PROGRESS ON THE LIQUID ABSORBER AND ITS CRYOGENIC SYSTEM FOR THE MICE COOLING CHANNEL

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Abstract This report describes the progress made on the design of the liquid hydrogen absorber for the international Muon Ionization Cooling Experiment (MICE). The absorber consists of a 21-liter vessel that contains liquid hydrogen (1.5 kg) or liquid helium (2.63 kg). The liquid cryogen vessel is within the warm bore of the superconducting 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 has two 300 mm-diameter thin aluminum windows. The vacuum vessel around the absorber also has a pair of thin aluminum 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. As a result, the absorber can be cooled using a single 4 K cooler. This report describes progress on the MICE liquid absorber and its cryogenic cooling system.

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 of superconducting magnets [2] that may be useful for a neutrino factory.

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. 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. In order to reduce the multiple scattering of the muon beam in the absorber, the muon beam beta must be low. The absorber focus coil (AFC module) [3] is shown in Figure 1.

The candidate absorbers for cooling muon beams include liquid H_2, LiH, Li, or Be. Since MICE is an experiment for measuring cooling properties of materials, liquid helium is also a candidate absorber material for the liquid absorber. The absorber in MICE is located within the absorber focus coil module where the beam has the lowest beta.

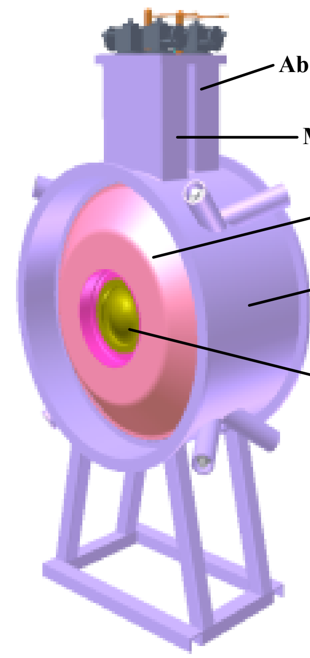

Figure. 1. A Three-dimensional View of the AFC Module

THE ABSORBER AND THE AFC MODULE

The proposed MICE experiment will test cooling on a low intensity muon beam, so heating of the fluid in the liquid absorber is not a factor in its design. Because beam heating is not a factor, the decision was made to use liquid helium in the MICE liquid absorbers as well as liquid hydrogen.

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, which are around the absorber. 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 itself, 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 which 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 calls for the ability to change absorbers during a two week shut down of the ISIS proton ring. The modularity of the absorber package is shown in the three dimensional view of the absorber shown in Figure 3.

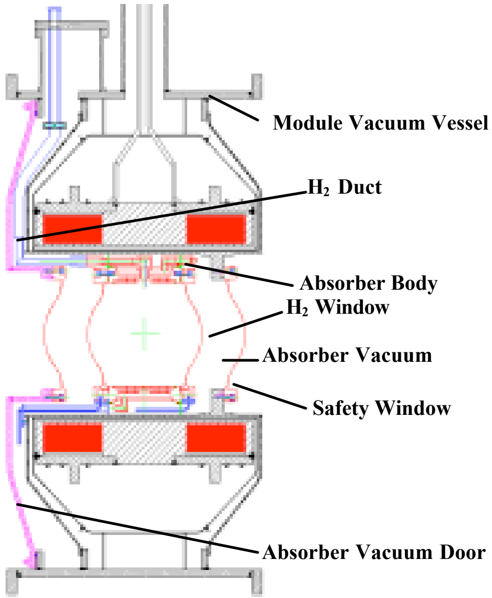

Figure 2. A Cross-section of the AFC Module showing a Liquid Absorber for Muon Ionization Cooling

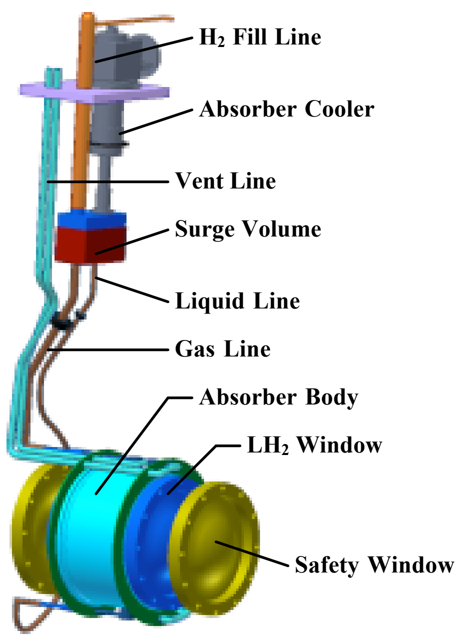

Figure 3. A Three Dimensional View of the Liquid Absorber and Its Cooling System and Hydrogen Supply System

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Figure 3 clearly shows the components in the liquid absorber system. Shown are the two types of windows, the absorber body, the piping that connects 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 is the liquid helium fill pipe needed to fill the absorber with liquid helium during helium absorber operation. A copper strap that connects the absorber to the second stage of the cooler is not shown either. The liquid and gas transfer lines from the surge volume act as vent lines during an incident that would cause hydrogen or helium to boil in the absorber. The surge volume allows for the change in density of the absorber liquid with temperature.

ABSORBER SYSTEM DESIGN AND SAFETY

The liquid absorber system design is dictated by hydrogen safety. The liquid absorber is designed in accordance with pressure vessel code for flammable liquids. The working pressure of the absorber was set to 1.7-bar (25 psig) to meet the minimum design working pressure the safety standard set by Fermilab, where many absorber tests will be done [4]. This means that the absorber thin windows must have a burst pressure of >6.8-bar (100 psi). 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 vacuum and the absorber are separated by 180-µm thick (center section) thin aluminum windows that have a diameter of 300-mm. There are also 180 µm thick aluminum windows between the absorber vacuum space and the MICE vacuum that can be found at both ends of the AFC module. The parameters of the liquid absorber are found in Table 1.

Table 1. The Basic Parameters of the MICE liquid Absorber

Parameter	
Absorber Body Inside Diameter (mm)	300
Absorber Thin Window Diameter (mm)	300
Maximum LH_2 Length in Absorber (mm)	350
Absorber Liquid Volume (liters)	20.69
Total Absorber Feed Tube Length (m)	~2.2
ID of the Absorber Feed Tubes (mm)	15
Surge Tank Volume (liters)	~3.4

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 must be surrounded by a vacuum or a blanket of inert gas. 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. As with any cryogenic tank, a duel flow path must be provided between the tank and the relief devices.

The connection of the cooler to the absorber is shown in Figure 4. A 1.5 W (at 4.2 K) cooler will be used to keep the absorber cold. At 20 K, the 4 K cooler will provide 20 W of cooling [5]. Since the absorber will be a helium absorber as well as a hydrogen absorber, the heat leak into the absorber must be kept below 1 W. The pipes into the absorber will be connected to the first stage of the cooler, in order to reduce the heat leak. The liquid in the absorber is connected to the cooler second stage cold head using a gravity heat pipe.

Not shown in Figure 4 is the hydride bed hydrogen gas feed and absorption system proposed by RAL. The absorber system shown in Figure 4 can be supplied with hydrogen either from gas cylinders or from the hydride bed.

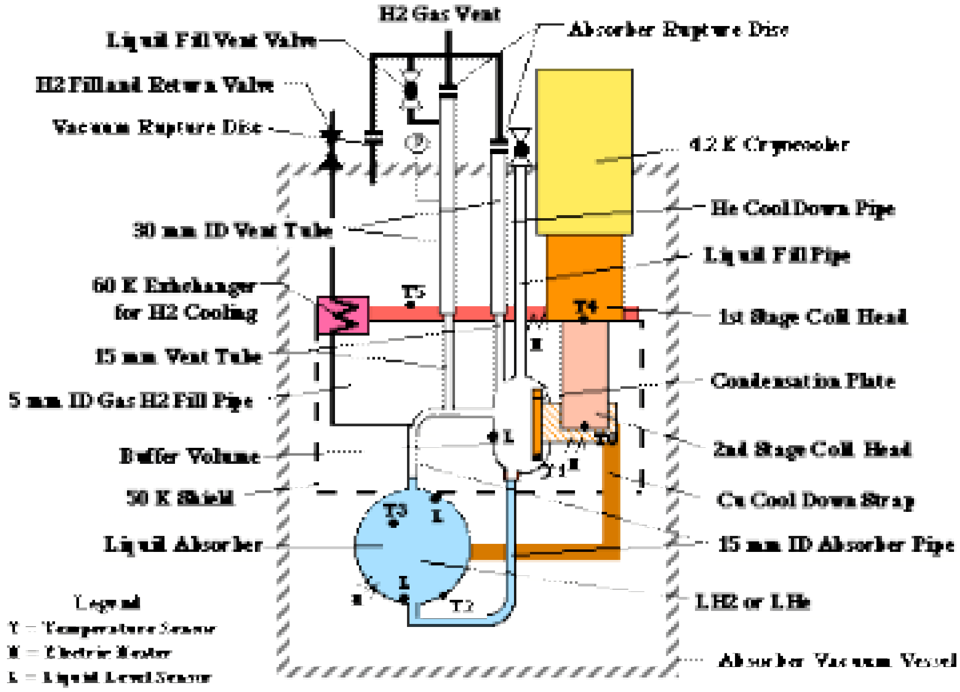

Figure 4. A Schematic Representation of the MICE liquid Absorber and Its Connection to the 4 K Cooler

MICE ABSORBER OPERATION

The schematic diagram shown in Figure 4 also shows 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 be liquefied in the absorber using the 4 K cooler alone.

The liquid level sensor within the surge volume shows the absorber maximum absorber fill. As the cooler cools the liquid down, 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. The liquid level can be kept above the top of the window by adjusting the absorber temperature with a heater. Table 2 shows the operating parameters for the absorber for liquid hydrogen and liquid helium. From Table 2, one can see that liquid helium volume change over operating temperature range determines the volume of the condenser-surge tank.

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

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.

ACKNOWLEDGEMENT

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REFERENCES

[1] R. B. Palmer, A. Sessler, A. Skrinsky, A. Tollestrup, et al, "Muon Colliders, " Brookhaven National Laboratory Report BNL-62740, January 1996

[2] "MICE and International Muon Ionization Cooling Experiment Technical Reference Document," co-authored with G. Gregoire, G. Ryckewaert, L. Chevalier, et al, (October 2004)

[3] S. Q. Yang, W. Lau, R. Senanayake, H. Witte, M. A. Green, Y. Ivanyushenkov, Progress on the Focus Coils for the MICE Channel," Particle Accelerator Conference, Knoxville TN, 16-20 May 2005, Paper MPPT058 (2005)

[4] M. A. C. Cummings, "New Technology in Hydrogen Absorbers for Cooling Channels," Particle Accelerator Conference, Knoxville TN, 16-20 May 2005, Paper FOAA001 (2005)

[5] M. A. Green, "Cooling the MICE Liquid Hydrogen Absorbers with Small Coolers," an Oxford University Report, 10 September 2004. Contact S. Q. Yang of the Oxford University Physics Department (email: s.yang@physics.ox.ac.uk) for a copy.