CHAPTER 12. Cryostat Design

1. Introduction

The LHC interaction regions consist of many components that make up the final focus elements on either side of each interaction point (IP). One of these is a series of quadrupole magnets that form the final focus triplet. The magnets in the triplet are called Q1, Q2a, Q2b, and Q3 and are collectively referred to as interaction region quadrupoles (IRQ). Q2a and Q2b are separate coils, but act as a single focusing element. The cold masses, consisting of the coil assembly, iron yoke, and helium containment vessel, for Q1 and Q3 are being manufactured by KEK. Fermilab will manufacture those for Q2a and Q2b. After collaring the coils, applying the iron yoke, and welding the helium containment vessels, the Q2a and Q2b are welded together to form a single cold mass known simply as Q2. Fermilab is manufacturing all of the magnet cryostats for Q1 through Q3, which is also where the final assembly takes place. This report is a brief summary of the design of the cryostats for these magnets. The design heat loads that govern much of the detailed design of the cryostat are shown in table 1.

Table 1. Estimated heat loads to each of the thermal stations – complete triplet

Temperature level	50 to 75 K	4.6K	1.9K	Notes
Static heat loads (W)	210	10	18	1,2,3
Dynamic heat loads (W)	0	16	169	4
Total heat loads (W)	210	26	187	

Notes
1. Static heat load to outer shield = 130 W conduction through supports + 80 W radiation and residual gas conduction.
2. Static heat load estimate to 4.5K is from support analysis only.
3. Static heat load to 1.9K = 12 W conduction through supports + 6 W radiation. Radiation estimate assumes ε=0.1.
4. Per latest N. Mokhov calculations.

2. Vacuum Vessel

A cross section through a typical support section of the cryostat is shown in figure 1. The vacuum vessel is the outermost component and serves to contain the insulating vacuum. In addition, it functions as the major structural element to which all other systems are ultimately attached to the accelerator tunnel floor. In order to ensure compatibility with existing and planned tunnel access points, the vacuum vessels for the inner triplet magnets are no larger than the main dipoles for the LHC. The vacuum vessel shown in figures 1 and 4 illustrates the present design. Two heavy wall sections serve as attachments for the internal supports, serve to join the thinner walled main vessel sections, and provide for connection of the vessel to the tunnel floor. We have elected to fabricate the vessel from several sections to allow for adjustment of the straightness during fabrication. At the present time the choice of material is uncertain. CERN has defined a toughness specification for the main dipole vacuum vessels that we are trying to satisfy. The prototype vacuum vessel will be fabricated using SA516 carbon steel. This is a material that is specially made for pressure vessels operating at below-normal temperatures, but which does so at reasonable cost.

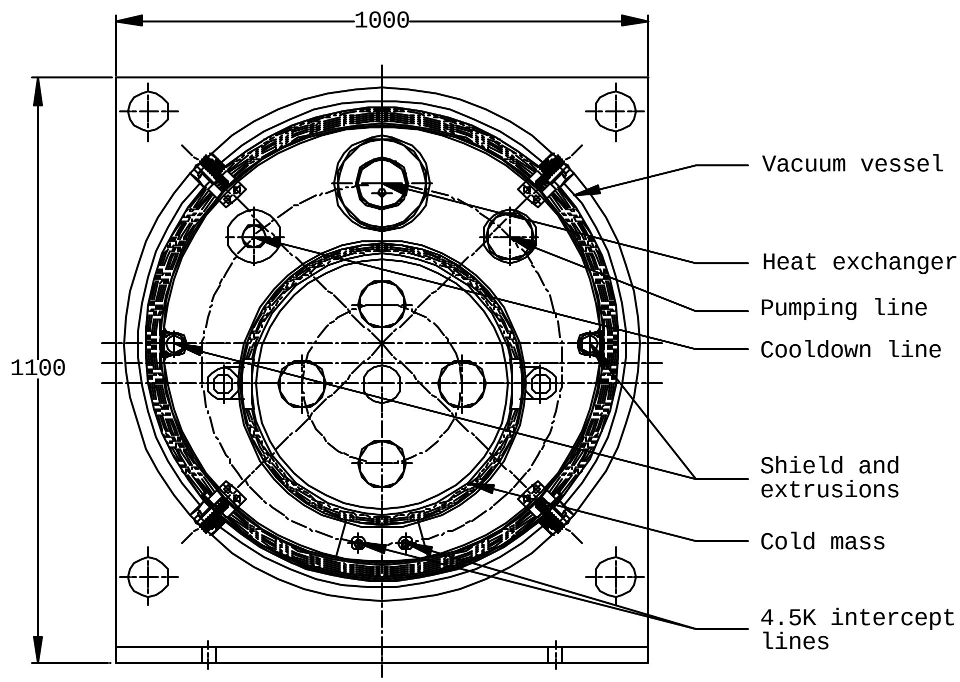

Figure 1. LHC IRQ cryostat cross section

3. Thermal shield and insulation

A single thermal radiation shield is the next layer in from the vacuum vessel. Its job is to intercept heat radiating from the 300K surface of the vacuum vessel. It also intercepts most of the heat conducted from the vacuum vessel through the suspension system before it reaches the cold mass. Finally, it also serves as a reservoir for liquid that may be lost in the unlikely event of a catastrophic failure of a pipe or interconnect bellows. This would preclude any direct impingement of liquid onto the vacuum vessel wall. The shield consists of an aluminum shell 3.18 mm thick cooled on both sides by helium gas flowing through aluminum extrusions. The operating temperature for the shield is between 50K to 70K with 60K being the nominal design temperature. The shields are segmented along their length to minimize the effect of distortions caused by axial or circumferential asymmetries in thermal gradients during cooldown. An aluminum to stainless steel transition joint is required at each end of each extrusion to facilitate connection to the interconnect bellows. At the present time we plan to use joints made by a diffusion bonding process.

The shield is covered by two multi-layer insulation (MLI) blankets fabricated from alternating layers of reflective mylar and a spacer material. The MLI blanket design is based on work done on SSC collider dipole cryostats. There is also a thin MLI blanket on the cold mass. It serves primarily as insulation against residual gas conduction at times of degraded insulating vacuum.

4. Internal piping

In addition to the shield extrusions, the cryostat also contains seven other cryogenic lines not including the cold mass itself. These are shown in figure 1. The pressurized helium II heat exchanger is the top-most pipe inside the vacuum vessel. The outer shell is the helium volume common with the main magnet helium volume. Next in from there is a copper corrugated tube containing sub-atmospheric helium. It serves as the main heat exchanger. Inside this is a small liquid supply line to transport liquid to the end of the heat exchanger and is used only during cooldown. To the left of the heat exchanger, the cooldown line passes from the feedbox through all of the cryostats in each triplet and connects to the outer shell of the heat exchanger at the IP-end of Q1. As its name implies, it is used only during initial operation. To the right, the pumping line also passes through all of the cryostats and connects to the copper corrugated tube of the heat exchanger at the IP-end of Q1. The 4.5K intercept lines at the bottom are used primarily to cool absorbers between Q1 and Q2a and between Q2b and Q3, but are also used to extract a small amount of heat from the support system. All of the cryostat piping is supported along the length of the cryostat by supports attached to the cold mass. This ensures accurate positioning with respect to the magnet position, but does not increase the heat load to 1.9K. Table 2 summarizes the fluid, size, and operating conditions of all the cryostat piping.

Table 2. Cryostat piping parameters

Description	Fluid	OD (mm)	ID (mm)	P oper (bar)	P max (bar)	T (approx)	Flow (g/s)
External hx outer shell	LHe	168.28	162.74	3.6	20.0	1.9 K	0.0
External hx inner tube	LHe	97.54	96.01	0.016	4.0	1.8 K	8.6
LHe supply	LHe	15.88	13.39	0.016	4.0	1.8 K	8.6
Cooldown line	LHe	44.45	41.96	3.6	20.0	1.9 K	30.0
Pumping line	GHe	88.90	85.60	0.016	4.0	1.8 K	8.6
4.5K intercept supply	LHe	19.05	15.75	1.3	20.0	4.5 K	1.1
4.5K intercept return	LHe	19.05	15.75	1.3	20.0	4.5 K	1.1
50-70K shield supply	GHe	76.20	69.85	19.5	22.0	60 K	5.0
50-70K shield return	GHe	76.20	69.85	19.0	22.0	65 K	5.0

5. Suspension system

The suspension system consists of support rings sometimes known as "spiders" located at two places along the length of Q1 and Q3 and three places along the length of a Q2. The support rings are attached to the vacuum vessel at four places around their circumference and to the cold mass at two places corresponding to the horizontal axis. This configuration minimizes the change in magnetic axis of the cold mass during cooldown. This design also results in a very stiff suspension that we believe will ensure the long-term stability of the magnet alignment. Due to thermal contraction, the cold mass is fixed with respect to the suspension at one of the supports and slides at the others. Invar tie rods connect the supports together as a means of distributing the axial forces generated during cooldown. The static heat loads to each of the thermal intercepts are summarized in table 1.

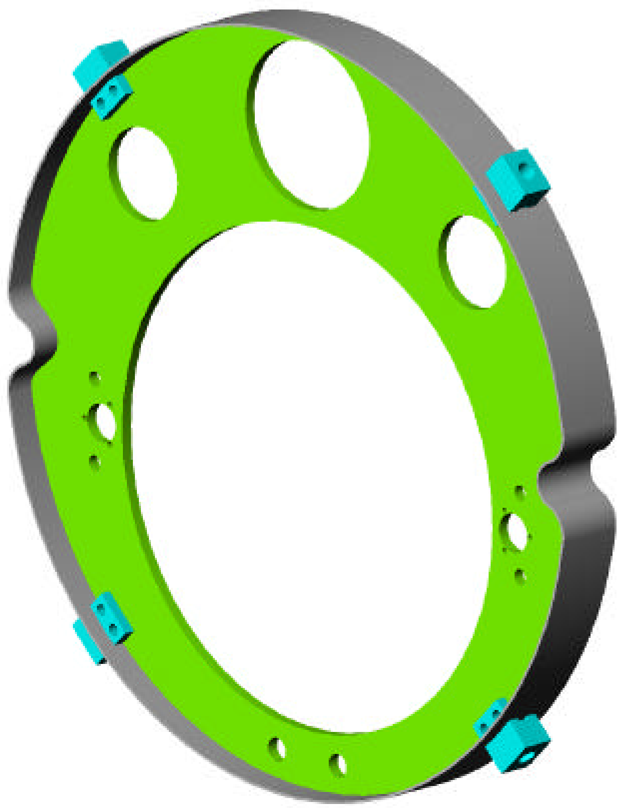

Figure 2. Suspension system support ring

6. Cold mass interface

The cold mass interface consists of the structural support for the cold mass. It connects the cold mass to the suspension system, supports the weight of the cold assembly, and allows for axial shrinkage during cooldown. It must be structurally strong, accurately positioned to accommodate alignment constraints, and compatible with approximately 18 mm of thermal contraction. The current conceptual design is shown in figure 3. The rod assembly is welded to the cold mass after assembly of the cold mass. The slide assembly is secured to it and to the support ring during the early stages of cryostat assembly. Sliding and non-sliding assemblies are identical with the exception of an additional collar in the case of the non-sliding end that prevents relative axial motion between the rod and support.

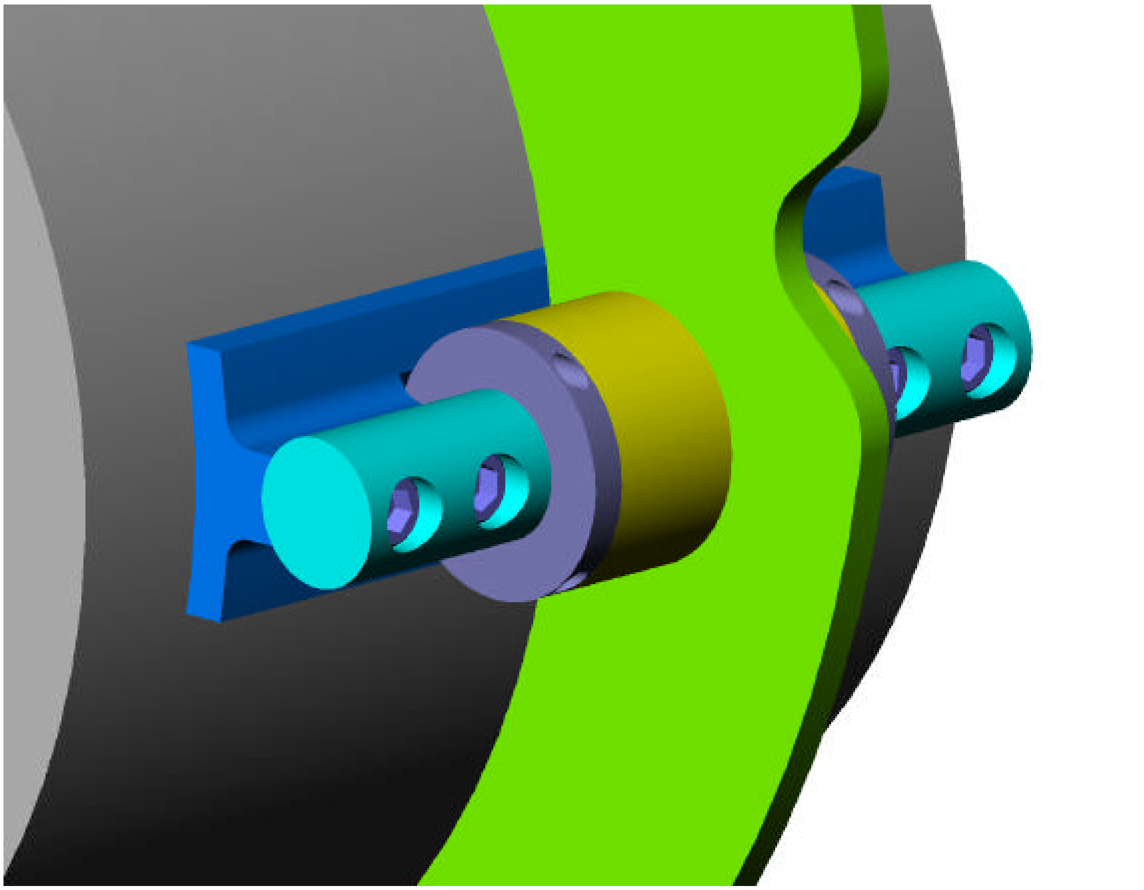

Figure 3. Typical cold mass to suspension system connection (non-sliding configuration)

7. Summary

At this writing the design of the first prototype cryostat is nearly complete. This assembly will house the first long Fermilab cold mass and will serve to verify the validity of the design. In addition it will be useful in the development of assembly procedures and assembly tooling, and will be used in the first magnetic test of a full length LHC IR triplet magnet. After completion of magnetic testing it will serve as a test article in shipping and handling studies. The present schedule has the completion of the prototype during calendar year 2000. Figure 4 shows an isometric view of this first magnet assembly.

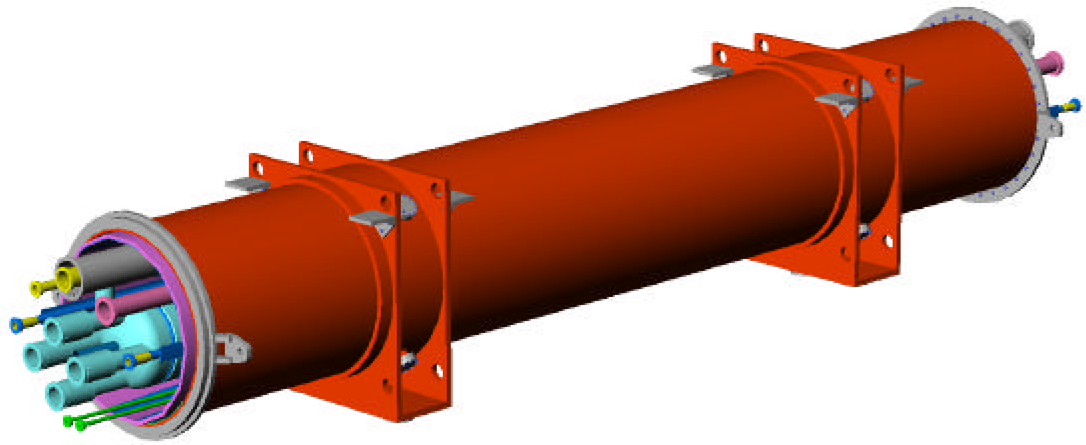

Figure 4. LHC IRQ cryostat prototype magnet assembly

References

1. Nicol, T.H., "Design Development for the 50mm Superconducting Super Collider Dipole Cryostat", Super Collider 3, Plenum Press, New York, 1991, pp. 1029-1036.
2. Boroski, W.N., T. Nicol and C. Schoo, "Design of the Multilayer Insulation System for the Superconducting Super Collider 50mm Dipole Cryostat", Super Collider 3, Plenum Press, New York, 1991, pp. 849-860.
3. Baritchi, D., T. Nicol and W. Boroski, "Conceptual Design for the Thermal Shield Bridges and Multilayer Insulation in the Interconnect Region for the SSC", Super Collider 3, Plenum Press, New York, 1991, pp. 217-224.
4. Huang, Y., J. Kerby, T. Nicol, and T. Peterson, "Cryogenic System and Cryostat Design for the LHC IR Quadrupole Magnets", Advances in Cryogenic Engineering, volume 43, Plenum Press, New York, 1998, pp. 403-410.
5. Huang, Y., Ch. Darve, T. Nicol, and T. Peterson, "A Proposed External He II Heat Exchanger for the LHC Interaction Region Inner Triplet Quadrupoles", presented at CEC/ICMC '99, Montreal, Quebec, July 12-16, 1999.
6. Darve, Ch., Y. Huang and T. Peterson, "He II Heat Transfer through a Corrugated Tube – Test Report", Fermilab Technical Division report TD-99-064.
7. Darve, Ch., T. Nicol and A. Knauf, "LHC IRQ Cryostat Support Mechanical Performance", Fermilab technical memo TM-2093.