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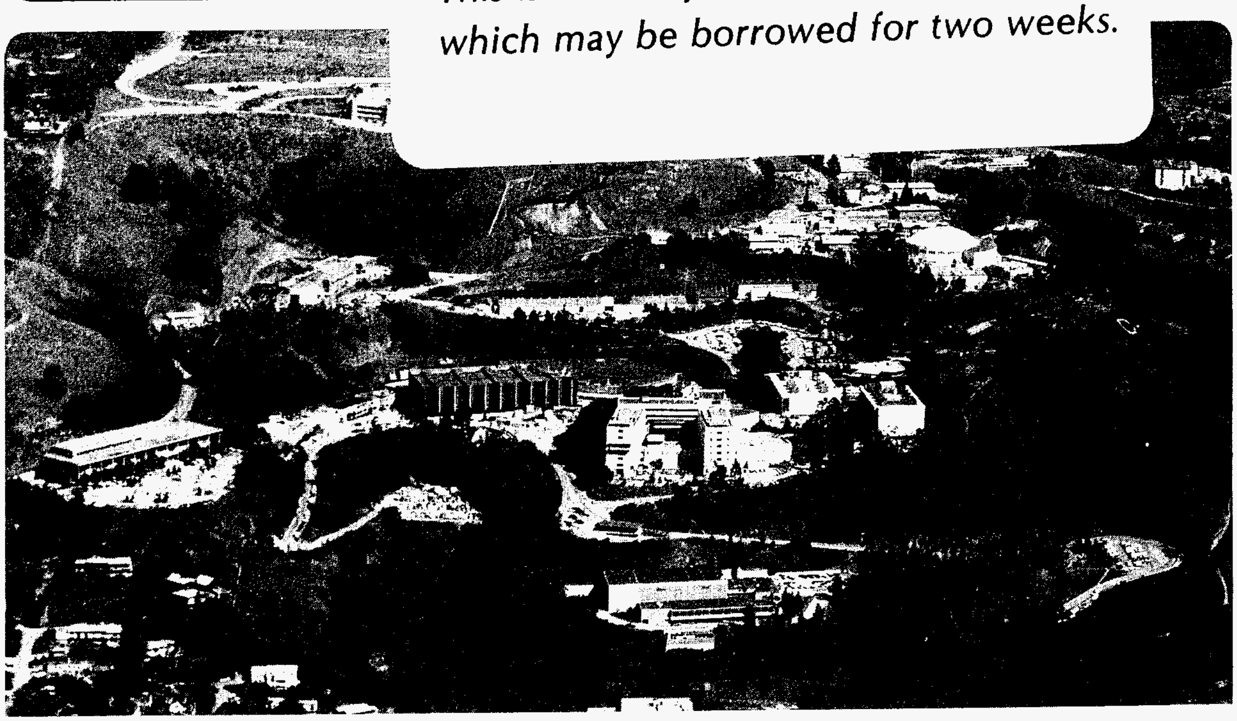

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THE CRYOGENIC SYSTEM FOR THE ASTROMAG TEST COIL

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This paper describes an all helium, low heat leak cryogenic system for the testing of a superconducting magnet coil for the ASTROMAG particle astrophysics experiment. The superconducting coil, which is projected to have a stored magnetic energy of 4 to 7 MJ, will be cooled by pumped helium from a liquid helium storage tank using a fountain effect helium II pump. The pumping system can be used to cool the cryogenic system down as well as keep the coil cold during its superconducting operation. The integration of retractable 900 A gas-cooled electrical leads with the intermediate shields and intercepts is discussed.

BACKGROUND

One of the important experiments in particle astrophysics during the next decade involves the use of a superconducting magnet facility on the Space Station.[1,2] The ASTROMAG experiment will investigate anti-particles and heavy nuclei in cosmic rays coming from deep space. The ASTROMAG experiment consists of a two-coil superconducting magnet and two experimental packages. (One will look at anti-proton positrons and anti-helium. The other will study the isotropic composition of particles from beryllium to copper.)

The superconducting magnet for ASTROMAG consists of two 1.3 to 1.6 meter diameter coils which are 1.7 to 2.0 meters apart. The two coils carry current so that the net magnetic dipole moment is zero and so that the magnetic induction 15 meters from the magnet is 0.0003 T or lower.[3] The magnet, when it carries 4.9 MA turns, will have a stored magnetic energy of 11 MJ. The mass of the magnet and its cryogenic system is directly related to the stored magnetic energy.

The ASTROMAG magnet is cooled using stored superfluid helium at 1.8 K.[4] The ASTROMAG coils are to be separated from the helium storage tank. The helium is circulated to the coils using a thermomechanical (fountain effect) pump. If the magnet quenches, the magnet will be thermally isolated from the helium tank. As a result, the cryogenic system mass can be reduced and recovery from a quench in space becomes possible. This report describes the test coil and cryogenic system which will verify the ASTROMAG magnet and cryogenic system design concept.

THE PURPOSE OF THE EXPERIMENT

The goals of the ASTROMAG test program are as follows: 1) The experiment will demonstrate that the cryostat and magnet coils can be cooled from 300 K to 1.8 K using only helium gas cooled by liquid nitrogen and liquid helium. 2) The experiment will demonstrate reasonably long lifetimes on the helium remaining in the storage tank after the magnet is cooled from 4.2 K to 1.8 K. 3) The experiment will demonstrate that helium can be circulated from the tank through the coils using a fountain effect pump. 4) The experiment will demonstrate that the coil can be charged and discharged through retractable electrical leads which operate in the cryostat vacuum space. 5) The experiment will find the safety quenching stored energy without external quench protection while the coil is operating in the persistent mode. If training is a factor, the maximum training current will be established. 6) The experiment will establish that the magnet coils can be discharged in a few seconds without damaging the magnet. 7) The experiment will establish that a magnet which has been quenched can be cooled to 1.8 K.

THE EXPERIMENTAL EQUIPMENT

Figure 1 shows the arrangement of the experimental equipment magnet coils and the cryogenic system. The major components for the experiment include: 1) two superconducting coils with indirect helium cooling, 2) a vacuum vessel with two gas-cooled shields, 3) a persistent switch, 4) retractable gas-cooled leads which operate in the cryostat vacuum, 5) a 500 liter helium storage tank, and 6) a thermomechanical (fountain effect) helium II pump to circulate helium from the tank to the coils.

The parameters for one of the superconducting coils (with a nominal stored energy of 5.5 MJ) are shown in Table 1. It is hoped that this magnet can be operated at stored energies as high as 7 MJ. Figure 2 shows the test coil cryogenic system. (Note: Figure 2 does not include some of the relief valves and bypass valves required by NASA safety regulations.) A schematic diagram for a superfluid helium thermomechanical pump is shown in Figure 3.

The cryostat helium vessel will be a 500 liter storage dewar helium vessel made from stainless steel. The high resistivity of the metal in this vessel will minimize the energy deposited in the tank when the magnet quenches. The shields and intercepts circuits will be isolated electrically to reduce the energy coupled into the shields. The retractable gas-cooled leads are a part of the gas-cooled shield and intercept flow circuit shown in Figure 3.[4]

The gas-cooled electrical leads are made in two parts, with the lower temperature end fixed and the high temperature end movable, permitting one to connect and disconnect the lead with a hydraulic actuator. The gas-cooled leads are an enhanced heat transfer tube in tube leads where the helium flow is in the annulus between the tubes.[5] The enhanced heat transfer leads have the following characteristics: 1) They are made from phosphour-deoxidized standard copper pipe with stainless steel inserts which are brazed together. 2) The leads are vacuum tight, and they can withstand high internal pressures. 3) This type of lead can be operated directly off of a helium flow circuit in any orientation, including the cold end up. 4) The leads have superconductor soldered directly to the copper tube. 5) The leads are low pressure drop leads. 6) The leads will operate for 30 minutes without gas flow.

The thermomechanical pump[6] shown in Figure 3 is one of two designs being studied. The pump shown in Figure 3, developed by Hofmann[7], has demonstrated superfluid helium flows of 2 gs^{-1} against a head of 0.4 bar when a heat load of 7 W is applied to an external coil. The key element in the pump is the parallel flow heat exchanger at the downstream end of the porous plug. The heater at that location is for starting the pump or increasing its mass flow when the persistent switch is opened and the coil is to be charged or discharged. The second design being considered leaves out the second heat exchanger in the tank downstream from the porous plug and the first heat exchanger. This type of pump will require that the heat and helium gas be rejected to the leads and shield through a separate porous plug to the leads upstream between the test magnet-persistent switch heat load and the helium tank (see Figure 2). The advantage of the second pump arrangement is that the pressure buildup in the tank is minimized during a charge or discharge of the magnet.

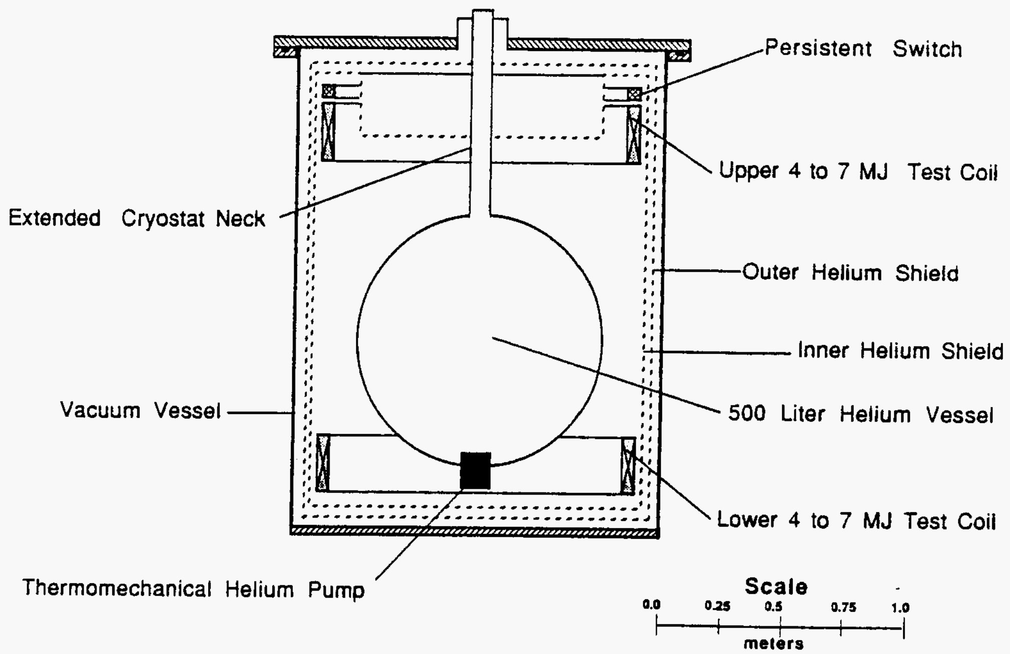
The flow circuit shown in Figure 2 should be capable of the following steps: 1) cooling from 300 K to 1.8 K, 2) filling the helium tank with superfluid or

TABLE 1
ASTROMAG TEST COIL PARAMETERS

COIL OUTSIDE DIAMETER	1.3 m
COIL WIDTH	230 mm
COIL THICKNESS	50 mm
NUMBER OF TURNS	3060
SELF INDUCTANCE	17.57 H
ACTIVE COIL COLD MASS	293 kg
MINIMUM DESIGN CURRENT	792 A
PEAK MAGNETIC INDUCTION AT MINIMUM DESIGN CURRENT	7.2 T
STORED MAGNETIC ENERGY AT MINIMUM DESIGN CURRENT	5.5 MJ
MATRIX CURRENT DENSITY AT MINIMUM DESIGN CURRENT	399 A mm^{-2}
EJ^2 LIMIT AT MINIMUM DESIGN CURRENT	7.45 x 10^{23} A^2 m^{-4} J
ENERGY PER UNIT ACTIVE COIL MASS AT MINIMUM DESIGN CURRENT	18.8 Jg^{-1}
QUENCH PROTECTION METHOD	QUENCH BACK
NUMBER OF TURNS IN SECONDARY CIRCUIT	360

Figure 1

ASTROMAG TEST COIL CRYOSTAT



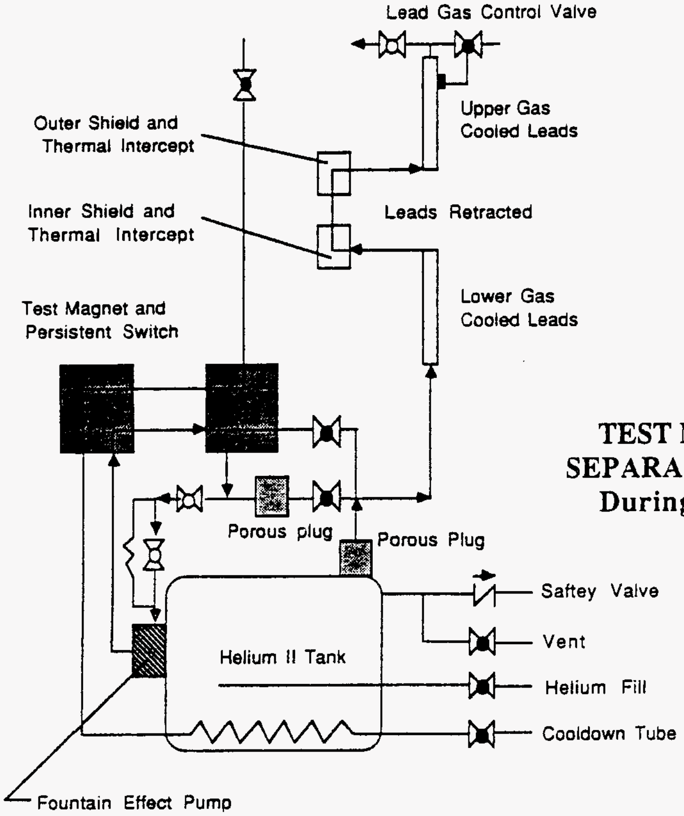


Figure 2

TEST MAGNET CRYOGENIC SYSTEM
SEPARATE LIQUID NITROGEN CIRCUIT
During Normal Operation at 1.8 K

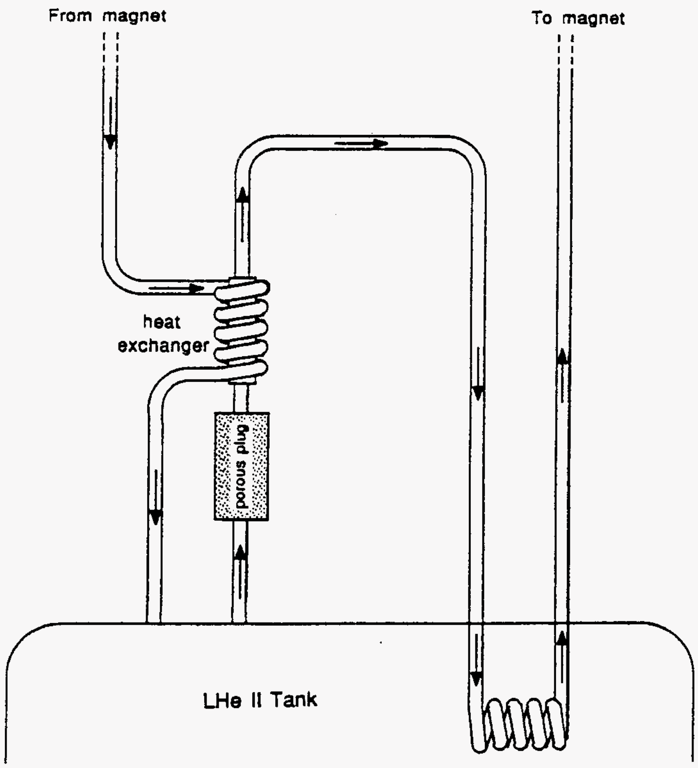


Figure 3 Thermomechanical Pump for Astromag

normal helium, 3) keeping the magnet coils cold while they are charged (or discharged) when the helium boiloff is minimum, 4) keeping the magnet coils cold when they are being charged or discharged (the helium boiloff is 15 times higher than when the magnet is in persistent mode with the leads detached), and 5) cooling the magnet coils back down after they have quenched (when coil temperatures are above 100 K).

A bellows type helium I pump with a superconducting linear drive has been studied for circulating helium I. After some study, this pump was eliminated from the flow system because the reliability of such pumps (for space use) is considered questionable and recent experiments suggest that the cooldown of a device at 50 K or above can be accomplished using a helium II thermomechanical pump provided the evaporated helium is not returned to the storage tank.

CONCLUDING COMMENTS

The LBL test facility will permit tests of ASTROMAG magnet coils under conditions which are similar to those on the space station. Helium II will be created by pumping on the helium tank through the gas cooled leads and shields (to a pressure of about 10 Torr). Once helium II has been produced in the tank, the magnet coils and persistent switch assembly can be cooled (from 100 K) and be kept cold by the circulation of helium generated by the thermomechanical pump. The operation of the magnet coil, persistent switch and retractable gas cooled leads will be demonstrated. The fast discharge of the coil can be accomplished by opening the persistent switch which will cause both coils to quench simultaneously.

ACKNOWLEDGMENTS

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