High Energy Facilities

Accelerator Development Branch

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A BRIEF SEMI-TECHNICAL DESCRIPTION OF THE SSC MAGNET

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Summary

This note summarizes the collared dipole design recently selected as the magnet type to be henceforth pursued for the Superconducting Super Collider. The dipole is a high field "cold iron, cold bore" magnet (i.e. both the iron yoke and bore tube are at cryogenic temperatures) of 16.6 m effective magnetic length. The two-layer coil, of a circular configuration with an aperture (I.D.) of 4.0 cm, is wound from a high-current superconducting cable, supported mechanically by stainless steel collars. The magnet is designed to operate at a field of 6.5 Tesla and a temperature of approximately 4.5K, obtained with forced circulation of high pressure supercritical (single phase) helium. In the following paragraphs the principal magnet components are described in somewhat greater detail.

Six model magnets, each of full cross section and 4.5 m long, were constructed and tested during the summer and fall of 1985. Their performance was excellent: all six magnets readily attained the design operating field, and they exhibited a magnet-to- magnet reproducibility in multipole components of the basic dipole field pattern well within the stringent tolerance required for the SSC (amounting to a variation in the dipole field of about a part in 10^4). Tooling, components, and measurement instrumentation for the first full-length prototype magnet are presently in preparation.

Bore Tube Assembly

The high vacuum chamber (which will contain the circulating proton beam) is a stainless steel tube of 3.3 cm I.D., copper coated on the inside to limit the electrical resistance of the wall to image currents. On the outside of the bore tube are mounted sextupole and decapole correction coils. These are also superconducting but of modest requirements; their function is mainly to correct for certain intrinsic magnetization effects at very low fields associated with the main superconductor. Between the correction coils and the main dipole coil are longitudinal plastic insulator-support strips spaced to furnish annular helium cooling passages.

Coil

The collared sub-assembly is shown in Fig. 1. The coil configuration is a well known approximation to an analytically ideal arrangement of conductors around a cylindrical volume such as to produce a uniform vertical (dipole) field within that volume. Both coil layers are wound from a slightly keystoned, flat cable manufactured from 23 strands (the "inner" cable) or 30 strands (the "outer" cable); it is shown highly schematically in Fig. 2. Each strand, approximately 0.076 cm in diameter, is a twisted composite wire, containing several thousand very fine (typically 10μm) filaments of a NbTi alloy (the superconductor) in a high-purity copper matrix. (Filamentary subdivision of the conductor is necessary to avoid cyclic power losses akin to eddy current effects in normal conductors and to minimize the magnetization effects referred to above). The outer cable has less superconductor than the inner cable because the field in the outer layer is lower. The two layers are powered in series, with approximately 6.5 kA corresponding to a field in the bore of 6.5 Tesla. The cable insulation consists of a double wrap of Kapton followed by one layer of fiberglass tape impregnated with B-stage epoxy; the latter serves to hold the coil together during handling until the magnet is fully assembled. The number of turns and positioning of the intervening copper wedges in the coil cross section are treated as variables providing degrees of freedom in the computer-aided procedure for optimizing the field homogeneity in the coil aperture.

Collars

The coils are compressed with collars of 1.5 cm radial width made of high strength, non-magnetic stainless steel pre-assembled in packs from laminations. No welding is involved; pins and keys are used instead. The collars simplify subsequent insertion of the coils into the iron yoke and provide the necessary restraint to maintain them under a compressive stress of about 8 kpsi in order to counteract the enormous magnetic forces generated when the magnet is energized to full field. (A conductor in a field of 6.5 T and carrying 6500 A experiences a force of 35 kg cm^{-1}.) The relatively thin radial width of the collars minimizes the loss in contribution to the magnetic field from the adjacent iron yoke; an added benefit from placing collars between coil and yoke is a sharp decrease in the perturbing effect at high field of iron saturation on the field uniformity. The coils are insulated from the collars with several layers of Kapton sheet.

Yoke and Cryostat

The iron yoke, 26.67 cm in O.D., is assembled from module blocks fabricated from laminations of low carbon steel, mounted in the helium containment shell as in Fig. 3. The laminations are punched with keyways for accurately locating the collared coil assembly within the yoke. The two large rectangular slots carry the main electrical bus (top) and correction element leads (bottom). The four large holes are channels for helium flow; the smaller holes near 40 degrees are for inserting tensioned alignment rods. The stringent tolerances on yoke length and weight (e.g., a weight uniformity of about 0.01% from yoke to yoke) are met with the aid of a select number of filler laminations and proper compression of the lamination stack. The helium vessel is fabricated from stainless steel half shells, welded shut on the midplane after a stainless steel backing strip is inserted in slots in the yoke laminations (not shown in the slightly alternative method of welding depicted in Fig. 3). The top and bottom subassemblies are held in contact under pressure while this welding operation is performed.

The high pressure (4 atmospheres) supercritical helium flows through the annular space between the correction coils and the main coil, through passages between the collars and yoke, and (the bulk of the helium flow, approximately 100 g/sec) through the larger bypass channels in the yoke. The helium permeates the superconducting cable and the electrical insulation. Note that this cooling scheme is applicable to cooling full length magnets and strings of magnets installed in the actual accelerator, not to the shorter magnet models, which are tested simply in boiling liquid helium.

Vacuum Vessel Assembly

The "cold mass" subassembly described in the preceding paragraphs, at 4.5K, is surrounded by concentric aluminum heat shields maintained at

20K and 80K, by helium gas and liquid nitrogen, respectively, with intervening thermal insulation consisting of layers of aluminized Mylar and fiberglass mats ("superinsulation"). Cryogenic headers are located in the annular space between the cryostat and heat shields (Fig. 4); these are two helium gas return pipes and two pipes carrying the heat shield coolants. The cold mass and the ancillary cryogenic components are supported relative to the outer cylindrical vacuum vessel by a suspension system based on compacted fiberglass-epoxy support posts, one of which acts as an anchor at the cryostat mid-length, as seen in Fig. 4. The vacuum vessel assembly is the responsibility of Fermilab.

Machine Environment

In service, the magnet system is required to meet stringent standards of reliability and accuracy. The failure rate of magnets in the SSC must be exceedingly small in order to attain the desired levels of productivity. Placement tolerances of the entire magnet system is 0.5 mm horizontally and vertically around the 90 km ring. The angular direction of the dipole field must be within 1 mrad of vertical. The magnets have been engineered to achieve the required performance levels over the full lifetime of the machine, which will extend well into the 21st century.