PROGRESS ON THE MICE LIQUID ABSORBER COOLING AND CRYOGENIC DISTRIBUTION SYSTEM

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Abstract

This report describes the progress made on the design of the cryogenic cooling system for the liquid absorber for the international Muon Ionization Cooling Experiment (MICE). The absorber consists of a 20.7-liter vessel that contains liquid hydrogen (1.48 kg at 20.3 K) or liquid helium (2.59 kg at 4.2 K). The liquid cryogen vessel is located within the warm bore of the focusing magnet for the MICE. The purpose of the magnet is to provide a low beam beta region within the absorber. For safety reasons, the vacuum vessel for the hydrogen absorber is separated from the vacuum vessel for the superconducting magnet and the vacuum that surrounds the RF cavities or the detector. The absorber thin windows separate the liquid in the absorber from the absorber vacuum. The absorber vacuum vessel also has thin windows that separate the absorber vacuum space from adjacent vacuum spaces. Because the muon beam in MICE is of low intensity, there is no beam heating in the absorber. The absorber can use a single 4 K cooler to cool either liquid helium or liquid hydrogen within the absorber.

INTRODUCTION

The development of a muon collider or a neutrino factory requires that beams of low emittance muons be produced. A key to the production of low emittance muons is muon cooling. A demonstration of muon cooling is essential to the development of muon accelerators and storage rings [1]. The international Muon Ionization Cooling Experiment (MICE) will be a demonstration of muon cooling in a configuration that may be useful for a neutrino factory [2].

Ionization cooling of muons means that muons have their momentum reduced in both the longitudinal direction and the transverse direction by passing them through a low Z absorber, which has low beam beta. RF cavities are used to re-accelerate the muons to their original longitudinal momentum. If the scattering in the absorbing medium is not too large, the reaccelerated muon beam will have a lower emittance than the original beam.

The candidate absorbers for cooling muon beams include liquid H_2, LiH, Li, or Be. Because beam heating is not a factor in MICE, liquid helium will be in the absorber as well. The liquid absorber in MICE is located within the absorber focus coil module where the beam has the lowest beta. The liquid absorber for MICE is more fully described in Reference [3]. A 3D view of the absorber focus coil (AFC) module [4] is shown in Fig. 1.

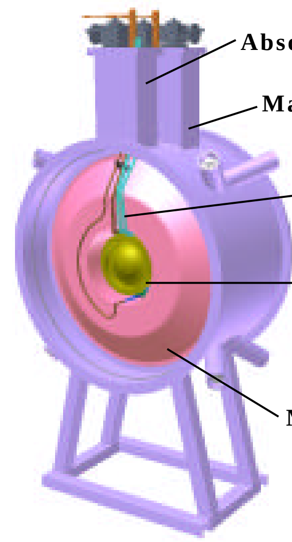

Figure. 1. A three-dimensional view of the AFC module.

THE ABSORBER AND AFC MODULE

A cross-section view of the AFC module with the absorber is shown in Figure 2. Figure 2 shows the liquid absorber in relation to the superconducting focus coils that surround it. The liquid absorber shown in Figure 2 may be replaced by a solid absorber made from beryllium or plastic.

Included in Figure 2 are the absorber body, the absorber thin windows, the liquid supply system that goes to the absorber from the buffer volume and condenser, the absorber vacuum, the absorber safety windows that separate the absorber vacuum from the machine vacuum, and the absorber vacuum door that permits the absorber to be removed from the AFC module.

The design of MICE AFC module calls for the ability to change absorbers during a two week shut down of the ISIS proton ring. Figure 3 shows the modularity of the components in the liquid absorber system. Shown are the two types of windows, the absorber body, the piping that connects the absorber to the surge volume and condenser, the condenser and the surge volume around it, the 4 K cooler, the vent lines and the supply system for the hydrogen gas. Not shown in Figure 3 are the liquid helium fill system, the 40 K shield, and the copper strap that connects the absorber to the second stage of the 4 K cooler.

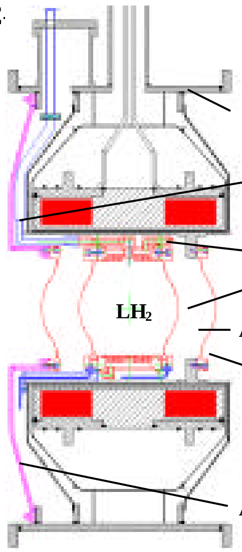

Figure 2. Cross-sectional view of the AFC module showing a liquid absorber for muon ionization cooling.

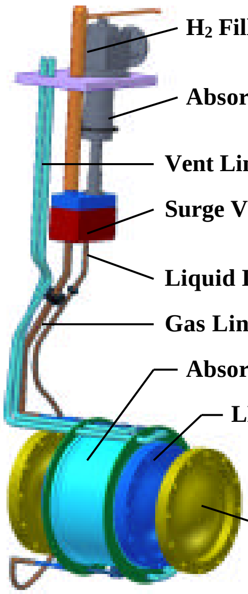

Figure 3. 3-dimensional view of the liquid absorber, its cooling system, and hydrogen (helium) supply system.

The liquid and gas transfer lines from the surge volume act as dual vent lines during an accident that would cause hydrogen or helium to be expelled from the absorber. The surge volume shown in Figure 3 allows for the change of liquid density in the absorber with a change in the absorber temperature.

ABSORBER SYSTEM SAFETY

The design of a liquid absorber and its cryogenic distributions system is dictated by hydrogen safety. The liquid absorber and distribution lines are designed in accordance with pressure vessel code for flammable liquids.

The absorber working pressure was set to 1.7-bar in order to meet the minimum design working pressure safety standard set by Fermilab. The absorber thin windows must have a design burst pressure >6.8-bar (100 psig) at 300 K.

The Rutherford Appleton Laboratory (RAL) safety standards require that the absorber withstand a double fault. As a result, there is a vacuum vessel around the liquid absorber volume. The absorber and its vacuum vessel are separated by 180-μm thick aluminum windows. There are also 180-μm thick windows between the absorber vacuum space and the MICE vacuum at the ends of the AFC module. The design parameters of the liquid absorber are found in Table 1.

Table 1. Parameters of the MICE liquid Absorber

Parameter	
Absorber Body Inside Diameter (mm)	300
Absorber Thin Window Diameter (mm)	300
Length of the Absorber (mm)	350
Absorber Liquid Volume (liters)	20.69
Total Absorber Feed Tube Length (m)	~2.2
ID of the Absorber Feed Tube (mm)	15.0
Surge Tank Volume (liters)	~3.0

The focusing magnet vacuum must be separated from the absorber vacuum by the magnet cryostat wall. RAL requires that the absorber vacuum be separated from the outside air, so that air leaks don't result in the condensation of oxygen on the absorber body and windows. This means that the absorber vacuum vessel must be surrounded by another vacuum or a blanket of inert gas, such as nitrogen. Under European safety standards, the MICE hydrogen zone can be defined as the region around the AFC module. The electrical systems in the hydrogen zone must be designed so that they don't cause hydrogen ignition.

A 4 K cooler will be used to cool the absorber. At 20 K, the 4 K cooler will lift ~20 W [5]. Since the absorber will be a helium absorber as well as a hydrogen absorber, the heat leak into the absorber must be <1 W. All pipes into the absorber must be connected to the first stage of the cooler, in order to reduce the heat leak into the absorber. The absorber is connected to the cooler 2[nd] stage cold head with a gravity heat pipe.

MICE ABSORBER OPERATION

The schematic diagram shown in Figure 4 shows the connection between the absorber and the cooler as well the minimum set of temperature sensors T, liquid level sensors L and heaters H needed for absorber operation. Figure 4 shows an absorber that can be filled with LHe or LH_2 from a storage dewar. Because there is a hydrogen heat exchanger connected to the cooler first stage, hydrogen can also be liquefied in the absorber using the 4 K cooler alone.

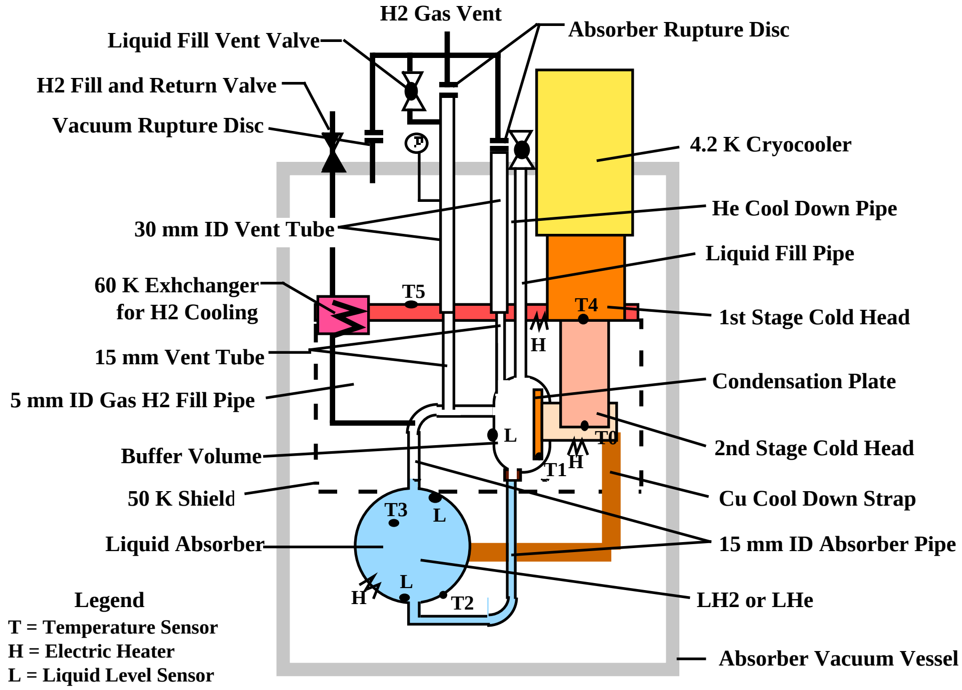

Figure 4. Schematic representation of the MICE liquid absorber and its connection to the 4 K cooler.

The liquid level sensor within the surge volume shows the absorber maximum absorber fill point for liquid hydrogen. As the cooler cools the liquid hydrogen below the fill temperature of 20.8 K, it contracts, causing the level to drop. The liquid level sensor at the top of the absorber window marks the minimum allowable absorber liquid level for hydrogen or helium. One can adjust the liquid level to keep it above the top of the window by adjusting the absorber temperature using a heater.

Table 2. Operating Parameters of the MICE Absorber with Liquid Helium and Liquid Hydrogen

Operating Parameter	LHe	LH_2
Maximum T at 1.7 bar (K)	4.82	22.1
Triple Point Temperature (K)	2.17	13.8
Fill Temperature (K)	4.4	20.8
Fill Pressure (bar)	1.2	1.2
Maximum Absorber T (K)	4.6	21.0
Minimum Absorber T (K)	3.8	15.0
Liquid Volume Change (liters)	2.65	1.79

Table 2 shows the absorber operating parameters for the liquid absorber filled with liquid helium and liquid hydrogen. The lowest possible operating temperature for a hydrogen absorber must be above the triple point temperature. From Table 2, one can see that the liquid helium volume change from 3.8 K to 4.6 K determines the surge volume of the condenser-surge tank. The condenser in the surge tank must not be covered by either liquid helium or liquid hydrogen during normal absorber operation.

CONCLUDING COMMENTS

The liquid absorber is at the heart of MICE. The liquid absorber has been designed so that it can be removed from the AFC module and be replaced with a solid absorber or another liquid absorber.

Considerable progress has been made on the design of the MICE liquid absorber and the cryogenic system that connects the MICE liquid absorber to the 4 K cooler that is used to keep the absorber cold when it is filled with liquid hydrogen or liquid helium.

ACKNOWLEDGMENT

This work was supported by the Oxford Physics Department and the Particle Physics and Astronomy Research Council of the UK and by the Office of High Energy Physics US Department of Energy under contract DE-AC03-76SF00098.

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