SUPERCONDUCTING
SUPER
COLLIDER

MATERIAL SPECIFICATION

NO. SSC-MAG-E-210

TITLE: 6.6 TESLA DIPOLE MAGNET EQUIPMENT SPECIFICATION

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• PREPARED BY ______________________________
V. N. Karpenko - SSC Division Head, Magnet Division

• APPROVED BY ______________________________
M. Tigner, SSC Central Design Group Director

REVISION RECORD

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1. Scope:

This specification establishes the SSC Project Requirements for the 6.6 Tesla Magnet System. The magnet performance fabrication and test requirements shall be used in conjunction with the SSC-CDG provided magnet design drawings and specifications to develop a contractor production baseline set of magnet drawings and specifications.

1.1 Applicability - The requirements of this specification apply to any SSC Project participant providing material or services under CDG Contract/Purchase Order control.

1.2 Contractor Changes - Where contractor production design activities identify the need for change to CDG design drawing or specification requirements such changes shall meet the design criteria of SSC Magnet Final Design Parameters (Ref. 2.3). The applicable requirements of this specification and shall be processed for CDG approval (Class I Changes) through the Subcontractor Change Proposal procedure of SSC-MAG-D-103 (SSC Configuration Management Plan).

2. Applicable Documents

2.1	SSC-MAG-D	- SSC Magnet System Requirements
2.2	SSC-6.6 Tesla Magnet	- Design Drawing and Specification Package No. . (Appendix A)
2.3	SSC-MAG-D	- SSC Magnet Final Design Report
2.4	SSC-MAG-D-103	- SSC Configuration Management Plan
2.5	SSC-MAG-D	- SSC Design Review
2.6	SSC Magnet Parameter List	- Appendix C
2.7	SSC Project Specifications	- Appendix B
2.8	SSC MAG Q 600	- SSC Quality Assurance Plan
2.9	SSC-MAG-D	- Standard SSC Drawing System

3. SSC Project Requirements

3.1 Magnet System Description - The SSC magnet system consists of the main ring magnets -- some 7680 dipoles, nearly 1800 quadrupoles, and an almost equal number of "spool pieces" which contain correction windings and other instrumentation.

A perspective drawing of the magnet components of the SSC dipole is shown in Fig. 1-1. At its center is the beam tube, whose high-conductivity liner minimizes beam image current losses. Two correction coils are wound on the outside of the tube to compensate for systematic distortion of the magnetic field from iron saturation and persistent currents in the main windings. Around it is placed a two-layer main coil of superconducting cable, with interspersed copper wedges to adjust the current density for a uniform dipole field inside. This coil, subjected to magnetic forces of about $7x10^5$ N m^{-1} at full current (6500 A), is held in place by laminated stainless steel or aluminum collars. The collars are keyed together after compression. Because the coil and collars shrink different amounts during cooldown, the room temperature preload is about 2.5 times greater than the remnant preload at 4 K needed to prevent coil movement caused by the magnetic forces. A yoke of laminated low-carbon steel, surrounded by a stainless steel skin which also serves as a pressure vessel, completes the inner assembly. Passages through the iron are provided for the liquid helium coolant, as well as for buses carrying current to adjacent magnets.

This yoked assembly is supported inside a cryostat. The cryostat is supported by pedestals consisting of concentric fiberglass-epoxy tubes, chosen for their low thermal conductivity and high strength. Intermediate thermal shields concentric with the assembly insulating blankets are at nearly 20 K and 80 K.

3.1.1 Magnet Design Drawing/Specification - Magnet design drawings are listed in Appendix A by optional fabrication and assembly sequence, with drawing nomenclature and numbers included. Magnet design, project controls, material, process controls, quality and data specifications are listed in Appendix B.

3.1.2 Magnet Parameters - Measurement parameters for the following magnet and magnet components are listed in Appendix C.

- General
- Bore Tube
- Coils
- Conductor
- Collars
- Yoke
- Cryostat

3.1.3 SSC Magnet Production Design Requirements:

a. Physical Characteristics - The design size and physical characteristics of the magnet and its components are defined by the SSC-CDG design data listed in Appendices A, B and C. The production design task includes the conversion of those requirements into a product drawing and specification set. That will optimize magnet fabrication, assembly and test operations for cost effectiveness, reliability and productivity.

b. Tolerances - Detailed production design activities shall be supported by sufficient tolerance models/studies to assure the maintenance of design interfaces and operating parameters.

c. Drawing Standards/Format - Production drawings shall be prepared in accordance with the requirements of SSC-MAG-D (Ref. 2.9).

d. Parts, Materials and Processes - Parts, materials and processes shall be in accordance with the following referenced requirements and/or with specifications or standards selected by the subcontractor and approved by CDG. All standard parts shall be adequately defined by specification or drawing and shall be defined in specifications which adequately control their composition, procurement and application. All processes shall be defined in specifications or standards which adequately control their application, materials, equipment and certification of operators.

e. Selection of Parts - Maximum use shall be made of standard or commercial parts.

f. Metals - Metals shall be of the corrosion-resistant type of suitably treated to resist corrosion caused by conditions encountered in handling, transportation and facility environments. The use of metals susceptible to stress-corrosion shall be avoided.

g. Dissimilar Metals - Dissimilar metals shall not be used in intimate contact with each other unless suitably protected against electrolytic corrosion. Dissimilar metals shall be as defined in MIL-STD-889 except aluminum shall be classified as Group II.

h. Nonmagnetic Materials - Nonmagnetic materials shall be used for all parts in the magnet except where magnetic materials are essential for the function of a part/component, are required for structural purposes, or as necessary to provide magnetic shielding.

i. Protective Finishes - Surfaces shall be adequately finished to prevent detrimental effects from exposure to handling, transportation and facility environments. Protective finishes/coatings shall not chip, crack or scale.

j. Welding - Welding shall conform to the requirement of the subcontractor's specifications, standards, drawings and the ASME code. ASME qualified welders are required.

k. Soldering and Brazing - Soldering of electrical connections and brazing shall conform to the subcontractor's specifications, standards and drawings. Superconductor joints/splices shall be qualified by separate test per Section 4.2.2.2.

l. Coating, Potting and Molding - Coating, potting and molding shall conform to the subcontractor's specifications, standards, and drawings.

m. Identification and Marking - Equipment furnished under this specification shall have a suitable name plate attached for identification. The identification and marking shall be in accordance with the best commercial practices. The following data shall be included on the nameplate.

1) Part name
2) Manufacturer's name
3) Specification number
4) Manufacturer's serial number
5) Date of manufacture
6) Contract number

The subcontractor shall also furnish and securely attach to the magnet a type 300 series stainless steel nameplate according to paragraph UG-119 of the ASME Code including the data required by paragraph UG-116 (if not included above).

n. Workmanship - The quality of workmanship shall be consistent with the ultimate use of the item involved. Workmanship shall be of acceptable quality such that the performance and reliability required of the item is not degraded. Workmanship and acceptability of manufacturing processes shall be in accordance with requirements in applicable drawings, specifications standards, and as further delineated by quality assurance requirements, the ASME Code, process specifications and workmanship standards.

o. Interchangeability - All demountable and replaceable parts having the same part number shall be functionally and physically interchangeable.

p. Safety - The magnet system shall be fabricated to comply with the National Electric Code (NFPA-70). Specific personnel hazards and/or special instructional markings of hardware shall be identified by the superconductor and noted on applicable production drawings or procedures. A failure modes and effects analysis identifying all potential safety hazards is required.

3.2 Magnet Configuration

3.2.1 General - A single Dipole Magnet Subassembly consists of a two-layer, "cos θ" dipole magnet with a magnetic length of 16.6 m. To accommodate interactions, 0.8 m is provided between "magnetic" dipole ends; giving a slot length, (over all length), of 17.34 m. The dipole magnet can be considered to be composed of six elements; the Beam

Tube, the Dipole Coils, the Coil Collars, the Yoke and Support Shell, the Cryostat and the Magnet Strands. Each of these is described below. The tube, Coils, Collars, Yoke and Support Shell comprise the "Cold Mass."

a. Cold Mass - The Cold Mass is cooled to 4.35 K by a flow of supercritical (single phase) helium through holes in the yoke structure and through the annular space between the trim coils and inner layers of the main dipole coil. The helium permeates the superconducting layers of the dipole coil and electrical insulation. The Cold Mass is supported by reentrant support posts made of low thermal conductivity materials and designed for minimum heat leak.

b. Thermal Insulation - Cold Mass thermal insulation is provided by radiation shields, the outermost being cooled by a liquid nitrogen (LN) circuit, and an intermediate shield cooled by a 20 K He (GHe) line and by multiple layers of superinsulation.. The insulating vacuum is contained by a cylindrical steel vessel and is maintained by cryopumping within the cryostat.

3.2.2 Beam Tube - The Beam Tube is a circular cross section tube that separates the LHe coolant from the beam vacuum chamber, furnishes a supporting structure for the sextupole/decapole/octupole correction coils and provides the aperture for the beam during its injection, acceleration and storage.

a. Physical Configuration - The beam tube has a minimum inside diameter of 30 mm. Since the inside diameter of the inner dipole coil is 40 mm, there is a radial clearance of 5 mm to accommodate the 1.4 mm minimum coolant (LHe) passage, the correction coils windings and the beam tube wall thickness. The tube shall be keyed to the dipole coil collar to maintain the orientation of the correction windings relative to the dipole magnetic axis. The correction coils are longitudinally wound superconducting coils spaced around the periphery of the outside of the beam tube. They are insulated with layers of Kevlar and Kapton. Spacing between the bore tube assembly and the inner main coil winding is maintained by spacers, (bumpers) which also serve to provide mechanical support to the beam tube when it is subjected to eddy current forces.

b. Electrical and Magnetic Configuration - The beam tube material is stainless steel having an initial permeability of 1.0025 or less with a copper coating on the bore. This is necessary to provide a relatively low resistivity surface facing the beam to carry the high frequency, (1 KHz to several GHz), beam induced image current. The copper surface facing the beam must be a precisely controlled coating of 0.05 mm ± 10%, continuous over the length of the bore tube. Additional requirements shall be developed to control the material, electrical and physical properties of the finished coating.

3.2.3 Dipole Coils - The dipole coils consist of windings in 2 layers, wound longitudinally around the vertical plane of the Magnet Assembly. Each layer consists of an upper and lower winding. The four windings are connected in series.

a. Physical Configuration - The coils are wound with flattened (partially keystoned) "Rutherford" cables. Because of the difference in magnetic field experienced by the inner and outer coils, each coils is wound with superconductor cable designed for its particular environment.

The cable is insulated with layers of Kapton tape and a layer of fiberglass tape with B-stage epoxy to hold the coil together during handling. The inner and outer coils are assembled with Kapton insulation and a Teflon slip-plane between and outside them. Four full length strip heaters are installed between the ID of the collar and outside diameter of the coil. The strip heaters are energized and fired during a quench to ensure that enough of the coil goes normal to prevent a localized hot spot that could damage the conductor or insulation.

b. Electrical Configuration - The cable strands are composed of NbTi superconducting filaments imbedded in a copper matrix. The minimum superconductor j_c (before cabling) is 1650 A/mm² measured at 4.22 K and 7 T for the inner coil cable and 2365 A/mm² at 4.22 K and 5.7 T for the outer coil cable. The design of the cables, their placement in the two layers and the turn spacing by the use of wedges is designed to approximate the uniform field dipole produced by a winding whose current varies with the cosine of the angle, (a "cosine θ" dipole). The coils are insulated from the beam tube, strip heaters and collars with several layers of Kapton. The insulation of each Dipole Magnet Assembly shall be tested to demonstrate a minimum stand-off voltage of 2 kV at operating conditions.

3.2.4 Coil Collars - The dipole coils are restrained in non-magnetic collars, having a permeability not exceeding 1.0025 at low fields. These collars provide the necessary radial restraint to keep the coils under a positive compressive stress at operating conditions. Each coil is appropriately shimmed to assure that this preload is sufficient to prevent conductor motion under the influence of the Lorentz forces when the magnet is energized. The collars are fabricated from two meshing halves of laminations whose thickness is determined by fabrication constraints. The two meshing tangs of the collars alternate in position between adjacent laminations so that the locking keys, once inserted, hold the halves together with the design compressive preload on the coils. The laminations shall be relatively thin in the radial direction to obtain the maximum field contribution from the iron yoke, consistent with field quality requirements. The design preload on the collars shall be such as to produce a minimum compressive prestress at the pole of the inner coil of 4 ksi and 3.8 ksi at the pole of the outer coil at the operating temperature of 4.35 K. These values may vary with the detail design of the coils. Upper and lower coil collars are separately assembled and pinned in packs of a length determined by the constraints of the assembly process and by heat transfer requirements for coolant circulation between packs. The packs are then interleaved around the coil assembly, preloaded in a press, and locked together by inserting the locking keys. Coolant circulation requires that a minimum spacing of 0.8 mm be maintained between packs to allow helium to flow ou of the space around the bore tube during a quench.

3.2.5 Yoke and Helium Containment Vessel - The magnet yoke consists of stacked metal laminations mounted in the helium containment shell. The laminations are 26.670 cm diameter and at a 6.6 T operating field contribute about 1.7 T to the central field. The stampings are punched with keyways to provide accurate positioning of the collared coil assembly which is mounted within the yoke. There is to be a uniform room temperature gap of 0.25 mm maintained between the yoke and the collars. Two rectangular slots are provided in the laminations; one for the main electrical bypass bus is located at the top; the other for the correction coil leads is at the bottom.

For the given yoke diameter, the integrated dipole field requirements dictate a uniform weight of steel per unit length of 159.1 kg/m ± 0.2 kg. A separation of 0.8 mm, ± ____mm shall be maintained between laminations at intervals of ______ m for coolant circulation.

The helium containment vessel, (Support Shell), is fabricated from stainless steel plate, fits snugly around the yoke, shall be capable of withstanding the internal pressure developed during quench, and must provide the necessary rigidity to keep deflection (sag) of the cold mass between supports within the specified drawing limits. Sets of holes are provided in the support shell for the insertion of fudicial marking plugs into recessed slots in the yoke. These plugs are sealed and are used as survey markers or indexing points for the magnet position.

3.2.6 Cryostat - The cryostat forms a cylindrical vessel of approximately 61 cm diameter over the full length of the dipole magnet. The major components of the cryostat are treated separately in a. through c. below.

a. Cryogenic Piping - The magnet and cryostat assembly contains all of the pipes to interconnect the magnet refrigeration system through the ring magnet components around the circumference. The first "pipe" is the complete single phase helium containment subassembly which delivers the supply cryogen that flows around the beam pipe and through the collared coil magnet assembly. The supercritical helium at about 4 atm is passed into the magnet assembly. The maximum helium temperature is 4.35 K. The second pipe is a stainless steel pipe operating at 4 atm and functions as the single phase helium system return and recooler supply line. The third pipe is a stainless steel pipe used as a 4.5 K, one atmosphere, recooler helium boil-off gas return line. The fourth pipe is an aluminum extrusion which is welded to the 20 K aluminum heat shield. This pipe connects to the helium relief header during system cooldown, or to the return or supply headers during operation. The cooldown is accomplished by a flow of 100 g/s of helium gas The fifth pipe is an aluminum extrusion which is welded to the 80 K heat shield. This pipe connects to the liquid Nitrogen (LN) system return or supply header.

b. <u>Heat Shields, Insulation and Cold Mass Suspension Configuration</u> - The Cold Mass is surrounded by concentric thermal shields, operating at 20 K and at 80 K, to reduce the radiant heat load on the cryogenic system. Shields are fabricated from aluminum flow channel and rolled shapes. Thermal insulation blankets will be employed between the 300 K vacuum vessel and 80 K shield, and between the 80 K shield and the 20 K shield. The insulation blankets consist of multiple layers of aluminized reflective plastic film. The cold mass and thermal shields with their distributed static, dynamic and magnetic loads are supported relative to the vacuum vessel by the suspension system. This system must function under conditions that include cryostat assembly, magnet shipping and installation, cooldown and warmup, steady-state operation, magnet quench, cryogenic fluid leakage resulting in up to 5 atm abs internal pessure, and loss of insulating vacuum in the vacuum vessel. The suspension system employs low heat leak compression post support members with a single anchor at the cryostat mid-length. In order to provide the necessary controlled motion to permit the relative thermal contraction/expansion of the cold mass and the supports, the supports, other than the central anchor, are mounted on sliding members. These sliding members must still provide sufficient transverse and rotational constraint under all operating and upset conditions. The sagitta and horizontal constraint of the cold mass is controlled at the base of the supports.

c. <u>Vacuum Vessel</u> - The cold mass, thermal shields, and suspension system are contained within, and supported relative to, the outer vacuum vessel. Vacuum vessel functions include the provision of thermal insulating vacuum, mechanical support and gas containment in the even to a leak in the contained piping. The vessel material is steel. The basic vessel cross section is cylindrical and is made in a manner that permits the cold mass and insulating components to be conveniently inserted and removed and the cold mass sagitta adjusted. No sagitta of the vacuumm vessel is required. All electrical and cryogen interface connections are made in Spool Pieces or in the interconnection region between magnets; there are no service penetrations of the vacuum vessel cylindrical shell. The Vacuum Vessel is supported by integral, external feet, so positioned longitudinally as to control the overall deflection of the cryostat within specified limits. The external feet for the lower magnet shall incorporate mating surfaces to support the feet of the upper magnet. Manufacturing tolerances shall be such that field shimming between the mating surfaces, (or other appropriate methods), may be employed to achieve necessary alignment of the upper collider ring and provide a distance of 70 cm between magnet centerlines.

3.2.7 Magnet Stands - The stands that mate with and support the lower vacuum vessel feet, shall be plates fastened and grouted to the tunnel floor. The plates shall provide sufficient clearance between the bottom of the lower dipole assembly and the tunnel floor to accommodate the automatic welding equipment required for field welds, (see C.8., below). These plates incorporate provisions for independent horizontal and vertical adjustments of the lower dipole assembly feet after grouting. The structure of the plates and the integral feet shall not interfere with operations required for the removal/replacement of dipole magnet assemblies. Provisions shall be incorporated into the plate design to permit horizontal, vertical, longitudinal and angular positioning prior to their grouting, assuming standard construction tolerances of ± 1/4 inch in the level of the finished tunnel flow.

3.2.8 Magnet and Cryostat Interconnections - The ends of the magnet utilize straight pipe connections between the magnets. Interconnections between magnets include: beam tube, mechanical and electrical; 4.35 K helium pipe; the helium return lines; the 20 K and 80 K shields; and the insulating vacuum. The connections are to incorporate bellows to accommodate magnet installation and thermal contraction. Thermal insulation is continuous across the end, thereby minimizing heat leak. All field welds of pipes, bellows and vacuum vessel are to be machine welds; no manual welding is permitted in the interconnection region. All cutting operations are to be machine operations also.

4.0 Quality Assurance Provisions

4.1 General - The ability of the magnet system defined by this specification to meet the requirements specified in Section 3 and the referenced drawings and specifications shall be verified by the performance of inspections, analyses and tests as set forth herein.

4.1.1 Responsibility - Unless otherwise specified in this specification or in the contract the subcontractor is responsible for all inspections and tests and shall be notified sufficiently in advance of the test so that a representative may be designated for this purpose.

4.2 Verifications - Verification activities shall be classified as follows:

a) Inspections and analysis
b) Acceptance tests

4.2.1 Inspections and Analysis - The following requirements shall be verified by inspections, visual examinations or review of design and fabrication data or by analyses of the design and construction as they pertain to the requirements.

a. Conductor Test (Critical Current Test) - Short samples of the conductor to be used in winding the magnet coil shall be subjected to tests at 4.5°K in magnetic fields having strengths up to the maximum fields predicted to occur in the coil winding to determine the critical current for that conductor.

b. Conductor Joints/Splices - Conductor splices and joints shall be qualified at operational temperature and shall withstand a minimum of 30% more than the maximum operational current at maximum operating magnetic field.

c. Cold Mass Supports - The cold mass support design(s) shall be tested to 150% to their worst case load combination while simulating the temperature profile at which that load combination occurs. Support designs employing non-metallic materials shall also be tested to failure. Tests below 77°K are not required.

d. Pressure Vessels - Pressure vessels as defined by ASME pressure vessel code shall be tested by the ASME code pneumatic method at room temperature. Allowance for the low temperature material properties shall not be made. Strain measurements at the critical strain points shall be recorded during the test.

e. Piping - All piping, valves, pressure transducers or other pressurized (or vacuum) components shall be hydrostatically tested or pneumatically tested to the appropriate requirements of ANSI B.31.1.

4.2.2 Acceptance Tests - The paragraphs noted below shall be verified by acceptance inspection and tests performed under supervision of the subcontractor. The subcontractor shall prepare detailed acceptance test procedures for the tests listed below. These procedures shall be approved by CDG prior to the tests. Test methods and general test approaches will be identified in the subcontractors proposal.

a. High Current D.C. Power Supply Test - The magnet D.C. power supply shall be acceptance tested prior to shipment to the production or test facility.

b. Current Leads Acceptance Test - Each of the current leads shall be acceptance tested at maximum operating current and minimum helium flow or at current and flow conditions which would simulate the worst case.

c. Relief Valve Acceptance Test - The helium vent relief valve(s) shall be tested for relief pressure, reseat pressure, reverse (vacuum) leakage and for forward leakage at room temperature.

d. Room Temperature Uniformity - The subcontractor shall test the superconducting coil prior to final closure of the helium vessel to verify temperature uniformity requirements. The proposed method for conducting this test shall be specified in the applicable specification. The test may be performed during or after winding.

e. Operational Acceptance Test - The subcontractor shall perform an operational acceptance test of the complete magnet system at the site to verify compliance with the requirements of the applicable SSC-CDG acceptance test plan.