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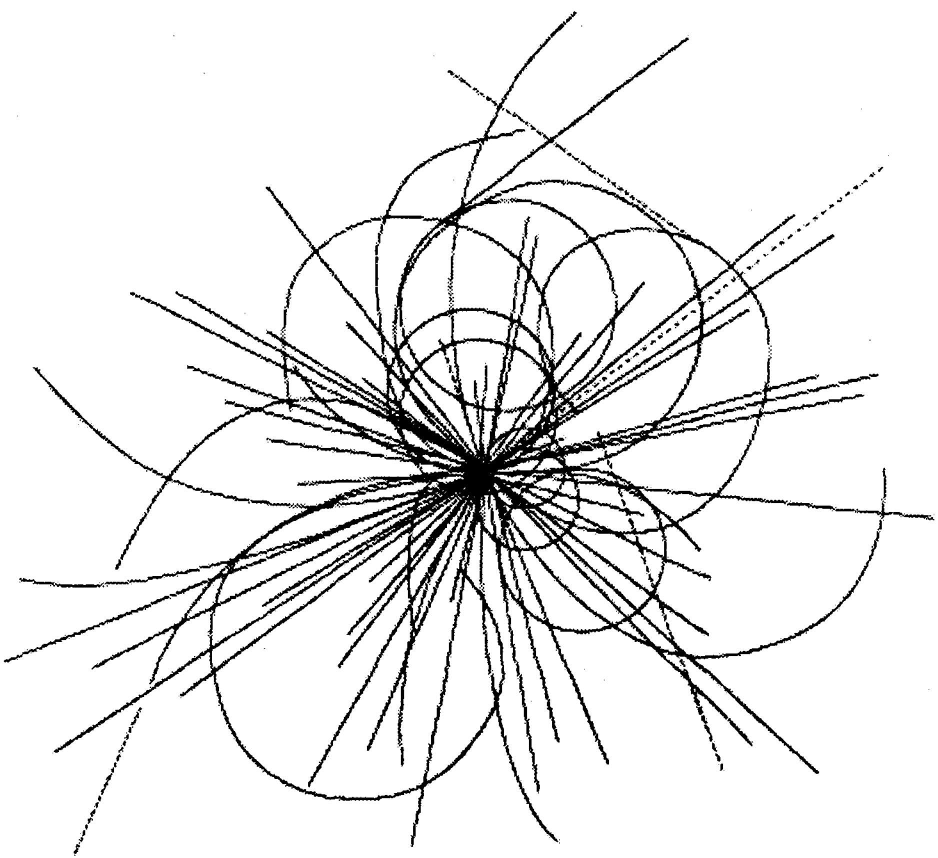
Overview of the Superconducting Magnet Subsystem for the GEM Detector at the SSC



Superconducting Super Collider Laboratory

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OVERVIEW OF THE SUPERCONDUCTING MAGNET SUBSYSTEM FOR THE GEM DETECTOR AT THE SSC

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INTRODUCTION

The SSC Laboratory plans to deploy two "large" detectors for the essential high-energy physics experiments at the initial startup of the collider. The GEM detector is optimized to emphasize precise measurement of photons and electrons, as well as precise tracking of high-energy muons. An essential part of the GEM detector is the magnet subsystem, which provides the magnetic field necessary for identification and high-resolution tracking of charged particles. This large superconducting magnet system, with ferromagnetic field-shapers, presents a variety of engineering challenges in superconductor technology, in magnet-winding technology, fabrication, assembly and installation of large and heavy components, and in ensuring the required high operating availability.

DESIGN OVERVIEW

A basic philosophy of the GEM Detector is to provide a large magnetized solenoidal volume, in which the rest of the detectors are installed[1]. Within this basic concept, the GEM magnet is required to provide a combination of size and magnetic field sufficient for high-

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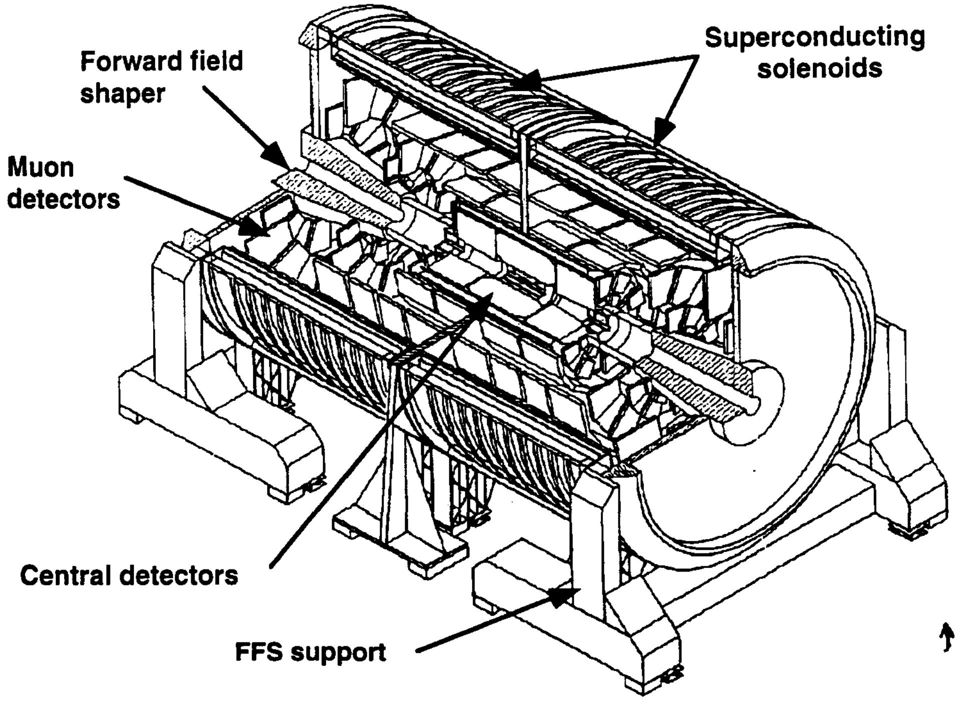

Figure 1. GEM Detector

resolution measurement of charged-particle momentum. Though better performance is achieved with larger, higher field magnets, certain detectors, which will be installed inside the solenoids, limit the magnitude of the allowable field, and the overall size of the underground detector hall restricts the magnet size. The overall cost of the detector favors both lower field and smaller radius. Trade studies indicated that the best choice was a large solenoid, 18 m inner diameter and 31 m overall length with modest magnetic field, 0.8T on center, and with no flux return. This approach satisfies the requirements at minimum cost, and avoids higher-risk magnet designs, such as multi-layer solenoids. In order to meet our muon-resolution requirements for trajectories which are close to the solenoid axis, each end of the solenoid is occupied by a large, conical, ferromagnetic steel structure, the "Forward Field Shaper".

The GEM Magnet, shown in Figure 1, comprises five main elements, two superconducting solenoids, two Forward Field Shapers, and the Central Detector Support, along with the required auxiliary systems, such as vacuum, cryogenics, power/protection, and control. The main system characteristics are listed in Table 1. The primary engineering challenges are associated with the large size and weight of the system. All major components must be field-assembled, and this often dictates different design approaches than used for previous large detector magnets. For example, the difficulties inherent in winding such a large coil in the field led, in part, to our choice of a conductor which was less sensitive to minor winding imperfections. Practical aspects of fabrication have been considered at each step, and will be brought into even clearer focus when an industrial contractor is retained, starting in summer of 1993, to complete the design, fabrication, and installation of the magnet subsystem. The design details are outlined below.

Cold mass

We chose to use a cable-in-conduit (CIC) superconductor design for GEM, because it offered excellent stability against quench, as well as enhanced opportunities for performing

Table 1. GEM Magnet System Parameters

Central induction	0.8	T	Stored energy	2.5	GJ
Mean winding radius	9.5	m	Peak field at conductor	1.6	T
Vessel inner diameter	18.0	m	Operating temperature	4.5	K
Vessel outer diameter	21.8	m	Total conductor length	27.2	km
Overall coil length	31.0	m	Charging time	8	hr
Number of turns	456		Total cold mass	1050	Mg
Operating current	50.2	kA	Total coil ass'y mass	1500	Mg
Inductance	1.98	H	Mass of FFS + support	2000	Mg

key quality-assurance tests prior to installation[2,3]. This conductor is formed in a single layer against the inside of a 76mm thick cylindrical aluminum coil form, which provides mechanical support and cooling (by conduction to helium tubes on the outside of the coil form) for the windings. The coil form also provides an axial mechanical prestress to the conductor to minimize slipping (and potential for quench) during charging. Each of the two separate cold mass halves consists of twelve coil segments, where each coil segment is a 19-turn single-layer coil, roughly 19m in diameter and 1.2m long, containing a single 1.2 km length of conductor. The twelve segments are connected mechanically with flanges, and electrically with low-resistance, large-area lap-type joints[1]. A completed cold-mass half contains a total of 228 turns and weighs 525 metric tons.

Vacuum Vessel

Each of the two cold-mass halves is enclosed in a separate annular vessel, which provides insulating vacuum and physical support[4]. The two vacuum vessels each consist of a simple membrane-like inner vessel, a reinforced outer vessel, and two thick end rings which add stiffness to the two vessels as well as provide stable attachment points for the cold mass supports. The vessels will be constructed of a combination of low-carbon steel and 300-series stainless steel, to satisfy the requirements on mechanical performance, magnetic field, cryogenic performance, and cost. These large structures are field-fabricated because of their large size and weight (nearly 22m OD, 15m long, and 900 metric tons). Assembly of the cold mass and the vacuum vessels is accomplished with their axes vertical, since this is the preferred orientation for fabricating vessels, and eases the problem of ensuring roundness. The cold mass and the vessels are assembled together by consecutively nesting the vessel shells with the cold mass, and then completing two final close-out welds. This assembly scenario requires, for each magnet half, at least two high, heavy lifts, with limited clearances (e.g., lift an outer vessel over and then onto the cold mass); a final lift to rotate the magnet axis to horizontal is also needed. The vessel design has been chosen to simplify these assembly operations.

Cold-mass supports and thermal shields

Two different sets of titanium rods are used to support the cold mass within the vacuum vessel. These rods are designed to support the weight and the considerable magnetic force on the coil (52MN), while preserving the roundness of the coil ends, allowing for dimensional changes during cooldown and charging, and minimizing the heat conducted to the 4.5K structure. A set of 32 rods lying in the plane of the coil ends, and oriented tangentially to the coil, support the coil weight. A system of 8 axial supports connect to the cold mass at roughly the middle of the coil, and to the outer end ring of the vacuum vessel; these axial supports resist the attractive force between the coil halves.

The 4.5K structure is completely surrounded by LN-cooled thermal radiation shields, consisting of lightweight aluminum panels with welded-on cooling tubes. These shields are surrounded on both sides by multilayer insulation, which reduces the consumption of LN and the heat load to the cold mass. The thermal shields also provide conductive thermal intercepts to reduce the heat conducted by the cold mass supports to the cold mass.

Forward field shapers

The two forward field shapers each consist of approximately 1300 metric tons of ferromagnetic steel, supported by a welded-steel support structure. The structure must resist both the magnetic force of 12MN pulling toward the center of the solenoids, and the large moment resulting from the cantilevered weight. The cantilevered design is required by the design of the detectors which fit around it. The FFS cones are constructed out of a number of disks, which interlock to support the large shear load from the cantilevered weight. The entire set of disks is held together with a number of pre-tensioned rods which penetrate the whole group. The FFS support is fabricated off-site in approximately 10 large pieces, which are then shipped to the detector site, where they are bolted together. The FFS is bolted on last, just prior to installation.

Auxiliary Systems

Cooling for the cold mass is provided by a passive thermosiphon system, with the LHe in tubes welded to the outside of the coil forms[5]. Supercritical helium (3 atm, 4.5K) is also supplied to the inside of the CIC, the joints between coil segments, and the vapor-cooled leads. Helium refrigeration requirements are comparable to those for the SSC's Accelerator System String Test, approximately 2kW refrigeration, plus 20g/s liquifaction. To improve availability, we plan to ensure that the magnet can operate even during refrigerator outage, by using the inventory of stored liquid.

The power, protection, and control system includes the main 50kA, 20V DC power supply, which can charge or discharge the magnet in 8 hours. The DC supply is connected to the magnet with forced-air cooled aluminum busses. A dump resistor and redundant circuit interrupters are included in the circuit to provide a means for quickly discharging the magnet in the event of an emergency such as a fire in the underground hall or a magnet quench. Finally, sensors and controls are provided to constantly monitor the condition of the magnet, and control all system simultaneously.

SUMMARY

The GEM magnet will be one of the largest superconducting magnets to be constructed. Although its size presents a number of engineering challenges, we have adopted a very conservative design in order to ensure the high operating availability required for a key system a major SSC experiment.

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