CDF Superconducting Solenoid

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A thin 3 mϕ x 5 m, 1.5 T superconducting solenoid for the Fermilab Collider Detector Facility (CDF solenoid) was constructed.[1] The initial cool-down and excitation tests without an iron return yoke were performed at the Hitachi Research Laboratory, Japan in the spring of 1984.[2] The final tests which include the full excitation of 5000 A were completed very successfully at Fermilab, March 1985 after the solenoid was installed in the CDF detector assembly with the iron return yoke. Figure 1 shows the installation work of the solenoid in the B0 Assembly Hall at Fermilab.

The main parameters of the CDF solenoid are summarized in Table I. The schematic drawing of the end section of the solenoid is shown in Fig. 2. A superconducting coil consists of a single layer helical winding of aluminum-stabilized NbTi/Cu superconductor of 1164 turns. The solenoid utilizes the forced flow cooling method of two-phase helium and does not possess a permanent inner bobbin. The radially outward magnetic forces are supported with an aluminum-alloy cylinder inside which the coil is mounted with the shrink-fit assembly.[3] The vacuum chamber of the cryostat is made of aluminum alloy. The overall material thickness of the main section of the solenoid is 0.85 radiation length in the radial direction. Figure 2 illustrates one of six axial support members placed only at one axial end in order to allow the thermal contraction of about 20 mm in length. Twelve radial support members are used at each end. The control dewar is located outside the iron return yoke and connected to the cryostat with the chimney in order to minimize the interference with the detector system. The total weight of the solenoid without including the chimney and control dewar is about 11 tons and the cold mass is about 5.6 tons.

The conductor was fabricated with the EFT method (Extrusion with Front Tension).[4] The schematic diagram of the conductor cross section is shown in Fig. 3. Aluminum of about 99.999% in purity was friction welded to the copper surface of the monolithic NbTi/Cu superconductor in the extrusion process. A 1 mϕ x 1 m R&D superconducting solenoid was constructed in order to develop a new fabrication technique and to study detailed characteristics of the conductor.[5] High thermal conductivity and electrical conductivity of the high purity aluminum stabilizer provide thermal stability to the coil. Electrical and mechanical properties of the binding between aluminum and copper were substantially better than those made with soldering.[6] The conductor width of 20 mm was primarily determined to hold the maximum coil voltage to ground less than 500 V and the maximum temperature rise less than or near 100 K during quenches. Extensive computer simulations were carried out by using quench data of the R&D solenoid.[7]

Figure 4 gives measured magnetic flux versus critical current data for ten conductor units used in the coil. Short sample data were measured for samples from the two ends of each unit of about 1350 m in length. The conductor was wound on a temporary mandrel which was removed after the shrink-fit assembly of the coil and support cylinder was completed. In total ten conductor joints were made with the welding method.[5] The resistance for each joint was estimated to be less than $6 \times 10^{-10}\ \Omega$ at 4.2 K.

Liquid helium cooling tubes of 20 mm in inner diameter were welded to the outside surface of the support cylinder before the shrink-fit assembly. The cooling path was arranged to be a single loop and to be mostly serpentine to avoid inhomogeneous liquid distributions due to the garden hose effect.

In the initial tests at Hitachi the maximum excitation current was limited to 2800 A because of the excessive compressive load to the coil in the axial direction without the iron return yoke. The coil was cooled from room temperature to liquid helium temperature in about seven days. The cooling rate was maintained at about 2 K/h until the coil was cooled to liquid nitrogen temperature and then it was raised appreciably. Thermal response of the solenoid during the cooldown and excitation tests was very steady and reasonable. A series of induced quench tests was attempted by using a heater installed at the outer support cylinder. The coil did not show any sign of development of a normal region even for a large heater input of about 10 kJ within a period of one minute at 2800 A. A warm-up test was carried out by stopping the helium flow at an excitation current of 10 A. The coil stayed superconducting for about 90 min and then the entire coil became normal very uniformly. This result is consistent with the heat load of the solenoid of about 35 W measured in a separate test.

In conclusion, the results of these tests reveal the excellent thermal stability of the CDF solenoid. It is remarkable that the solenoid with the forced flow cooling system did not quench for a heater input of 10 kJ. This thermal stability may be due to the following reasons: (a) good quality of the aluminum stabilized NbTi/Cu superconductor with the EFT method, (b) the shrink-fit assembly of the coil and support cylinder, (c) the mechanical structure of the coil without having a permanent inner bobbin, (d) the arrangement of the cooling tubes which were welded to the outer support cylinder, and (e) the good design of the cryostat.

Essentially the same results were obtained in the cooling test at Fermilab and details of those tests including the full excitation will be given later. It should be noted that the CDF solenoid is the first thin, large superconducting solenoid that met the design goal without any difficulty.

The auhtor would like to thank the members of the CDF solenoid group for their contributions to the success of the CDF solenoid.

References

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Figure Captions

1. Picture of the installation work of the solenoid in the B0 Assembly Hall at Fermilab.
2. Schematic drawing of the end section of the CDF solenoid at the chimney side. An enlarged view shows the coil conductor and FRP layer. All dimensions are in mm.
3. Schematic diagram of the conductor cross section.
4. Measured magnetic flux versus cririical current data for 20 short samples at 4.2 K. The vertical bars drawn correspond to distributions of the data. The load line for the CDF solenoid with the iron returen yoke is shown. The design current is 5 kA for 1.5 T. Also shown are the standard curves at 4.2 and 4.7 K.

Table I. Main parameters of the CDF solenoid.

Items	Parameters
Vacuum vessel	
Diameter; outer/inner	3353 mm / 2858 mm
Length	5067 mm
Material	A5083 aluminum
Wall thickness; outer/inner	20 mm / 7 mm
Central field	1.5 T
Material thickness	0.84 radiation length
Total weight	11 tons
Cold mass	5.6 tons
Coil	
Current	5000 A
Inductance	2.4 H
Stored energy	30×10^6 J
Number of turns	1164
Winding scheme	Single layer helix
Supporting structure	Shrink-fit assembly with outer support cylinder; no inner bobbin
Conductor	
NbTi/Cu/Al ratio	1/1/21
Dimensions	3.89×20.0 mm^2
NbTi filaments	Nb-46.5 Ti , 50 μmφ x 1700
Standard short sample current	10.4 kA at 1.5 T and 4.2 K
Purity of aluminum stabilizer	~ 99.999%
Outer support cylinder	
Material	A5083 aluminum
Thickness	16 mm
Liquid helium cryogenics	Forced flow two-phase
Liquid nitrogen cryogenics	Forced flow

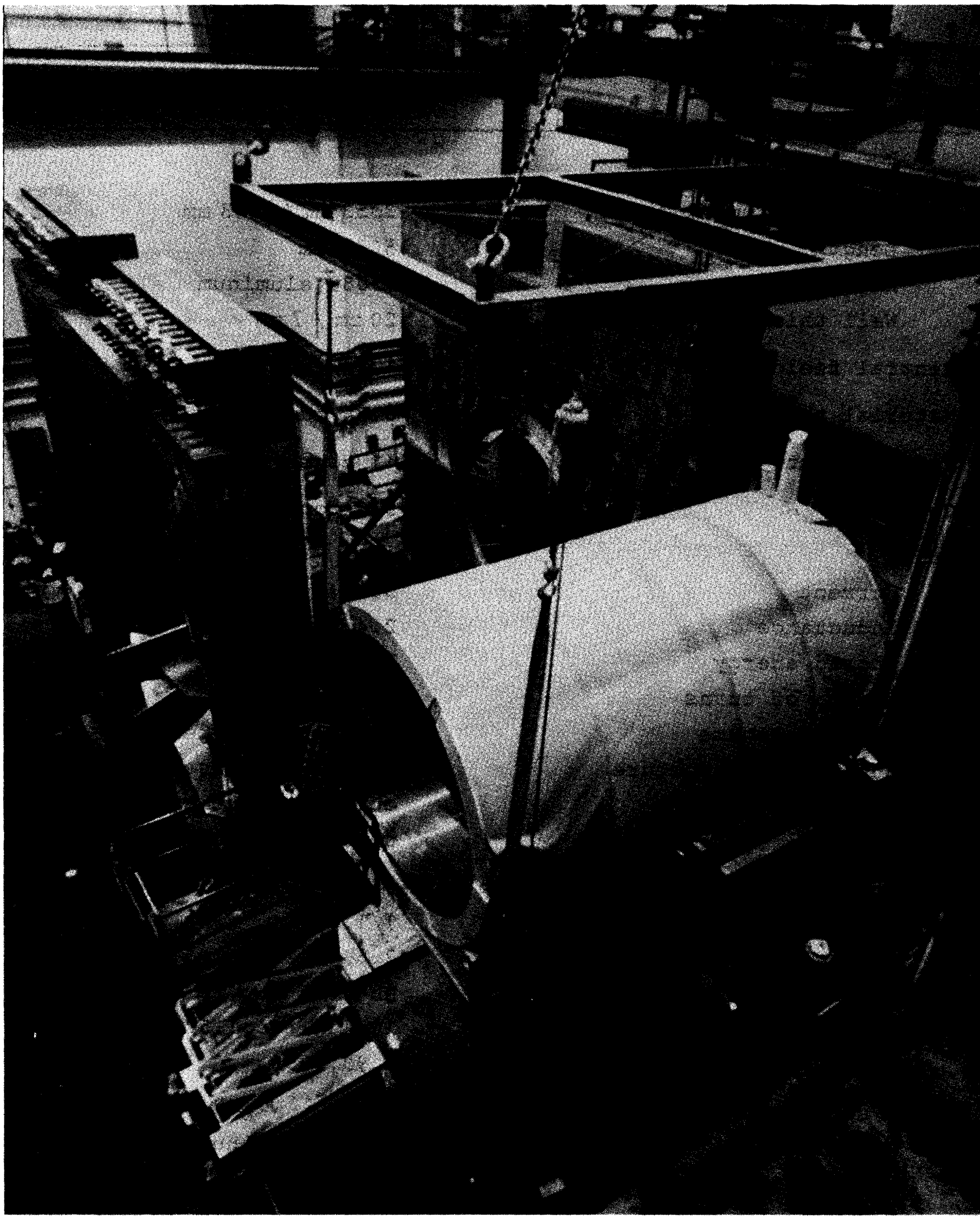
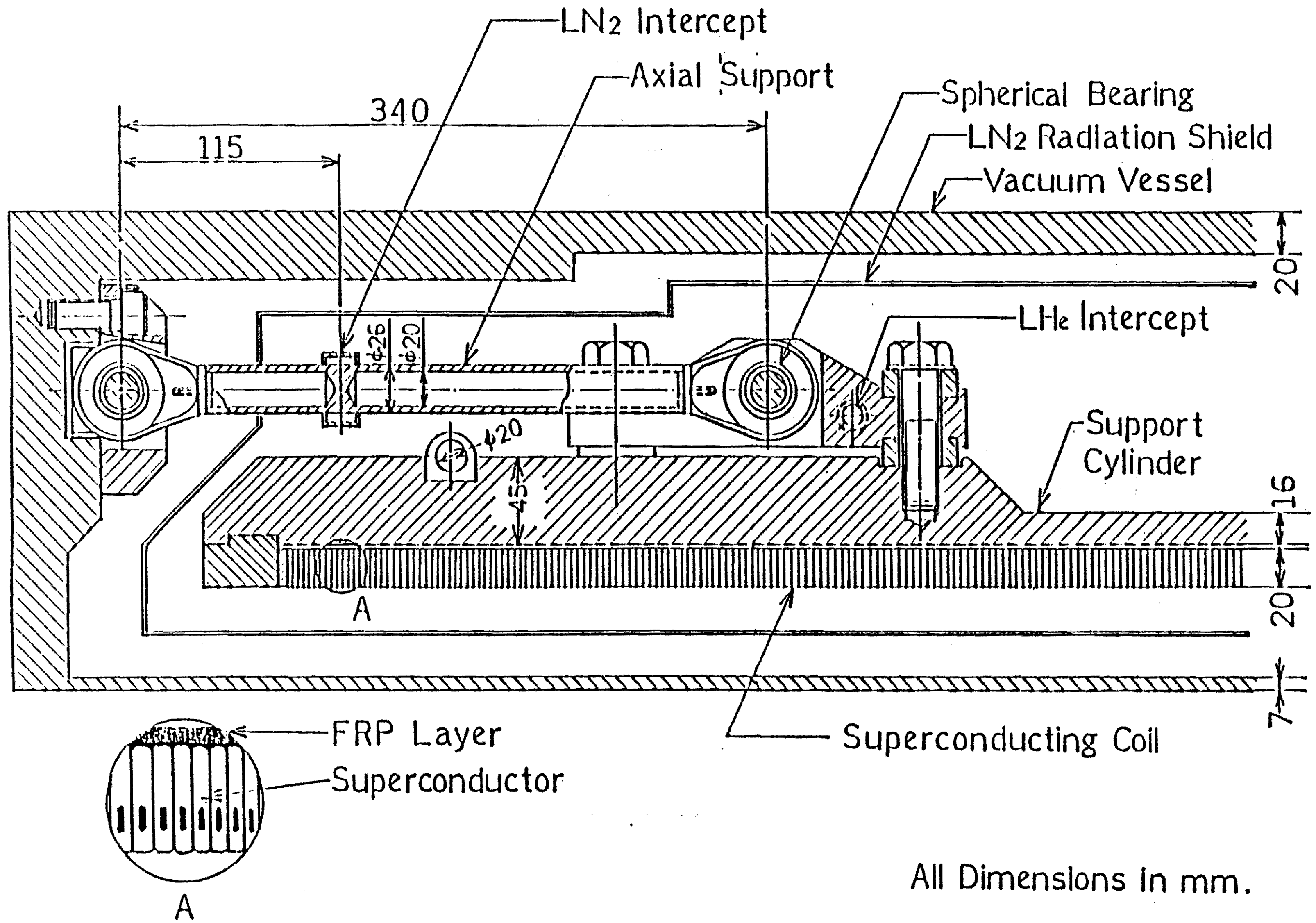


Figure 1.



LN2 Intercept
Axial Support
Spherical Bearing
LN2 Radiation Shield
Vacuum Vessel
340
115
φ26
φ20
φ20
45
LHe Intercept
Support Cylinder
20
16
20
7
A
Superconducting Coil
FRP Layer
Superconductor
A
All Dimensions in mm.

Figure 2.

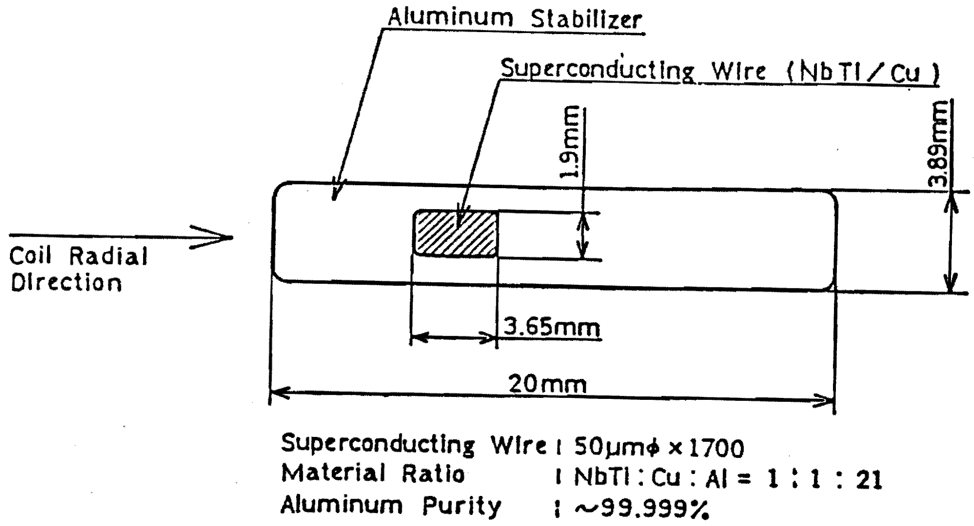


Figure 3.

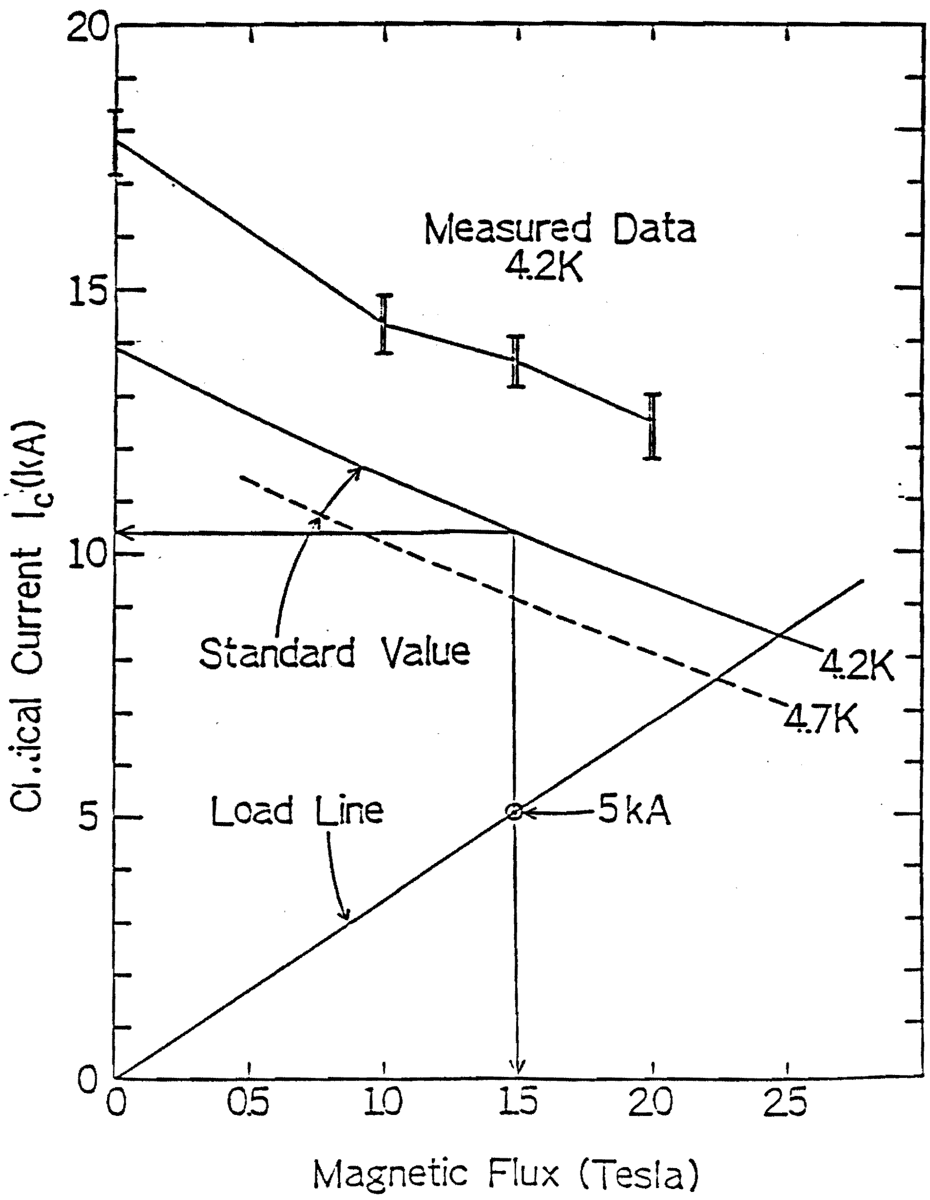


Figure 4.