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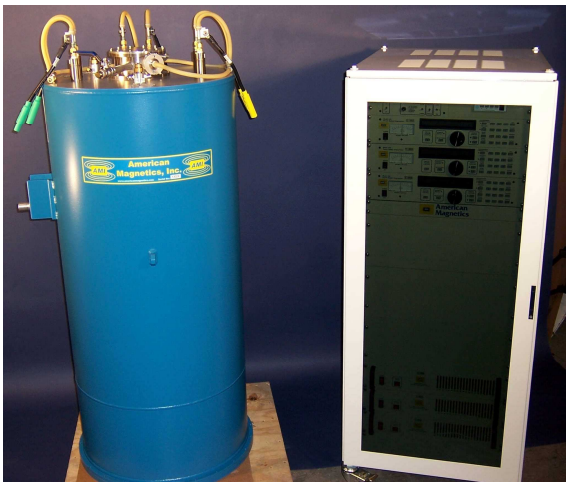
American Magnetics
Excellence in Magnetics and Cryogenics,Since 1968

112 Flint Rd Oak Ridge, TN 37830 Phone: (865) 482-1056 Fax: (865) 482-5472

Information Brief

Multi-Axis Magnet systems for Vector Fields (MAxes™)



American Magnetics, Inc. Multi-Axis (MAxes™) systems allow the user to easily program an infinite number of high magnetic field vectors. Our combination of user friendly electronics, reliable cryogenic vessels, and robust multi-axis superconducting magnets combine to make our MAxes™ systems an excellent choice for any application where the outcome is dependent on precise magnetic field vector orientation. Transport studies on anisotropic materials at high magnetic fields & low temperatures have revealed many exciting properties. Even though anisotropic magneto resistance is a century old phenomena, advancements in nanotechnology has created increased importance to attain precision angular control, while positioning samples in magnetic field. There has been significant progress in technologies that allow sample manipulation at atomic level, however at sub Kelvin temperatures, there is limited thermal budget and hence it's preferable to rotate the magnetic field than rotating the sample. Additional constraints come into play when systems are cooled using closed cycle coolers as thermal budget is further restricted. Some of these requirements have pushed advancements in areas of Multi-axis magnets, as using these it is possible to align samples in magnetic field to an accuracy of better than 0.01 degrees.

A typical MAxes™ magnet is comprised of two or three independently controlled coil sets. A solenoid coil produces the highest field along one axis. One or two sets of split coils produce fields along the other 2 axes. By correctly energizing the coils with programmed coil constant a combined vector field can be produced in a given direction of a known magnitude. This allows users to electronically manipulate the field relative to the sample without the use of complex sample rotation equipment or physically rotating the magnet position. Coil configurations could be with the split coils surrounding the solenoid or the split coils nested inside the bore of a large solenoid. Typical specifications include high field up to 9 Tesla (T) for the principal axis, having 2.0/3.0 inch vertical clear bore and 1T or 2T rotating vector using any combination of x, y and z-axis magnets. Users needing higher vector field typically opt for 2-axis systems.

The following table gives a snap shot sample of the capabilities of our MAxes™ systems.

Bore size	MX-2 (YZ)	2D Vector field	MX-3 (XYZ)	3D Vector field
2.0"	4.5T/9T	4.5T	1T/1T/12T 2T/2T/9T	1T 2T
2.5"	5T/7T	5T	1.5T/1.5T/9T	1.5T
3.0"	5T/6T	5T	1T/1T/9T	1T

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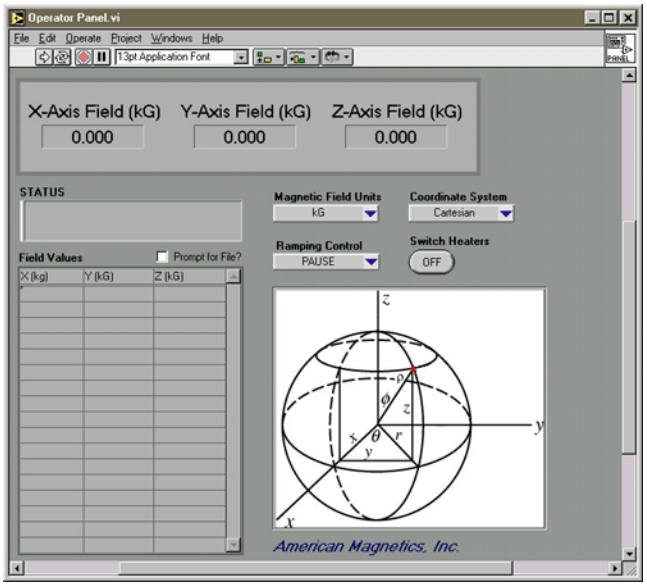

Forces in such magnets can be extremely high due to the interaction between each coil when they are energized simultaneously. Care must be taken to stay within the factory defined operating envelop or one could end up damaging the magnet and cryostat. This risk is minimized by operating multiple coils of the MAxes™ system using AMI's Free LabVIEW virtual interface which allows the users to specify and control the magnetic field vector from a single computer screen. High resolution power supplies are computer controlled using an AMI model 430 power supply programmer. The programmer is also web enabled using an Ethernet option. Infinite combinations of magnetic field vectors are hence possible. Calculated field components, based on actual current measurements and predetermined coil constants for a given magnet, are continuously displayed on the screen. The interface allows the users to enter in the desired field vector of a 3-axis magnet in Cartesian, cylindrical, or spherical coordinates (2-Axis in Cartesian or polar). Once the desired vectors are specified in tabular format or as read from a file, a "NEXT VECTOR" control from the program initiates appropriate control commands to the AMI power supply programmers which are connected via an RS-232/GPIB or an Ethernet port.

MAxes™ MX-2 (2-axis) Vector Magnet System

Over the last few years American Magnetics has delivered wide ranging 2-axis systems with vector fields ranging from 1T to 5T. These have been offered for different bore sizes for use with He3 inserts and dilution fridges. American Magnetics has excellent working relationships with various OEM's and we work diligently to offer customized solutions. With the advent of high power pulse tube cryocooler technology, Cryogen free magnet systems are becoming virtual research laboratories in various branches of condensed matter physics. AMI offers cryogen free MAxes™ systems in both dry and recondensing geometry. The picture on the left shows a conduction cooled MAxes™ magnet integrated with dilution refrigerator manufactured by Leiden Cryogenics. It is a 2-axis 3T/9T conduction cooled magnet and offers 3T vector field with 9T in vertical plane. Users desiring to use existing inserts that operate in liquid He may opt for Recondensing style systems. The recondensing configuration produces Near Zero He Boil-off systems (NZHB) and allows users to benefit from the latest technology without investing in new and expensive sample insert.

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A typical MAxes™-2 VTI based system has the following features:

- 2-axis magnetic field vector magnet with vertical access.
- Low-loss liquid helium cryostat with top loading sample insert with variable temperature from <2K to 400K
- 3.0 Tesla vector field in any direction with up to 12.0 Tesla in vertical axis
- 4-quadrant power supplies and web enabled magnet controllers for fast ramping capability
- Cryogen level instrumentation
- Two channel temperature controller
- Color coded, quick-disconnect power cables (e.g., no tools required)
- Pumping station for variable temperature insert (VTI)
- System software interface for magnet control (LabVIEW ™)
- Integrated instrumentation console and associated cables
- Customized system manual

MAxes™ MX-3 (3-axis) Vector Magnet System

Over the last year American Magnetics has delivered many unique MAxes™ systems. This includes the world's first Nb_3Sn high field vector system as well as Cryogen free MAxes™ system. The high field 3-axis system produced 12T in vertical plane combined with two 1T split coils in the horizontal plane. It could also be run with peak fields of 1T, 1T and 9T simultaneously. The cryogen free MAxes™ shown below produced 1T vector field with a 100 mm room temperature bore. These systems are being offered with either a GM or pulse tube 4K cryocooler. For users desiring lower vibration, a pulse tube cryocooler has been used & in these cases the cryocooler is mounted using bellows assembly while the motor is mounted remotely.

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Typical VTI based liquid helium cooled MX-3 systems have specifications similar to the ones listed for two axis geometries. There are numerous benefits from cooling large magnets with liquid Helium. Most customers prefer fast ramping of various coils and desire very low levels of vibration. Near Zero He Boil off recondensing style systems offers such benefits. A ReCon MAxes™ with VTI or other inserts are one of the most desired options by our users. Our standard product offerings includes such a system wherein a MAxes™ magnet is mounted in ReCon style dewar and He gas from the VTI or the insert is cycled back into the Dewar using an oil free or "dry" scroll pump. Any loss of LHe is easily compensated for by the introduction of gaseous Helium.

Opti-MAxes™

Opti-MAxes™ systems provide variable magnetic field on two or three principal axes and optical access in two orthogonal planes. These are particularly useful for orientation studies on a variety of samples for optical & beam line applications. In light of the growing interest in spin-related phenomena and new generation devices for processing information, there is now renewed interest in the science and engineering of magnetic semiconductors. Magneto-optic studies provides an ideal means for studying properties of magnetic semiconductors and other materials where spin related phenomena are of paramount importance. The system is comprised of a 2 or 3-axis superconducting magnet, low helium consumption current leads, magnet Dewar, optical windows, and associated electronics. Typical specifications include magnetic fields up to 4T for the principal vertical axis, 1T rotating vector using any combination of x, y and z-axis magnets. These are typically offered for 1.0" OD sample tube. Systems with re-entrant bore tubes are also supplied. Wide varieties of combinations are possible. The system is supplied with a variable temperature insert which operates from <2K to 300K. These are also available in ReCon style NZHB system.