A 3-m DIAMETER x 5 m SUPERCONDUCTING SOLENOID FOR THE COLLIDER DETECTOR AT FERMILAB

R. Fast, J. Grimson, K. Kondo, R.D. Kephart,
S. Mori, R. Wands, R. Yamada
The CDF Collaboration

Summary

The Collider Detector at Fermilab (CDF) is a large detector system designed to study $\bar{p}p$ collisions at cm energies up to 2 TeV produced at the Fermilab Tevatron Collider. The central detector of this system is designed to momentum analyze particles using wire ionization chambers located in an axial magnetic field. To provide the required momentum resolution, a superconducting solenoid 3 m in diameter and 5 m long with a central field of 1.5 T is being built. The coil will reside in a 2200 metric ton instrumented steel return yoke.[1] Since particles produced at large polar angles must pass through the coil before they are measured by calorimetry, the coil must be "thin" both in radiation and absorption lengths.

The coil was designed by a collaboration of personnel from Fermilab, Tsukuba University, Japan, and Hitachi Ltd., Japan. The coil is being fabricated by Hitachi, Ltd. under contract to Tsukuba University. The refrigeration system, power supply, controls and magnet yoke are being built by Fermilab.

Magnet Design

The solenoid design has been presented previously[2] and is discussed in detail in the design report[3]. Therefore, only a summary is presented here. The requirements mentioned above resulted in a design consisting of an indirectly cooled bobbinless superconducting solenoid with an external support cylinder. A cross section of the coil is shown in Fig. 1. The coil is a single layer helical winding of a monolithic superconductor. This conductor consists of a high purity aluminum stabilizer coextruded with a copper/NbTi composite. Details of this conductor along with other coil parameters are given in Table 1 and Fig. 2.

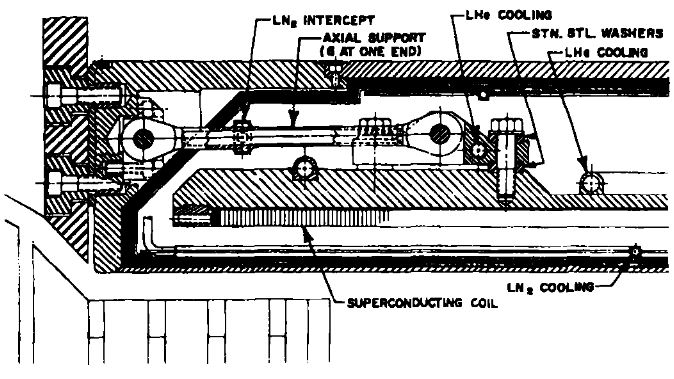

Figure 1

Cross Section of Coil

Table 1

Coil Parameters

Solenoid clear bore:	2858 mm
Coil inner diameter:	2966 mm at 300 K
Coil winding length:	4797 mm at 300 K
Overall thickness:	247.5 mm
Overall radiation lengths:	0.83
Overall absorbtion lengths:	0.19
Design operating field:	1.5 T at 5 kA
Guaranteed operating field:	1.35 T at 4.5 kA
Inductance:	2.4 H
Stored energy:	30 MJ at 1.5 T
Cold mass:	5568 kg

Conductor

Overall dimensions:	3.89 mm x 20 mm
Al:Cu:NbTi radio:	21:1:1
Aluminum purity:	>99.99% (RRR>1200)
Superconducting strands:	50 μm x 1700
Bare conductor current density:	63.3 $^{A}/_{mm^2}$ at 5 kA
Fraction of short sample at 5 kA:	60% along load line to 4.4 K
Conductor weight/length:	3000 kg/11.2 km

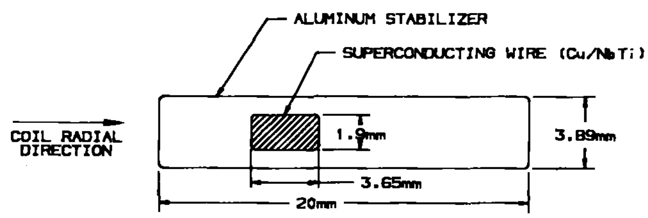

Figure 2

Conductor Cross Section

The conductor will be insulated with half lapped Kapton tape coated with B-stage epoxy for turn to turn insulation and wound on a temporary mandrel. After axial compression and curing of the B-stage epoxy, an external layer 2-3 mm thick of glass-polyester resin will be applied to insulate the coil from ground. This layer will be machined round and a 16 mm thick aluminum external support cylinder will be shrink fitted and bonded to the insulated winding. The outward radial force on the coil during excitation (.9 MPa at 1.5 T) will be reacted as hoop stress in this cylinder. After shrink fitting the temporary inner mandrel will be removed.

The solenoid will be installed in an iron flux return yoke consisting of two end walls and four flux return legs. Calorimeterized poles attached to the end walls extend into the solenoid field volume. The pole and end wall geometry determines the electromagnetic forces on the solenoid coil and the axial and radial decentering forces. The axial force is ∿ 1 MN (compressive) at 1.5 T. The radial and axial decentering force constants are approximately 12 MN/m and 18 MN/m respectively.

The cold-to-warm support system consists of six axial members on one end to provide axial stiffness and 12 tangential members on each end to carry the cold mass and provide radial stiffness. These members are thermally intercepted at 77 K and 4.5 K to reduce the heat flux to the outer support cylinder and avoid quench-producing hot spots. Spherical bearings on both ends of each support eliminate bending stresses due to differential thermal contraction.

The behavior of the coil following a quench has been computer modeled including the effects of eddy currents in the outer support cylinder and the insulation layer between the coil and the outer support cylinder. The calculation shows the coil winding will be completely normal several seconds after quench initiation. With a 74 mΩ dump resistor connected in parallel across the coil, the maximum expected conductor temperature is less than 100 K and maximum terminal voltage during discharge is 370 V. The coil will have five voltage taps to help locate quench origins. It will also have quench initiation heaters to permit quench studies at low stored energy levels.

The coil will be conduction cooled by two-phase helium flowing in an aluminum tube attached to the outer support cylinder. The system will be operated with the helium stream at a temperature of ∿ 4.4 K. A finite element thermal analysis was performed on the outer support cylinder. A maximum temperature of 5.3 K resulted from this calculation. The coil and support cylinder are screened from 300 K radiation by inner and outer liquid nitrogen cooled shields of 3 mm thick aluminum.

Refrigeration System

The identified steady state 4 K heat load to the coil is 40 W + 14 L/h with an additional 100 W during charging due to eddy current heating in the support cylinder. This refrigeration will be provided by a modified version of the Energy Doubler/Saver satellite refrigerator. The refrigerator consists of a 350 HP Mycom screw compressor, a four stage counterflow heat exchanger with LN_2 precooling and two expansion engines. Figure 3 shows a simplified flow diagram for the refrigerator and magnet. The refrigerator is capable of providing up to 600 W at 4 K of refrigeration in the mode in which it will be employed. This additional capacity is necessary to provide quick recovery from quenches (4-6 hrs) and fast cooldown.

The flow schematic of the helium system in Fig. 3 also illustrates how the satellite refrigerator is integrated with the other system components. Refrigerator output is into a 2000 L storage dewar, which provides the reservoir from which the magnet LHe flow originates. From the dewar, He passes through one of two transfer lines to either the assembly or BØ collision areas. The helium flows from the transfer line into the control dewar subcooler located on the magnet, where it is cooled by the magnet return flow. After leaving the subcooler, the helium is expanded through a J-T valve and begins traversing the magnet cooling circuit.

The magnet is cooled by approximately 150 m of 20 mm ϕ diameter aluminum tubing welded to the solenoid external support cylinder. The bulk of the cooling path is axially serpentine, with intercepts at all support attachment locations. A circumferential loop at each end of the solenoid provides additional end cooling. Upon leaving the magnet, the helium returns through the subcooler in the control dewar, then back through the return side of the heat exchanger to compressor suction.

The liquid nitrogen is supplied by a storage dewar and is used in two independently controlled circuits to cool support rod intercepts and the solenoid radiation shields. Return flow is used to shield the transfer lines and control dewar.

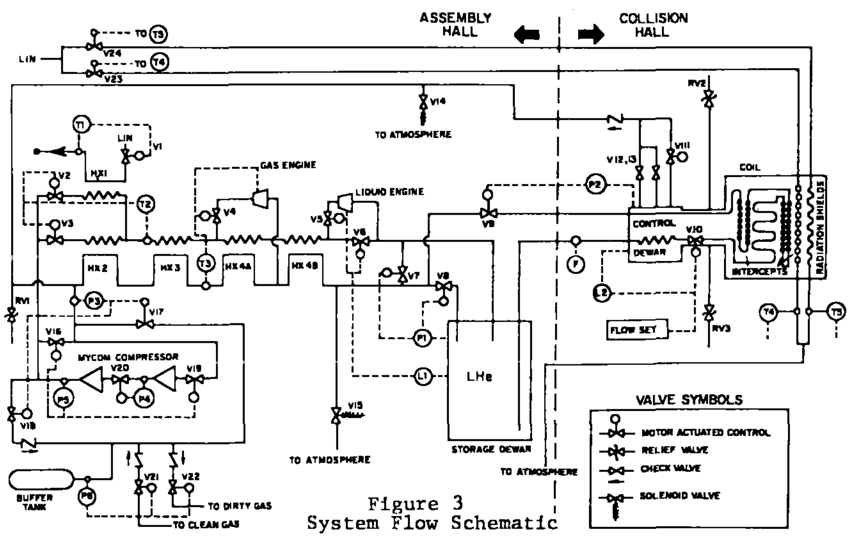

Figure 3
System Flow Schematic

Control System

The control system is based on the Fermilab Energy Doubler control system as much as possible[4]. A block diagram of this system is shown in Fig. 4. Transducer outputs of pressures, temperatures, engine speeds, etc., are received by specialized multibus modules and passed to a Z-80 microprocessor located in a multibus crate. A program residing in the Z-80 performs the appropriate control functions and sends commands to valve actuator modules located in the crate. The multibus system is linked through a Camac 0-8Ø module to the accelerator main control console. Input and output variables, set points, operating limits for valves and engine speeds can be easily changed and monitored from the console.

The control loops associated with the refrigerator are identical with those of current Energy Doubler/Saver satellite installations. However, those loops controlling flow from the helium storage dewar to the solenoid are unique to this system.

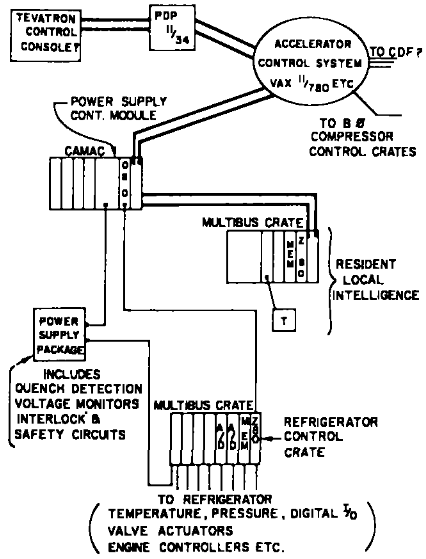

Figure 4

Control System Block Diagram

Power Supply

The magnet will be powered by a 100 kW supply rated for 20 V and 5000 A continuous service. This supply will be located in the BØ assembly hall and connected to the magnet and dump resistors with water cooled bus. A schematic of the magnet's DC circuit is shown in Fig. 5. Two resistors are provided for discharging the magnet. The "slow dump resistor" (R_s =4 mΩ) is chosen such that the maximum eddy current heating during a slow discharge is equal to that generated during the normal magnet charge cycle. This results in a 600 sec discharge time constant and should not quench the coil. In the event that a quench or other magnet fault is detected by the control system, the magnet may be fast discharged into resistor R_f = 74 mΩ by opening switch S_2. This will produce sufficient eddy current heating in the support cylinder to rapidly quench the entire coil and discharge it safely. The effective discharge time constant in this case is ∽ 10-15 sec.

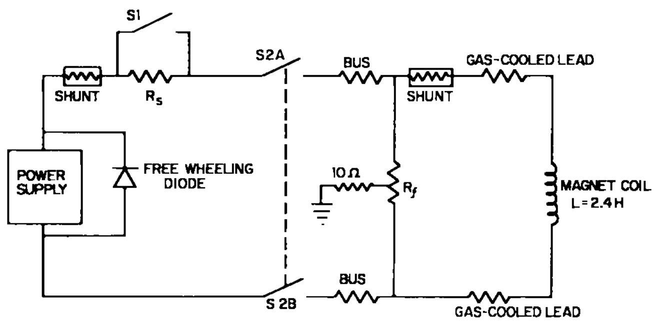

Figure 5

DC Circuit

Project Status

A 1 mϕ x 1 m long prototype coil has been built and successfully tested to verify conductor performance and quench calculation codes. A 3 mϕ x 1 m long test coil was wound and the shrink fitting technique was successfully tested. The solenoid is currently being manufactured by Hitachi, Ltd of Japan with conductor winding in progress.

Following testing in the spring of 1984, the coil should arrive at Fermilab in June, 1984. The refrigeration system is currently being assembled, and should begin liquid helium production in February, 1984. The magnet yoke assembly will begin at Fermilab in fall of 1983. The completed magnet and refrigerator should begin testing in August of 1984.

References

1 See J. Grimson et. al., "Magnetic Structure of the CDF Detector --- these proceedings.

2 R. Wands et. al., IEEE Trans. Magnetics, MAG 19: Page 1368 (1982).

3 "Design Report For an Indirectly Cooled 3-m Diameter Superconducting Solenoid for the Fermilab Collider Detector Facility" Fermilab TM-1135 (1982).

4 "Computer Operated Control System for the Energy Saver Satellite Refrigerator" Fermilab TM-1024 (1981).