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A MAGNET SYSTEM FOR THE TIME PROJECTION CHAMBER AT PEP

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ABSTRACT

A superconducting solenoid with a conductive bore tube is under construction for use with the time projection chamber (TPC) detector at PEP. It will be a uniform induction of 1.5 T over a 6.3 m^3 volume. Its stored energy will be 11 MJ while maintaining a radiation thickness of 0.3 radiation lengths for the coil package. The coil will operate at a current density of 7×10^8 Am^{-2} and it will be cooled by force flow two phase helium in a tube. The final design details are given here.

I. INTRODUCTION

High Energy Physics has historically played a major role in the development of superconducting magnet technology. The new colliding beam facility PEP which is under construction at the Stanford Linear Accelerator Center requires new technology in many of the experiments which are being built. The PEP-4 experiment, which is a collaboration of scientists from LBL, UCLA, UCR, Johns Hopkins and Yale, has an entirely new type of detector which is surrounded by a large thin superconducting solenoid.[1] The choice of a superconducting solenoid is dictated by both economics and physics.

The PEP-4 experiment, which also is called the TPC experiment, is built in layers like an onion (see Fig. 1). The time projection chamber (TPC), which is the heart of the experiment, is in a magnetic field which bends charged particles in order to measure their momentum. The next layer is the superconducting solenoid which generates this field. Other detectors such as the argon calorimeters and muon detectors detect and analyze neutral particles and particles which are very penetrating. These detectors are outside the solenoid. The TPC solenoid provides an induction of 1.5 T in a room temperature volume 2.04 m in diameter and 3.25 m long. This magnetic field should have good uniformity in order that the TPC function correctly. The magnet is thin from a radiation standpoint so that γ rays and electrons can be detected outside the coil. The TPC solenoid is almost totally surrounded by experimental apparatus. The inside bore of the magnet is filled with the TPC, its electronics and two end cap argon gas calorimeters which are attached to the iron poles. The outside surface of the cryostat is surrounded by argon calorimeters and drift chambers. Service from the ends is restricted because nearly 25000 wire pairs from the TPC which must be brought out past the end of the magnet. In reality services for the solenoid can only be supplied from the outside corner on either side of the supports at 3, 7, and 11 o'clock at the north end of the magnet.

II. BASIC PRINCIPLES OF THE TPC MAGNET DESIGN

The high energy physics use of the magnet has led to a rather unconventional magnet design. The TPC magnet is unusual in the following ways: 1) The coil is thin; the total radiation thickness of the magnet is 0.65 radiation lengths (including an 11 atm pressure vessel for the TPC). 2) The current density in the coil superconductor is an order of magnitude higher

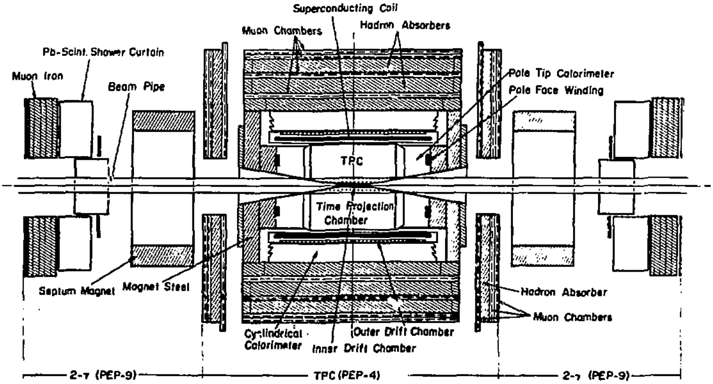

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Fig. 1. A cross section of the TPC experiment and its companion PEP-9 experiment.

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*Lawrence Berkeley Laboratory, University of California, Berkeley, CA 94720 than conventional superconducting magnet of the same size and stored energy. The high coil current density is dictated by the low radiation thickness requirement. 3) The magnet is cooled by a forced two phase tubular cooling system. This feature eliminates a cryogen vessel and all of its necks for relief valves and other services. The TPC magnet has a number of other advantages over conventional superconducting magnets. These include low cold mass, enhanced cryogenic safety, in short cooldown time and lower capital cost.

The TPC magnet design principles were developed over the last three years, and a number of test coils have been built.[2,3,4] High current density operation of the coil is possible because there are shorted secondary circuits which carry the magnet current during a magnet quench. The shorted secondary circuits affect the quench process in the following way: 1) The shorted secondary permits the current to shift from the coil to itself as the quench proceeds. This reduces the hotspot temperature in the superconductor and it permits the shorted secondary to absorb a substantial amount of the magnet stored energy. 2) The shorted secondary circuit permits fast coil current decay while limiting the transient voltages in the magnet. 3) The shorted secondary causes the entire coil to become normal long before it would through ordinary quench propagation. This phenomenon is called "quench back". 4) The shorted secondary circuit permits effective methods of "dynamic quench protection" to be used, which would not be used on conventional superconducting coils.[3] Since the use of shorted secondarys permits safe high current density operation of the coil, the TPC magnet can be made adiabatically stable rather than cryogenically stable. As a result, tubular two phase cooling can be used instead of a helium bath vessel. High current density operation of the coil reduces the cold mass of the coil. The combination of tubular cooling and low coil mass will greatly simplify the cryogenic system for the magnet while enhancing its cryogenic safety.

III. A DESCRIPTION OF THE TPC MAGNET SYSTEM

The TPC magnet consists of five primary subsystems. They are: 1) The coil package, 2) The cryostat vacuum vessel and coil package support system, 3) The helium refrigeration distribution system, 4) The power supply and quench protection system, and 5) The iron poles and return yoke. This report deals with the first four subsystems, but the iron pole and return yoke are important if the field uniformity requirements for the TPC are to be met. Table 1 presents the parameters of the magnet and a number of its subsystem parameters.

The coil package consists of three layers of material which are wound on an annealed 1100 aluminum bore tube which has an RRR (residual resistance ratio) of 25. (Figure 2 shows a cross section of the coil package.) A layer of ultra pure aluminum (RRR>1500) insulated turn to turn by spacers made from fish line is wound in the bore tube. The ultra pure aluminum and bore tube are the shorted secondary circuits. the key to quench protection. During a quench, the ultra pure aluminum shifts current from the coil quickly causing quench back while the bore tube absorbs most of the magnet stored energy. Two layers 1.0 x 3.7 mm copper based superconductor are wound over the ultra pure aluminum. (Table 1 shows the basic superconductor parameters.) The coil layer to layer and layer to ground insulation is epoxy impregnated glass tape. The final layer is the forced flow cooling tube. Three oval tubes are wound, but only one carries two phase helium. The layer of cooling tube helps to carry some of the magnetic forces

The magnet cryostat vacuum vessel consists of inner and outer aluminum cylinders. See Fig. 3 for a view of the magnet coil package in its vacuum vessel. The inner cylinder is also an ASME Coded 11 atm pressure vessel for the TPC gas. The helium is contained in the cooling tube which has a pressure rating in excess of 100 atm. The magnet contains only about 65 liters of liquid helium, therefore, the ratio of vacuum volume to liquid volume (about 40) leads to a very safe cryogenic system. The magnet coil package is supported by compression rods at each end in six places.[3] (See Fig. 4.) The number of supports is dictated by deflection of the thin coil package. All services entering the magnet enter through the outer corner of the North wall of the vacuum vessel. The gas cooled electrical leads, which are at the 11 o'clock position, are completely buried within the vacuum enclosure. Liquid helium and liquid nitrogen enter and exit at the 7 o'clock position. Vacuum services are at the 3 o'clock position.

Refrigeration will be supplied to the TPC magnet by a 200W refrigerator to be built by CTi. A control dewar separates the refrigerator from the load. The control dewar system controls both cool-down and normal operation of the magnet. The control dewar itself contains 200 liters of liquid helium, two heat exchangers, a helium pump, and various valves.

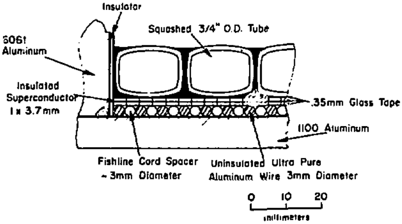

Fig. 2. A cross section of the TPC magnet coil package.

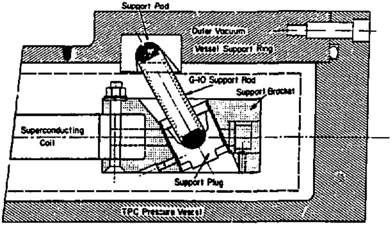

Fig. 3. The end of the TPC coil package within the vacuum vessel (at a radial support rod).

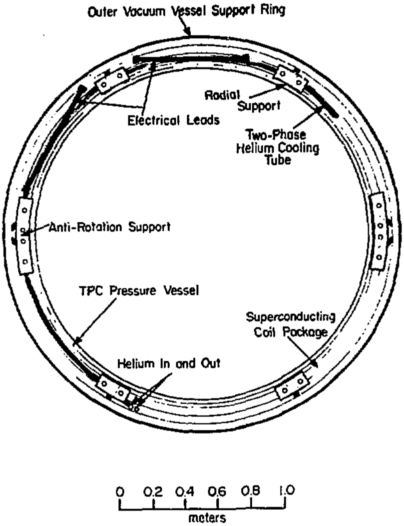

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Fig. 4. A cut away view of the north end of the TPC magnet within the vacuum vessel.

The helium pump provides backup circulation of liquid in the event of refrigerator failure. The control dewar is connected to the coil cryostat with semi-flexible shielded transfer lines which carry both liquid nitrogen and liquid helium to and from the coil.

The magnet will be powered by a 3000 A six phase power supply which is SCR regulated on the primary side of the transformer. The power supply can provide up to 10 V which is sufficient to charge the magnet in as little as 40 minutes. The quench protection system for the magnet consists of 4 distinct elements. They are: 1) The 9.5 mm thick 1100 aluminum bore tube; 2) The layer of ultra pure aluminum 3) An SCR circuit breaker with a varistor resistor across the leads, and 4) A capacitor bank which discharges into a center tap between the two layers of the coil. The first two quench protection elements are passive. The latter two elements are dynamic quench protection systems[5] which require the quench to be detected quickly. Both of the dynamic quench protection methods have been tested on a 2 MJ thin solenoid. This work is reported in the proceedings of this conference.[7]

ACKNOWLEDGMENTS

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TABLE I
The Basic Parameters of the TPC Magnet
And its Major Subsystems

Magnet Package Parameters	
Vacuum Vessel Warm Inside Diameter	2.040 m
Vacuum Vessel Warm Outside Diameter	2.440 m
Vacuum Vessel Length	3.840 m
Distance Between Poles	~ 3.26 m
Package Mass	4400 kg
Coil Package Parameters	
Coil Diameter	2.168 m
Coil Length	3.300 m
Coil Package Thickness	~33 mm
Number of Turns in Coil	1740
Number of Turns of Pure Aluminum	550
Coil Inductance with Iron	4.26 H
Coil Package Cold Mass	1440 kg
Superconductor Parameters	
Type of Conductor	Nb-Ti
Bare Matrix Dimension	0.9 x 3.6 mm
Insulated Matrix Dimension	1.0 x 3.7 mm
Insulation Type	Formvar
Copper to S/C Ratio	1.8 to 1
Number of Filaments	2200
Filament Diameter	~26μm
Twist Pitch	~40mm
Critical Current @ 4.2K & 2.0T	3400 A
Magnet Design Electrical Parameters	
Design Central Induction	1.5 T
Induction Uniformity in TPC	±0.015 T
Coil Current	2270 A
Magnet Stored Energy	11.0×10^6J
Superconductor Matrix Current Density	$7.00 \times 10^8 \mathrm{Am}^{-2}$
EJ^2 Product[4,5]	$5.4 \times 10^{24}\ \mathrm{JA}^2\mathrm{m}^{-4}$
Magnet Cooling System Parameters	
Static Refrigeration Load	30 W
Lead Gas Flow	~0.25 gs^{-1}
Cooling Circuit Length	360 m
Cooling Tube Area	177 m^2
Cooling Circuit Design Mass Flow	12 gs^{-1}
Magnet Operating Temperature	~4.8°K
Two Phase Cooling Pressure Drop	~0.4 atm
Cooling Tube Volume	64 liters
Estimated Magnet Cool Down Time	~30 hours