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PROGRESS ON THE FOCUS COIL FOR THE MICE CHANNEL

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Abstract

This report describes the progress on the magnet part of the Absorber Focus Coil module for the international Muon Ionization Cooling Experiment (MICE). The MICE absorber focus coil module consists of a pair of superconducting solenoids, mounted on an aluminum mandrel. The coil package that is in its own vacuum vessel is around an absorber. The absorber is within a separate vacuum vessel that is within the warm bore of the focusing magnet. The superconducting focus coils may either be run in the solenoid mode or in the gradient mode. The coils will be cooled using a pair of small 4 K coolers. The progress on the MICE focusing magnets, the magnet current supply system, and the quench protection system are discussed.

Introduction

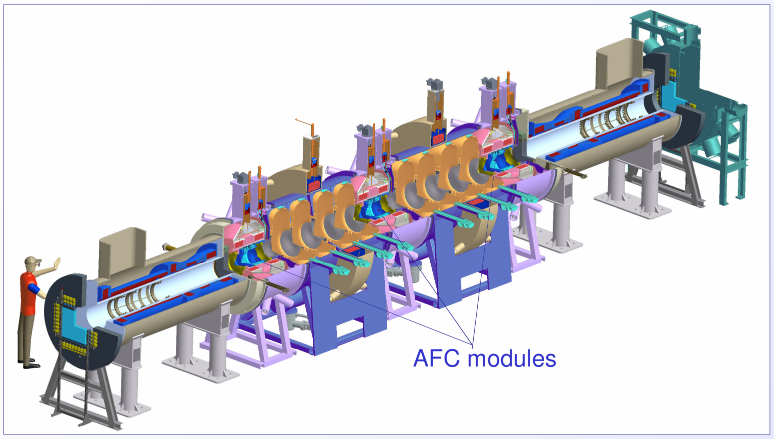

Fig.1. MICE Cooling Channel

Fig.1. shows the general layout of the MICE cooling channel. The proposed MICE experiment will test cooling on a low intensity muon beam from the ISIS ring at the Rutherford Appleton Laboratory in the United Kingdom.

Absorber Focusing Coil Module

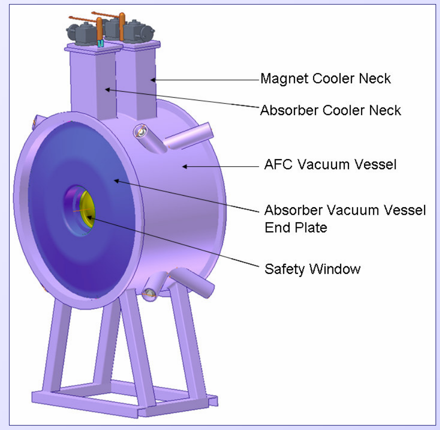

Fig.2. 3D AFC module

Fig.2. shows the 3D view of the Absorber Focusing Coil Module. The absorber cools the muon beam by ionization cooling.

The Focusing Magnet Design

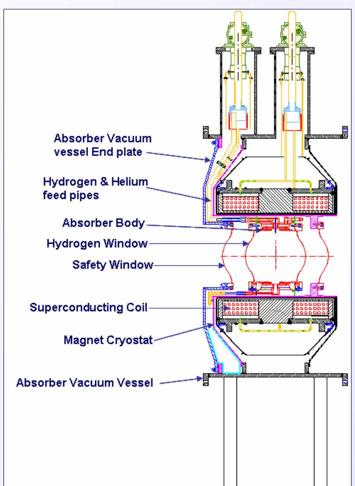

Fig.3. 2D AFC

The MICE focusing magnets are designed to be operated either a split pair solenoid or a a gradient solenoid. When the focusing magnet operates in the gradient mode, the field is zero at the magnet center and the center of the absorber.

Fig.3. shows the cross-section of the AFC with the superconducting coils that surround a liquid cryogen absorber.

The focusing magnet cold mass support is a self-centering support system, see Fig 4. The support system is designed to carry a sustained longitudinal force up to 500 kN (50 tons) and transient forces up to 1000 kN (100 tons).

Table 1. The Basic Parameters of the Focusing Magnet in the Non -flip and the Flip Mode

Parameter	Non-flip	Flip
Coil Inner Radius (mm)	263	
Coil Thickness (mm)	84	
Number of Layers	76	
No. Turns per Layer	127	
Magnet J (A mm^{-2})*	71.96	138.2
Magnet Current (A)*	130.5	250.7
Magnet Self Inductance (H)	137.4	98.6
Peak Induction in Coil (T)*	5.04	7.67
Magnet Stored Energy (MJ)*	1.17	3.10
4.2 K Temp. Margin (K)*	~2.0	~0.6
Inter-coil Z Force (MN)*	0.56	3.40

* Design based on p = 240 MeV/c and beta = 420 mm

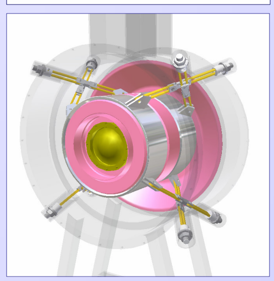

Fig. 4. Cold mass system

Magnet Cooling

The MICE focusing magnets are designed to be cooled using a pair of small two stage (1 to 1.5 W) 4.2K coolers.

Because the temperature margin in the focusing magnet is quite low at its maximum design current, it is important to minimize the temperature rise from the cooler second stage cold head and the hot spot in the magnet.

The connection of the cooler to the magnet is designed to maximize the focusing magnet operating temperature margin.

Power Supply and Quench Protection

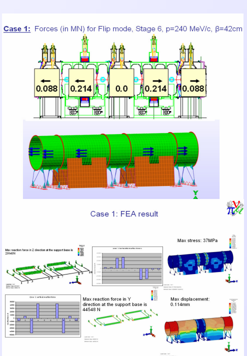

Fig.7. shows the FEA study case for the quench analysis.

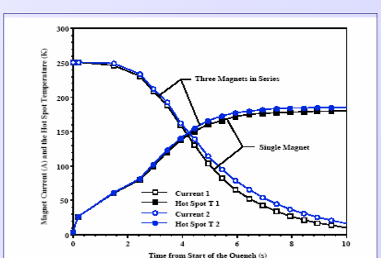

Fig. 5. The Focusing Magnet Current and Hot Spot Temperature as a Function of the Time from the Quench Start for the Magnet Coils Hooked together in the Flip Mode.

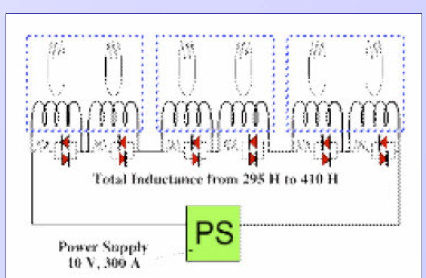

Fig.6. . Circuit Diagram for Three Focus Magnets in Series

Table 2. The Basic Quench Characteristics of the Focusing Magnet Operating at Peak Current in the Flip Mode

Parameter	
Maximum Current (A)	250.7
Conductor Current Density (A mm^{-2})*	181.7
Magnet Self Inductance (H)	98.6
Magnet Stored Energy (MJ)*	3.10
E J^2 at Maximum Current (J A^2 mm^{-4})*	1.02×10^{23}
Quench Velocity along Wire (m s^{-1})	5.2
Coil Average Radius (mm)	305
Coil Thickness (mm)	84
Coil Length (mm)	210
Time Constant for a Safe Quench (s)	7.33
Nominal Quench Back Time (s)	1.07

* Design based on p = 240 MeV/c and beta = 420 mm

The focusing magnet is designed so that it can be operated in the MICE cooling channel where the fields from other magnets interact with the focusing magnet. The focusing magnet quench characteristics permit the three magnets to be operated in series.

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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. 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. The development progress on MICE liquid absorber and its cryogenic cooling system are discussed.

Introduction

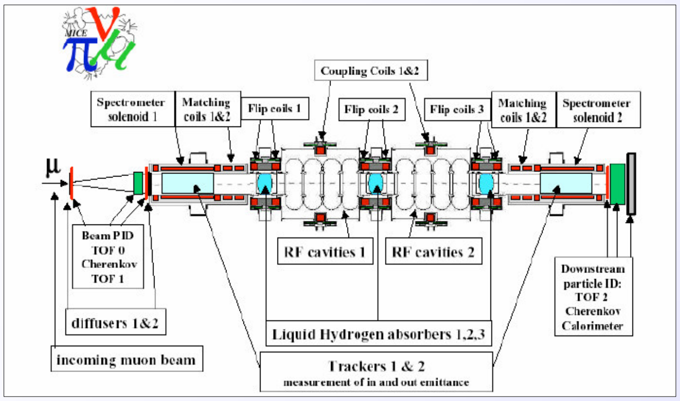


Fig.1. MICE general layout

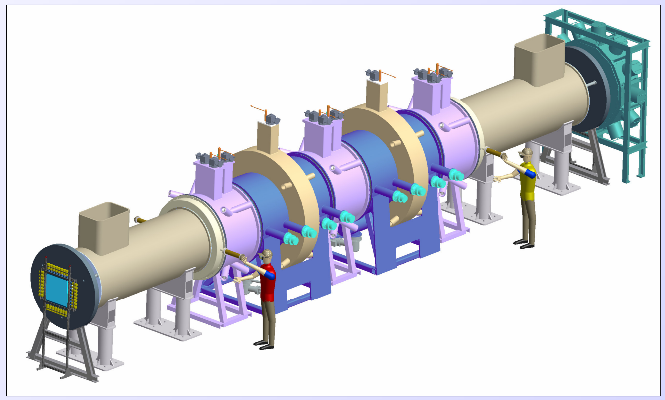
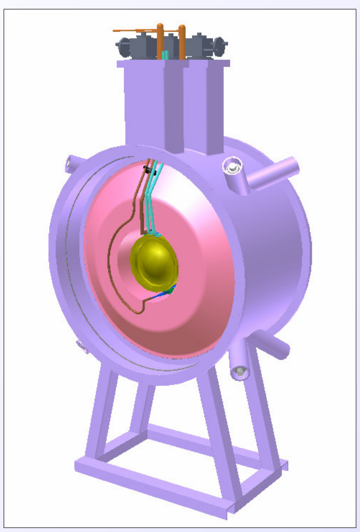
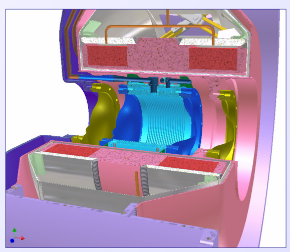


Fig.2. 3D MICE cooling channel

The Absorber and AFC module



AFC 3D view



Three quarter section view of AFC module shows the liquid absorber in relation to the superconducting focus coils.

The absorber System Design and 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 psi) and the burst pressure of >6.8 bar (100psi) . The RAL safety standards require that the absorber withstand a double fault. As a result, there is a vacuum vessel around the liquid absorber volume.

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 connection of the cooler to the absorber is shown in the Fig 4. A 1.5 W (at 4.2 K) cooler will be used to keep the absorber cold.

Figure 4 also shows an absorber that can be filled with LHe or LH2 from a storage dewar.

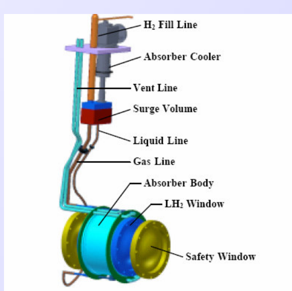


Figure 3. A Three Dimensional View of the Liquid Absorber and Its Cooling System and Hydrogen Supply System

The Sumitomo RDK-415GM Cooler, which is proposed to use for MICE

Absorber window and body prototype

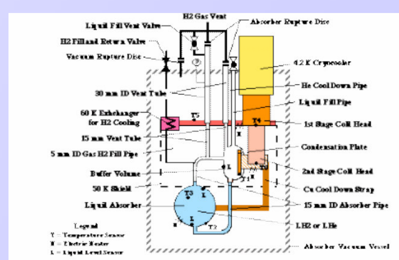


Figure 4. A Schematic Representation of the MICE liquid Absorber and Its Connection to the 4 K Cooler

MICE Absorber Operation

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

From Table 2, one can see that liquid helium volume change over operating temperature range determines the volume of the condenser-surge tank.

Conclusion

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.

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PROGRESS ON THE COUPLING COIL FOR THE MICE CHANNEL

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Abstract

This report describes the progress on the coupling magnet for the international Muon Ionization Cooling Experiment (MICE). MICE consists of two cells of a SFOFO cooling channel that is similar to that studied in the level 2 study of a neutrino factory [1]. The MICE RF coupling coil module (RFCC module) consists of a 1.56 m diameter superconducting solenoid, mounted around four cells of conventional 201.25 MHz closed RF cavities. This report discusses the progress that has been made on the superconducting coupling coil that is around the center of the RF coupling module. The process of cooling the coupling coil using single small 4K cooler, the coupling magnet power system and quench protections system are also discussed.

Introduction

The proposed MICE experiment will test cooling on a low intensity muon beam generated on a plunging target in the proton beam in the ISIS ring at the Rutherford Appleton Laboratory in the United Kingdom.

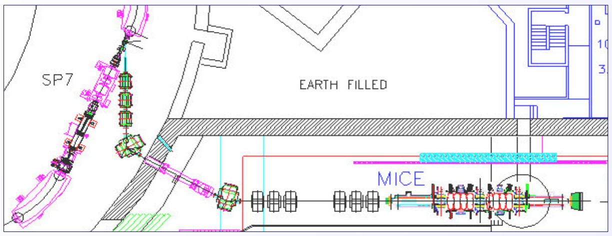


Fig.1. shows the layout of the ISIS Muon beam into MICE

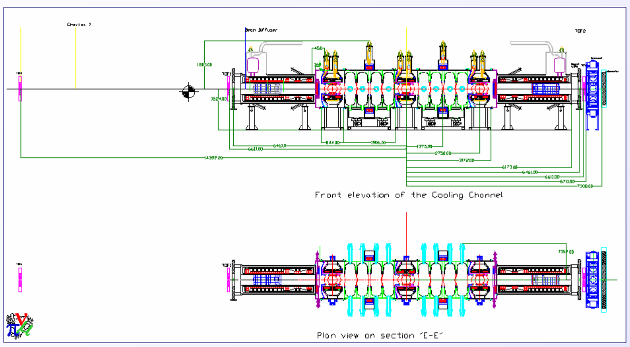


Fig.2. shows the 2D engineering drawing of MICE layout

The RFCC module

The RFCC module consists of four cells of 201.25 MHz RF that are in a 2.5 T solenoidal magnetic field that is generated by the coupling.

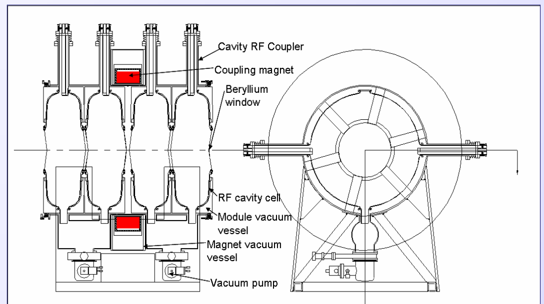
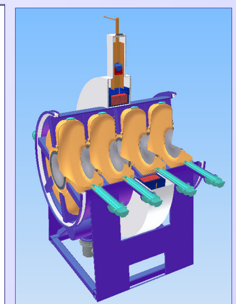
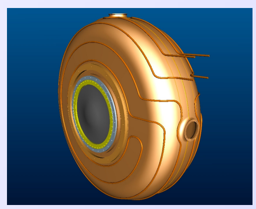


Fig.3. 2D drawing of the RF module



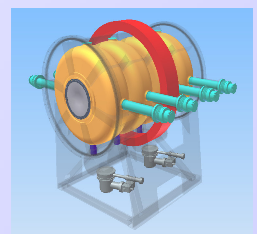
RFCC 3D section view

Fig.3. shows the 2D RFCC module, Four 201 MHz cavities are shown installed in the MICE cooling channel.



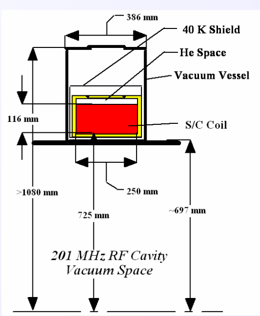
Cavity model showing external cooling tubes

An 8-cm-radius curved Be window made by Brush-Wellman for 805-MHz RF cavity tests. An equivalent 21-cm-radius window will be used for the MICE 201-MHz cavity.



3D view of Coupling Coil

The Coupling Magnet Design



A Cross-section View of One Half of the Coupling Magnet Showing the Magnet Dimensions

Table 1. Design Parameters for the Coupling Magnet

Parameter	
Coil Length (mm)	250
Coil Inner Radius (mm)	725
Coil Thickness (mm)	116
Number of Layers	104
No. Turns per Layer	151
Magnet J (A mm^{-2})*	115.5
Magnet Current (A)*	213.2
Magnet Self Inductance (H)	563
Peak Induction in Coil (T)*	7.81
Magnet Stored Energy (MJ)*	12.8
4.2 K Temp. Margin (K)*	~0.6

* Design based on p = 240 MeV/c and beta = 420 mm

The coupling magnets for MICE can be built using commercial niobium titanium MRI conductors. The diameter of the coupling magnet is determined by the diameter of the 201.25 MHz RF cavities and the vacuum vessel that must go around the cavities. The length of the coupling magnet is determined by the space between the cavity RF couplers and the cavity tuners.

Cooling the magnet with a Cooler

Fig.6 shows the Sumitomo RDK-415GM Cooler, which is proposed to use for MICE

The MICE coupling magnets is designed to be cooled using a single (1 to 1.5 W) 4.2 K cooler. The connection of the cooler to the magnet is designed to maximize the coupling magnet operating temperature margin.

Table 2. The Basic Quench Characteristics of the Coupling Magnet Operating at Peak Current in the Flip Mode

Parameter	
Maximum Current (A)	213.2
Conductor Current Density (A mm^{-2})*	154.5
Magnet Self Inductance (H)	563
Magnet Stored Energy (MJ)*	12.8
E J^2 at Maximum Current (J A^2 mm^{-4})*	3.06x10^{23}
Quench Velocity along Wire (m s^{-1})	4.0
Coil Average Radius (mm)	783
Coil Thickness (mm)	116
Coil Length (mm)	250
Time Constant for a Safe Quench (s)	10.09
Nominal Quench Back Time (s)	2.17

* Design based on p = 240 MeV/c and beta = 420 mm

Power supply and Quench protection

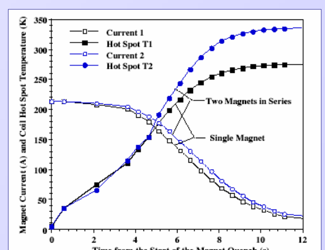


Figure 4. The coupling Magnet Current and Hot Spot Temperature as a Function of Time from Quench Start for a Single Magnet and Two Magnets in Series in the Flip Mode

Two coupling magnets is proposed to be powered in series.

however because of the high stored energy and long quench back time, two magnets in series will have a higher hot spot temperature at the point of the quench.

Sub–division of the coupling magnet using cold diodes and resistors will result in lower quench voltages and a lower hot spot temperature even when the magnets are in series. The concept of sub-dividing the magnet with cold diodes and resistors is illustrated in Figure 5.

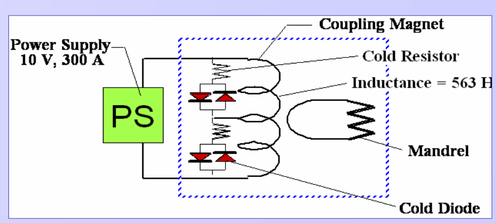


Fig.5. shows circuit diagram for a single coupling magnet

The coupling magnet will quench safely without quench protection. The two coupling magnets can be connected in series, but separate power supplies for each magnet will result in a shorter charging time for the coupling magnets.