IMPLEMENTATION OF MICE AT RAL

Paul Drumm RAL, Chilton, UK
for the MICE collaboration

Abstract

MICE will replicate a piece of a Neutrino Factory cooling channel. The engineering of a safe system, with thin windows for the containment of liquid hydrogen and other features needed to safely operate MICE will test the practical application of the cooling scheme and its performance. MICE is proof of principle for this untried technology. This paper reviews the progress of plans for the implementation of MICE on the ISIS synchrotron at the Rutherford Appleton Laboratory in the UK.

MICE

The Muon Ionisation Cooling Experiment (MICE) [1] is motivated by the vision of a Neutrino Factory (NF). The cost and practicality of the NF depends on an early control of the emittance of the muon beam that will be accelerated and stored to produce the neutrino beams. A number of possibilities for transverse cooling of the emittance have been proposed including ionisation cooling in a linear channel. In such a concept, the muon beam is alternatively slowed down in cryogenic absorbers (energy loss by ionisation) and then re-accelerated in RF cavities to replace the lost energy. This process reduces the transverse momentum of the beam while maintaining the average momentum in the z-direction. The energy absorbing material should be characterised by a high stopping power and low multiple scattering, and the material of choice is liquid hydrogen. MICE will replicate a piece of the NF cooling channel, realistically engineered to be a safe system with thin windows for the containment of the liquid hydrogen and other features needed to safely operate MICE: MICE will consist a repeated set of modules to replicate one cooling cell; one module contains the cryogenic absorber and another the RF cavities, Figure 1. These modules incorporate superconducting solenoidal magnetic coils to contain and guide the muon beam. In particular, the absorber module contains a pair of magnets ("focus coil pair") designed to provide a strongly focused beam into the absorber to minimise the effects of multiple scattering (heating) in the absorber. The beam enters and exits the absorber through thin windows which also contribute to the heating. Additionally, MICE is instrumented; as particles enter and exit the channel with particle identification (TOF detectors, calorimeters and Cherenkov detectors) and also tracking at each end to measure the incoming and outgoing momentum and emittance. The channel is designed to measure a cooling effect (emittance reduction $\Delta\varepsilon$) of the order of 10% of the initial emittance. The required precision is an accuracy of 1% of the change over a range of muon momenta and emittance.

This paper reviews progress in MICE and the plans for its implementation at Rutherford Appleton Laboratory (RAL). MICE is responsible for the supply of the cooling channel. RAL, as the host laboratory, will provide facilities for MICE including the muon beam line and the additional infrastructure needed to support the project.

IMPLEMENTATION

MICE & ISIS

MICE has the benefit of an existing experimental hall and the MICE muon beam [2] which is an upgrade to a detector test beam line. The position of the synchrotron and the layout of the beam line and MICE in the hall are shown in Figure 2. The principle interaction between ISIS and MICE during the build phase will be during the installation of a target in the ring and the muon beam line. Most significant of this work is to make an aperture between the synchrotron vault and the MICE hall through which the beam is transported. This installation consequently has to take advantage of extended ISIS shutdown periods one of which is scheduled for April to September 2004. The hall has already been cleared of the original beam line and an aperture, which will take the nose of the decay solenoid [3], has now been made. This piece of civil engineering has been done in advance to free time in a later extended shutdown (expected 2005/6) to be used for the installation of the beam line itself: It is planned to have built and commissioned parts of the beam line in time for installation during this future shutdown, in particular the superconducting solenoid will need to be installed in such a way that commissioning with cryogenics can be done in the MICE hall while the aperture is shielded and ISIS is running. It is proposed to install the solenoid on a rail system that will allow the

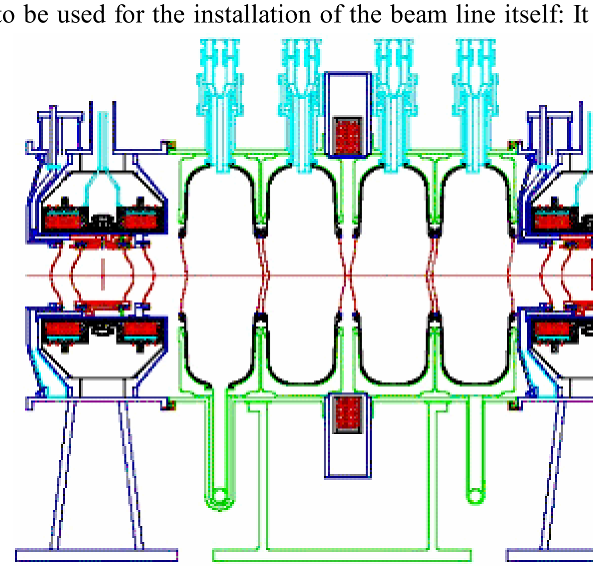

Figure 1. Part of the MICE cooling channel.

magnet to be pushed into place during a future shutdown, once commissioned.

During the operation of MICE, a target sitting on the ISIS ring dips into the halo of the proton beam just before extraction; this ensures the maximum beam energy (800 MeV) for the production of pions (and thus muons by decay). It is expected that a small loss of proton beam will be caused by this interaction and MICE will not be a major consumer of protons. The ISIS beam cycles at 50 Hz but MICE will operate at 1 Hz, and will see a burst of muons of about 1ms duration.

Cryogenics

Cryogenic Systems are needed for the superconducting solenoid in the muon beam line, for the superconducting magnets and absorbers [4] of the MICE cooling channel, and the sensitive photon detectors of the tracking devices [5]. The beam line solenoid is configured to use supercritical cryogenic helium; the superconducting magnets (4K) and absorbers (18K) of the cooling channel will be designed to be cooled using cryocoolers. The capacity to remove heat at 4K is low but careful design work has shown that this is sufficient for MICE. Cryocoolers are attractive to MICE; a central plant has a long delivery and installation time and consumes a large part of the capital expenditure, it may also be redundant following the completion of the experiment. It has also been observed that significant cooling power would be used in the transfer lines and does not benefit the experiment. The cryocoolers have the advantage of being compact and can be installed as part of the module to test the magnets or absorber at the point of manufacture. There is also a substantial overall saving, although a small cryogenic plant will still be needed for the decay solenoid.

Hydrogen System

The MICE absorbers operate with liquid hydrogen at 18K and sit in the vacuum of the MICE cooling channel. Hydrogen gas is condensed in the body of the absorber which is cooled by circulating liquid helium through the body walls. The design of a safe system is of paramount importance and the MICE absorber and hydrogen system have evolved significantly since the initial concept of the proposal, with a key criteria being the assurance that vacuum leaks cannot result in the freezing of oxygen onto cold surfaces that could later come into contact with hydrogen. The latter would result from leaks of hydrogen from the absorber vessel. Any oxygen in these circumstances would not be detectable and hence could generate the potential of an explosive mixture as the system is warmed up. The solution adopted surrounds the absorber vessel by a second vacuum containment isolating it from the cooling channel vacuum. Leaks into the vacuum surrounding the absorber would be detected first in the outer region which is warm enough not to condense oxygen. The shrouding of external vulnerable areas by an argon jacket is also proposed. The drawback of the extra vacuum containment is that the beam sees two sets of windows. These in turn have an affect on the performance of the channel but are necessary to ensure a safe system.

Another of the key features of the hydrogen system is the proposed use of passive storage of the hydrogen as a metallic hydride. The advantages are better safety (inert storage), cost and a much more tractable system (it might be noted that the density of liquid Hydrogen (0.07gm/cc)

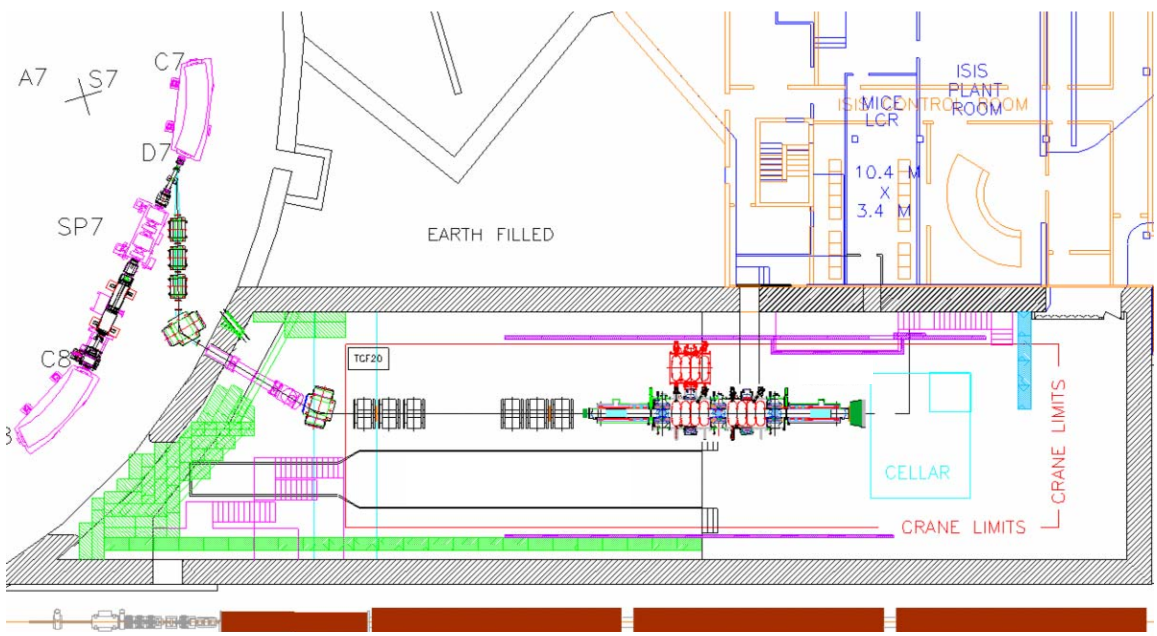

Figure 2. Layout of MICE on ISIS. The ISIS synchrotron is on the far left and MICE on the far right.

is comparable with the density of hydrogen stored in a metal-hydride. Hence a volume of hydride similar to that of the liquid is required - many times smaller than the volume occupied by the liquid in the form of hydrogen gas at STP).

RF Power Sources

The baseline design of MICE includes eight RF cavities operating at 201 MHz, and requires at least 8 MW of RF power at low duty cycle. RF power is expensive, and so the MICE RF Power source is based on the reuse of 2 MW, 201 MHz Linac RF power amplifiers from LBNL and CERN. Four of these ancient power systems will be refurbished to deliver at least 1 MW into each of the eight cavities by sharing the output of each amplifier between two cavities. Since MICE will be assembled in stages, the four amplifiers will initially be equipped with used-TH116 tubes from ISIS which should be capable of delivering provide power at 1MW (or higher for shorter periods of time). Higher power levels can be obtained with either new TH116 (4MW) or TH170 tubes (2.5MW). The TH170 tube can be used should supply of TH116 be withdrawn. The RF pulse lasts for ~1ms at a repetition rate of 1Hz which matches the insertion of the target into the ISIS synchrotron beam. The configuration of the RF system is shown in Figure 3. The system has the possibility to drive four cavities at higher power by directly connecting the amplifiers to the cavities. For a description of the cavities, see [6].

A particular issue for MICE is the level of X-ray activity generated by the cavities. The influence of the solenoidal magnetic field on the field emission of electrons and the generation of X-rays is being actively studied [7]. The anticipated operating level of MICE is a peak accelerating field of ~10MV/m. At this level, the X-ray activity around the cavities is too high to allow personal occupation and implies that the experimental hall will be excluded to personal occupancy while RF-power is in the cavities.

Magnetic Shielding

The MICE magnetic lattice contains no iron to restrict the return flux of the magnetic field. Consequently, significant fringe fields would extend into public areas around the MICE experimental hall and into the ISIS control room and so these must be shielded. Iron sheets are used to "soak" up the fringe fields. These sheets represent an inconvenience when accessing the experiment. Modelling thus far suggests that a minimum structure of two sheet of iron (each 2cm thick) either side of and parallel to MICE would be sufficient for personal shielding purposes. The detectors used for particle identification in MICE (photo-multiplier tubes) are also affected by the extended magnetic fields and these must also be shielded, but this can be done locally by introducing iron sheets perpendicular to the MICE axis. These have the consequence of distorting the fields seen by the muons passing through MICE and of introducing non-negligible forces between the shielding and the solenoids themselves.

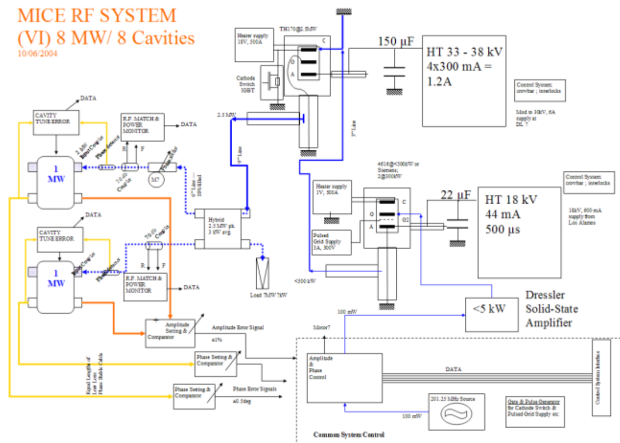

Figure 3. Schematic Layout of the MICE RF System.

OUTLOOK

A significant amount of work has been performed in the name of the MICE project since the submission of the proposal to RAL at the beginning of 2003. This has led to a better understanding of the experiment, better technical solutions, better understanding of its costs and of the remaining areas of difficulty. Importantly, the major hazards and risks have been identified and solutions found. It is hoped that funding will become available in the next financial year so that the construction of MICE can continue at a timely pace. At present, the experiment appears both practical and affordable.

ACKNOWLEDGEMENTS

Material described in this paper reflects the combined efforts of colleagues at the Rutherford Appleton Laboratory and within the MICE collaboration.

REFERENCES

[1] A full description of MICE can be found in the proposal submitted to the Rutherford Appleton Laboratory: (http://mice.iit.edu/mnp/MICE0021.pdf), and more details are available on the MICE collaboration web site: http://www.mice.iit.edu/ .
[2] see K. Tilley, these proceedings.
[3] MICE will incorporate the muE4 superconducting solenoid which has been removed from service at the Paul Scherer Institute in Switzerland.
[4] see M.A. Green et al., these proceedings.
[5] see M. Ellis et al., these proceedings.
[6] see D. Li et al., these proceedings.
[7] see J. Norem, V. Wu, A. Moretti, M. Popovic, Z. Qian, L. Ducas, Y. Torun and N. Solomey, Phys. Rev. Spec. Top. /Accl and Beams, 6, 072001 (2003).