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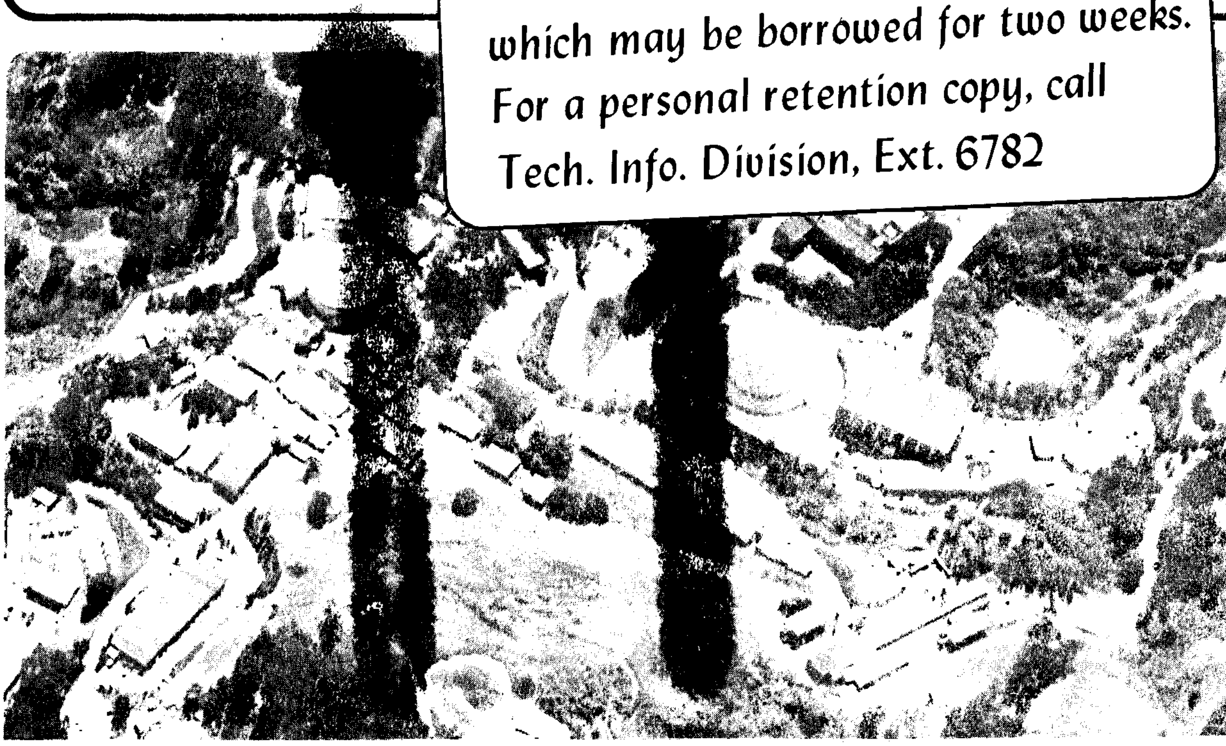

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DISCLAIMER

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INTRODUCTION

A thin superconducting solenoid for the Time Projection Chamber (TPC) experiment at PEP was constructed at Lawrence Berkeley Laboratory (LBL) in 1979[1] and tested in 1980. A failure of the ground plane insulation damaged the coil to the point that it required rebuilding. An extensive study of this failure[2] indicated that an iron chip embedded in the bore tube had penetrated the insulation. Before rebuilding the coil, an investigation of the insulation system was done with the goal of determining the most reliable techniques and materials for withstanding high voltages in the coil package.

The experience with the TPC coil and its prototypes indicate that glass cloth vacuum-impregnated with epoxy is an excellent material for cryogenic applications from the mechanical standpoint.[3] Further, since the LBL assembly shop had extensive experience with the epoxy formulation used in the coil, there was

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reluctance to change that component. Therefore, the investigation concentrated on different types of glass cloth and on composites containing glass cloth.

PROCEDURE

The samples of insulation were wrapped on an aluminum tube 8 cm diameter and 30 cm long. Formvar-coated rectangular (0.9 mm x 3.6 mm) wire was wound spirally and closely packed over the insulation. Another layer of glass cloth was wrapped on top of the wire before epoxy impregnation. Figure 1 shows the cross section of a typical sample. The samples were vacuum cast and cured using the epoxy resin system described in Ref. 3. Figure 2 shows a sample cylinder after casting but before thermal cycling.

The wire used in making the samples was superconductor from the same lot used to wind the TPC magnet in 1979. This wire is rectangular with bare dimensions of 3.6 x 0.9 mm. It was insulated with formvar, 0.05 mm thick. When the superconductor was tested at 750 V from a wire brush covering a one centimeter length, the insulation failed at a nearly continuous rate. Almost all of the formvar insulation failures occurred because the formvar was not continuous on the corners. (A sample of wire was tested for breakdown through the formvar at the center of a flat face. The 0.05 mm layer of formvar broke down at 15 kV. The formvar itself is good insulation, provided it is continuous.)[4]

Since the goal of the experiment was to learn how the insulation system as a whole worked, we decided to use wire previously insulated. Two samples were wound with uninsulated wire. Almost all of the insulation system failures, when disected, were found to have occurred at the edge of the wire. Since the insulation is very bad on the corners of the wire, the insulation values measured should probably be considered to be due to the insulation components other than formvar.

The samples were subjected to severe thermal shock by dipping in liquid nitrogen (LN) until boiling stopped and then in warm water. This thermal cycle was repeated 25 times. After thermal cycling, the samples were tested at voltages incremented to an upper limit of 25 kV. The sample was held for 60 sec at each voltage.

TEST RESULTS

Twenty-three samples were tested: Tables 1 and 2 give a summary of these samples and their performance. The samples fell into two categories: Samples were made either with glass cloth

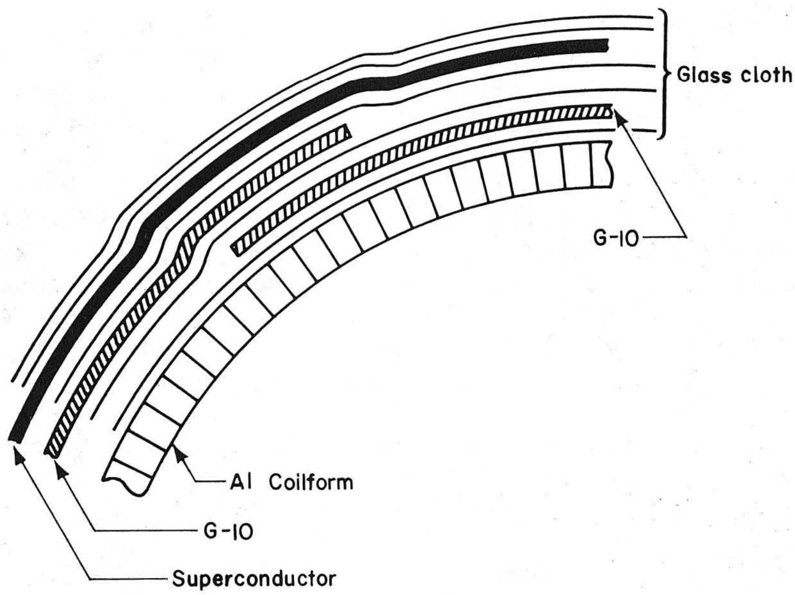

Fig. 1. Cross sectional view of a typical sample, showing "sandwich" construction.

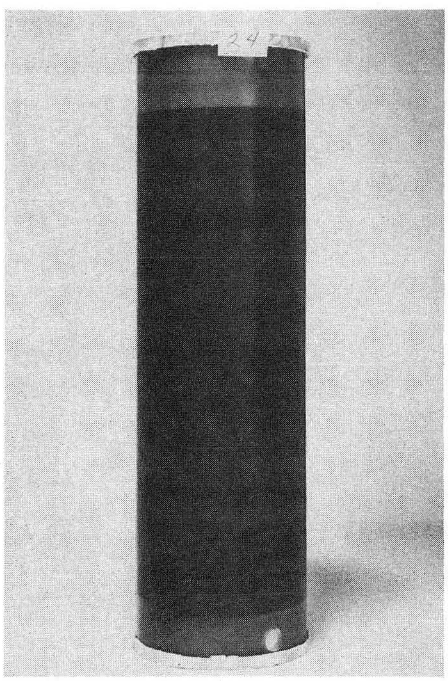

Fig. 2. Typical sample after casting, before thermal cycle.

alone between conductor and ground plane, or with a sandwich of additional insulation material and glass cloth separating conductor and ground plane. The additional insulation material was intended to act as a chip barrier as well as to ensure continuous insulation in the event of imperfect epoxy filling when potting. All sandwich samples were capable of holding off 25 kV. Many of the sandwiches were holding off more than 40 kV/mm (1 kV/0.001 in.) at 25 kV, with the Nomex sample holding off in excess of 80 kV/mm. A test was performed on an area of FR-4 a fire retardant glass epoxy laminate similar to NEMA G-10 that was 20 x 20 cm square. The 0.016 in. thick piece of FR-4 held off 25 kV even before adding it to a sandwich of additional glass fabric and epoxy.

The glass fabric samples were wrapped using narrow tape spiral wrapped around the sample form. This was done in one of two techniques:

(1). Half-lap: the trailing edge of the tape on a given turn would fall near the center of the tape of the previous turn and fall near the leading edge of the tape two turns previous while not overlapping it.

(2). Butt-lap: the trailing edge of the tape on a given turn would fall near the leading edge of the previous turn but not overlap it.

Two major trends developed in the tests of the glass fabric (non-sandwich) samples: 1) The finest weave samples held the highest voltage gradients, around 40 kV/mm, and 2) when samples broke down, the fault often was at the edge of the glass fabric tape. This would represent an area where there was one less layer than nominal of glass fabric, but the overall thickness of the laminate would not be changed since the void was filled with epoxy.

When the samples were thermal cycled, a very limited amount of cracking was observed. This cracking occurred in areas where unfilled epoxy had built up in layers of a thickness greater than 0.8 mm. In areas where the epoxy was well filled with glass, there was no cracking. If the glass cloth was not treated for use with epoxy (Volan treatment) a cloudy appearance developed in the laminate after only a few cool downs. The cloudy appearance is caused by failure of the bond at the boundary between glass and epoxy. This did not seem to affect performance of the insulation electrically, but it probably affects the strength of the composite. It is felt that the special glass treatment will result in a stronger composite structure over the long term.

Table 1. Sandwiched insulation samples (all withstanding 25 kV).

Sample 1	Sandwich material[a]	Glass cloth Thickness (inches)	Glass cloth Width (inches)	Overall nom. thickness (inches)	Voltage stress at 25 kV (kV/mm)
4	0.016 FR-4	0.010 x 1 0.007 x 2	12.0 0.75	0.040	25
6	0.016 FR-4	0.030 x 1 0.007 x 2	12.0 0.75	0.060	16
7	0.005 Kapton	0.010 x 1 0.007 x 2	12.0 0.75	0.029	34
8	0.16 FR-4	0.010 x 1 0.007 x 2	12.0 0.75	0.040	25
15	0.016 FR-4	0.010 x 1 0.007 x 2	1.5 0.75	0.040	25[b]
17	0.16 DMD[c]	0.003 x 2	1.5	0.022	45
18	0.007 Mica-glass[d]	0.003 x 2	1.5	0.013	76
19	0.16 FR-4	0.003 x 2	1.5	0.025	39
20	0.0055 Nomex	0.003 x 2	1.5	0.0155	86
25	0.007 G-10	0.003 x 3	0.75	0.16	62

[a]FR-4, G-10, and Kapton were sandblasted; DMD, Micaglass, and Nomex were not sandblasted.
[b]Not thermal cycled.
[c]DMD is a dacron-mylar-dacron laminate.
[d]Micaglass is also known as "Isomica," produced by US Samica Corp.

Table 2. Glass cloth alone insulation samples

Sample Number	Glass thickness[a]	Tape width (in.)	Filling picks (per in.)	Warp ends (per in.)	Breakdown voltage[b] (kV)	Voltage stress at breakdown (kV/mm)
3	0.007 x 3	0.75	31	41	22.5	42
5	0.007 x 3	0.75	26	48	20	37
9	0.010 x 3	1.5	15-1/2	17-1/2	22.5	30
10	0.015 x 2	1.5	14	26-1/2	10[c]	13[c]
11	0.010 x 2	3.0	17	18	7.5[d]	15[d]
12	0.022 x 2	3.0	15	27-1/2	25	22
13	0.014 x 2	3.0	14-1/2	16-1/2	10	14
14	0.010 x 2	3.0	17	18	17[e]	33[e]
16	0.007 x 3	0.75	31	41	25[f]	47[f]
21	0.007 x 2	3.0	30	38	16.5	46
22	0.010 x 2	1.5	15-1/2	17-1/2	6	12
23	0.007 x 3	0.75	31	41	10[g]	19[g]
24	0.003 x 3	0.75	40	64	15	66

[a] x 2 = half lap; x 3 = half lap + buttlap.
[b] Formvar insulation was bad at wire edges, see text. Samples 16 + 22 used uninsulated wire.
[c] A special fabric with glass fibers woven across the tape (filling picks) and dacron fibres running along the length of the tape (warp ends).
[d] Failed at 7.5 kV after cycling, sample had held 10 kV before thermal cycling, with fault removed it went to 14 kV.
[e] Not thermal cycled.
[f] Did not fail at 25 kV.
[g] Failed at 10 kV before cycling, with fault removed it held 25 kV after cycling.

After the thermal cycling and electrical breakdown tests, the samples were disected. The strength of the bond between various materials was observed as well as any signs of delamination. The DMD was found to have separated at the commercially joined boundaries between the dacron and mylar. The mica-glass was found to be easily parted at the mica surfaces; this is a property of mica rather than an adhesive failure. The bond between the treated glass and sandblasted NEMA G-10 or FR-4 is very strong, comparable to that of NEMA G-10 itself. The bond of untreated glass cloth seemed to be slightly less strong, followed by Kapton and Nomex.

CONCLUSIONS

On samples 11 and 23, the initial breakdown voltage seemed unusually low. When the conductor was peeled back in the failed region, the remainder of the sample went to much higher voltages. This would indicate that local imperfections in the materials are likely to be the cause of a failure in a large casting, even though the material may have good characteristics when tested in small batches. By using the sandwich of non-porous insulator between layers of glass cloth fabric, the chances of failures of this sort should be markedly reduced. The non-porous insulation should be checked for pinhole faults before assembly. Since this layer also represents a barrier to chip penetration, the sandwich fabrication is our first choice insulation method. We prefer glass-epoxy such as FR-4 or NEMA G-10 since we have previous experience with them in similar potted coils. Materials such as Kapton or Nomex look promising for future development.

Glass fabric provides a path for epoxy flow to all the non-porous insulator; it should be a fine woven fabric for maximum insulation value. Additional epoxy flow channels are also provided in the TPC magnet design, due to the large size of the coil.

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REFERENCES

1. M. A. Green et al., "Progress on the Superconducting Magnet for the Time Projection Chamber Experiment (TPC) at PEP," Lawrence Berkeley Lab. Rpt. LBL-11007, May 1980.
2. M. A. Green et al., "Ground Plane Insulation Failure in the First TPC Superconducting Coil," Proceedings of 7th International Conference on Magnet Technology, Karlsruhe, W. Germany, 30 March - 3 April 1981.
3. M. A. Green et al., "Vacuum Impregnation with Epoxy of Large Superconducting Magnet Structures," Nonmetallic Materials and Composites at Low Temperature, pp 409, Plenum Press, New York, 1979.
4. J. Billan, "Selection of the Insulation of Superconducting Wires for D.C. Magnet," Proceedings of the International Symposium on High Voltage Insulation for Low Temperature Application, Wroclaw, Poland, 13-17 September 1976, CERN-ISR-LTD/76-13.

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