A Single-band Cold Mass Support System for the MICE Superconducting Coupling Magnet

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A Single-band Cold Mass Support System for the MICE Superconducting Coupling Magnet

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ABSTRACT

The cooling channel of the Muon Ionization Cooling Experiment (MICE) consists of eighteen superconducting solenoid coils, which are magnetically hooked together and contained in seven modules. The operations of a pair of MICE superconducting coupling magnets are affected directly by the other solenoid coils in the MICE channel. In order to meet the stringent requirement for the magnet center and axis azimuthal angle at 4.2 K, a self-centered tension-band cold mass support system with intermediate thermal interruption was applied for the MICE superconducting coupling magnet. The physical center of the magnet does not change as it is cooled down from 300 K to 4.2 K using this support system. This paper analyzed and calculated force loads on the coupling magnet under various operation modes of the MICE cooling channel. The performance parameters of a single-band cold mass support system were calculated also.

INTRODUCTION

The development of a muon collider or a neutrino factory requires beams of low emittance muons to be produced. A key to the production of low emittance muons is muon ionization cooling. The MICE will be a demonstration of muon cooling in a configuration of superconducting solenoids and absorbers [1]. The MICE magnetic channel consists of seven magnet assemblies composed of eighteen superconducting solenoid coils. The solenoid channel is physically symmetric about its centre, which is defined locally as z = 0. There are three types of magnet assemblies: 1) the focusing magnets that produce the magnetic field in the absorbers within the absorber focus coil module (AFC module), 2) the coupling magnets that generate the magnetic field for the RF coupling coil module (RFCC module), and 3) the tracker solenoids that generate the uniform and matching fields within the tracker module. The MICE channel totally consists of three AFC modules, two RFCC modules and two tracker modules. Muon ionization cooling occurs when there is a net loss of transverse muon momentum when the muons pass through the absorber material and are reaccelerated by adjacent RF cavities [2]. The MICE channel may be operated in the flip mode (gradient mode) or non-flip mode (solenoid mode) based on the way that focusing coils to be electrically connected [1]. The physical locations and current densities for the MICE coils in both flip mode and non-flip mode are referred to [3].

In order to meet the stringent requirement for the magnet center and axis azimuthal angle at 4.2 K, a self-centered tension-band cold mass support system was applied to the MICE superconducting coupling magnet [4]. This paper discusses possible forces on the cold mass support system in detail. The thermal and structural parameters of a self-centered single-band cold mass support system is calculated and analyzed by the FEA.

FORCE LOAD ON MICE COUPLING MAGNET

For all the coils in the MICE cooling channel, if their centers are aligned on the same axis, the magnetic forces on the coupling coils due to inductive coupling between it and the other coils are always in the longitudinal direction. This peak longitudinal force determines the longitudinal design load for the cold mass support system of the coupling magnet. The dominant radial force results from gravity and shipment load.

The focusing coils in the three AFC modules are connected in series to form circuit F. Coupling coils C1 and C2 are individually powered. The end coils and the center coil of the tracker spectrometer magnet are connected in series and in series with the same coils at the other end of the channel forming circuit S. Each match coil in the tracker solenoid is connected in series with the corresponding match coil in the tracker module at the opposite end of the MICE channel forming circuit M1 and M2 [3].

Table 1 shows the longitudinal magnetic forces on a coupling magnet at various normal operation modes. The peak longitudinal force happens in flip mode and at muon momentum p of 240MeV/c, β of 420 mm because the currents in most of the coils are highest. Table 2 shows the longitudinal magnetic forces on a coupling magnet due to quench of three AFC coils, both tracker coils and a sing coupling coil. Once one AFC magnet quenches, it will bring about quench of three AFC magnets because they are connected in series. A coil in one tracker magnet quench will quench all coils in the tracker magnet because they have the same Al bobbin, and furthermore both tracker magnets will quench for they are in series. The peak force on a coupling magnet during a quench is 338.1 kN, which occurs when both tracker magnets quench at 240 MeV/c in flip mode. Table 3 shows the longitudinal magnetic forces on a coupling coil when the leads in each coil's circuit are reversed separately. The longitudinal forces due to lead reversal on most coils' circuits are lower than that due to quench of both tracker magnets, except when the leads are reversed on one coupling coil. The peak longitudinal force on a coupling magnet in this case is 416.4 kN. In the above tables, a negative force is toward the channel center, and a positive force is away from the channel center. RFCC1 is the left coupling coil ($z<0$) in MICE channel, and RFCC2 is the right coupling coil ($z>0$). The current densities for the above cases are calculated based on the warm coil positions and dimensions [3]. If the cold coil positions and dimensions are used, the current densities go up from 0.8 to 1.5 percent, and as a result the calculated forces go up as much as 3 percent which are within the accuracy of such calculations [3].

According to the above analyses and calculations, the longitudinal design force for the cold mass support system of a coupling magnet is set at 500kN. The radial design force is set at 50kN, considering the 3 g shipment load during long-distance transportation provided that the cold mass of a coupling magnet is of the order of 1500kg) [4].

Table 1. Magnetic Forces on a Coupling Magnet during Normal Operation Modes (kN)

Case		RFCC1	RFCC2
Flip	200Mev/C	170.7	170.7
	240Mev/C	253.2	253.2
Non-Flip	200Mev/C	-160.4	-160.4
	240Mev/C	-237.3	-237.3

Table 2. Magnetic Forces on a Coupling Magnet during Various Quench Modes and 240 MeV/C (kN)

Case		Three AFC	Both Trackers	Coupling C1	Coupling C1
Non-flip	RFCC1	-228.3	-307.1	0	60.6
	RFCC2	-228.2	-307.1	60.6	0
Flip	RFCC1	249.7	338.1	0	-81.6
	RFCC2	249.8	338.1	-81.6	0

Table 3. Forces on a Coupling Magnet during Various Lead Reversal Modes in the Flip Mode at 240MeV/c (kN)

Module	RFCC1	RFCC2
AFC Reversed	246.3	246.3
Coil C1 Reversed	-253.5	-416.4
Coil C1 and Coil C2 Reversed	416.1	416.2
Coil M1 Reversed	331.2	331.2
Coil M2 Reversed	281.4	281.5
Spectrometer Reversed	316.0	316.0

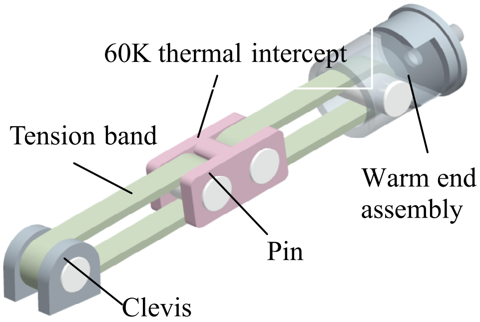

Figure 1 A 3D view of a single-band cold mass support strap assembly

DESIGN OF COLD MASS SUPPORT SYSTEM

The cold mass support system for a MICE coupling magnet must carry up the force up to 50 kN in the radial direction and up to 500 kN in either longitudinal direction. During normal operation the magnet center doesn't move more than ±2 mm and the angle of the axis of the magnet doesn't change more than ±0.7 mrad. The heat leaks through the cold mass supports are required no more than 0.25 W at 4.2 K because the MICE coupling magnet is proposed to be cooled using a cooler with cooling capacity of 1.5W at 4.2K [4].

A self-centered support system was adopted for the coupling magnet since it has the characteristic that the physical center of the magnet doesn't change during cooling down from 300K to 4K [4]. It consists of eight support strap assemblies (four at each end of the magnet). Each support strap assembly consists of two or four fiberglass epoxy support bands with attachment hardware at each end and an intermediate temperature intercept between the two or four bands. A single-band support assembly is shown in Figure 1. The warm ends of the supports will be near the vacuum vessel ends at azimuthal angles of 45, 135, 225, and 315 degrees. The cold ends will be at the same angles but off by plus or minus 5 to 10 degrees toward the mid-plane. The tension force along one support strap assembly is about 127 kN. Table 4 shows behavior of a single-band support system for the coupling magnet as a function of the various levels of design pre-stress in the tension bands at a 500 kN longitudinal force.

Table 4 Design Parameters for a Single-band Cold Mass Support System for a MICE Coupling Magnet

Support System Parameters	Level of Pre-stress		
	Low	Medium	high
300K Band stress (MPa)	53.0	123.2	198.5
4.2K Band stress (MPa)	146.9	217.3	292.9
4.2K& Charged Band stress (MPa)	140.9	211.3	286.8
Band Cross-section Area (mm^2)	900	600	442
Width x thickness (mm^2)	40 x 11.25	40 x 7.5	40 x 5.5
Heat leak at 60K (W)	0.629	0.419	0.309
Heat leak at 4.2K (W)	0.041	0.027	0.02

The FEA analysis of the thermal-structural coupled field for a single-band support strap assembly has been carried out as well. As a 127 kN tension force was applied on the support strap assembly, the average von Mises stress in the support band was 198 MPa, and the peak stress of about 269 MPa on the band occurred on the inner surface of the bend around pin due to the integration of tension and bending effects. The heat leak based on the properties of G-10 for one support strap assembly from 60 K to 4.2 K is 0.022 W, and from300K to 60K is 0.354 W. Based on the above calculation and analyses, the nominal lengthes for the warm and the cold tension bands are respectively about 220 mm and 289 mm. Each band has a width of 40 mm and a thickness of 8 mm.

CONCLUSIONS

A self-centered tension-band cold mass support system is adopted in the MICE coupling magnet. According to the analyses and calculations of forces imposing on the coupling coil at normal and failure operation modes, the longitudinal design force on the cold mass support system is set at 500 kN. The radial design force is set at 50 kN considering the 3 g shipment load during transportation. The main parameters for a single-band support system were calculated and FEA analyzed. The nominal lengthes for the warm and the cold tension bands of a single-band support strap assembly are respectively about 220 mm and 289 mm. Each band has a width of 40 mm and a thickness of 8 mm.

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REFERENCES

1. Gregoire G., Ryckewaert G., Chevalier L., et al, “MICE an International Muon Ionization Cooling Experiment Technical Reference Document,” http://hep04.phys.itt.edu/cooldemo.
2. Li D.R., Green M. A., Virostek S. P., Zisman M. S., “Progress on the RF Coupling Module for the MICE Channel,” *Proceedings of 2005 Particle Accelerator Conference* (2005), Knoxville TN, pp 3417-3420.
3. Green M. A., Senanayake R. S., “The Cold Mass Support System for the MICE Focusing and Coupling Magnets,” MICE Note 106, http://hep04.phys.iit.edu/cooldemo/notes (2004).
4. Institute of Cryogenics and Superconductivity Technology, Engineering design of MICE/MUCOOL coupling solenoid magnet (2007), Harbin Institute of Technology.

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