

Development of the Cryogenic Ground Support Equipment (CGSE) for the Superconducting Magnet of the Alpha Magnetic Spectrometer (AMS-02)

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AMS-02 (http://ams.cern.ch/AMS/ams_homepage.html) is a particle detector based on the International Space Station (ISS). Its mission is to search for antimatter, dark matter and missing matter in space. At the heart of the detector is a large, powerful superconducting magnet. The CGSE is required to cool down the 2000 kg magnet to its operating temperature of 1.8 K, and to fill the magnet helium vessel with 2500 l of superfluid helium on the ground and before launch.

INTRODUCTION

The Alpha Magnetic Spectrometer (AMS-02) is a particle detector designed to search for anti-matter, dark matter and the origin of cosmic rays in space. The detector will be assembled in CERN, Geneva and installed on the International Space Station (ISS). The planned duration of the experiment is between 3 and 5 years. One of the major components of the detector is a superconducting magnet, currently under construction by Space Cryomagnetics Ltd of Culham, England. The magnetic dipole field is achieved by an arrangement of 14 superconducting coils. The magnet system [1, 2] consists of a pair of large Helmholtz-like coils together with two series each of six racetrack coils, circumferentially distributed between them. This arrangement was mainly chosen to minimize the stray field outside of the magnet and so reduce the magnetic dipole moment. The magnet generates a field of 0.9 T in the centre of the 1.1 m diameter clear bore. All the superconducting coils were wound from a high-purity, aluminium-stabilised mono-strand niobium-titanium (NbTi) conductor. The coils are located inside a toroidal vacuum vessel, and are indirectly cooled by superfluid helium at 1.8 K. The cooling circuit is thermally connected to a 2500 l superfluid helium vessel that serves as a cold reservoir. This cooling system is designed to ensure that any loss of superfluid helium, following a quench on orbit, is minimised.

The Cryogenic Ground Support Equipment (CGSE) for AMS-02 will be used to cool down the magnet and to fill the vessel of the magnet with superfluid helium. It is currently under development by the magnet group of the AMS collaboration and will be manufactured in China. The main requirements of the system are as follows.

- Compactness and mobility for testing the detector in different parts of the world (China, Europe, USA). Ultimately it has to be located in the confined space of one of the launch pads at the Kennedy Space Center, and it must be able to be disconnected quickly and safely only hours before the shuttle launch.
- Reliability and safety are especially important during preparation of the detector for operations at the launch pad. The last top-up with superfluid helium is planned to be just 88 hours before launch to ensure as much helium as possible is available to keep the magnet cold on orbit. All electrical equipment used on the launch pad has to be explosion-proof because of the hazards peculiar to this environment.

- The helium used for filling the magnet has to be particularly pure. Any impurities - even small solid particles of frozen gases or water - can prevent sealing of a cryogenic valve, leading to high heat loads and rapid consumption of the superfluid helium. This would limit the useful lifetime of the experiment.
- Controlled, gradual and uniform cooling down of the magnet, with temperature gradient not more than 50 K across the coils. This eliminates the risk of damage to the magnet due to thermal stresses at temperatures above 90 K.

CHOICE OF THE METHOD FOR GENERATING SUPERFLUID HELIUM

During development of the system, it is particularly important to consider how to cool down to superfluid helium temperature. One notable feature of the AMS-02 magnet system is that – for various reasons - its cryogenic valves are rather small. This makes it relatively difficult to pump helium vapour from the helium vessel owing to the substantial hydraulic resistance, which limits the flow rate during pumping.

Usually, superfluid helium can be produced by pumping vapour from the vessel. In this case approximately half of the initial volume of liquid helium is lost. Then the vessel has to be topped up. For this purpose helium is supplied to the vessel through a Joule-Thomson (J-T) valve to provide the required pressure drop between the supply Dewar and the target vessel. The temperature and pressure of the liquid helium before the J-T valve are of great importance in determining how much vapour will be produced by the expansion across the valve. Fig.1 shows that, if normal liquid helium at 4.2 K is expanded through the J-T valve, the downstream vapour fraction exceeds 40%. To pump such a large quantity of vapour from the flight vessel would be a very difficult and time-consuming operation. It is therefore better to pre-cool the liquid helium before throttling. One possibility is to use a filling line with heat exchange between the supply flow of liquid helium and the return flow of low temperature pumped helium vapour. In this manner it is possible to reduce the temperature of the liquid helium to around 3 K before the valve: this will reduce the vapour mass fraction to 21%. This method was used for the launch of the Infrared Space Observatory (ISO), a European Space Agency (ESA) mission. Experience with this system showed that this is a large amount of vapour and it is difficult to pump through narrow flight valves. It is best to reduce the amount of vapour pumped from the vessel as much as possible.

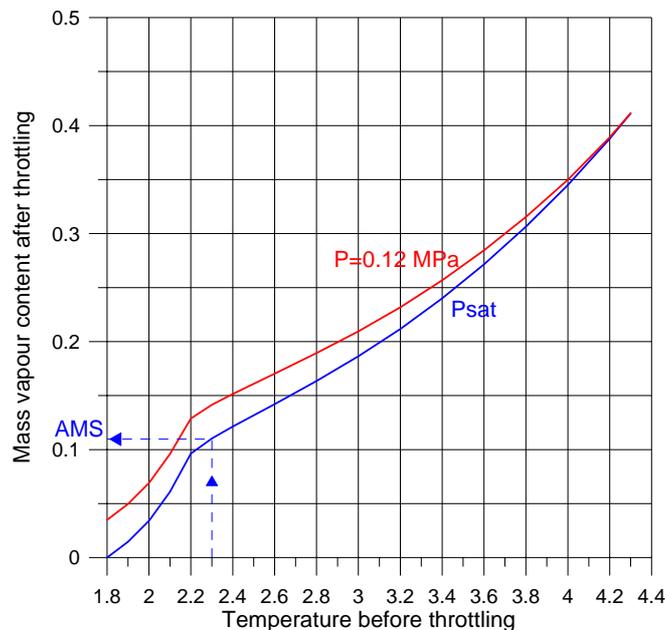


Figure 1 Mass vapour content after throttling versus temperature before throttling at pressure 0.12 MPa and at saturated pressure for helium

The following procedure has been developed for filling AMS magnet with superfluid helium. First, the AMS magnet is pumped to the operating conditions of 1.8 K at the saturation pressure of 16 mbar. Then, during the top-up operation, the master liquid helium Dewar is pumped to a state close to superfluidity (2.3 K, 53 mbar): this pre-cooled helium flows through the J-T valve and enters the AMS

magnet. In this case the mass vapour content will be only 11%, which is not too difficult to pump. This method for topping up has been experimentally tested in the Kurchatov Institute, Russia and showed good results.

SHORT DESCRIPTION OF THE SYSTEM

The main components of the CGSE are (Fig. 2): a system for controlled cool down and warm up in the temperature range between 300 and 80 K; liquid nitrogen tank; main (master) 1000 l Dewar for liquid helium permanently connected to the system; a few interchangeable 1000 l Dewars for supply with liquid helium; cold valve box; a vacuum pump system consisting of two Leybold vacuum pumps RUTA WS2001FU/SV630F/A with total capacity $2 \times 2000 \text{ m}^3/\text{h}$ at 8 mbar; a gaseous helium supply for the Superfluid Cooling Loop (SCL) of the magnet; set of cryogenic lines; and a cryostat to simulate the AMS magnet.

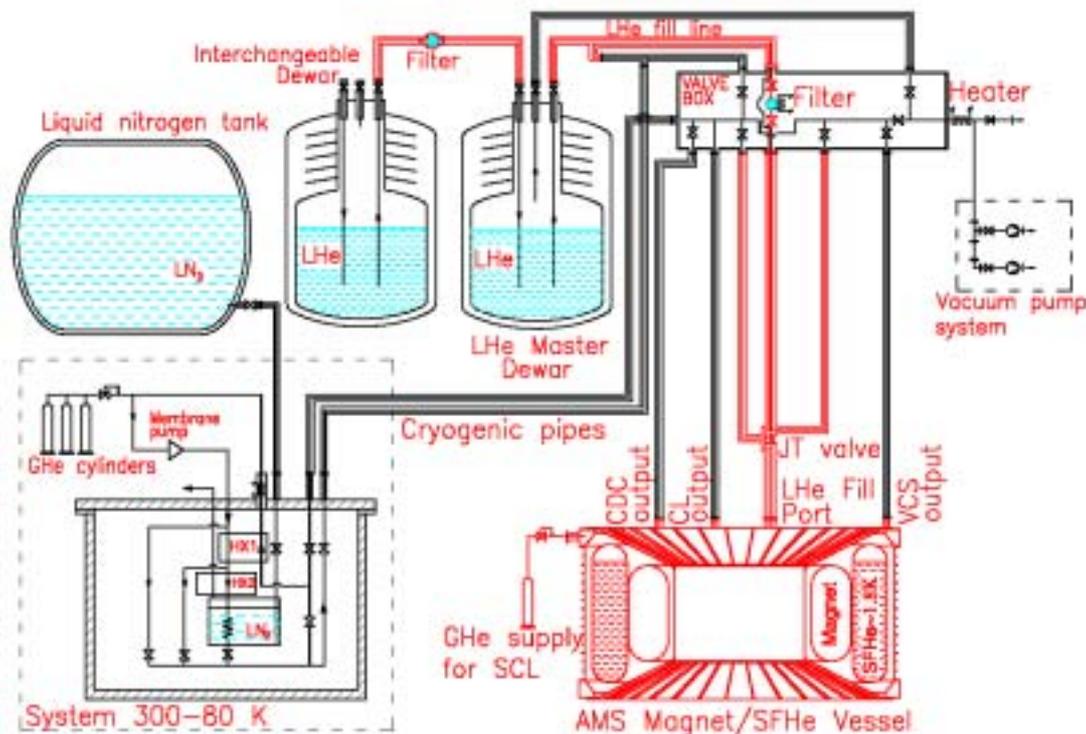


Figure 2 Simplified layout of the CGSE

The principle for cooling between 300 and 80 K is to circulate the helium gas through heat exchangers HX1, HX2 and a liquid nitrogen bath, with the return gas flowing through heat exchangers. The temperature of the cooling flow is controlled by mixing warm or intermediate and cold flows to provide smooth cooling of the magnet without large thermal stresses. At temperatures between 80 and 4.2 K the magnet is cooled down by liquid helium from Dewars. From 4.2 to 1.8 K the vessel is pumped down to 16 mbar. Liquid helium is added from Dewars through the J-T valve.

Table 1 Key CGSE parameters

Parameter	Value
Cooled mass (magnet, helium vessel)	2000 kg
Temperature range of cooling	300~1.8 K
Maximal temperature gradient during at the magnet at the range 300 – 90 K	50K
Volume of the magnet helium vessel	2500 l
Maximal pressure in the helium vessel	1.6 bar
Consumption of cryogenes for one cool down and filling cycle	$5 \text{ m}^3 \text{ LHe} + 2 \text{ m}^3 \text{ LN}_2$

The minimum time required to cool down from 300 to 4.2 K is 14 days (Fig.3). The time taken to pump from 4.2 to 1.8 K is not more than 22 hours (Fig.4). The flow rate of superfluid helium during the top-up operation is between 40 and 100 l/h.

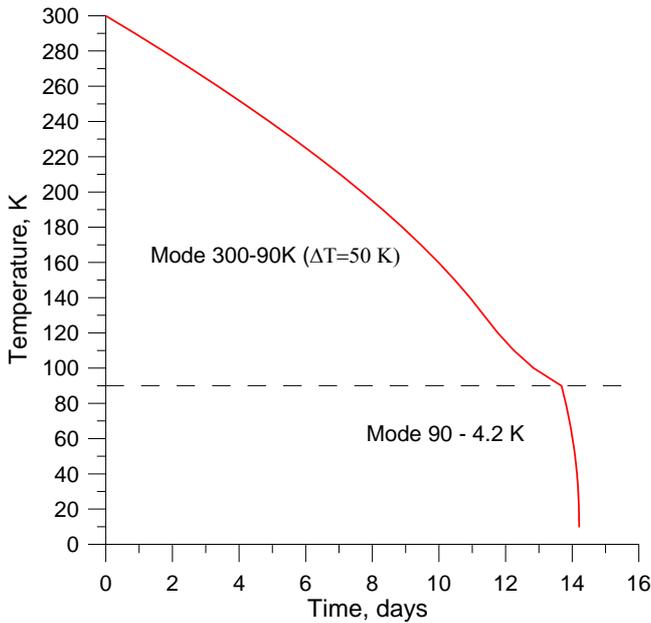


Figure 3 Cool down time estimation for the temperature range 300-4.2 K. Calculated for two 4 mm ID AMS valves in series and maximum flowrate 2 g/s

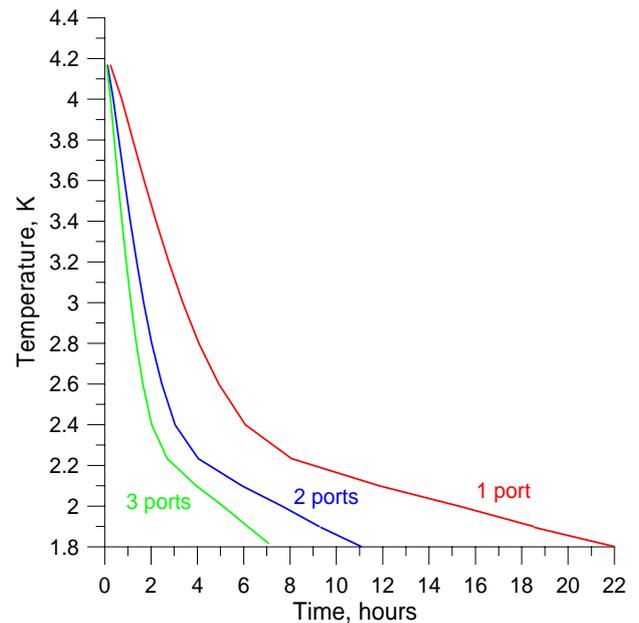


Figure 4 Cool down time estimation for the temperature range 4.2-1.8 K with different numbers of ports for pumping

Some special features of the system.

- 5 ports for helium connections to AMS-02: liquid helium fill port, output of helium from the Cool Down Circuit (CDC), output from Vapour Cooled Shields (VCS), output from current leads (CL), supply of helium to the superfluid Cooling Loop (SCL).
- Clean compressors without oil lubrication and with a double membrane system are used in the system 300-80 K to ensure the purity of circulating helium.
- Utilization of cold helium return flow for cooling shields in the liquid helium filling line to ensure low heat inleak to the helium supply
- Fine filters installed at the liquid helium filling line to remove any solid particles. The filter in the valve box can be cleaned in situ without opening the system
- The main (master) Dewar can work with internal vacuum. It is equipped with a cold coupling with specially-designed helium lines to guarantee leak tightness and eliminate any possibility of air leakage into the system. For the same reason burst disks are used throughout the system instead of relief valves which cannot guarantee tightness when the internal pressure is sub-atmospheric.
- A cryostat simulating the AMS magnet allows the system to be tested before commissioning with the flight magnet.

SUMMARY

The procedure for the production of superfluid helium has been chosen and experimentally demonstrated. The design of the AMS-02 CGSE is in progress. The test of the system is scheduled for the end of 2005.

REFERENCES

1. Blau, B., Harrison, S.M., et al., The superconducting magnet system of AMS 02 - a particle physics detector to be operated on the International Space Station, *IEEE Transactions on Applied Superconductivity* (2002) 12 349-352
2. Harrison, S.M., Ettlinger, E., et al., Cryogenic system for a large superconducting magnet in space, *IEEE Transactions on Applied Superconductivity* (2003) 13 1381-1384