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SSC DETECTOR SOLENOID

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Abstract

A detector utilizing a superconducting solenoid is being discussed for the Superconducting Super Collider (SSC). A useful field volume of 8 m diameter x 16 m length at 1.5-2 T (~1 GJ at 2T) is required. It has been decided that all of the particle physics calorimetry will be inside the bore of the solenoid and that there is no need for the coil and cryostat to be "thin" in radiation lengths. An iron yoke will reduce the excitation required and will provide muon identification and a redundant momentum measurement of the muons. We have developed a conceptual design to meet these requirements. The magnet will use a copper-stabilized Nb-Ti conductor sized for a cryostable pool boiling heat flux ~0.025 W/cm^2. A thermosiphon from a storage vessel above the cryostat will be used to prevent bubble stagnation in the liquid helium bath. The operating current, current density, coil subdivision and dump resistor have been chosen to guarantee that the coil will be undamaged should a quench occur. The axial electromagnetic force will be reacted by metallic support links; the stainless steel coil case will support the radial force. The 5000 metric tons of calorimetry will be supported from the iron yoke through a trussed cylindrical shell structure separate from the cryostat. The coil and case, radiation shield and stainless vacuum vessel would be fabricated and cryogenically tested as two 8-m sections. These would be lowered into the underground experimental hall and installed into the iron flux return yoke to provide the required 16-m length.

Introduction

The SSC will have six interaction regions which, depending on the laboratory location, could be as deep as 120 meters. A large superconducting solenoid is being considered as a part of a detector facility for one of the interaction halls. Figure 1 is the SSC detector. The calorimetry and central tracking chambers, which will be located inside the solenoid, require a field volume 8 m in diameter by 16 m long. The field in the bore will be 2 T; the field in the iron flux return yoke will be ~1.5 T. Locating the calorimetry internal to the solenoid eliminates the need to have a "thin" coil and cryostat in terms of radiation lengths; we may therefore employ a cryostable pool boiling coil.

The required field volume will be provided by two solenoids, each 9.5 m in diameter and 8 m in length, connected in series electrically with a common power supply. Each 8-m unit will contain four identical 2-m long liquid helium/coil modules. The modules are mechanically connected and share a common vacuum vessel. Helium is supplied by thermosiphons to an 8-m assembly from a storage vessel located on top of the iron, with each of the four modules having its own helium supply and return piping.

The calorimetry and flux return iron will be split at the longitudinal center and the halves can be moved independently; therefore, we will use two 8-m support structures to support the 5000 metric tons of calorimetry and central tracking chamber. There are notches in the iron for hangers for the supports and for instrumentation cables. The support structures are immediately inside the solenoids but are completely independent of the cryostat and vacuum shell. The ends of each structure will be supported from the iron. The support structures, consisting of concentric stainless steel cylinders with a trussed web, having a radial thickness of 25 cm are expected to have a deflection of ~3 cm when loaded with the tracking chambers and calorimetry. The calorimeter will rest on rails and can be inserted from either end.

Quench Protection

Four 2-m modules are connected in series with the superconducting bus between the modules being in liquid helium filled interconnecting pipes. It is essential that the coil survive quenches without damage and to this end a low current density and an external fast dump resistor were chosen. This resistor was chosen to be 0.1 Ω to limit the discharge voltage to 500 V across the terminals. The eddy current heating in both the coil and helium vessel during a fast dump is expected to be ~1300 W for an 8-m assembly. This might be sufficient to quench the coil and so the discharge will be through the fast dump resistor only if a normal zone is detected. The highest temperature reached in the coil due to a quench will be 100 K. A discharge for any other reason will be through a 0.02 Ω slow dump resistor with the power supply reversed to maintain a constant discharge voltage. The routine charge or discharge time, with 100 V across the terminals, would be 100 min and the eddy current heat load would be 26 W per 8-m assembly. Figure 2 is the electrical schematic.

Conductor and Coil Specifications, Winding and Assembly Scheme

The superconductor will be copper stabilized Nb-Ti wire which has a short sample current of 10 kA at 3 T and 4.5 K. This wire will be soldered into additional copper stabilizer. The final conductor will be 26 x 18 mm and will have a copper to superconductor area ratio of 146 to 1. The operating current will be 5000 A resulting in a current density of 1.56 x 10^5 A/cm^2 in the superconductor and 1068 A/cm^2 overall. The surface heat flux, with 25% wetting and a RRR of 100, is 0.025 W/cm^2.

There are seven conductor layers having a total of 651 turns in each 2-m coil module. Since the forces are radially outward, the coil will be wound starting with the outside layer, using the outer shell and flat annular heads as a coil form. Insulation will consist of G-10 buttons between turns, slotted G-10 sheets between layers and slotted G-10 and Kapton adjacent to the helium vessel. The packing factor will be 74% with 13% being helium space.

Each 2-m coil module will be designed in accordance with Section VIII of the ASME Boiler and Pressure Vessel Code for an internal pressure differential of 0.8 MPa (116 psia) and will be adequately relieved for a loss of insulating vacuum or a quench of the coil. The axial electromagnetic force will be transmitted through the shells to the supports, and the radial force will be resisted by both the conductor and outer shell.

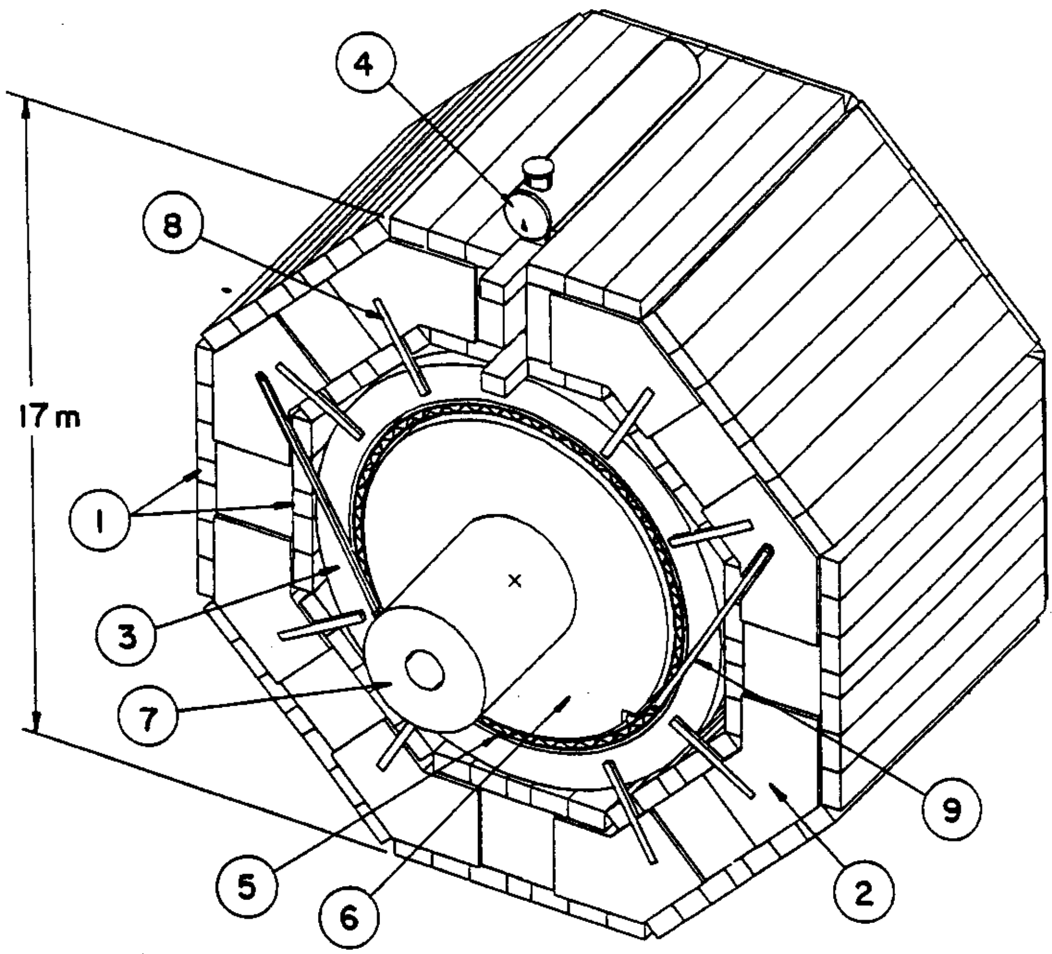

Figure 1. SSC Detector: 1, muon tracking; 2, flux return iron; 3, coil assembly; 4, 5000 L helium dewar; 5, calorimeter support structure; 6, calorimeter; 7, central tracking chambers; 8, coil supports; 9, support structure hangers.

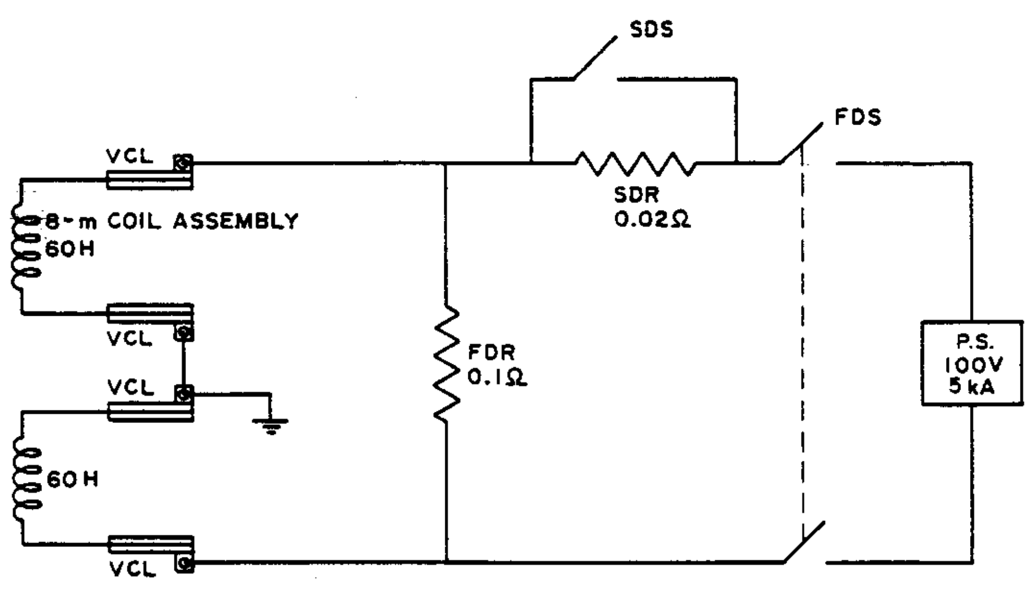

Figure 2. Electrical Schematic: FDR, fast dump resistor; FDS, fast dump switch (NC, open to initiate a fast dump); SDR, slow dump resistor; SDS, slow dump switch (NC, open to initiate a slow dump); VCL, vapor cooled leads; P.S., power supply.

Winding will be done with the coil axis vertical. The winding fixture will provide the radial preload and a series of compression bars at one end of each coil can be individually adjusted to provide a circumferentially uniform axial preload. These axial compression bars are adjustable only during assembly. After winding, the inner shell of the helium vessel will be welded to the coil form. After the four 2-m modules are bolted together and interconnections are made, the outer vacuum jacket and integral nitrogen shield are lowered over the 8-m cold mass. The coil supports will be attached, the 8-m assembly rotated to a horizontal position and the inner vacuum shell and nitrogen shield slid in. Figure 3 is a cross section of the coil, cryostat and vacuum vessel.

Supports

The axial body force on the 8-m cold mass is dependent on the geometry of the end wall and studied thus far, calculations indicate that this force, which is towards the symmetry plane, cannot be eliminated but is a minimum of 7.3 MN (1.64×10^6 lb) when there is no re-entrant iron. The supports are designed for an axial or radial misalignment, or the equivalent due to iron non-homogeneity, of 2.5 cm. The force constants are 8.8 MN/m (5×10^4 lb/in) for radial and 149 MN/m (8.5×10^5 lb/in) for axial misalignment. The supports to the cold mass have been chosen to be metallic and to have both a forced flow liquid nitrogen and a thermosiphon liquid helium intercept.

The supports for the cold mass can be either combined function or separated function with different elements to react the axial and radial forces. We initially favored a combined function support because by properly adjusting the angle of the support with the axial direction, the force due to thermal contraction could be eliminated, but, since these supports are at an angle to the axial direction, they generate a large radial buckling force while reacting the axial body and decentering forces. This disadvantage does not occur with a separated function support, and therefore we now favor this style. An additional advantage is that both elements of the separated function supports can be much longer and therefore greatly reduce the heat load.

The warm ends of all supports will be attached near the ends of the vacuum vessels to avoid transmitting the loads and weight through the shells. Both the axial and radial supports are located on the outer diameter of the helium vessel. The axial supports will have their cold ends connected near the inside bolted flange on the outboard 2-m module; whereas the cold ends of the radial supports will be attached near either end of the 8-m assembly.

Refrigeration and Cryogenics

The thermal shield cooling tubes and the support intercepts are fed with forced flow subcooled liquid nitrogen at an average temperature of 83 K. The inner and outer shields and each set of supports will have independent heat intercept circuits. The expected heat

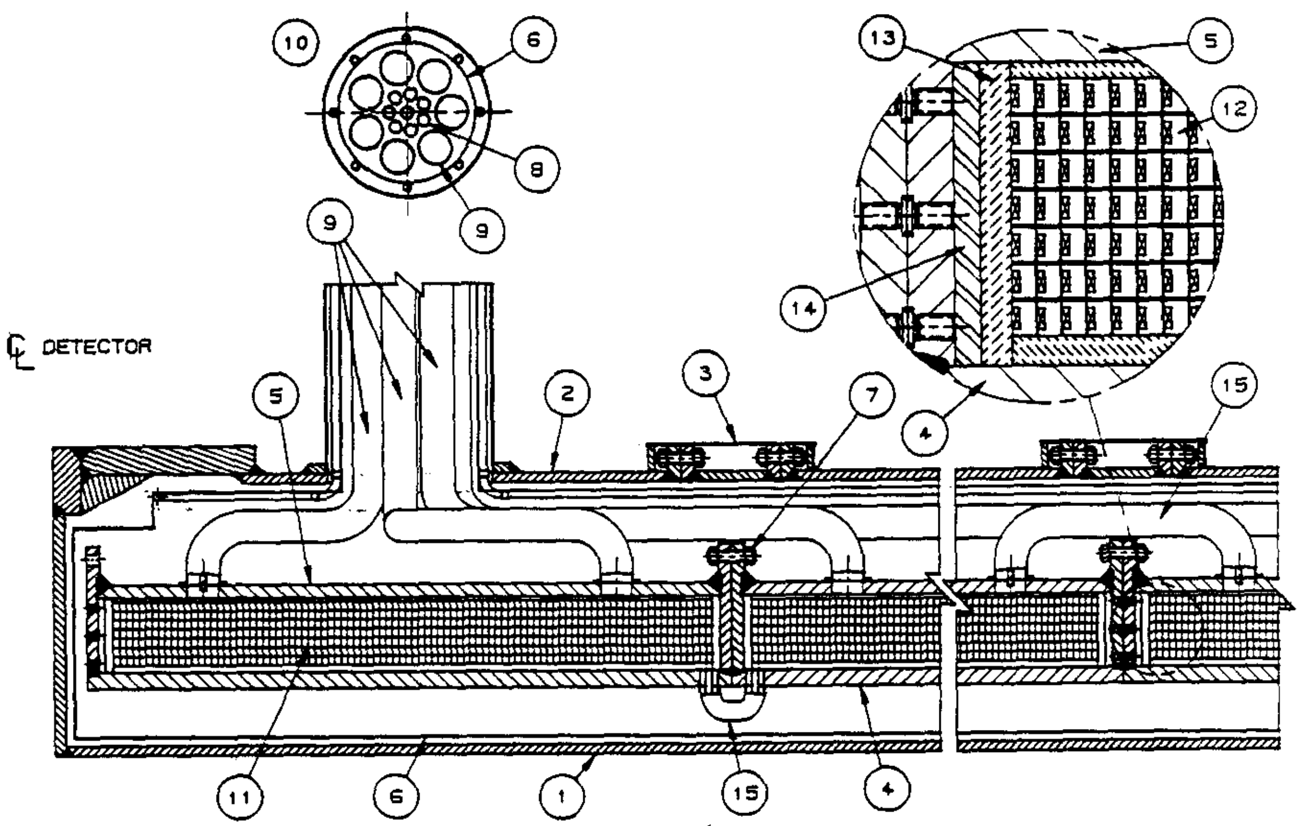

Figure 3. Axial cross section of coil, helium and vacuum vessels: 1, inner and 2, outer, vacuum shells; 3, assembly joint (if required); 4, inner and 5, outer helium vessel shell; 6, radiation shield; 7, coil module attachment; 8, liquid helium supply pipe; 9, helium return/vent pipe; 10, chimney to storage dewar; 11, coil winding; 12, conductor; 13, G-10 insulation; 14, axial preload bar; 15, electrical interconnect pipe.

load to the nitrogen system could be as much as 5 kW for the complete 16-m magnet.

A refrigerator at the surface supplies helium to two 5000-L storage dewars on top of the iron. A cold compressor will be used if needed to maintain the storage dewar at about 30 kPa and 4.5 K. Each dewar has supply and return lines to the four modules in one 8-m assembly. These lines are sized such that the return helium is less than 1% gas by weight and the supply lines are carefully insulated to ensure the maximum liquid fraction entering the bottom of the magnet. The steady state thermosiphon flow will be about 25 g/s to each module. Separate helium circuits, which will have a return flow of less than 7% by weight, will intercept the supports. The heat load from the separated function support system might be as high as 100 W depending upon the design. The total steady state heat load for the magnet system could be 410 W (230 W plus 36 L/h for lead flows). The 4.5 K refrigerator will have a capacity of 1600 to 1800 W.

In order to facilitate cooldown, a separate refrigerator would probably be employed. It would consist of a GHe/LN_2 heat exchanger and a turbo-expander which could provide 400 g/s of 55 K helium gas. This would be adequate to cool down the total cold mass (both 8-m sections) of 1000 tons in approximately two and a half weeks.

Conclusions

Preliminary work has indicated that the size and field requirements of this magnet are a reasonable extrapolation of existing superconducting magnet technology. The magnet design must be very conservative to guarantee high reliability, since the time to fix even a small problem could have a major impact on the SSC physics program. More detailed study must be done to optimize parameters both in terms of reliability and cost-effectiveness. Fabrication techniques must be examined more closely and the necessity of on-site construction must be rigorously evaluated. However, at this point, we see nothing that would preclude the construction of such a magnet.

Acknowledgements

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