The Superconducting Magnet System of the Alpha Magnetic Spectrometer AMS-02

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Abstract

The Alpha Magnetic Spectrometer AMS-02 is a particle physics detector designed to search for anti-matter, dark matter and the origin of cosmic rays in space. The detector will be installed on the International Space Station in 2005.

A key feature of the detector is a strong superconducting magnet with a bending power Bl^2 of approx. $0.8 Tm^2$. The magnet consists of a pair of dipole coils and two sets of six racetrack coils. This special arrangement was chosen to suppress the stray field and the magnetic moment of the magnet. The magnet is operated at a temperature of 1.8 K by means of 2500 l of superfluid helium. Since the magnet design is optimized with respect to very low heat losses, the magnet is intended to be operated for 3 years without refilling.

The AMS-02 magnet will be the first large superconducting magnet used in space. This paper describes its main features including the principle concept of the cryogenic system. The development of special cryogenic equipment required for operation of a large superconducting magnet under microgravity conditions is also presented.

1. Introduction

The Alpha Magnetic Spectrometer (AMS) is a space-borne large acceptance magnetic spectrometer designed to search for charged particles outside the earth's atmosphere. In addition to searching for dark matter and the origin of cosmic rays, a major objective of this experiment is to search for antinuclei.

The AMS-02 experiment will be installed on the International Space Station (ISS) in 2005 for a period of about 3 years. As compared with the precursor experiment AMS-01 [1], which used a permanent magnet arrangement, AMS-02 will operate with a six times stronger magnetic field created by a superconducting magnet system. Although there have been a number of cryogenic helium space missions, AMS-02 will be the first large superconducting magnet to be used in

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space. The designers have therefore been presented with a number of unique challenges, especially with respect to the cryogenic system required to keep the magnet operational and safe.

2. AMS Magnet

The superconducting magnet system for AMS-02 consists of a pair of large "dipole" coils together with two series of six smaller racetrack coils circumferentially distributed between them, as shown in Fig. 1. The dipole coils are used to generate the majority of the transverse magnetic field. The racetrack coils are included for the following purposes: (a) to increase the magnitude of the overall dipole field; (b) to reduce the magnitude of the stray field outside the magnet (maximum stray field is 4 mT at a radius of 2.3 m); (c) to reduce the magnetic dipole moment of the magnet system to avoid an undesirable torque on the ISS resulting from the interaction with the Earth magnetic field.

The dipole coils have a height of 1081 mm and a width of 681 mm. Each racetrack coil has a height of 826 mm and a width of 306 mm. All superconducting coils are situated inside a vacuum tank and operated at a temperature of 1.8 K with superfluid helium. The magnet coils and the toroidal helium storage vessel with a volume of about 2500 l are screened from heat radiation by a series of cold helium gas cooled thermal shields. Fig. 2 shows a layout of the AMS-02 magnet system including helium vessel and vacuum tank. The free bore of the magnet system has a diameter of 1.1 m. The outer diameter of the vacuum tank is 2.7 m and its height is 1550 mm. The magnetic field is pointing in $-$x direction.

All coils are electrically connected in series carrying a current of 459 A. The total inductance is 49 H. The magnet system is designed, built and tested by *Space Cryomagnetics Ltd.* (UK). To date, all 12 racetrack coils have been completed.

All magnets are wound from the same kind of conductor which consists of a NbTi/Cu superconducting wire embedded in a high purity aluminium stabilizer. Aluminium has been chosen in view of the strict limit on weight. A total of

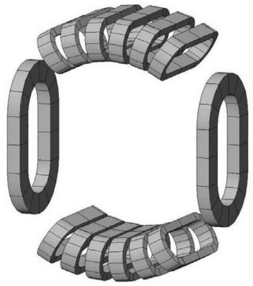

Fig. 1. AMS-02 coil configuration

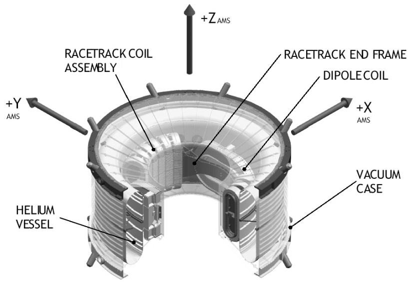

Fig. 2. Layout of the superconducting magnet

about 55 km of superconducting strand is required for all coils. For electrical and thermal stabilization the strand is enclosed in a rectangular high purity aluminium sheath with the dimensions 2.00 mm × 1.55 mm. Details of the conductor are given in [2].

3. Cryogenic System

3.1. Cooling Method

The purpose of the cryogenic system is to keep the coils superconducting at 1.8 K under all operating conditions for the entire lifetime of the experiment. The system will be launched cold, carrying 2500 l of liquid helium which has to last for the entire mission. The AMS magnet is cooled by using superfluid helium (He II) rather than normal fluid helium (He I). This is advantageous because He II has higher specific latent heat and density than He I. Since the helium inventory is limited by the available volume this yields a useful endurance benefit. Furthermore, in zero gravity there is no thermal convection which in He I can result in a thermal stratification, making it difficult to ensure that all parts are at the same temperature. He II, however, exhibits an extraordinary high thermal conductivity ensuring that the entire liquid content remains isothermal.

As in all helium cryogenic systems, the key to maximizing the endurance is to keep the heat flow to a minimum while using the entire enthalpy of the boiled-off vapor to remove incoming heat at the highest possible temperature. To achieve this, it is necessary to separate the liquid and vapor phases and constrain the vapor to flow through a series of radiation shields (at different temperature levels) before venting it into space.

All magnet coils are cooled indirectly by heat conduction only. The coils are connected with the 2500 l helium tank via pipes containing pressurized superfluid helium. The helium in the pipes acts as a perfect heat shunt because of its extremely high heat conductivity.

3.2. Phase Separation

Once on orbit, separation of the helium vapor from liquid cannot be achieved in conventional ways because under zero gravity there is no buoyancy and therefore no spatial separation between gas and liquid phase. Instead, a passive phase separator consisting of a sintered stainless steel porous plug in as steel housing will be used. This technology utilizes the fountain effect [3] for separation of the vapor phase from the liquid superfluid helium which is a unique effect of the quantum fluid He II.

3.3. Mass Gauging

Since there is no clearly defined liquid level under zero gravity conventional helium level probes cannot be used to measure the liquid inventory of the helium vessel. Instead, a calorimetric method is used to determine the amount of liquid helium. A defined heat pulse is applied to the helium. Because of the extremely high thermal conductivity of the superfluid, the helium in the tank stays always isothermal. The heater energy is therefore transformed into a small temperature rise of the entire helium bath. Knowing the dissipated heater energy and measuring accurately the small temperature rise of the bath, the mass of liquid helium can be deduced.

3.4. Thermo-mechanical Pump

When the magnet is being charged, the electrical connections require an increased amount of cooling power. This will be achieved by pumping an enhanced flow of cold helium through the current leads. Since the use of conventional helium pumps is not advisable in a strong magnetic field, the use of a thermo-mechanical pump is foreseen. The principle of this pump is again the fountain effect as described for the phase separator but operated in the reverse mode. I.e. by means of a small electrical heater on the downstream side of the porous plug some superfluid liquid helium passes the plug depending on the applied heater power.

3.5. Cryocoolers

The helium vapor leaving the tank via the phase separator will cool four concentric radiation shields before being vented to space. The outermost shield will also be cooled by four Stirling cycle coolers to reduce the cryogenic heat load and, thus, to extend the helium lifetime. These cryocoolers are expected to remove a total of approximately 12 W at around 68 K.

4. Summary

The construction of the AMS-02 magnet system is in progress. All race-track coils have been produced to date and the dipole coils will be finished this year. The development and the production of the special components of the superfluid helium system (1.8 K) is in good progress. The launch and the installation of the AMS-02 detector on the ISS is scheduled for 2005.

5. References

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