1/2	19-1/2	19-1/2	19-1/2	24
	W	Adjust.	Adjust.	Adjust.	Adjust.	Adjust.	Adjust.	Adjust.	1-1/2	2	2	2	4
	X	1/4	1/4	1/4	1/4	3/8	3/8	1/2	3/4	1	1-1/8	1-3/8	2-1/8
	Y	5/8	5/8	5/8	5/8	1/2	1/2	1/2	3/4	1	1	1	1

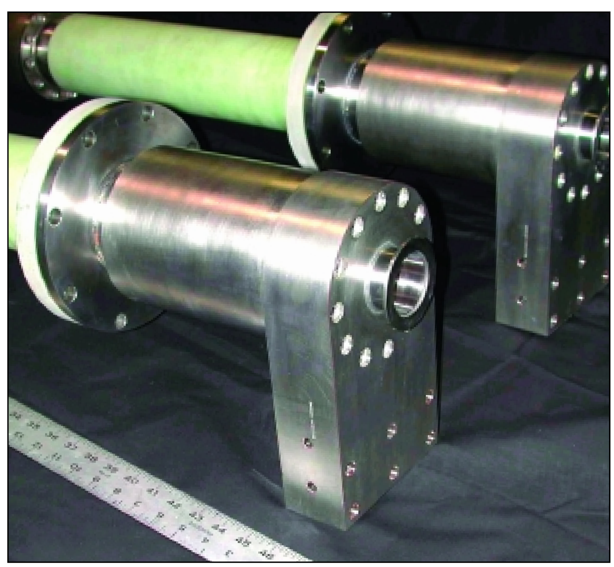
VOLTAGE ISOLATION

There are at least three areas of concern when dealing with proper voltage isolation of current leads:

- Isolation from the cryostat
- Isolation from other leads or structures internal to the cryostat
- Isolation from any helium gas recovery system.

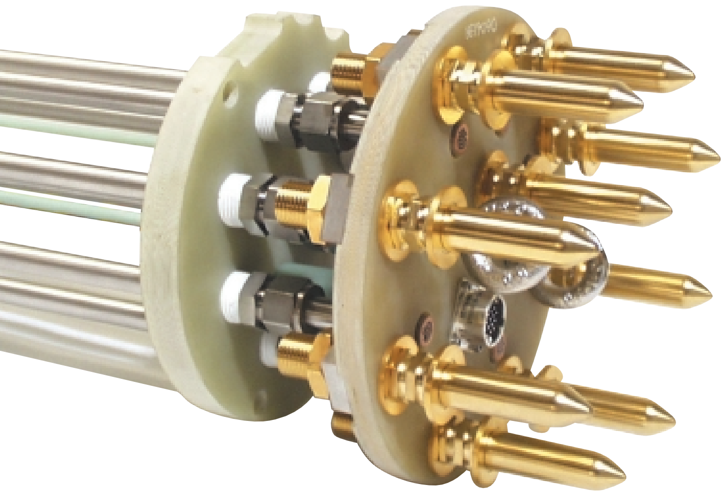
AMI has the capability to address all of these issues. Fiberglass is commonly used on the lead shaft and warm end tabs to isolate the leads from the cryostat and other leads.

Flanged ceramic-to-metal type isolators are often used in-line on the gas collection system and are available for most sizes of current leads.

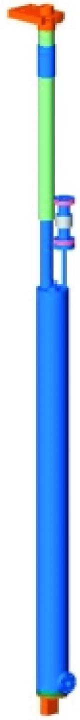


High current leads pictured with voltage isolation flanges and tubes installed

APPLICATION EXAMPLES

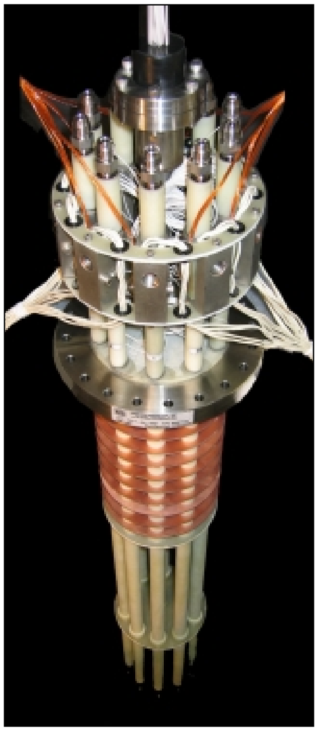


Current lead assembly for
Short Sample Test Stand



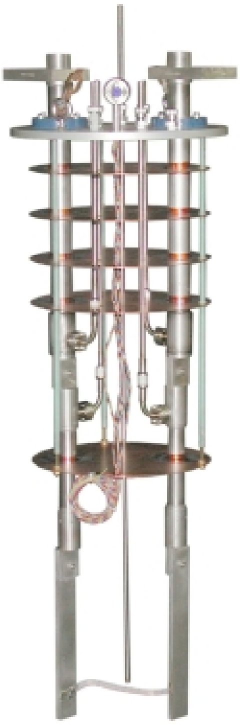
Model of lead operated in
vacuum with integral supercon
bus bars and Lhe supply
canister for wiggler system

aPhoto of actual leads
modeled on left with
removable upper tabs
detached



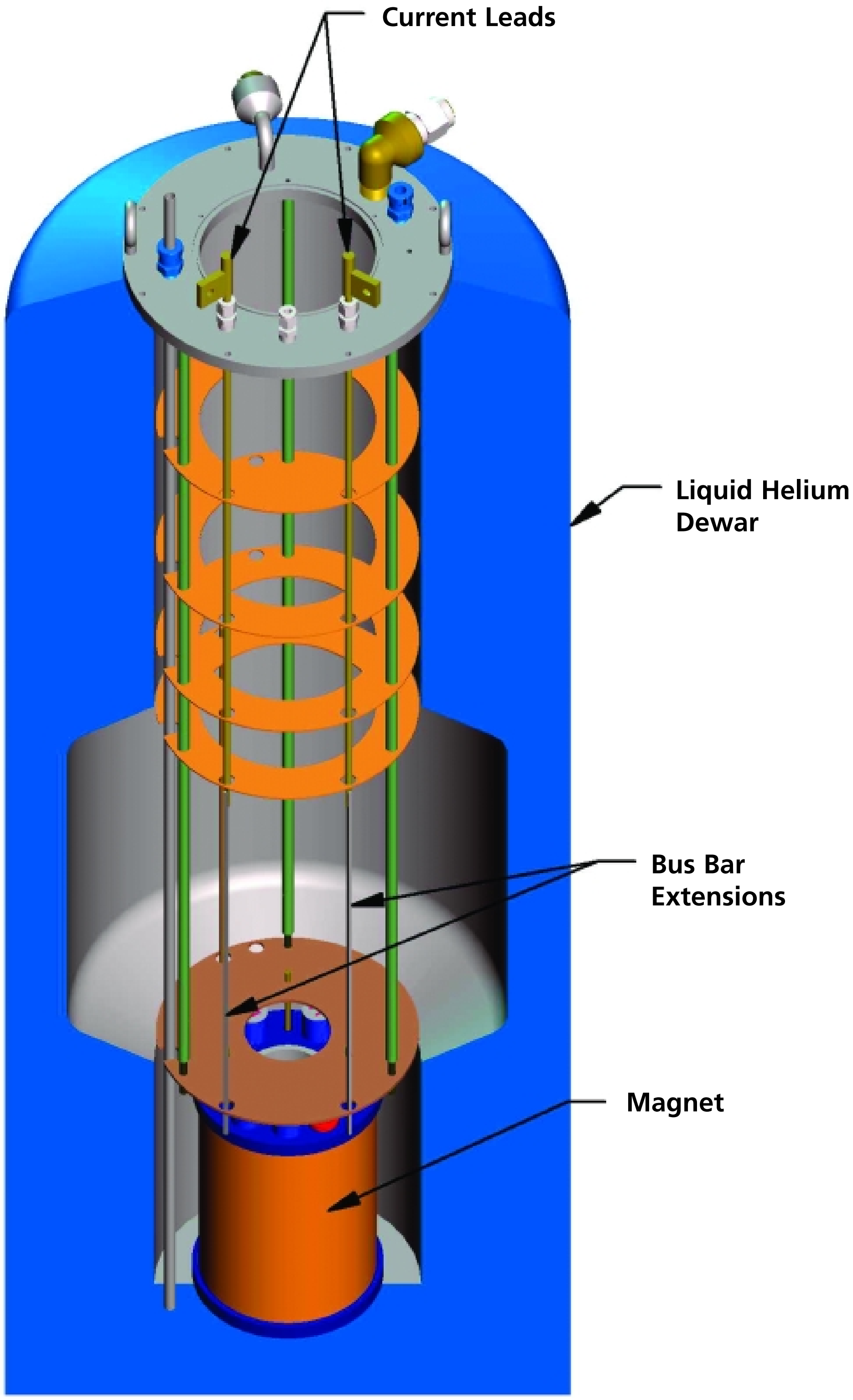
120A current lead cluster
for Collider

600A current lead cluster for Collider



6000A Helium Gas Cooled
Hybrid HTS Lead Assembly
for Fusion Device

Model of typical liquid helium cryostat with vapor cooled leads and series superconducting bus bars installed on magnet support stand.



In bucket dewar systems the magnet support stand is designed to accommodate either fixed position or retractable current leads. In bottom loading dewars or cryostats with room temperature bores the dewar itself supports the magnet and integrates the current leads into the design.

OTHER TYPES OF CURRENT LEADS

HIGH TEMPERATURE SUPERCONDUCTOR (HTS) LEADS

HTS leads are available on a custom basis in both Vapor Cooled or Conduction Cooled versions. The most commonly used conductor material is BiSCCO 2223 doped with a Au/Ag alloy. In cryogenic systems with liquid helium the vapor cooling of the HTS section with helium gas provides low losses, high current density and good system stability. The transition from the warm end of the HTS lead to ambient temperature is made using conventional AMI leads cooled with a forced flow of liquid nitrogen. In systems operating in a vacuum environment the HTS lead is conductively cooled with a mechanical refrigeration system (cryocooler).

BREAK-AWAY LEADS

The Break-Away option allows the leads to be manually retracted once the magnet is in the persistent mode. This essentially eliminates the heat load from the leads and minimizes the liquid helium boil off. This type of lead is ideal for systems operating in persistent or standby mode for long periods of time. Leads of this type are available up to 1000 Amps.

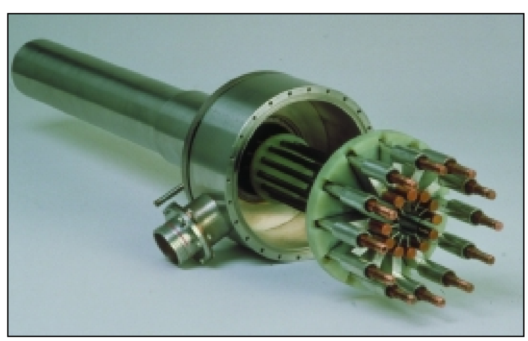
The mechanical and electrical connection between the lower end of the current lead and the superconducting bus bar is made with a low resistance socket-to-post connection. The male post is mounted onto an insulated support at the lower end of the cryostat neck region. The female socket is integral to the lead and slides up and down within a guide tube to ensure proper alignment. Multi-conductor wands are also available for NMR style systems requiring multiple shim coil operation.

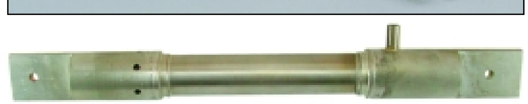
FLEXIBLE BREAK-AWAY LEADS

Helium gas cooled leads are available in a flexible package that is self-contained and self-supporting. The leads are straight in the relaxed position and rigid enough to easily connect/disconnect from the cold end current post. This option allows the leads to be bent as they are inserted or retracted where restrictions such as low ceiling height are an issue. This is yet another example of innovative current lead design.

SPECIAL APPLICATION LEADS

Some applications require special considerations and AMI has the ability to provide solutions for these as well. Examples of such applications include radial array lead clusters, Alternating Current (AC) systems, leads for cryogenic systems using nitrogen gas cooling, and leads operating in a vacuum space with force fed helium gas cooling. Helium reservoirs with level controls are available as an integral part of the current lead construction for vacuum space installations. Coaxial leads can be provided to reduce system penetrations when needed.





HTS Lead

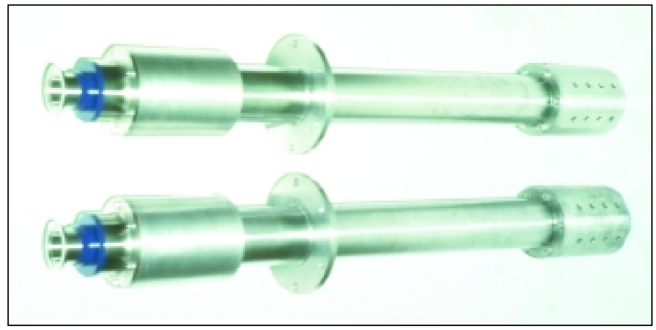
OTHER TYPES OF CURRENT LEADS (CONT.)

BRASS LEADS

Current leads are also available using brass (Cu/Zn) conductor. Because brass has higher thermal and electrical resistivity, these leads will have higher losses during charge mode but lower losses in standby mode compared to copper leads. Brass leads are a good choice for systems operating in standby or persistent mode for long periods of time.

HIGH CURRENT LEADS

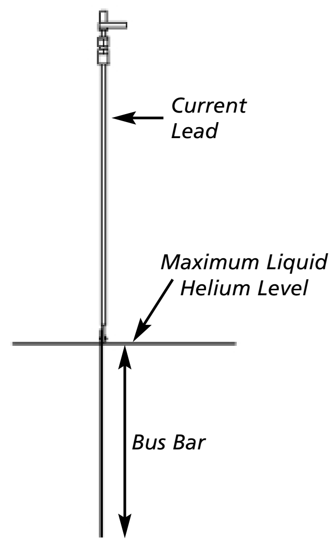
AMI routinely designs and manufactures custom designed current leads over 10,000 amperes. These current leads are designed for the same low helium boil-off and high reliability as our standard leads. Custom configurations are available for both the warm and cold end connections.



High Current Leads with custom upper and lower contact points

BUS BARS

Bus bars carry the current between the magnet and the current leads. Unlike standard NbTi superconducting lead wires, AMI optimized bus bars will carry the rated current even as the level of helium drops across the full height of the bus bar. This prevents magnet quenches from being initiated in the lead wires due to normal fluctuations in liquid helium level and extends your useful helium level operating range. AMI superconducting bus bars are designed to span the distance between the cold end of a current lead and the magnet leads. Resistance heating (I^2R) is eliminated because the bus bar is superconducting and thus liquid helium boil off is minimized. Most bus bars are a soldered laminate of Nb_3Sn/Cu and will remain superconducting as long as the lower end, closest to the magnet, is kept at liquid helium temperature. These bus bars are specifically designed to self supply enough helium boil off so that the operation of an AMI vapor cooled lead is optimized over the full operating range so long as the cold end of the bus bars is always in contact with the liquid helium. The choice of Nb_3Sn/Cu also provides good critical current performance even in the presence of high background magnetic field.

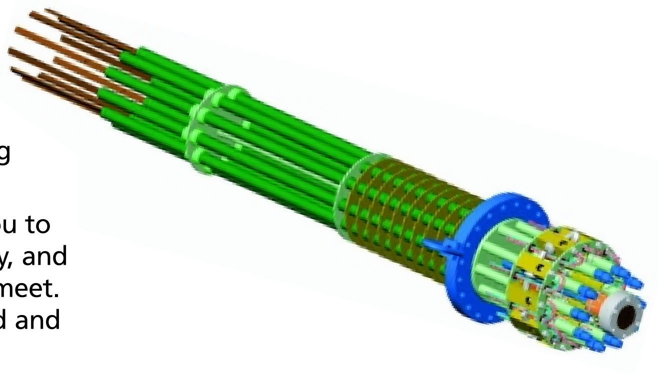


80,000 Amp Bus Bar with Vacuum Seal

DESIGN

AMI uses proprietary design programs developed in-house for most current lead design projects. We also employ the latest in solid modeling software, including the use of finite element analysis (FEA).

Our design engineers work closely with you to fully understand the features, functionality, and stringent requirements your system must meet. From this, prototype units can be designed and quoted, prior to any manufacturing.



MANUFACTURING

AMI has been an industry leader for over 35 years in the design and supply of superconducting magnet systems, current leads, cryogenic liquid level instrumentation, and cryogenic system components. We are qualified to provide leads of either a standard or custom design. Our manufacturing personnel and facility are able to handle any type of production demand, from the small custom lead designs to a high volume order of leads over 10 kA for a large international project. Performing high quality TiG welding on aluminum, stainless steel, copper and various exotic metals is routine.

QUALITY ASSURANCE

AMI offers extensive Quality Control and testing. Whether you need a Certificate of Compliance, vacuum leak testing or material certificates, AMI can meet your requirements. Repair and engineering support services are additional benefits.

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