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A SUPERCONDUCTING DIPOLE FOR THE FERMILAB SWITCHYARD

J. Walton, R. Dixon, H. Edwards and J. McCarthy*

Summary

A prototype superconducting dipole for the Fermilab switchyard has been built and tested. The design is warm iron, cold bore, 2½-inch circular aperture, 3 tesla at 2850 amps. The length is 3½ feet. This will be increased to 10 feet in the final design.

Superconductor

NbTi cable of the Rutherford style was used. The 11 strand cable is rectangular, .044 inch x.144 inch, with 3000 filaments in each strand. The strands are .025 inch in diameter, with a 1.25 to 1 copper-to-superconductor ratio. Short-sample properties measured at Fermilab are shown in Fig. 1.

The cable is insulated by a half-lap wrapping of .002-inch Kapton film, giving a final dimension of .052 inch x .152 inch. Experience at Fermilab has indicated that the presence of epoxy in superconducting coil structures has a degrading effect on the training. For this reason no epoxy-impregnated glass tape was used in preparing the cable.

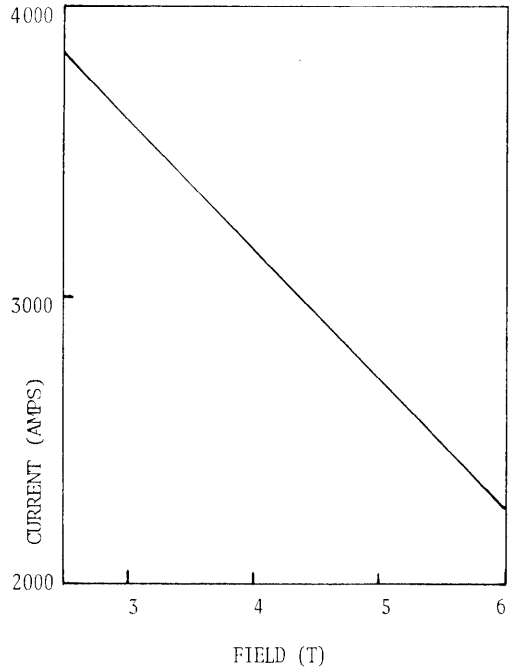

Fig. 1 Short Sample Characteristics of 11 Strand Cable

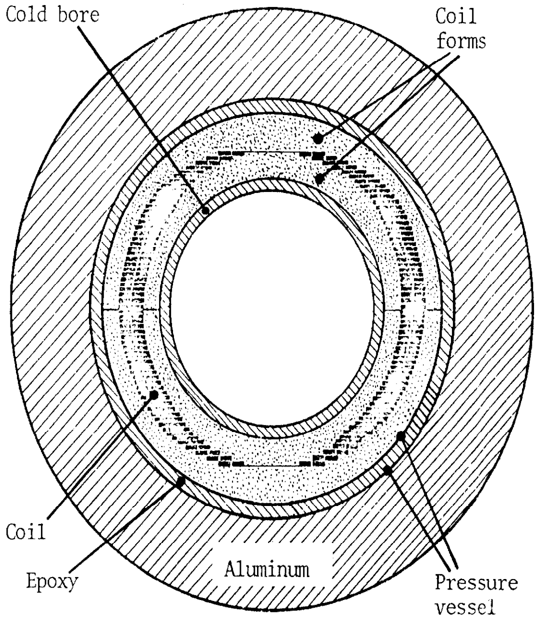

Fig. 2 Magnet cross section

Mechanical Construction

Figure 2 shows a magnet cross section. The bore tube is 2½-inch I.D. stainless steel, 1/8-inch wall. A $\cos\theta$ distribution of current density is approximated by conductor placement. The coil is wound in 2 layers, with a total of 124 turns. After winding in a fixture the coil is assembled on the bore tube. Coil forms are glass cloth-epoxy composite, molded by a vacuum impregnation process.

A 6½-inch O.D., 1-inch wall aluminum tube provides mechanical rigidity and preloading. The coil structure is clamped within the tube by pressurizing a small annular space (3/16-inch) with epoxy at 1500 $\mathrm{lbs/in^2}$. The epoxy is contained in a stainless steel vessel constructed with .018-inch wall concentric tubes. As the epoxy cures (about 2 hours) pressure is maintained to compensate for shrinkage. Tests have shown that the final structure is prestressed as desired, ie, maintaining pressure on the epoxy during the cure does correct for any shrinkage. One major advantage of this technique is that uniform prestress is assured without need for precision tolerances of component parts. Training curves of Fig. 4 attest to the success of the process.

Contraction of the massive aluminum tube relative to the stainless steel bore tube, coils and coil forms results in a net gain in preloading as the magnet is cooled to liquid-helium temperature. This is seen as an advantage, even though the increase in loading is not uniform due to azimuthally varying thickness of coils and coil forms.

End Configuration

The end configuration of Fig. 3 follows naturally from the cross section of Fig. 2. Two prototype magnets were built. The angle θ was 20° for the first and 30° for the second. A major difficulty is the appearance of turn-to-turn shorts at the ends as the coil is compressed. With this configuration, high stress points are unavoidable and cable insulation failed. This was overcome by embedding the end turns in a small amount of "green putty". The putty, a filled epoxy designed for cryogenic applications, is cured before compressing the coil, giving unifrom support to the cable.

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*Fermi National Accelerator Laboratory, P. O. Box 500 Batavia, Illinois 60510**

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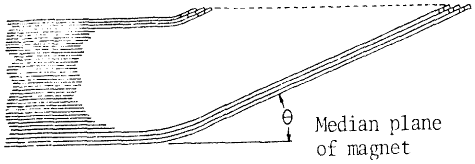

Fig. 3 Coil end configuration

Cooling

The cooling scheme requires a flow of subcooled liquid helium in contact with the coil and returning as a two-phase mixture along the outside of the coil structure. Spiral cooling passages are provided on the inside coil form. Two phase return flow passes through a spiral channel on the inside diameter of the aluminum tube. The passages are sized to give a flow of 4 lb/hr with a driving force of about 4 lb/in^2.

Training

The second of the two magnets built was assembled with the pressurized epoxy process. For the first magnet the aluminum tube was split and drawn together with bolts. Preload in both cases was approximately the same. Difference in ultimate current (Fig. 4) is due to slightly different end configurations, resulting in higher peak fields for the second magnet. Note especially a virtual absence of training for the pressurized epoxy magnet.

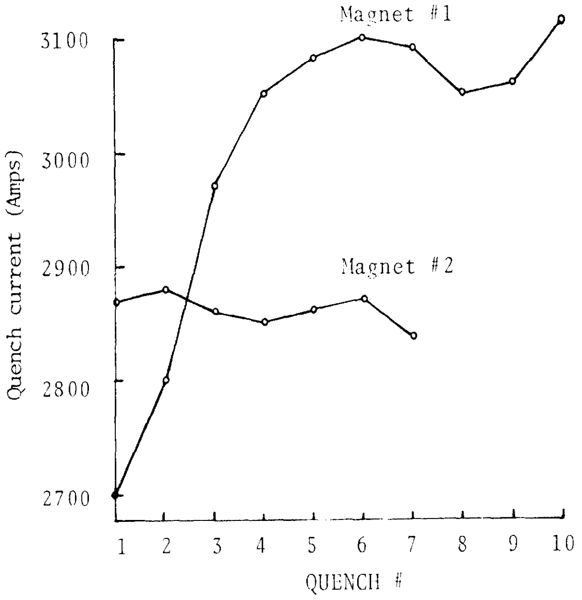

Fig. 4 Training Curves

Cryostat

The cryostat is of all welded construction with superinsulation on both sides of a liquid-nitrogen shield (Fig. 5). The magnet assembly is supported inside an 8 3/4 inch, .036-inch wall stainless steel tube by 2 sets of 4 G-10 posts. The posts, 3/4 inch in diameter, have glass cloth layers normal to the axis for maximum strength in compression. Each post is intercepted by the liquid nitrogen shield, giving a calculated heat leak for the support system of less than 2 watts. Superconducting power leads enter through a liquid helium supply line.

A 2-piece laminated iron yoke clamps on the cryostat and is spring-loaded against the G-10 posts (Fig. 5). During cooldown, the yoke halves mate together. Travel is about 1/32 inch. By compensating for contraction this scheme insures positive centering of the magnet in the iron when cold.

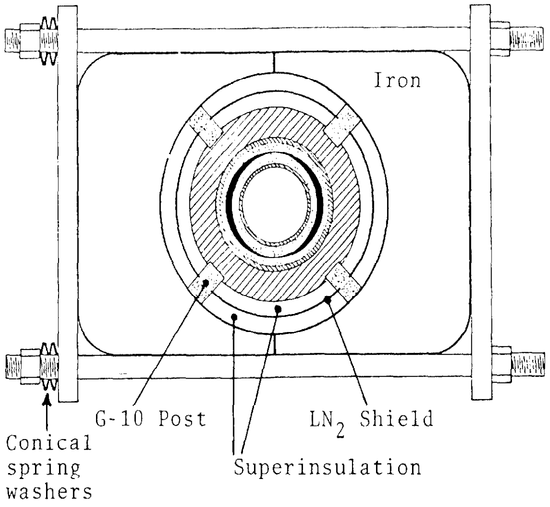

Fig. 5 Cross section of magnet and cryostat

Field Quality

Initial emphasis in this project is on mechanical and cryogenic problems. Adjustments of conductor placement can be made to improve field quality in the final design. Initial measurements at low current (room temperature) show a field error of about .2% in a 1.6-inch aperature. Happily, these errors are largely cancelled by the end fields for a 10-foot magnet. Measurements of harmonic components as a function of excitation have not yet been done.

Acknowledgements

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