CEMENT POTTED COILS FOR MUON CHANNEL MAGNETS*

by

H. F. Vogel and J. J. Rosenthal
Los Alamos Scientific Laboratory
University of California
Los Alamos, New Mexico

ABSTRACT

The Stopped Muon Channel at LAMPF will be exposed to an intense flux of high energy neutrons. The first magnet is to be installed at a distance 60 cm from the source; the estimated radiation level for this magnet is 10^{10} to 10^{11} rads/year.

The first four magnets of the channel utilize inorganic, radiation-resistant insulation materials. The conductor insulation consists of glass tape. An alumina-calcium aluminate composition is used for potting the coils and providing the ground insulation of these coils. These magnets are quadrupoles with 14 in. and with 12-in. bore, and a bending magnet with 11 in. gap dimension and 32 in. pole width.

I. INTRODUCTION

The first four magnets of the Stopped Muon Channel at LAMPF are exposed to direct radiation from the production target, which emits in the direction of the muon channel a neutron flux estimated[1] at $3 \cdot 10^{14}$ (sec^{-1} sr^{-1}) in the range 0 - 1 MeV; $3 \cdot 10^{14}$ (sec^{-1} sr^{-1}) in the range 1 - 10 MeV; and $2 \cdot 10^{13}$ (sec^{-1} sr^{-1}) in the range 100 - 800 MeV.

The set of magnets exposed to substantially these fluxes consists of two 14 in. quadrupoles 14QE22, one 11 in. gap C magnet C32XI18, and one 12 in. quadrupole 12QE20.

Magnets were constructed for LAMPF, which use mineral-insulated cable in square cross section.[2] The obvious problem with this cable is the low conductor packing factor resulting from the copper sheath around the insulator and conductor bar; and from the comparatively large tolerance on the outer dimension of the cable. This packing factor has a substantial effect on the dimensions of magnets with large aperture dimensions. In the case of the muon channel magnets, this would lead to overall dimensions difficult to handle, or to increased power loss.

It has been demonstrated[3] that hydraulic cements and concretes can be prepared with good resistivity and mechanical integrity. Hammond and Robson[4] give a good account of volume resistivity for hydraulic cements and concrete. We measured on our finished coils under room temperature (20°C) and humidity (500 g/m^3) conditions

$\rho \approx 10^{10}$ (Ωcm) at 800 (V/cm), and

$\rho \approx 0.5 \cdot 10^{10}$ (Ωcm) at 2 (kV/cm).

The resistivity decreases noticeably with increasing moisture content. Study of the breakdown voltage indicates that gradients of several kV/cm can be withstood. If one raises the voltage to breakdown, then after the first breakdown, subsequent ones occur at a voltage slightly lower than the initial breakdown voltage.

After several breakdowns, the breakdown voltage remains fairly constant. This phenomenon is explained by the absence of carbon tracking. This observation is of great importance, because it explains the fact that the coil may virtually short to ground as a result of accidental water saturation, and still recover to the original insulation characteristics, after dry-out.

II. CONSTRUCTION

The coils are constructed with conventional inner-cooled copper conductor with outer dimensions 0.54 to 0.6 in. operated at a maximum temperature rise of less than 30°C. The turn insulation consists of glass tape, 7 mils thick, applied in three layers half-lap. The coil is wrapped with additional layers of glass tape serving as cushion for cement shrinkage during curing.

The cement potting mold is constructed of aluminum lined with sheets and blocks of polyethylene. The mold is open at the top. All polyethylene surfaces that will come in contact with cement are coated with a film of petroleum jelly for mold release.

The coil is placed in the mold and spaced up with alumina spacers approximately 3/8-in. thick. The coil is spaced laterally in the mold by means of temporary polyetheylene spacers that will prevent shifting of the coil during the vibrating process.

The mold and coil are filled with room temperature water prior to the casting operation; the water to be drained immediately before potting is started.

A casting mix consisting of 70 wt% fused 60 mesh Al_2O_3, 30 wt% calcium aluminate cement, and 14-15% distilled water (expressed in dry-weight units of the alumina-cement mixture) is thoroughly wet-mixed in a paddle-type mixer.

The wet mixture is then poured into the mold, which is being vibrated on a table with vibrating capacity of 1200 lbs. In order to fill in blind spots and narrow crevices, an air-powered vibrating 1/4-in.-diam nylon rod hand tool is used as shown in Fig. 1, in order to increase the fluidity of the thixotropic cement. When the mold cavity is completely filled and after the temporary spacers have been removed, the vibrating table is turned off.

In order to minimize stress and cracks in the cured insulation, the cement is prestressed. This is accomplished by circulating 60°C water through the cooling passage for 48 hrs starting at the time the vibrating table is turned off. At this time then, excess material is struck off level with the top of the mold; a set of ten 250 W heating lamps seen mounted in a rack, in Fig. 1, is turned on and left on for 48 to 72 hrs depending on casting size.

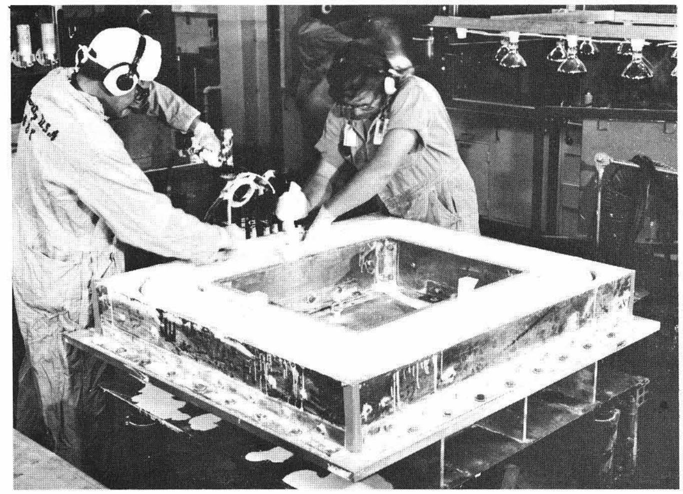

Fig. 1.

Subsequently, the outer mold faces are removed and the heat lamps left on for an additional period of 72 hrs after which the center mold section is removed. Any conspicuous surface irregularities are then filled with Sauereisen cement.

III. TESTING

Each coil is subjected to 100 to 200 thermal cycles of 15 min. each, raising the temperature when current is turned on and cooling water shut off, and lowering the temperature by the reverse process. The coil temperature is thus cycled between 25°C and 70°C.

Two prototype coils had been subjected to 300 cycles each, extending from 25°C to 95°C.

In an attempt to destruct a prototype coil in a meaningful test, the specimen was wrapped with aluminum foil permitting to measure insulation resistance between the copper and the grounded foil. The coil assembly was then placed flat into a tub and subjected to the tests described as follows.

Resistance to ground was measured to be 0.6 MΩ at 1 kV, and 1 MΩ at 400 V, when the coil was dry under room condition. Current and cooling water were then circulated so that only a 6°C temperature rise in the copper was observed by resistance rise; the coil resistance then being 2.733 MΩ. The current was 500 A. Then, water was poured into the tub so that approximately half of the coil was submerged. No decrease in coil resistance was observed over a time interval of 15 min. The current was then increased to 750 A -- corresponding to an additional copper temperature rise by resistance of 1°C. The coil resistance was then observed for an additional time of 15 min. during which the resistance rose slowly, indicating that the coil temperature was now rising by 3°C.

The coil was then completely submerged in water, the current lowered to 100 A, and the leakage current to ground measured after two hrs had elapsed. The leakage turned out to be 100 mA as measured at 14 V dc. The coil current was then raised to 667 A, the coil temperature by resistance rose consequently to 29°C, thus indicating a temperature rise over ambient of 9°C, which implies no deterioration of the turn insulation was taking place. It was clear that no appreciable temperature rise could in this way be achieved with reasonable values of circulating current; the heat dissipation through the wet insulation being too great.

The tub was then drained, the cooling water shut off, the coil current set to 660 A, and the coil observed for 10 min. It was seen that the residual cooling water in the water passages of the coil was boiling off as expected under these conditions, and the water in the coil and in the concrete insulation was boiling off as well.

No damage could be observed to the insulation. No cracks in the concrete had developed. There was water still contained in the parts of the insulation where the ground foil slowed the boiling off. The insulation to ground at 200 V was then measured to be 40 kΩ. The ground resistance recovered later to its original value of 1 MΩ at 400 V.

Acknowledgment

Discussions encouraging this program were conducted with S. D. Stoddard, R. Sheldon, and E. Bush who contributed a great deal of experience from their earlier work on cement-insulated magnets.

Early tests on prototypes were done by T. Montoya. Much of the engineering work on the final coils was done by Richard Rhorer. Howard Richardson and Howard Clifton of the Ceramics Section at Los Alamos did most of the potting work. The tests attempting to destruct the prototype were done by D. Casperson and R. Stambaugh from Yale University during their summer stay 1972 at Los Alamos.

References

1. P. A. Thompson, "Shielding for the LAMPF Muon Channel," Internal Report, MP-7-54 (April 1972).
2. A. Harvey and S. A. Walker, LA-DC-10380, 1969.
3. R. Sheldon and G. B. Stapleton, Private communication.
4. E. Hammond and T. H. Robson, The Engineer, Vol. 199, 78 (1955).