Title

A 40 mm BORE Nb-Ti MODEL DIPOLE MAGNET

Author

Taylor, C.

Publication Date

1984-09-01

LBL-17667

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

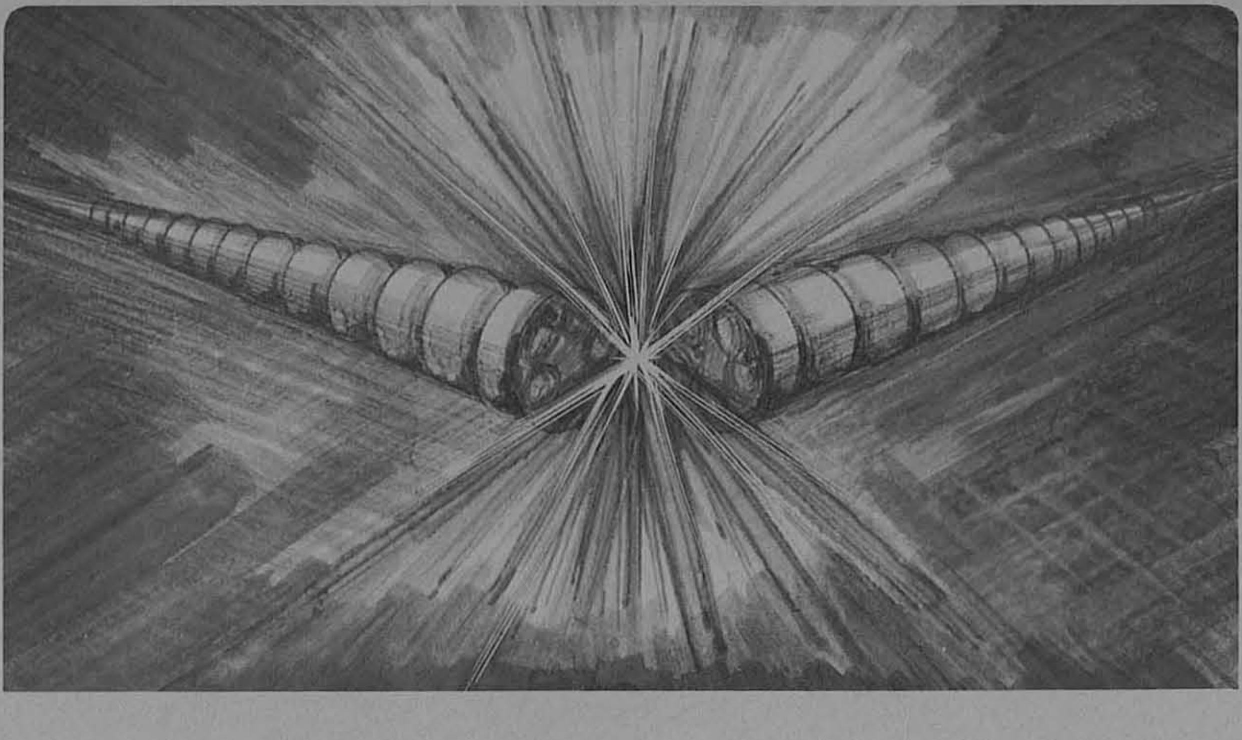
Accelerator & Fusion Research Division

Presented at the Applied Superconductivity
Conference, San Diego, CA, September 9-13, 1984

A 40 mm BORE Nb-Ti MODEL DIPOLE MAGNET

C. Taylor, W. Gilbert, W. Hassenzahl,
R. Meuser, C. Peters, J. Rechen,
and R. Scanlan

September 1984



Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

LBL-17667
SSC-MAG-22

A 40 mm BORE Nb-Ti MODEL DIPOLE MAGNET*

C. Taylor, W. Gilbert, W. Hassenzahl, R. Meuser, C. Peters,
J. Rechen, R. Scanlan

September 1984

Accelerator and Fusion Research Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

---

*This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, High Energy Physics Division, U.S. Dept. of Energy, under Contract No. DE-AC03-76SF00098.

A 40 mm BORE Nb-Ti MODEL DIPOLE MAGNET*

C. Taylor, W. Gilbert, W. Hassenzahl, R. Meuser, C. Peters, J. Rechen, R. Scanlan
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

Abstract

Preliminary R and D has been started on magnets for a next-generation high-energy-physics accelerator, the 20 TeV Superconducting Supercollider (SSC). One design now being developed at LBL is described in this paper. The design is based on two layers of flattened Nb-Ti cable, a 40 mm I.D. winding with flared ends, and an operating field of 6.5 T. Experimental results are presented on several one-meter-long models tested at both He I and He II temperature. Measurement of field, residual magnetization, quench propagation velocity, and winding prestress are presented. (A 2-in-1 magnet based on this coil design is being jointly developed by LBL and Brookhaven National Laboratory, and 15 ft. long models are being constructed at BNL).

Introduction

Preliminary R and D has been started on magnets for a next-generation high-energy-physics accelerator, the 20 TeV Superconducting Supercollider (SSC).[1] Different magnet designs are being investigated at several laboratories. Initial development of superconducting cables, construction techniques, and coil configurations for one of these designs is reported here. To minimize magnet costs, the bore diameter is small, and to minimize the costs of tunnel, land, etc., the magnetic field is high. This magnet has two layers of Nb-Ti cable, a 40 mm inside diameter winding with flared ends, a close-fitting iron yoke, and is designed to reach a 6.5 T central field at 4.5 K. One-meter-long models are being tested to evaluate training behavior, magnetization, structural integrity, and construction details. The first model, D-12A-1, reached 6.09 T at 4.4 K, and 7.4 ± 0.1 T at 1.8 K. Field uniformity, residual magnetization, quench propagation velocity, and operating stresses were measured. (A 2-in-1 magnet based on a similar coil design is being jointly developed by LBL and Brookhaven National Laboratory, and long models are being constructed at BNL.)

The first two models were wound with rectangular cable and used a ring-collet structural support system. Subsequent models, more closely resembling the SSC design goal, were wound with wedge-shaped ("keystoned") cable, have a more compact, improved end design, and use a split-iron support system. Test results are given here for the first two models, called D-12A-1 and D-12A-2. Two later models, D-12B-1 and D-12B-2, are described, but testing has not been completed.

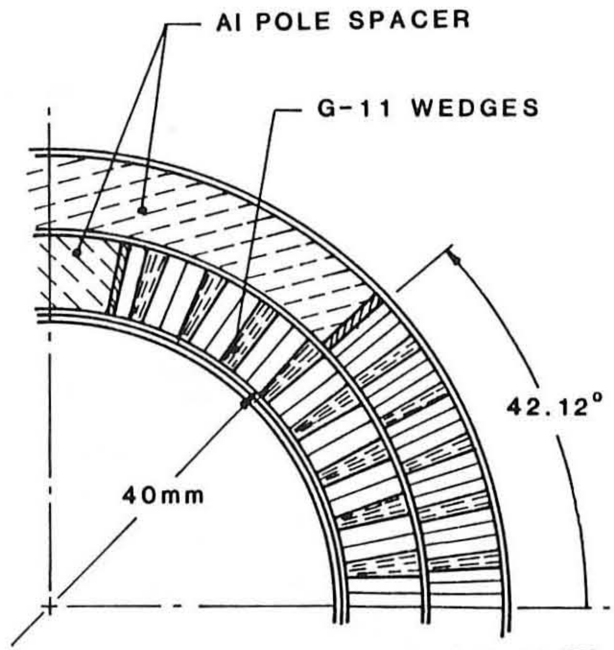
Coil Winding, D12A

The coils were wound on a cylindrical mandrel with an aluminum pole spacer and epoxy-fiberglass wedges inserted between groups of 2 or 3 turns to maintain an approximate radial position of the rectangular cable. Coil parameters are listed in Table 1, and a cross-section of the windings is shown in Fig. 1. Insulation is two layers of 8-mm-wide, 25 μm thick, Kapton, with approximately 5 μm of B-stage epoxy adhesive on the outer surface of each wrap. It was necessary to flare or enlarge the ends of the inner layer to be able to conveniently wind this size cable on a 40 mm bore diameter. The second layer does not have flared ends.

Table I

Parameters of the D-12A-2
1 Meter Long SSC Model Dipole

	Layer 1	Layer 2
Number of Turns	17	17
Inside Diameter (mm)	40.0	59.5
Outside Diameter (mm)	59.1	76.7
Pole Angle (°)	73.48	40.76
End Outside Diameter (mm)	76.7	76.7
Number of Wedges	10	6
Wedge Angle (°)	7.6	6.9
Precompression (MPa)	83	140
Midplane Shim (mm)	0.8	0.8
Coil Length (mm)	995	692
Number of Strands	23	27
Strand Diameter (mm)	0.808	0.635
Cu/S.C. Ratio	1.03	1.33
Nominal Cable Dimensions (mm^2)	1.44x9.35	1.19x8.56



XBL 849-3726

Figure 1. D-12-A Winding Cross-Section (Rectangular Cable).

The ends of the coil were wound on a conical form of epoxy-fiberglass laminate. After winding, the coil was clamped to about 83 MPa (12000 psi) and the

---

*This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, High Energy Physics Division, U.S. Dept. of Energy, under Contract No. DE-AC03-76SF00098.

Manuscript received September 10, 1984.

B stage epoxy cured at 150°C for 3 hours. This heating and compression process sets the adhesive which serves to hold the cable in place during subsequent assembly operations, and helps ensure a well-compacted, high-density structure.

Coil Assembly

The coils were assembled around a collapsible assembly mandrel. The two layers were pinned together and keyed into the mandrel for alignment. The coil halves were then held at a precompression of about 17 MPa (2500 psi) with a wrap of 0.25 mm thick by 2.5 mm wide Kevlar braid. The Kevlar was saturated with TFE to produce a slip-plane effect between magnet layers.

Layer 2 coils were then assembled in a fashion similar to Layer 1 and also held together with a layer of Kelvar braid.

Clamping

A tapered iron ring and aluminum collet system was used to clamp the coil assembly to produce a precompression of about 83 MPa (12,000 psi) in the inner layer and 140 MPa (20,000 psi) in the outer layer. A layer of 0.8-mm-thick aluminum slats plus a 0.4-mm-thick mylar radial spacer are placed between the coil and the collet.

The inside leads of the two halves of the outside were brought radially to the outside of the winding. All coil leads were brought axially to the magnet end as shown in Fig. 2. All connections between coils were made at the end of the magnet after coil assembly.

A split ring was used to transfer axial magnetic forces at the end of the outer winding into the magnet structure. After clamping, the magnet ends were loaded axially with eight 16 mm diameter aluminum tie rods external to the structural rings. A schematic drawing of the completed coil is shown in Fig. 2.

The compression of each layer during assembly and operation was measured by full bridge strain gages. Compression of both layers decreased to less than 14 MPa (2000 psi) during cooldown to liquid helium temperature. This loss of compression upon cooldown is due to the difference in thermal contraction between the iron rings and the coils.

Test Results, D-12A-1 and D-12A-2

D-12A-1 attained a maximum field of 6.09 T at 4.4 K with 5459 A after three training quenches. In helium II, between 1.8 K and 1.9 K, it reached 7.4 ± 0.1 T, 6823 A, after one training quench. The current is limited, in this magnet, because the short-sample limit was reached at the lead connection to the outer winding.

A second nearly identical magnet, D-12A-2, with more extensive instrumentation and re-designed leads was constructed and attained 6.51 T at 4.4 K with 6376 A; this corresponds to the expected "short sample" limit of the inner conductor. However, considerable training was experienced (~14 quenches). Normal testing is conducted at a rate of field increase of about 0.03 tesla per second. When field is increased at 1 tesla per second, the maximum current is 5310 A. Lower temperature tests were not made.

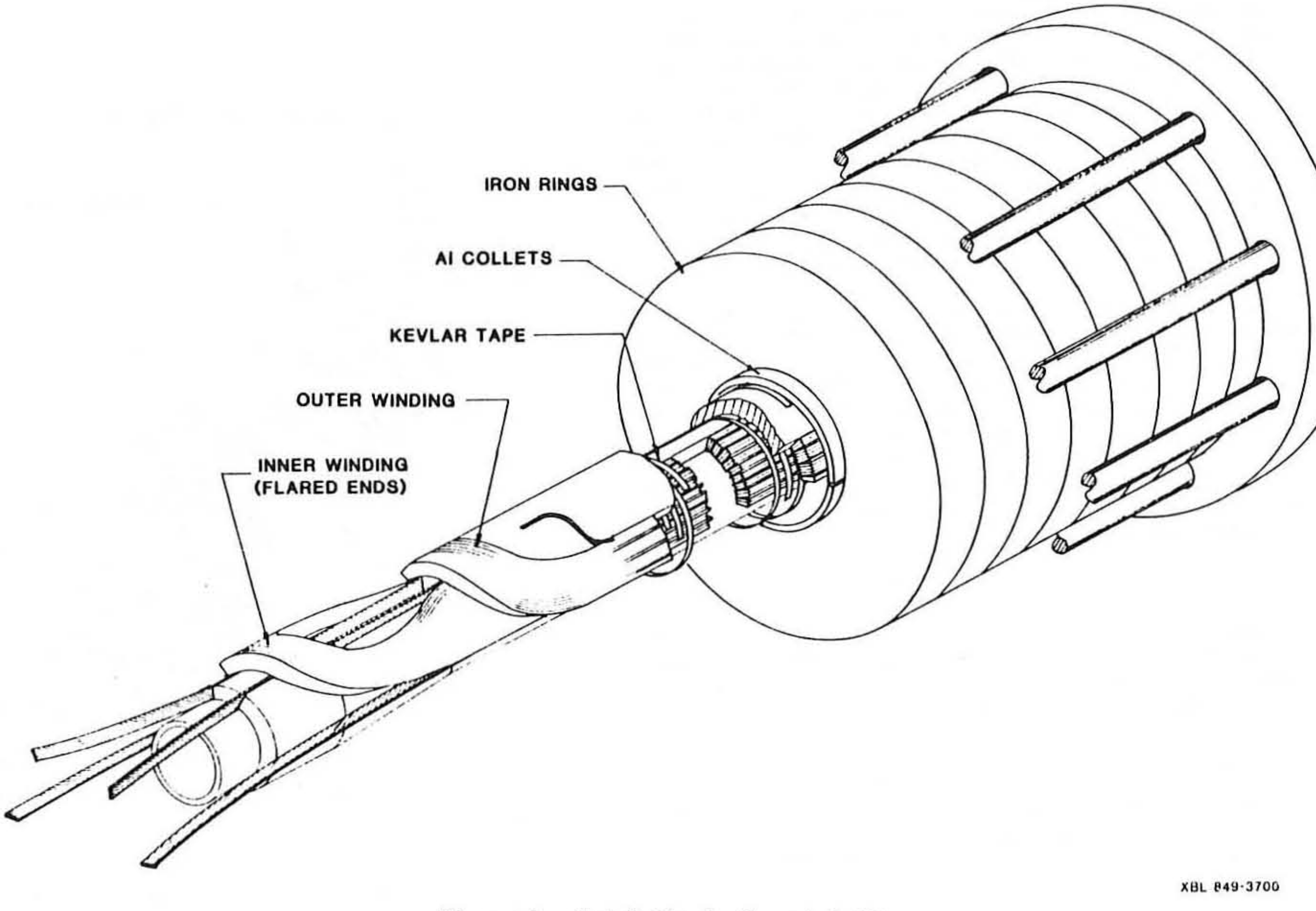


Figure 2. Model Dipole Magnet D-12A

Strip heaters 100 cm-long were installed between the pole and the first turn of each winding. Quenches were induced in the inner winding at several values of current; the rate of propagation of the normal region along the cable is given in Table II.

Table II

Current (A)	Velocity (m/s)
3000	3 - 6
4000	8 - 15
5000	18 - 25
6000	40 - 60

Figure 3 shows the continuous heater power required to initiate a quench. For a pulse of 25 ms duration, the required power is eight to ten times the continuous power for currents up to 5 KA.

One purpose of the test was to measure the residual magnetic field produced by a two-layer coil of this general design using Nb-Ti conductor with filaments approximately 20 μm diameter, and to explore a method for correcting the resulting field distortion. At a field of 0.325 T, corresponding to a possible injection field for an SSC, the maximum field distortion due to residual currents is approximately $\Delta B/B = 0.3$ percent at $r = 1$ cm, which agrees closely with theoretical predictions. The results of these measurements are described in a companion paper in these proceedings.[2]

Construction of Additional Models

Two additional model magnets, D-12B-1 and D-12B-2, with the same 40-mm-bore-diameter have been built incorporating the following features: split iron yoke (replacing the ring-collet yoke), improved superconductor with high J_c,[3] keystoned conductors, reduced number of wedges, metal wedges, more compact ends. These features are all included in a preliminary design for the SSC magnets (Fig. 4). Wedges inserted in each layer and constructed of copper to maximize heat conduction serve to make the central field sufficiently uniform and to make the winding mechanically self-supporting under radial compression. Table III gives parameters of the keystoned cable. Figure 5 shows the way the coil ends are flared to permit easy winding. Fabrication details and cable description will be reported later when tests have been completed.

Table III

Parameters of the D-12B
1 meter-long SSC Model Dipole

Number of Turns	17	17
Inside Diameter (mm)	40.0	59.7
Outside Diameter (mm)	59.3	78.9
Pole Angle (°)	74.01	44.85
End Outside Diameter (mm)	93	97
Number of Wedges	2	1
Precompression (MPa)	80	74
Coil Length (mm)	940	1006
Number of Strands	23	30
Strand Diameter (mm)	0.808	0.635
Cu/S.C. Ratio	1.3	2.0
Nominal Cable Dimensions (mm)	1.402x1.673 x0.30	1.15x1.406 x9.53

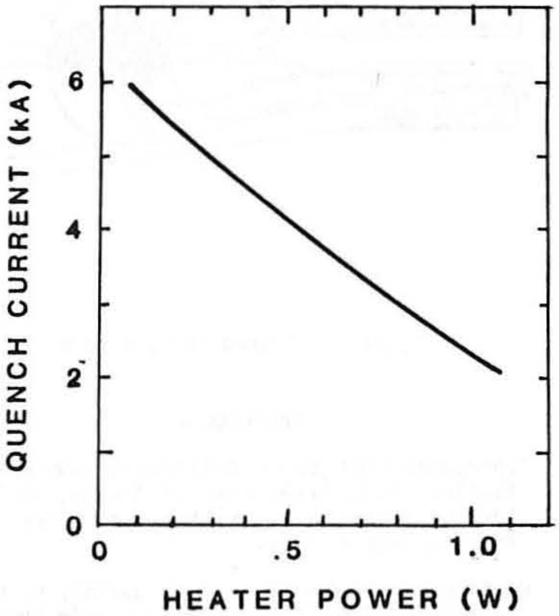
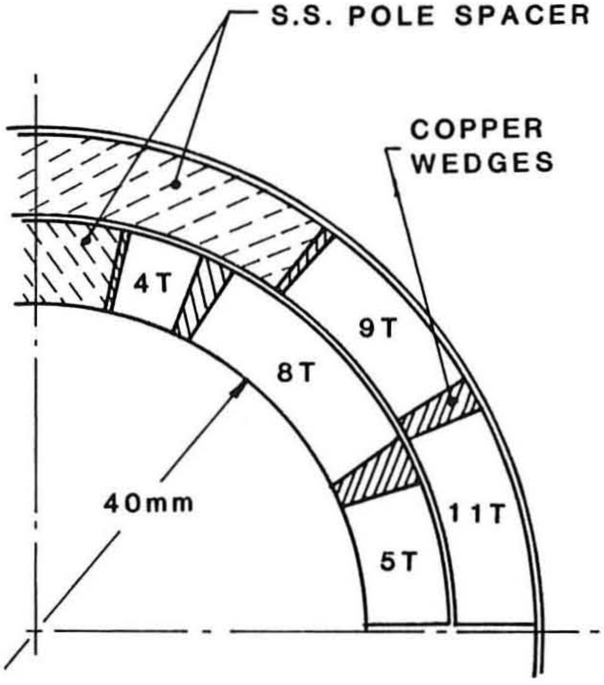


Figure 3. Heater Power Required to Initiate Quench.



XBL 849-3727

Figure 4. D-12-B Winding Cross-Section (Keystoned Cable)

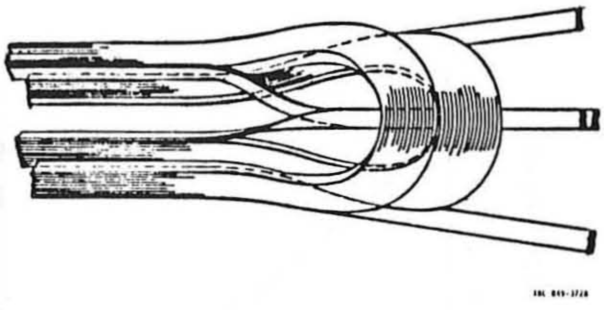


Figure 5. Flared Ends, D-12-B.

References

1. Superconducting Super Collider-Reference Design Studies, U.S. Department of Energy, Office of Energy Research, Division of High Energy Physics, May 8, 1984.

2. W. Gilbert, A. Borden, W. Hassenzahl, G. Moritz, C. Taylor, "Superconducting Sextupole Correction Coil Operating in Persistent Mode," Paper GL-3, this conference.

3. D.C. Larbalestier et al., "First Evaluation of Composites Made from Homogeneous Nb-46.5 w/o Ti," Paper CM-3, this conference.