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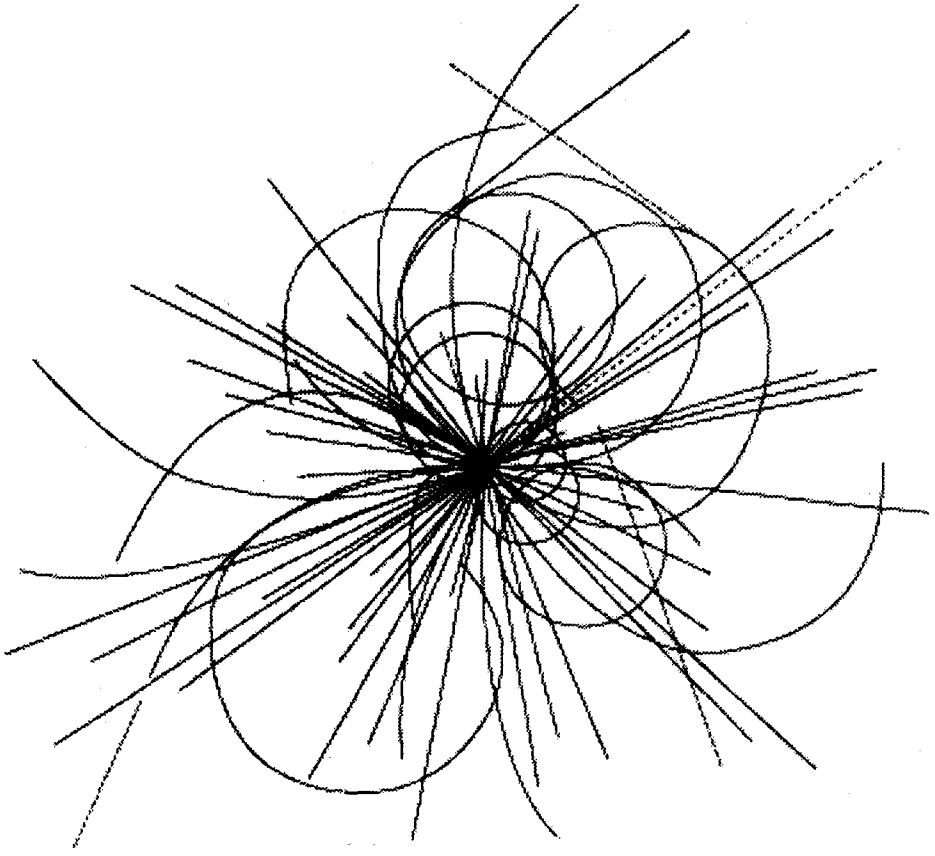

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A Study of Variations in Dipole Cable Insulation Systems and Their Effect on Creep*

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A STUDY OF VARIATIONS IN DIPOLE CABLE INSULATION SYSTEMS AND THEIR EFFECT ON CREEP

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INTRODUCTION

In late 1991 the Fermilab Manufacturing Group was directed by the Superconducting Super Collider Laboratory (SSCL) to investigate, build and test a series of magnets utilizing a low temperature cured all polyimide insulating system. Since an all polyimide insulated system was suspected to have higher post- collared stress relaxation than the existing glass tape system, a study was initiated to find ways to minimize the stress relaxation.

For the study six different polyimide films possessing different modulus characteristics, coated with either 3M type 2290 Epoxy or Allied Signals Cryorad† were wrapped onto five inch pieces of 50 mm inner cable in various combinations and in various build-ups. Ten of these wrapped cable segments were made into vertical stacks and cured with a low temperature cure cycle of approximately 290°F. The curing cycles were carefully reproduced for each sample. Samples were run with constant cure pressures of both 6 K psi and 10 K psi. These stacks were then measured for creep at a constant pressure of 12 K psi for one hour and for modulus of elasticity using the size delta between 8 K psi and 12 K psi. The results of this data as compared to the glass tape base line are presented here.

In the graphs and charts in this paper the legend code is as follows: i.e., HA5, 2/3HA, BLT means a stack named HA5 was composed of a first layer containing a 2/3 overlap (3 layers) of type HA film and a second layer of butt wrapped type LT film. Later in the study the name became the description plus a dash number (i.e., the above stack would be HA3LT-1). When the lower layer contained glue the letter E for epoxy or C for Cryorad was added in.

Figure 1 is a plot of "equivalent coil creep" versus cure pressure. Equivalent coil creep is obtained by multiplying the measured stack creep by 2.033 which adjusts the ten material layers of the stack data to approximate the layers in a curved inner 50 mm dipole coil. (It is derived from the 19 turns of cable and insulation plus the insulation only on the wedges). This scale adjustment allows a rough indication of how the various wrap combinations would perform in a coil configuration.

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† "Cryorad" and "Apical" are trade names of Allied Signal. "Kapton" is a trade name of Dupont. "3P" is a trade name of Sheldahl.

The number of layers of polyimide insulation around each cable is indicated down the middle of the graph. The legend identifies the two stacks cured at 6K psi and 10 K psi used for each graph line as well as the shorthand code for the layer identification.

The following indications can be drawn from Figure 1:

1. The glass tape baseline has a low creep compared to this selection of layer combinations.
2. Lower numbers of layers of polyimide produce less creep.
3. The creep is generally lower when the first layer is composed of a higher tension modulus material such as type H Kapton (Dupont) or type N Apical (Allied Signal).
4. Lower number of layers and higher tensile modulus materials are less effected by the 6K psi to 10K psi curing pressure variation.
5. Increasing the number of layers which contain glue decreased creep greatly (the three glue layer systems are only shown as 10K psi points).
6. Bare cable stacks have less creep when "cured" at 6K psi than at 10K psi, the opposite of insulated stacks. This is not well understood but may be a mechanical effect caused by friction of the polyimide film on the individual cable strands not allowing the strands to move in the length direction. The bare cable was surrounded by steel mold during the cure measure.

The strongest effect found in these studies was that the number of layers of insulation that were glued together had a strong effect on coil equivalent creep and on the stack modulus of elasticity (as shown in Figures 2 and 3, respectively). The scatter in theses graphs is because the number of layers and combinations of materials are varied in each data point. The lines shown are least-squares curve fits.

Some of the scatter was cleared by plotting the first layer grouped by their brand names, Kapton and Apical. Since the two brands of polyimide film are made by different processes, the film characteristics are somewhat different. The author suggests that these differences are measurable by the tensile modulus. Figure 4 displays the equivalent coil creep of a narrow selection of stacks with either one or two glue layers cured at 10K psi mold pressure versus the tensile modulus of the material of the first layer. This display generally shows that the higher tensile modulus films yield lower creep results.

Studies of stack modulus do not predict coil modulus directly because the curved shape of the coil and keystoned shape of the cable distribute the pressure very unevenly compared to the even pressure distribution in a vertical ten stack. However, the stack modulus may be used to rank the effects of the various layer combinations (see Figure 5).

Figure 6 displays a selection of stacks with various film layer and glue layer combinations ranked in order of creep. A legend has been added indicating the number of glue layers within the insulation layers. The lowest creep stacks have glue on the first layer and the second layer. Microscopic studies were made of a dissected stack made with Cryorad on the first and second layers. Because the Cryorad (as well as epoxy) viscosity drops to a watery state before hardening and the stack is under great pressure during cure, the glue was squeezed onto the superconducting cable at the underside of the wrap line. The amount of glue was small (approximately 0.002 to 0.020 inches in diameter puddles and loose spheres) but any glue in contact with superconducting cable is thought to be a possible source of quenching.

CONCLUSION

In conclusion, this study suggests for lowest stress relaxation, the preferred cable insulation system should have the fewest number of layers of insulation (three is practical) which are high tension modulus polyimide films. The system should be cured at the highest practical mold pressure for the longest practical time. In order to reach a compromise in obtaining low creep without using glue on the bottom wrap it is suggested that the top layer have glue on both sides and the bottom layer have no glue. This would constitute a two glue layer system that should come close to the attributes of a three glue layer system. The resultant coil system should have a stress relaxation of only slightly greater than the glass tape system. This choice was pursued by Fermilab on one of the low temperature cured study magnets made in 1992.

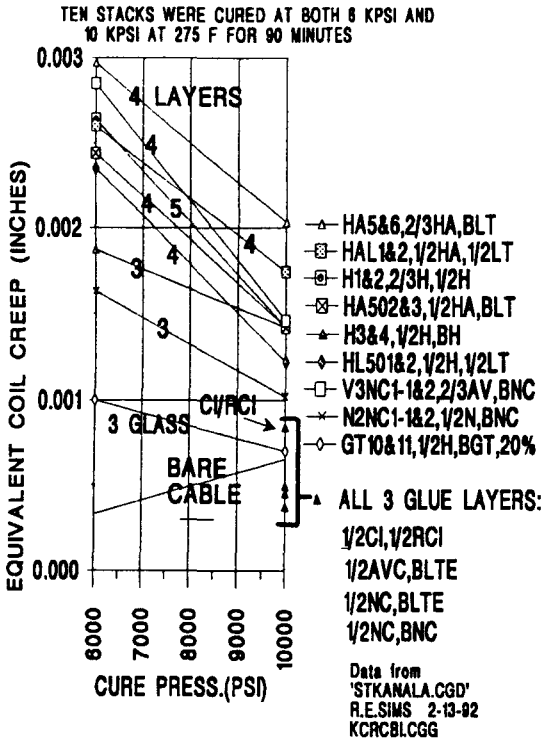

Figure 1. Coil Equivalent Stack Creep vs. Cure Pressure

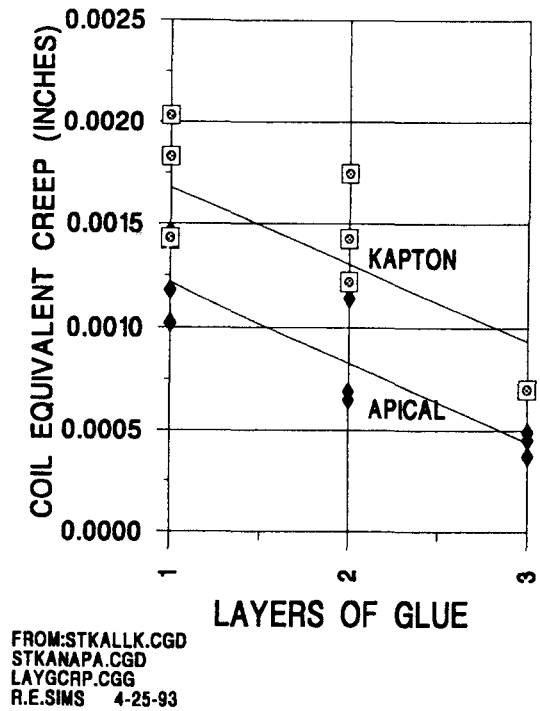

Figure 3. Apical and Kapton Stack Modulus of Elasticity vs. # of Glue Layers.

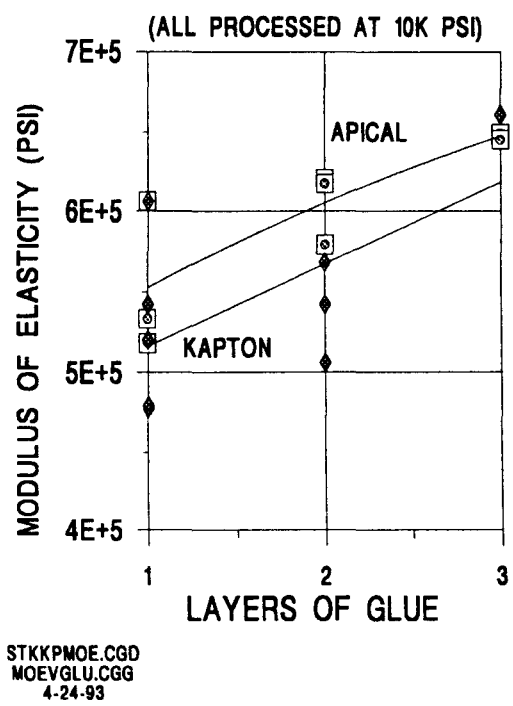

Figure 2. Effect of # of Layers of Glue on Coil Equivalent Creep.

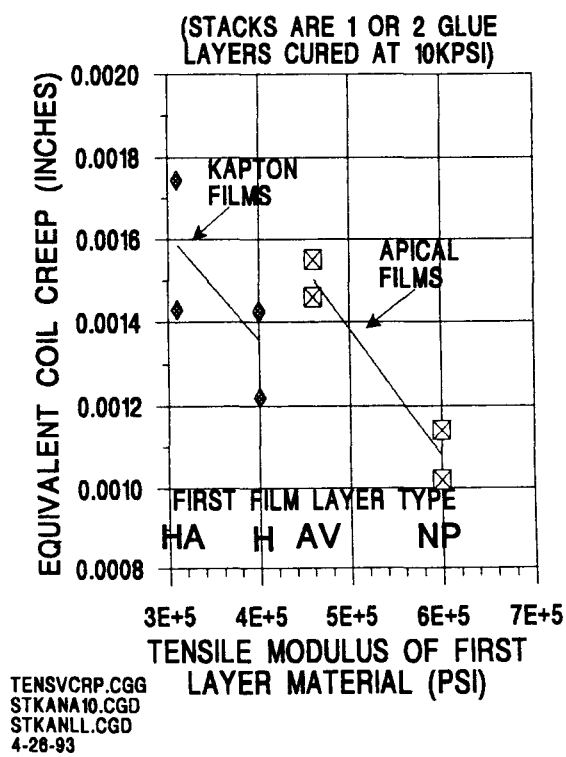

Figure 4. Equivalent Coil Creep vs. Film Tensile Modulus

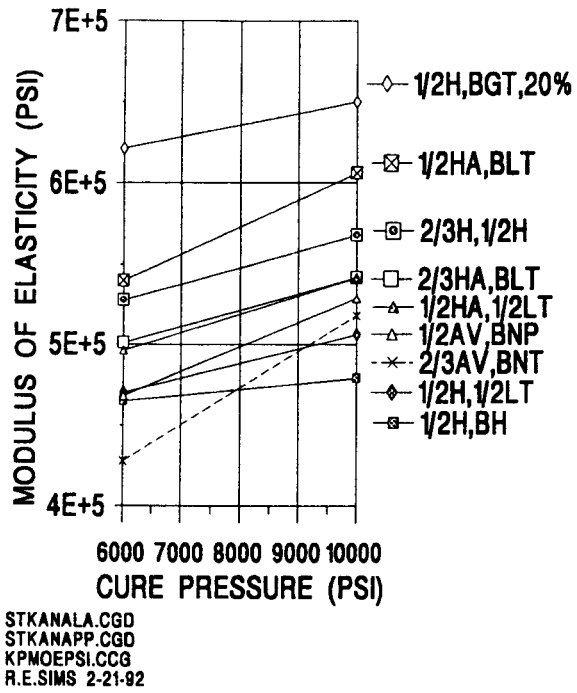

Figure 5. Modulus of Elasticity vs. Curing Pressure for Various Films.

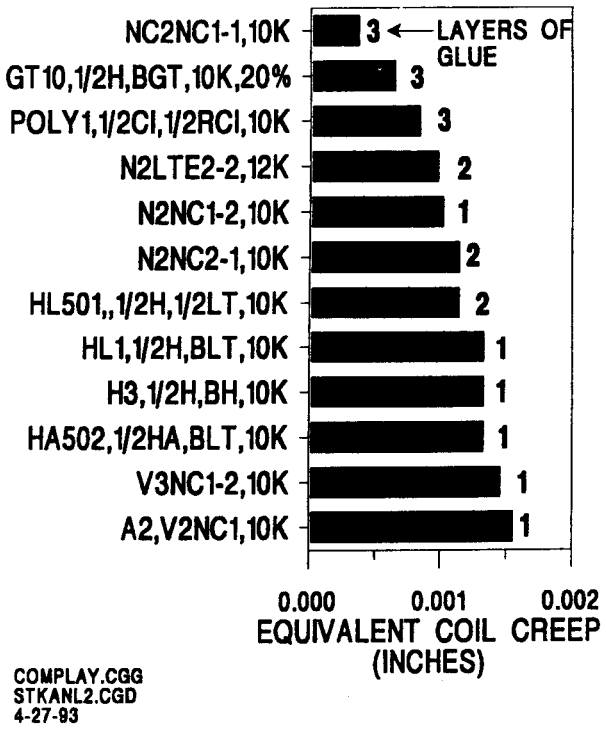

Figure 6. Comparison of Various Layering Schemes.

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