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THE MUCOOL/MICE LH2 ABSORBER PROGRAM

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The continuing LH2 R & D by the MuCool group, conducted by Illinois Consortium for Accelerator Research (ICAR) institutions (NIU, IIT and UIUC), the University of Mississippi, Oxford University and Fermilab, are summarized here, including results for the first hydrogen tests of an absorber prototype from Osaka University and KEK cooled by internal convection at the newly constructed FNAL MuCool Test Area (MTA). The program includes designs for the high-powered test of an absorber prototype (external heat exchange) at the MTA which are nearing completion to be installed by fall 2005, an alternative absorber design (internal heat exchange) being finalized for the approved cooling experiment (MICE) at Rutherford-Appleton Laboratory, and a novel idea for gaseous hydrogen absorbers being developed at Fermilab for a high powered test at the MTA in 2006.

Keywords: cooling; muon; absorber.

1. Introduction

Muon beams at the required intensity for neutrino factories or muon colliders can only be produced into a large phase space and need to be focused fast enough to outlive the 2.2 μs muon lifetime. Ionization cooling, in which muons repeatedly traverse an energy absorbing medium, alternating with accelerating RF cavities within a strongly focusing magnetic lattice, addresses the latter challenge. The ionization energy loss, dE_μ/ds, decreases all three muon momentum components without affecting beam size, reducing the overall phase space by reducing the transverse momentum spread of the beam.

The design of ionization cooling channels have been motivated by the following equation for the rate of change of the normalized transverse emittance [1]:

$$\frac{d\varepsilon_n}{ds} = -\frac{1}{\beta^2}\frac{dE_\mu}{ds}\frac{\varepsilon_n}{E_\mu} + \frac{1}{\beta^3}\frac{\beta_\perp (0.014)^2}{2E_\mu m_\mu L_R}, \tag{1}$$

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where s is the path length, E_{μ} is the beam energy in GeV, $\beta = v/c$, L_R is the radiation length of the absorber material and $\beta_{\perp}$ is the betatron function describing the size of the beam. The first term describes the cooling from ionization loss. The second term describes beam heating and is minimized when absorbers are placed in a strong focusing field (low $\beta_{\perp}$) and consist of material of a low atomic number (high L_R), the optimal choice being hydrogen.

2. The MuCool Test Area at Fermilab

In late 2003, construction of the MTA was completed at the site of the old access tunnel to the Fermilab Linac, and is now the focus of MuCool activity at FNAL. The MTA is designed to accommodate the full Linac intensity of $1.6X10^{13}$ protons/pulse at 15Hz or $2.4X10^{14}$ protons/s, or 600W energy deposition into a 35 cm long liquid hydrogen absorber at 400 MeV. The test area will provide power from the Linac to operate 201 MHz and 805 MHz test cavities. A first LH2 test has been completed with the KEK convection absorber, and RF testing (both 805 and 201 MHz) is planned. A cryogenic facility is scheduled for completion near the end of 2005. Additionally, there is a program for a new gaseous hydrogen absorber system, described below.

3. Hydrogen Absorbers

The issues that drive the absorber design and tests are: 1) extraction of large heat loads and 2) minimization of multiple scattering. Additionally, the combustive nature of hydrogen requires special safety considerations that drive a large part of the engineering and design.

Minimizing the multiple scattering has lead to novel window designs that depart from the standard spherical and torispherical shells [2]. For efficient heat removal, two different absorber designs have been proposed: 1) an internal heat exchange design, where the LH2 mixing is achieved by natural convection cells, driven by the beam-deposited heat and the cold walls of the heat exchanger (with cold He gas) and 2) an external heat exchange design where the heat exchanger is in an external loop of hydrogen and the LH2 mixing is achieved with an external pump with nozzles oriented at various angles to establish turbulent flow. These are shown in Figure 1.

Designs for thin windows have matured, where windows of equivalent strength to standard designs have been realized with less than 30 % their minimum thickness. Figure 2 shows the evolution of the window profiles. The current design has a profile with an inflected curvature where the thinnest section (around the center) is membrane-stress dominant: under extreme pressure (rupture) the greatest stress is experienced not at the center, but closer to the rim where the stress is bend (compression) dominant. This would result in the kind of rupture least likely to create shards.

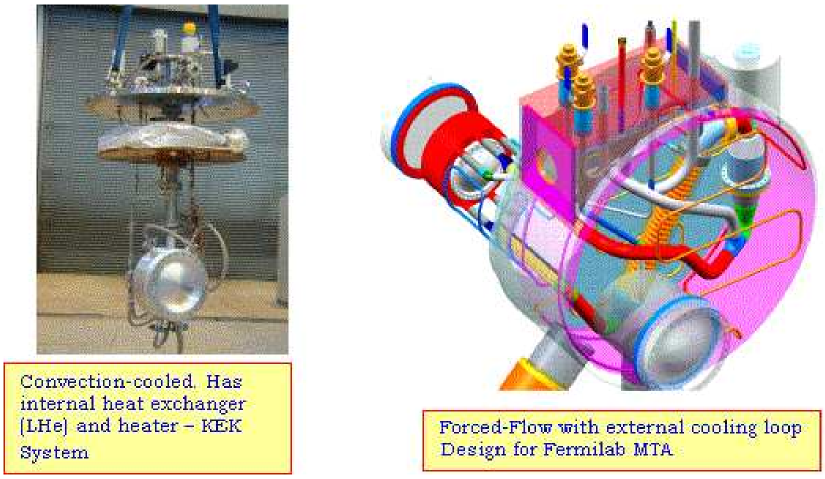

Fig. 1. Two LH2 absorber prototypes: Convection (internal heat exchange) left, and Force-flow (external heat exchange) right.

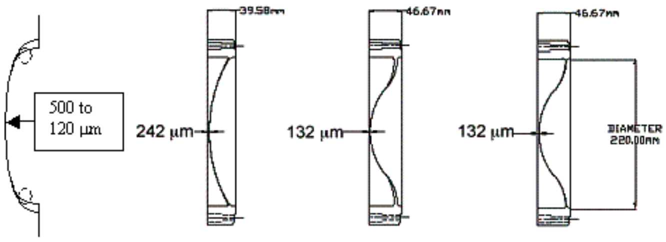

Fig. 2. Evolution of window profiles. From left to right: standard torispherical shell with tapered ends to a normal surface, tapered torispherical to flange, inflected to flange, and thinned inflected.

To test the window performance, photogrammetry was used as a non-contact, large sampling method of deformation measurement, using points of light projected onto the window surface, whose space locations were determined by a camera programmed to make parallax calculations [3]. The system has been upgraded to include a new projector lens and new camera software. Additionally, vapor deposition is replacing manual painting for optical coating application as the thinness of the windows makes the variations in the thickness of the TiO optical coat a potential source of error. A set of safety requirements for the window design have been established for the MICE and MuCool experiments, and the MuCool window approach has passed the initial MICE safety review. A certification procedure for windows used in the cooling cells is being developed.

The program for the absorber manifolds is proceeding in parallel paths. The external heat exchange, or forced-flow prototype has been built, and is currently set up in Lab P8 at Fermilab for room temperature flow tests using an infrared camera. A design for an absorber manifold, cryostat and external hydrogen loop with pump and heat exchange is near completion and will be the first absorber tested in a beam at the MTA. The cryostat is designed to slide into the solenoid now installed at the MTA, with the absorber in the magnets center.

A prototype for the convection design has been manufactured and tested by the KEK/Osaka group (shown in Fig. 1). The absorber is cooled by cold helium gas (15°K) circulated behind the wall of the absorber interior. Heating coils are installed at the bottom of the absorber and in the center using warmer helium gas. An initial test with liquid hydrogen at the MTA was successfully completed in August 2004, after a lengthy safety review. The hydrogen was cooled and condensed using cold helium from dewars. The absorber was completely filled, with a temperature of 18°K maintained stably over a period of several hours. Several operational issues were successfully resolved and the safety and controls system refined with this first run. Initial heat loading tests indicated that heat absorption of 20W or more can be accomplished at a stable temperature. Plans for the next test in 2005 will include upgrades to the absorber instrumentation: new, better resolution temperature probes, a level sensor, and temperature probes placed inside the input and output cold helium for better determination of cooling efficiency. The work involved in achieving safe, stable operation of the KEK absorber builds a foundation for all subsequent reviews of operation, including a high-powered beam test at the MTA with a complete cooling cell.

Results from both the KEK tests and the room temperature flow tests will be compared with flow simulations of both prototype designs to predict performance in a real beam.

A novel approach to ionization cooling is being developed that uses hydrogen gas at high pressure at nitrogen temperatures, with a density 0.5 that of liquid hydrogen [4]. Instead of discrete absorbers, the gaseous hydrogen would fill the accelerating RF cavities. Dark currents are suppressed due to Paschens Law, a property first observed in 19th century vacuum tubes when sparking suppressed when the tubes where filled with a pressurized inert gas. A small RF cavity was built and run up to 80MV/m before breakdown with H2 gas at 450 psig at 80 °K. A test with a lower luminosity beam is scheduled for 2006 in the MTA.

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