Lawrence Berkeley National Laboratory

Title

Progress on the MICE Tracker Solenoid

Authors

Green, Michael A.
Virostek, Steve P.
Lau, W.
et al.

Publication Date

2006-06-10

PROGRESS ON THE MICE TRACKER SOLENOID

M. A. Green, and S. P. Virostek, Lawrence Berkeley National Laboratory, Berkeley CA 94720, USA; W. Lau and S. Q. Yang, Oxford University Physics Department, Oxford, OX1-3RH, UK

Abstract

This report describes the 400 mm warm bore tracker solenoid for the Muon Ionization Cooling Experiment (MICE) [1]. The 2.923 m long tracker solenoid module includes the radiation shutter between the end absorber focus coil modules and the tracker as well as the 2.735 m long magnet cryostat vacuum vessel. The 2.554 m long tracker solenoid cold mass consists of two sections, a three-coil spectrometer magnet and a two-coil matching section that matches the uniform field 4 T spectrometer solenoid into the MICE cooling channel. The two tracker magnets are used to provide a uniform magnetic field for the fiber detectors that are used to measure the muon beam emittance at the two ends of the cooling channel. This paper describes the design for the tracker magnet coils and the 4.2 K cryogenic coolers that are used to cool the superconducting magnet. Interfaces between the magnet and the detectors are discussed.

INTRODUCTION

MICE consists of two tracker solenoid systems and the MICE cooling channel [1]. The MICE cooling channel consists of three absorber focus-coil modules (AFC modules) and two RF coupling-coil modules (RFCC modules). The muon ionization cooling occurs in the absorbers in the middle of the AFC modules [2], [3]. The muons are reaccelerated within the RF cavities in the RFCC modules [4], [5]. The tracker modules couple the muon beam to the adjacent AFC modules and they measure the emittance of the muons [6]. The trackers within the tracker modules are five planes of scintillating fibers that measure the position of the particles within the tracker volume. The trackers are key to measuring the emittance of the muons from the MICE cooling channel.

Since MICE operates over a range of momenta (from 140 MeV/c to 240 MeV/c) and β at the center of each AFC module (from 55mm to 420 mm), the tracker solenoid must be tuned over a wide range of currents in the coils. The tracker solenoid must match to the MICE cooling channel as it operates in the flip mode, the non-flip mode and two semi-flip modes (the center AFC field flips while the two the end AFCs don't flip or the two end AFC fields flip while the center AFC doesn't flip).

The tracker solenoid consists of two match coils and three coils that are spectrometer part of the solenoid. The spectrometer section consists of two end coils and a long center coil. The spectrometer coils generate a uniform field ($\Delta B/B < 3 \times 10^{-3}$) over a length of 1 meter and in a diameter of 0.3 meters. The two match coils combined with the first end coil matches the β in the adjacent AFC coils with the β in the uniform field region of the spectrometer.

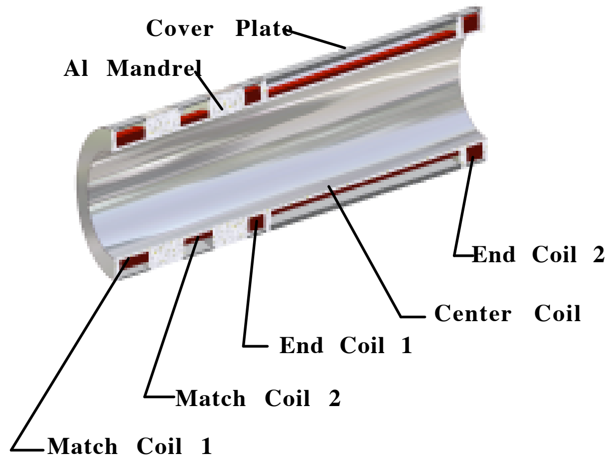

Figure 1 The Tracker Magnet Cold Mass Assembly

TRACKER MAGNET COLD MASS

A three-dimensional cross-section of the MICE tracker magnet cold mass is shown in Fig. 1. The tracker magnet consists of five coils. The two match coils plus end coil 1 act like a quadrupole triplet to match the beam in the tracker with the beam in the end AFC modules. The three-coil spectrometer solenoid consists of the two end coils and the center coil. End coil 1 serves double duty in that it helps shape the field in the uniform field section of the tracker as well as help with the muon beam tuning process. The three spectrometer coils are hooked in series and are powered by a single 300 A power supply. An added small current (up to ±50 A) can be put into each of the end coils. The small current in end coil 1 helps tune the tracker magnet (along with match coil 1 and match coil 2) with the MICE cooling channel. The small current in end coil 2 is used to counter the effects of the iron ring at the end of the magnet that serves as a shield for the photo multiplier tubes for one of the detectors that is upstream and downstream from the experiment. Each of the two match coils will be separately powered using a 300 A power supply. Various design parameters for the MICE tracker solenoid are shown in Table 1.

The five coils in the tracker solenoid are wound with the same superconductor. The superconductor properties are: 1) the insulated conductor dimensions are 1.00 by 1.65 mm; 2) the conductor critical current is 760 A at 5 T and 4.2 K; 3) the conductor Cu to S/C ratio is 3.9 ±0.4; 4) number of filaments is 222 (41 μm in diameter); and 5) conductor twist pitch is 19 mm. The two tracker solenoids will use 110.7 km of this conductor.

Table 1. Design Parameters for the MICE Tracker Solenoid

Parameter	Match 1	Match 2	End 1	Center	End 2
Inner Coil Radius (mm)	258	258	258	258	258
Coil Thickness (mm)	46.2	30.8	61.6	22.0	68.2
Coil Length (mm)	198	197	110	1294	110
Current Center Axial Position* (mm)	3611.0	4051.0	4451.0	5201.0	5952.0
Current Center Radial Position* (mm)	281.1	273.4	288.8	269.0	292.1
Coil Average J (A mm^{-2})	118.04	138.28	136.80	146.90	142.49
Number of layers per Coil	42	28	56	20	62
Number of Turns per Layer	120	119	66	784	66
Design Current (A)**	214.2	251.8	249.5	265.9	265.2
Coil Self Inductance (H)^	13.1	5.8	9.6	41.6	11.4
Coil Stored Energy (MJ)**	0.47	0.20	0.30	1.49	0.40
Peak Field in Coil (T)**	4.7	2.42	5.61	4.02	5.62
Temperature Margin at 4.2 K (K)**	~2.0	~2.5	~1.9	~2.3	~1.7
Conductor Length (m)	8902	5724	6707	26502	7511
Coil Mass (kg)	116	72	89	347	98
Total Conductor Magnet Length (m)			55346		
Cold Mass Inner Diameter (mm)			490		
Cold Mass Outer Diameter (mm)			690		
Cold Mass Length (mm)			2554		
Vacuum Vessel Outer Diameter (mm)			1404		
Magnet Warm Bore (mm)			400		
Vacuum Vessel Length (mm)			2923		
Total Tracker Magnet Cold Mass (kg)			~1390		
Copper Shield and Intercepts Mass (kg)			~290		
Vacuum Vessel and Cooler Mass (kg)			~1990		
PMT Iron Shield Mass (kg)			~1240		
Total Tracker Solenoid Mass (kg)			~4910 (with iron shield)		
Peak Cold Inter Coil Force (MN)**			~1.47		

* R and Z are with respect to the centre of MICE (the centre of the central AFC magnet). R = 0 is the MICE axis.
** For the standard (Case 1) with p = 200 MeV/c and □ = 42 cm based on the 300 K dimensions of the coils.
^ The self-inductance of the two end coils and the centre coil in series = 78 H.

COLD MASS SUPPORTS AND MAGNET CRYOSTAT HEAT LEAKS

The magnet has a self-centering cold mass support system such that the center of the cold mass remains unchanged as the magnet is cooled from room temperature to 4 K. The magnet cold mass support is designed to carry 0.5 MN (50 tons) in either longitudinal direction and 0.05 MN (5 tons) in the radial direction. The cold mass support system must have a large spring constant in the longitudinal direction (>200 MN m^{-1}), so that the magnet doesn't move in the longitudinal direction more than 1.5 mm when MICE is powered. The axis of the solenoid must be co-axial with the warm bore axis to ±0.3 mm. The maximum allowable tilt is ±0.001 radian.

Table 2. Tracker Magnet Design Heat Leaks

Component	Heat Leak (W) @ 50 K	Heat Leak (W) @ 4 K
Cold Mass Supports	~8	0.35
Radiation through MLI	~17	~0.3
Necks and Instrumentation	~4	~0.3
Current Leads	~80	0.85
Total Design Heat Leak	~109	~1.90

Table 2 shows the estimated heat leak into the tracker magnet cryostat. The heat leak into the 50 K region and the 4 K region is dominated by the heat coming down the magnet current leads. The tension band supports represent the second largest heat leak into the 4 K region. At 50 K the second largest heat leak is thermal radiation through the MLI. The total heat leak at 4 K and 55 K suggests that the each tracker magnet can be cooled using two 1.5 W (at 4.2 K) coolers [7]. A third cooler is shown in Fig. 2, but this appears to be unnecessary.

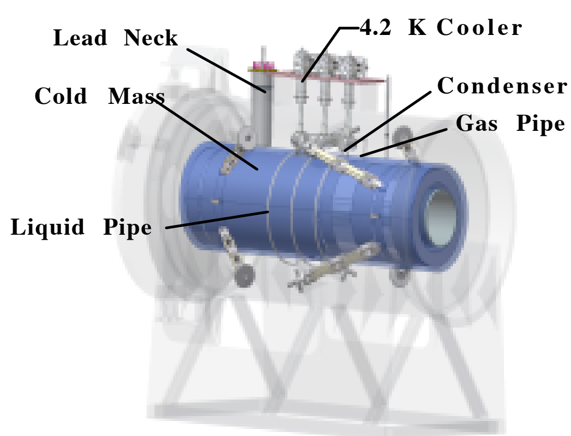

Figure 2. Magnet Cold Mass and Cryostat

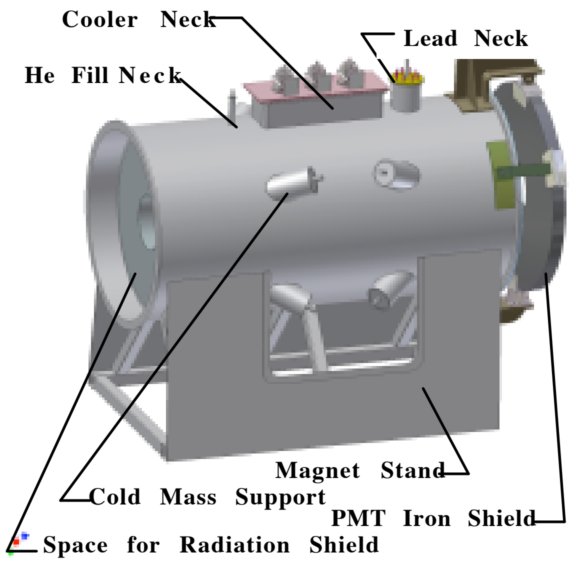

Figure 3. Tracker Magnet Vacuum Vessel

TRACKER VACUUM VESSEL AND INTEGRATION WITH OTHER SYSTEMS

Fig. 3 shows the vacuum vessel for the tracker module. The overall length of this vacuum vessel is 2923 mm. The magnet vacuum vessel is 2735 mm long. At the AFC module end of the tracker module there is a 188 mm long space for a radiation shield that shields the scintillating fiber detectors in the magnet bore from the electrons and gamma radiation that comes from the RF cavities as they are being conditioned. The total shield thickness is equivalent to 50 mm of lead. The AFC end of the tracker module connects to the AFC module through a bellows and through studs. There is a window at the AFC end of the magnet so that the scintillating fiber tracker can be operated in a helium atmosphere.

The stand shown in Fig. 3 is designed so that all of the magnetic forces (up to 50 tons in the longitudinal direction) on the tracker module can be directed to the floor of the experiment. Because the tracker module vacuum vessel is the same diameter as the AFC module vacuum vessel, one can also transmit forces from the tracker module to the MICE cooling channel.

Fig. 3 shows an iron ring that shields the photo multiplier tubes (PMT) from the magnetic field generated by the tracker magnet. This iron shield must be attached to the end of the magnet cryostat using the brackets shown in Fig. 3. Between the iron shield ring and the end of the magnet cryostat (in a space of about 250 mm) is a patch panel that carries the light fibers from the scintillating fiber detector to the readout device. In the upstream tracker solenoid is a diffuser system that produces a muon beam with the desired input emittance.

CONCLUDING COMMENTS

The tracker solenoids for MICE are about to be fabricated. The conductor for these magnets has already been delivered to the vendor who will fabricate the magnets. The tracker solenoid consists of five coils. Two of these coils are used to match the uniform field in the tracker with the field in the adjacent AFC magnets. The primary function of the other three coils is to generate the uniform field needed for the tracker. The field uniformity in the tracker will be better than 0.3 percent over a length of 1 m and a diameter of 0.3 m.

The two MICE tracker solenoids will be powered by three 300 A power supplies. The currents in the two end-coils of the spectrometer section are tuned using a pair of 50 A power supplies.

The tracker solenoid cold mass support is designed to carry longitudinal forces in either direction of 50 tons. The same support system must carry at least 5 tons in the radial direction.

It appears that a MICE tracker solenoid can be cooled using a pair 1.5 W (at 4.2 K) pulse tube coolers. The same coolers will produce 55 W of cooling at 50 K.

The MICE tracker solenoid interfaces with the PMT iron shield, the tracker patch panel that connect the tracker with the fiber light detectors, and the radiation shutter that is upstream from the magnet.

ACKNOWLEDGEMENT

This work was supported by the Office of Science, United States Department of Energy, under DOE contract DE-AC02-05CH11231. DOE funding for the US Neutrino Factory and Muon Collider Collaboration is gratefully acknowledged.

REFERENCES

[1] G. Gregoire, G. Ryckewaert, L. Chevalier, et al, "MICE and International Muon Ionization Cooling Experiment Technical Reference Document," http://hep04.phys.itt.edu/cooldemo

[2] D. E. Baynham, T. Bradshaw, et al., "A Liquid Absorber for MICE," *Advances in Cryogenic Engineering* **51**, AIP Press, Melville NY, (2005)

[3] M. A. Green, G. Barr, U. Bravar, et al, "The Mechanical and Thermal Design for the MICE Focusing Solenoid Magnet System," IEEE Transactions on Applied Superconductivity **15**, No. 2, p 1259, (2005)

[4} D. Li, M. A. Green, S. Virostek, and M. S. Zisman, "Progress of the RF coupling Module for the MICE Channel," Proceedings of 2005 Particle Accelerator Conference Knoxville TN, p 3417

[5] M. A. Green, S. Q. Yang, U. Bravar, et al, "The Mechanical and Thermal Design for the MICE Coupling Solenoid Magnet," IEEE Transactions on Applied Superconductivity **15**, No. 2, p 1279, (2005),

[6] P. Fabbricatore, S. Farinon, U. Bravar, and M. A. Green, "The Mechanical and Thermal Design for the MICE Detector Solenoid Magnet System," IEEE Transactions on Applied Superconductivity **15**, No. 2, p 1255, (2005)

[7] M. A. Green, "Cooling the MICE Magnets using Small Cryogenic Coolers," Oxford University Physics Department Engineering Note 10, MICE Note 109, http://hep04.phys.itt.edu/cooldemo, Sept. 2004