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Radiation Hardening of Electromagnet Coils Using Sulphur

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Abstract

A convenient method of radiation hardening of high current density electromagnet coils using a mineral insulation has been investigated and developed at FNAL. Liquid sulphur was used to vacuum impregnate a test coil with good results. The preparation and potting techniques used were almost the same as those used for epoxy impregnation.

Introduction

The most common electrical insulation used to build electromagnets for particle accelerator applications is a composite of glass tape and epoxy. Epoxy is an organic material and as such it is susceptible to damage if used in a high radiation environment. Therefore, electromagnets which operate in high radiation areas can not use the standard insulation system.

The object of this investigation was to find an inorganic material which could be used as a substitute for the epoxy component of the glass tape and epoxy insulation system. This new material must also withstand low to moderate voltages and should serve as support structure for the coil.

Mineral insulations have been used successfully by others to harden electromagnet coils. Magnesium oxide powder sandwiched between a copper sheath and electrical conductors has been used to radiation harden particle accelerator magnets at moderate current densities at LASL and CERN.[1,2] Concrete impregnation techniques [3,4] involving compressive structure have also been used by CERN to radiation harden magnets.

Another method of radiation hardening with a mineral insulation is described herein. The same vacuum impregnation techniques developed for epoxy impregnation can be used to vacuum impregnate coils with liquid sulphur.

Sulphur Properties

At room temperature and up to 95°C sulphur is a yellow solid with crystals with orthorhombic symmetry; it is called orthorhombic sulphur or, usually rhombic sulphur. Between 113°C and 119°C sulphur melts to form a straw-colored liquid of low viscosity. The viscosity of liquid sulphur is low because of the S_8 molecules which compose it are nearly spherical in shape and roll easily over one another. Between 120°C and 160°C the viscosity of liquid sulphur decreases with increasing temperature. In this temperature range the viscosity of liquid sulphur is approximately the same as crude oil and it works well as a potting material. Above 160°C the viscosity increases with the formation of long-chain polymers. A vapor pressure curve for sulphur is shown in figure 1.

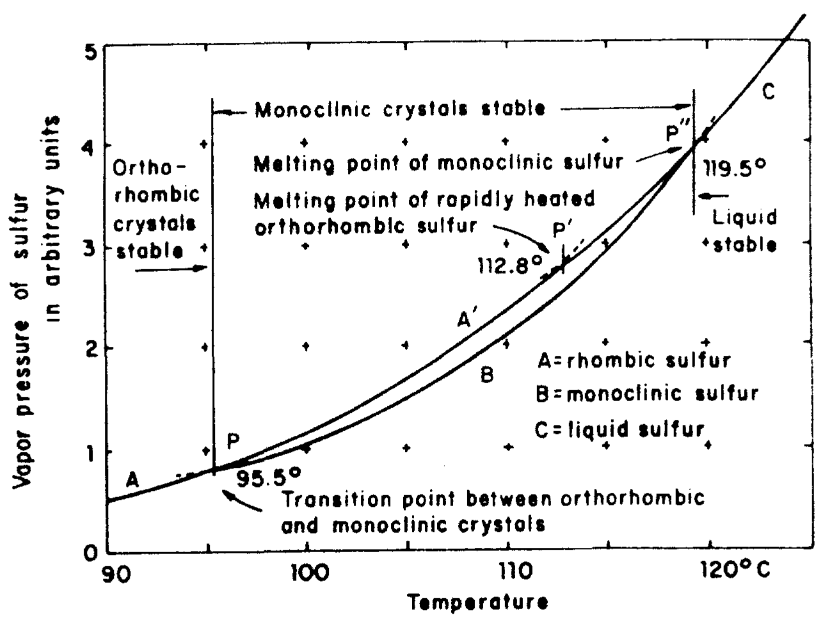

FIGURE 1 VAPOR-PRESSURE CURVES FOR SULFUR

Test Coil

A 6 inch inside diameter double pancake test coil was wound with four turns of 0.3 inch square copper conductor. The upper to lower jog was cut and insulated so that turn to turn insulation could be evaluated. The coil conductor was wrapped half lap with .007 inch thick glass tape. The finished coil was then ground insulation wrapped with the same glass tape in the same way and installed into a potting fixture as shown in figure 2.

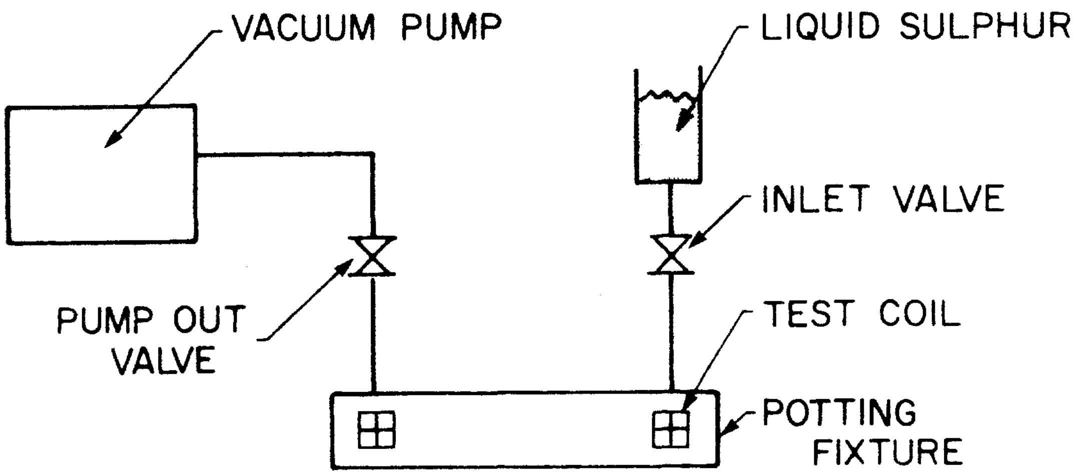

FIGURE 2 TEST COIL POTTING SYSTEM

An O-ring sealed potting fixture and associated plumbing was put into an oven and preheated to approximately 150^{o}C. Simultaneously a container of sulphur was melted on a hot plate and heated to approximately 150^{o}C. The oven door was then opened and a vacuum pump was connected to the pump-out valve. With the pump-out valve in the open position and the inlet valve in the closed position the potting fixture was evacuated. The liquid sulphur was then poured into the liquid sulphur container and the pump-out valve was closed. The inlet valve was then opened and the liquid sulphur was transferred into the potting fixture by atmospheric pressure. The vacuum pump was then disconnected from the potting fixture, the oven door was closed and the test coil and potting fixture were furnace cooled to room temperature.

Test Results

Hi-pot tests were then conducted between coil and potting fixture and also turn to turn with the following results:

Breakdown Voltages	
Coil half to potting fixture	2.6 kV
Coil half to potting fixture	2.6 kV
Coil half to coil half	1.6 kV

Conclusions and Recommendations

1. Liquid sulphur behaves well as an inorganic potting material using the same techniques that are used to date with epoxy. The liquid sulphur completely saturates the glass cloth and reacts with the copper conductor forming a light coating of copper sulfide at the sulphur to copper interface.
2. Breakdown voltages greater than one kilovolt may be expected for a sulphur and glass composite thickness of approximately .028 inches.
3. The vacuum shell which encloses the coil for vacuum impregnation may be used as a protective covering for the coil. This skin will protect the coil from fire and moisture.

4. Radiation hardening of electromagnet coils using sulphur should be studied in more detail. Testing of a full size magnet in a high radiation environment should be done prior to full scale use of sulphur impregnation because of the limited data available on the radiated properties of sulphur.

Acknowledgements

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