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SSC Dipole Long Magnet Model Cryostat Design and Initial Production Experience*

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Abstract. - The SSC dipole magnet development program includes the design and construction of full length magnet models for heat leak and magnetic measurements and for the evaluation of the performance of strings of magnets. The design of the model magnet cryostat is presented and the production experiences for the initial long magnet model, a heat leak measurement device, are related.

CRYOSTAT DESIGN

The cryostat must facilitate proper magnetic functioning of the magnet assembly housed within it, provide low refrigeration loads, be highly reliable and be mass produceable at low cost. Conditions that control and affect the cryostat design include magnet assembly; transportation and installation; and transient, steady-state and upset operating conditions. Component design considerations include fluid flow, material performance, structural integrity, positional stability and thermal performance. Functional design tradeoffs are used to optimize the effectiveness of each component as it relates to the overall, long-term performance of the integrated magnet system.[1]

General Arrangement

The general cryostat arrangement is shown in Figures 1 and 2. The major elements are the cryogenic piping, cold mass assembly, thermal shields, suspension system, insulation, vacuum vessel and interconnections.

Cryogenic Piping

The cryostat assembly contains all piping that interconnects the magnet refrigeration system throughout the circumference of the ring. A system consisting of five pipes was selected for cryogenic and magnet safety reasons. The pipes are the cold mass helium containment assembly, the 4.35K helium fluid return and recooler supply pipe, the 4.35K helium gas return pipe, the 20K helium thermal shield cooling pipe and the 80K LN_2 thermal shield cooling pipe.

Cold Mass Assembly

The cold mass assembly consists of the beam tube, collared coils, stacked iron yoke laminations and outer helium containment shell, joined together to provide a leak-tight and structurally rigid welded assembly. The helium containment shell is the principal structural element of the cold mass assembly and provides the required flexural rigidity between suspension points.

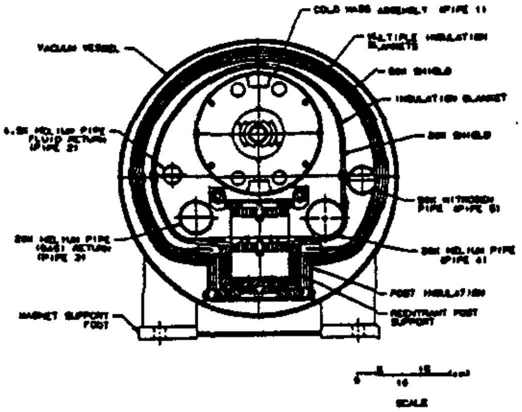

Figure 1. Cross section of the dipole magnet assembly at a support location.

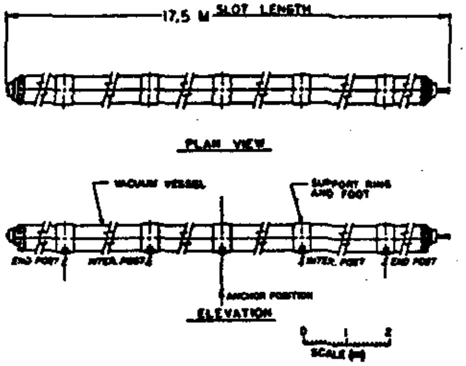

Figure 2. External details of the dipole magnet assembly. The cold mass is supported at five points relative to the vacuum vessel which is the principal flexural element of the assembly.

Supercritical helium at 4.5K and 4 atm is passed through the cold mass assembly to remove heat and to maintain the coil temperature at or below 4.5K. The static heat load from conduction and radiation is estimated to be 0.02 W/m and that due to synchrotron radiation is 0.12 W/m. The synchrotron radiation load is seen by the helium between the beam tube and the inner coil. The annular aperture for this helium flow is small; however, the load is transferred radially by the 1 g/s flow that passes through the region to the main coils and subsequently to the main helium flow. Approximately 100 g/s total flow is required to limit the temperature increase to less than 0.2K between recoolers spaced every 200 m. This larger flow passes through the four holes in the yoke laminations.

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Thermal Shields

Thermal shields, maintained independently at 20K and 80K, surround the cold mass assembly. They absorb the radiant heat flux and provide heat sink stations for the suspension system intercepts. The shields are constructed of aluminum. The shields are supported by, and are thermally anchored to, the cold mass assembly supports. The liquid and gaseous helium return pipes are supported from the cold mass assembly by hangers.

Suspension System

The cold mass assembly and thermal shields with their distributed static and dynamic loads are supported relative to the vacuum vessel by the suspension system.[3] The system functions under conditions that include assembly, transportation and installation, magnet cooldown and warmup, and magnet steady-state and transient conditions. The cold mass and shields are supported at five points along their lengths. The number and location of the support points were determined by the 0.5mm cold mass assembly beam deflection limit and by the need to minimize the number of support points for reasons of fabrication and heat leak.

After consideration of tension member, compression member, elliptical arch and post type suspension systems; a reentrant post support was selected. The support's insulating sections are fiber reinforced plastic (FRP) tubing having metallic connections and heat intercepts. The junctions between the FRP tubing and metallic connections which must be able to effectively transmit tension, compression, bending and torsional loads, are made by shrink fitting. Control of internal axial and radial thermal radiation is achieved by the use of multilayer insulation.

Proper design of the thermal connections between the 20K and 80K intercepts of the supports and the thermal shields is essential to control the heat leak. A 5K temperature rise at 80K and a 1K temperature rise at 20K are budgeted. The details of the thermal connections are shown in Figure 3.

The support post is fixed at its 300K end and incorporates a slide at the cold end to accommodate the axial differential contraction between the mid-span anchored cold mass assembly and the vacuum vessel. Analysis of transient conditions indicates that significant transient bowing of the cold mass assembly is not expected. The 20K and 80K shields will undergo transient bowing, so the shield-post interfaces are designed to allow for relative motion.

In order to permit the support to withstand the lateral handling loads without incurring a severe operational heat leak penalty, the design incorporates an integral, coaxial, removable shipping restraint. The restraint is installed at the time of magnet assembly and is removed at the site. The details are shown in Figure 4.

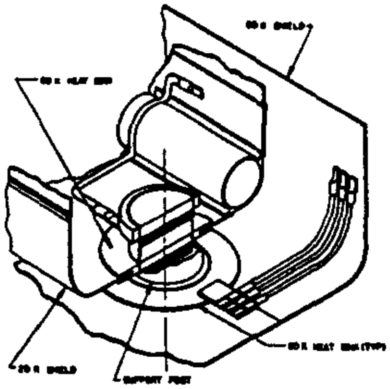

Figure 3. Heat intercept linkage between support post and thermal shields. Large area cables with welded connections provide a low ΔT across the connection.

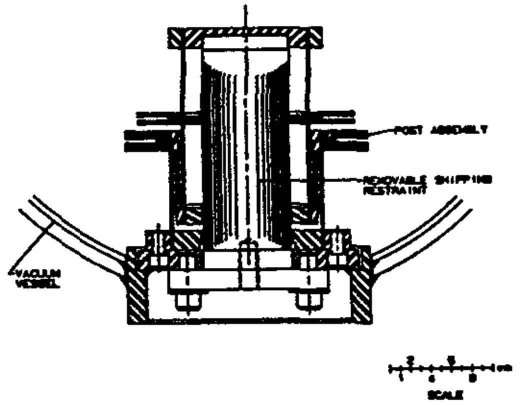

Figure 4. Support post with integral shipping and handling restraint installed. The restraint resists lateral loads.

The cryostat incorporates a similarly removable axial shipping restraint. This restraint provides a strong axial connection between the cold mass assembly and the vacuum vessel shell. It is installed during magnet assembly and is removed before cryogenic operation.

Insulation

Insulation is installed on the 80K and 20K surfaces. The insulation system consists of flat, reflective radiation shields of aluminized Mylar film with randomly oriented fiberglass mat spacers and is prefabricated in blankets of 13 Mylar and 12 fiberglass layers. Four blankets are installed on the 80K surface and one is installed on the 20K surface.

Vacuum Vessel

The vacuum vessel provides the insulating vacuum space as well as the connection for the support system of the magnet to the tunnel floor. Since the vessel has no magnetic requirements, candidate materials were carbon steel, stainless steel, 9% nickel steel and aluminum. Carbon steel was selected for reasons of cost.

Interconnections

Mechanical and electrical interconnections are required at the magnet ends. It is essential that the connections be straightforward to assemble and disassemble, compact, reliable and low cost. The mechanical connections are beam tube vacuum, cold mass assembly helium containment, helium lines, shield lines, insulating vacuum, thermal radiation shield bridges and insulation. The electrical connections are magnet current bus, quench bypass bus, quench protection diodes, instrumentation leads, quench detection voltage taps, correction coil leads, etc.

The interconnection design stresses the assembly and disassembly operations in the SSC tunnel. The resulting geometry permits the use of automated welding and cutting equipment that is essential for installation efficiency and interconnection reliability.

Heat Leak

The estimated heat leak totals for the installed cryostat are 27 watts to 80K, 3.3 watts to 20K and 0.32 watts to 4.35K. Other contributions to the total heat leak at 4.35K include 0.1 watt/dipole due to conductor splice ohmic heating and 2.34 watt/dipole due to synchrotron radiation.

LONG MAGNET MODEL PRODUCTION

The long (16.6m magnetic length) magnet model program is intended to evaluate the functional nature and produceability of the conceptual design, to evaluate production methods and procedures, to add to the production cost and time data base and to produce test articles for the continued experimental evaluations of the magnet design. The present program includes a heat leak model and 4 to 6 magnetic models for magnetic measurements and string tests.

Internal Assembly

As the initial operation of magnet assembly, the cold mass assembly is located on an assembly station. Suspension system slide cradles with the associated support subassembly and alignment fiducials are installed on the cold mass assembly as shown by Figure 5.

At the next assembly station, the axial anchor subassembly and helium return lines are attached as shown in Figure 6. The support heat intercepts are attached and the 20K and 80K shields are installed in sections as shown in Figure 7. The insulation blankets are installed followed by heat conduction straps. The complete internal assembly is ready for insertion into the vacuum vessel.

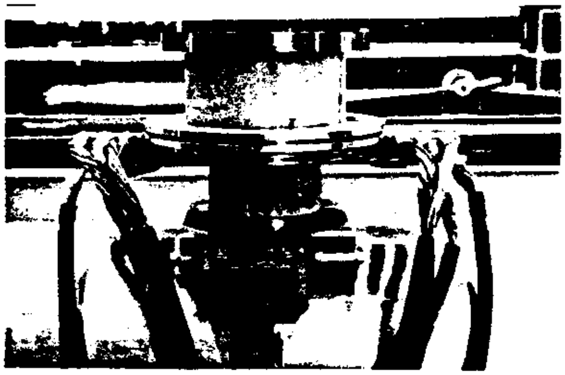

Figure 5. Installation of support assembly on cold mass assembly. Cables provide the thermal linkage between the shields and the support post heat intercept stations.

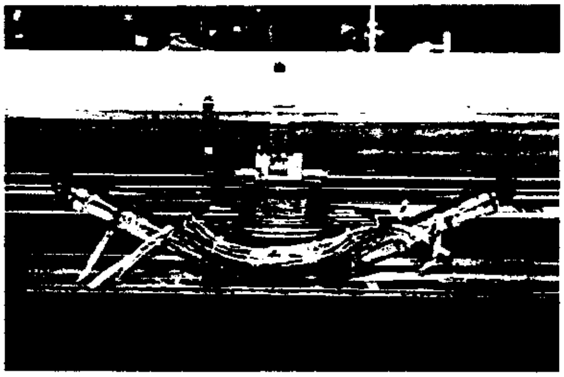

Figure 6. Midspan support point with support post and anchor assemblies. Helium return piping is in the background.

Vacuum Vessel Assembly

The vacuum vessel is fabricated from steel pipe with precision mounting feet attached as shown in Figure 8. The machined surfaces of the feet are perpendicular and parallel to surfaces of the supports. This arrangement provides the alignment of the center of the cold mass beam tube with respect to the vacuum vessel shell. End rings to hold shipping restraints and reinforcing segments at the support points are attached. The assembly is then transferred to the final assembly station where the alignment and cold mass subassembly insertion track is installed.

Insertion

The internal assembly and the vacuum vessel assembly are aligned and a slide and pulley system is used to draw the cold mass into the vacuum vessel as shown in Figure 9.

Figure 7. Installation of thermal shields and insulation. The 20K shield is installed and insulated with a single MLI blanket. The lower portion of the 80K shield is being installed. The cold mass assembly is for heat leak measurements.

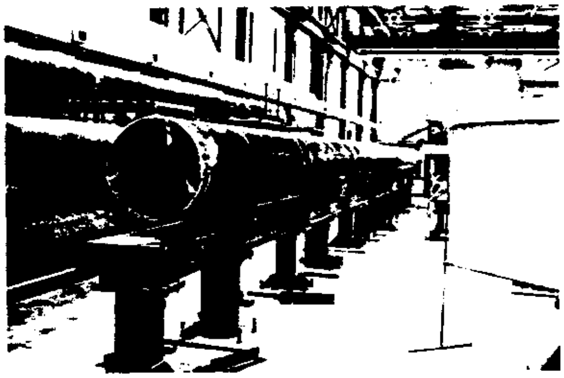

Figure 8. Completed vacuum vessel assembly. The vacuum vessel with aligned support feet has been welded, leak checked and is ready for the insertion of the internal assembly.

Precision fixture points, together with the precise location of the support feet, locate the internal assembly relative to the vacuum vessel. A system of optical fiducials is checked to assure the correct alignment. The assembly is clamped and welded together. All external vacuum vessel alignment fiducials are set. The magnet is then inspected and shipping restraints installed.

The initial long magnet model, an assembly intended for the measurement of cryostat heat leak,[3] is shown in Figure 10 and has been assembled by the abovementioned procedures. The model is identical to a magnet model with the exception of a simulated collared coil assembly and the addition of instrumentation for the measurement of temperature, force and acceleration.

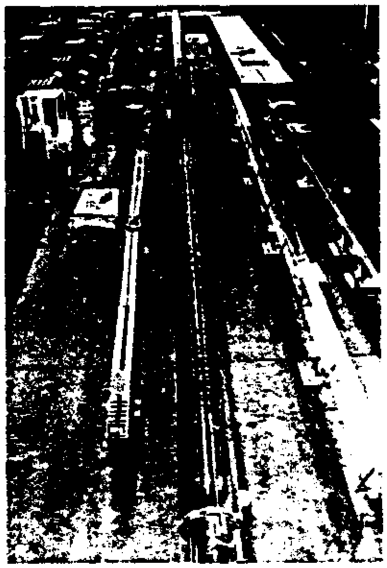

Figure 9. Internal assembly (foreground) and vacuum vessel assembly (background) at the beginning of insertion.

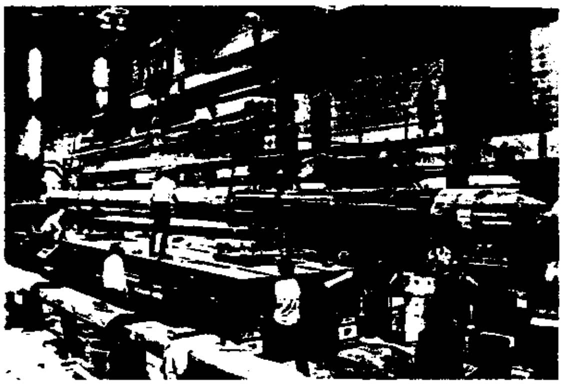

Figure 10. The completed center section of the dipole heat model being loaded for shipment to the test facility.

The assembly of the heat leak model progressed smoothly using the as designed components, tooling and procedures. The assembly experience resulted in an improved understanding of the production process. The major conclusions resulting from the initial production experience are as follow:

- The design can be improved, in a straightforward manner, with regard to function and produceabilty.
- The design lends itself to mass production:
  - Components from a variety of sources
  - Subsystem preassembly and inspection
  - Subsystem transfer between work stations
  - Assembly, alignment and inspection with specialized tooling
- High quality can be achieved with as procured components, production assembly procedures and tooling and production travelers.
- The "slide in" assembly method works well.
- Cryostats are recyclable.

Acknowledgements

The progress achieved to date is the result of the diligence and intensity of the total personnel participating in the development, design and production efforts of the long magnet model program. Of particular importance were the contributions of the Fermilab Technical Support design, materials procurement and superconducting magnet production groups.

The progress was enhanced by the patience, understanding and support Fermilab and SSC Central Design Group management teams.

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