PROGRESS ON THE LIQUID HYDROGEN ABSORBER 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 cryogen vessel is within the warm bore of the superconducting focusing magnet for 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 has a pair of thin aluminum windows that separate the absorber vacuum space from adjacent vacuum spaces. The absorber will be cooled using a heat exchanger that is built into the absorber walls. Liquid nitrogen is used to cool the absorber to 80 K. Liquid helium completes the absorber cool down and condenses hydrogen in the absorber. The absorber may also be filled with liquid helium to measure muon cooling in helium.

INTRODUCTION

A high intensity muon beam is required for future muon colliders and neutrino factories [1]. Because of the finite muon lifetime, the cooling of muons to reduce their beam emittance needs to occur before acceleration. To accomplish this, muon ionization cooling has been proposed, and R & D efforts are being pursued. The cooling scheme consists of alternating energy absorption via ionization loss and high-gradient RF acceleration. As an energy absorber, liquid hydrogen (LH_2) is the most efficient material, owing to its sufficient ionization loss and small multiple scattering. The multiple scattering of muons, as a heating process, can disturb the cooling performance, and should therefore be minimized. Muons deposit energy in an LH_2 absorber by ionization loss, and this energy loss heats in liquid hydrogen. A 100 ~ 300 MeV muon beam of 10^{11} ~ 10^{12} ppp at 15 Hz, results in a heat load of ~ 100 to 300 W for absorbers 20 to 35 cm in length. The major issue concerning the LH_2 absorber R&D is how to remove this large amount of heat deposition.

Two methods have been considered to cool this amount of heat. One is the forced-flow cooling of LH_2. This method was successfully developed at SLAC for an atomic parity experiment (E158) LH_2 target using a cryogenic pump and an external heat exchanger. The other method of cooling the LH_2 absorber is convection cooling with an internal heat exchanger [2]. KEK has built a convection prototype absorber similar to that planned for the MICE cooling channel which has been tested with LH_2 at Fermilab (FNAL).

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KEK ABSORBER TESTS AT FNAL MTA

In August 2004 the KEK convection type absorber was tested using LH_2 at the MuCool Test Area (MTA) at FNAL (Figures 1 and 2). The MTA facility was built to test muon cooling channel components with a high power beam from the FNAL Linac. The maximum proton beam intensity that can be delivered to the MTA is 1.6 X 10^{13} p/pulse @15 Hz for the high powered tests.

Figure 2 shows the setup of the KEK test cryostat at the MTA, and the LH2 absorber that goes inside the cryostat Also shown are the flexible pipes for the cold He line, and 1/4 inch rigid pipes for the gaseous He heaters. The large vacuum pipe is connected to a $21 m^3$ vacuum buffer tank (see Figure 1). The tank keeps any possible H_2 gas leakage out of the absorber from making contact with the air.

The absorber has a heat exchanger inside the absorber manifold, which surrounds the LH_2 volume and is cooled by cold gaseous He at about 17 K [3]. The heat load was supplied from pipes with warm He gas. Two gas heater pipes were set inside the absorber as shown in Figure 3, one at the center and the other at the bottom of the LH_2 volume.

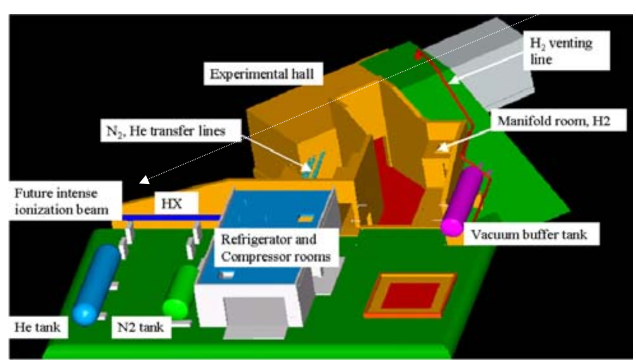

Figure 1: The MuCool Test Area (MTA) at Fermilab (FNAL).

CRYOGENICS

Cold gaseous He was used as the coolant, and was supplied from two 500 liter LHe dewars. The heat leak for the piping/transfer of helium from the dewars was ~

23 Watts (+/- 10%). This amounted to 1 g/s of helium flow to overcome the nominal heat leak.

Figure 2: Setup for convection LH_2 absorber: Convection LH_2 absorber with He gas heating/cooling lines (right) and the cryostat at the MTA (left).

In the initial configuration, using a high pressure helium bottle to pressurize the 500 liter He dewar, the system was unstable. Two-phase He flow caused instability in the refrigeration process with the temperature fluctuating on the order of 3 K as the hydrogen was being condensed below 25 K (Figure 4).

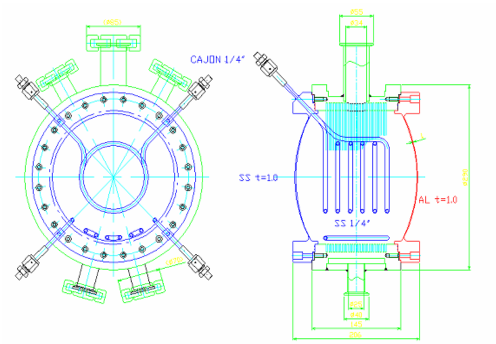

Figure 3: Cooling and heating He gas lines inside the LH_2 absorber.

Heaters were immersed inside the two existing liquid He dewars in order to boil the liquid phase and to transfer only gaseous He to the cooling tubes. This method successfully achieved stability during cooldown. Taking the 23 W transfer line heat loss into account, the refrigeration could be usefully monitored. (The maximum helium flow was limited by the 10 psig reliefs on 500 liter LHe dewars.) The hydrogen liquid bath temperature of about 14.5 K was attained (13.8 K is the freezing point of hydrogen at 14.7 psia). A platinum cobalt (PtCo) resistance thermometer that read the coldest temperature was used for controlling the ultimate temperature limit. Eight PtCo temperature probes were set inside the LH_2 absorber, around the window perimeter. The devices tracked quite consistently and appeared to correlate with known saturated conditions.

RESULTS FROM FIRST TEST

After the filling process was stabilized, the absorber was completely filled with LH_2. There was no indication of any H_2 leak into the vacuum. With the gas heater flow turned off, the cold He gas flow, pressure and outer temperature readings were used to estimate the accuracy of the PtCo thermometers at $\Delta T/T = +/-1.2\%$ at 17 K LH_2 temperature.

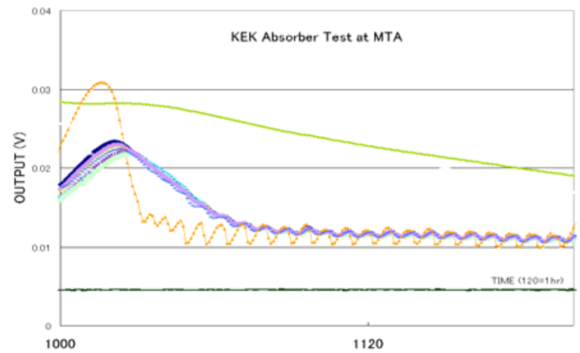

Figure 4: Thermal vibration at ~25 K (the vertical axis is the reading of thermometers in volts, the horizontal axis is the run time in seconds)

The cooling power was measured by flowing warm He gas through the central heating pipe (see Figure 3), and reading the He flow rate and temperature probes at the heater pipe inlet and outlet. The heat deposition was calculated from the helium gas enthalpy difference.

The results of the cooling power measurements are plotted in Figure 5. The maximum cooling power was limited primarily by the instability of the cold He cooling

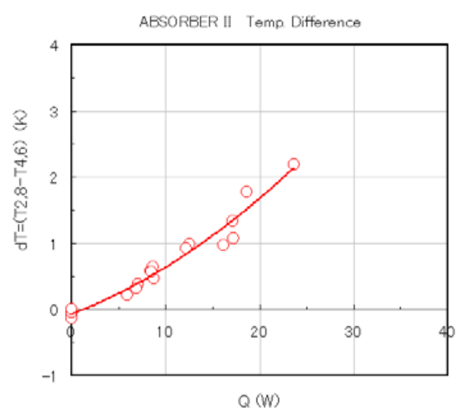

Figure 5: Maximum temperature difference in absorber vs. cooling power in the LH_2 absorber.

system. The temperature difference ΔT among the 8 probes was seen to increase roughly proportionally with cooling power. A maximum cooling power of 23.6 W was obtained with ΔT=2.2 K. From these results, we can estimate the cooling power of present system as ~95 W with ΔT=9 K. This result will be improved using an electrical heater with wide heat exchange area.

FUTURE KEK MTA ABSORBER TESTS

The aim of the 2nd cooling test at the MTA in the Fall of 2005 is to determine the highest heat loading and cooling power allowable by convection, within acceptable temperature variation limits for absorbers in a real cooling channel. The helium dewar is to be positioned closer to the absorber cryostat, shortening the helium transfer line and lowering the heat loss. This will allow longer runs on a single dewar and increase the range of heat loading.

Other modifications on the absorber manifold include installing an electrical heater and fins inside the cryostat to replace the warm gaseous He for heating which will better simulate heat deposition by a beam (Figure 6). In addition, the PtCo resistance thermometers will be replaced with Cernox 1050SD's for better accuracy. A level sensor will be installed inside the absorber to more accurately determine fill completion, and new housings for the thermometers at the cold He inlets and outlets will be implemented to better measure the cooling efficiency of the system. Finally, an electrical gas flow meter will be installed on the cold He line.

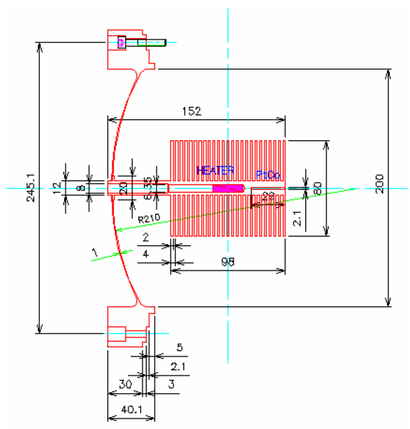

Figure 6: Plan of electrical heater and fins in the absorber (attached from the window).

MICE LH_2 ABSORBER COIL MODULE

The LH_2 absorber in the MICE experiment will be mounted inside a focusing solenoid magnet to form a single module, the MICE absorber/focus coil (AFC) module. The configuration of this module is shown in Figure 7. The focus coils are contained within a warm bore cryostat mounted in the outer vessel. The absorber is a KEK design similar to that being tested at the MTA, but with slightly larger dimensions [4]. The absorber unit is mounted within the solenoid warm bore in such a manner that it is independent of the solenoid. Services for the solenoid will enter through a dedicated turret in the outer vessel. The hydrogen feed/return, helium coolant, and vacuum connections to the absorber will likewise be via dedicated feeds through the outer vessel. Thermal radiation shields on the cryostat will reduce cryogenic heat loads, and the magnets and absorber fluid will be cooled by cryogenic coolers. The design allows the two elements that comprise the AFC module to be separated, a feature which provides for additional safety and operational reliability and which factorizes aspects of absorber design, fabrication, test, and commissioning from the final cooling channel assembly. With the envelopes and interfaces between the focus solenoid and the absorber element defined, all the interfacing parts are referenced to the warm bore of the cryostat and the outer vessel shell. The hydrogen absorber can also be assembled and fully tested as a complete unit before installation in the bore of the solenoid. This will be done as part of the operational procedure. Measuring single particles, the MICE cooling channel will not have to accommodate the large heat loads of a real cooling channel, and the refrigeration of the LH_2 absorbers and coils will be handled by cryocoolers, to save costs [4].

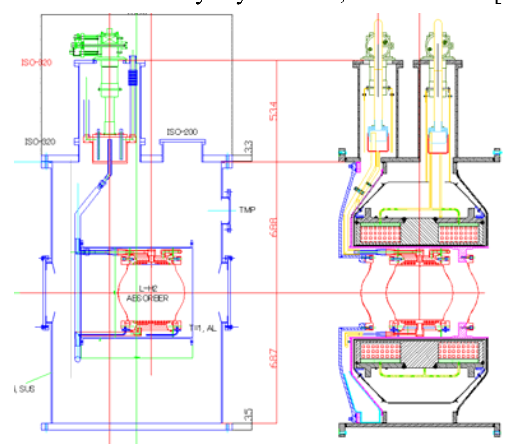

Figure 7: Plan views of the LH_2 absorber inside the AFC module cryostat with cryocooler (left) and within the focussing solenoid (right).

CONCLUDING REMARKS

The absorber R & D for the MICE cooling channel has taken advantage of the Mucool Collaboration efforts in cooling channel component R & D (particularly in thin window designs) and the KEK prototyping of convective absorbers [5]. The configuration of the AFC module in the MICE cooling channel allows for continuing refinements in LH_2 absorber manifold and window design to be accommodated without having to alter the other aspects of the MICE channel.

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