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Manufacture of Fast-Pulsed Magnets for the SLC Damping Rings

R. Cassel, G. Gross, A. Harvey and T. Mattison
Stanford Linear Accelerator Center
Stanford University, Stanford, California 94309, USA

Abstract— **A second-generation fast kicker magnet (and its power supply) was designed by Fermilab for the SLC electron damping ring [1]. The requirements were to inject and extract two bunches of electrons, with the following magnetic field specifications:**

- **Integral peak magnetic field = 0.021 T-m**
- **Rise/fall time (0-100%) = 56.03 ns maximum**
- **"Flat-top" duration = 61.63 ns**

The "flat-top" does not imply a plateau, but two time-stable spots of equal magnitude, since the electron bunches are short (20 ps).

Many of the early problems with these magnets [2] have been studied intensely during the last two years, and substantial progress has been made. In particular, vacuum potting with room-temperature curing silicone rubber (RTV) has been refined to give reliable high-voltage service up to 18 kV/mm, and lifetimes of about a year despite stored beam intensities of 3×10^{10} electrons/bunch at 120 pps.

Further improvements in RTV formulation are suggested, and the direction of future insulation-system development is indicated.

INTRODUCTION

This paper describes the processing of the room-temperature vulcanizing silicone rubber which is used as the primary electrical insulation in the kicker magnets of the SLC facility. These magnets operate on short-pulse voltages up to 35 kV. In the case of the Fermilab-designed kicker (Figs. 1 and 2), this leads to a voltage gradient of 18 kV/mm, making stringent demands on the integrity of the insulating medium—in particular, its freedom from voids that would initiate corona break-down. A procedure for processing a commercial silicone rubber that has given successful results is described.

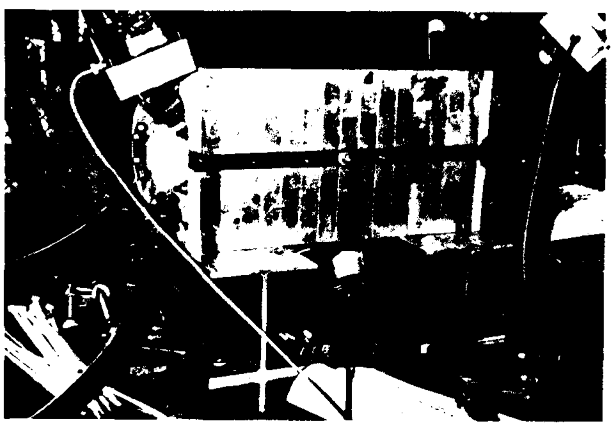

Fig. 1. Fermilab-designed kicker magnet on test.

THE PROBLEMS

Room-temperature vulcanizing silicone rubbers are usually two-part mixtures with, in the case of General Electric's 615 which is used at SLAC, a pot-life after mixing of four hours.

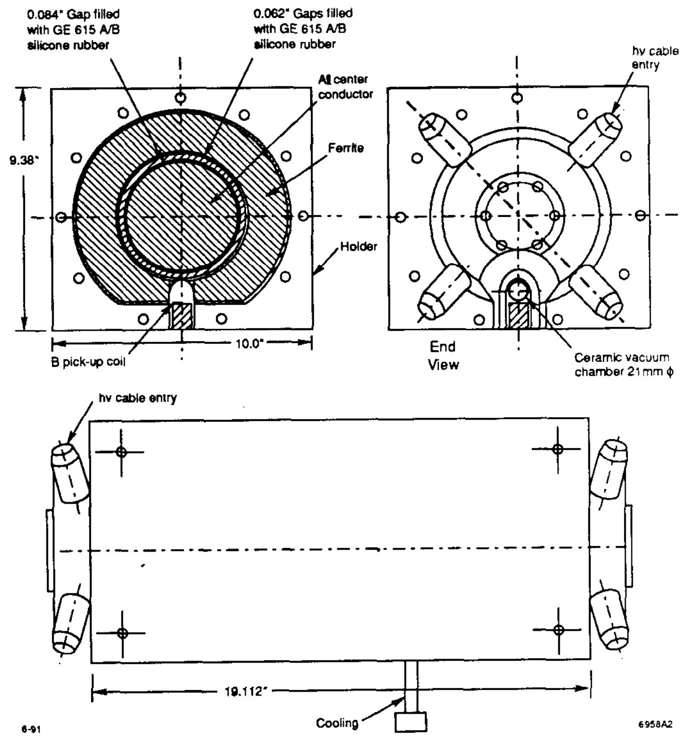

Fig. 2. Fermilab-designed kicker magnet.

The mixing process, even if done in vacuum, still leaves dissolved gas that in the process of being transferred into the magnet, undergoes pressure changes that can result in bubbles—i.e., gas-containing voids in which corona can occur. Since the degassing time is limited by the pot-life of the mixture, it is never possible to remove all the dissolved gas.

THE SOLUTION

Successful processing takes advantage of Henry's Law, which states that the ratio of partial pressure in the gas phase (P_a) to the mole fraction of gas in the liquid phase (X_a) is a constant, H; i.e., $P_a/X_a = H$. It is therefore possible to redissolve gas in bubbles into the liquid phase by raising the ambient pressure. The apparatus to do this is illustrated in Fig. 3.

The magnet is placed in a vacuum/pressure vessel, arranged with a vertical filling funnel that acts as a reservoir for the silicone rubber when the magnet is full. The silicone rubber is mixed in an adjacent vessel, under vacuum, for about two hours. This process is characterized by violent gas evolution early on, gradually subsiding until, at a pressure of 1–2 Torr, bubbles rarely form. To make the degassing more effective, the vessel has an agitator which is rotated fast enough to produce a cavity in the rubber mixture that enhances the rate of gas evolution, while avoiding stratification.

The transfer to the magnet in its tank has to be done in the minimum possible time, to make it possible to redissolve any gas bubbles while the mixed RTV is still liquid. With the SLAC equipment, the pressure in the potting tank is maintained

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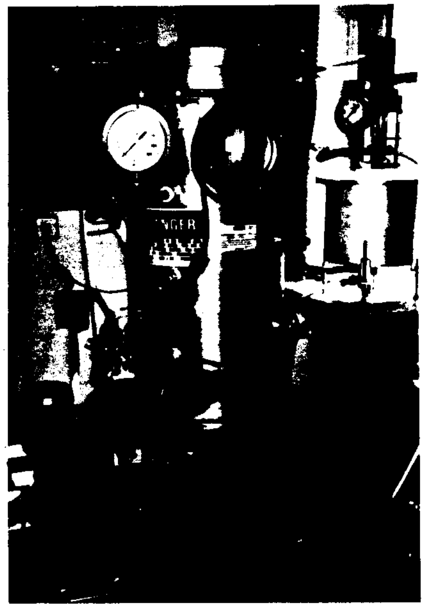

Fig. 3. Vacuum/pressure potting tank.

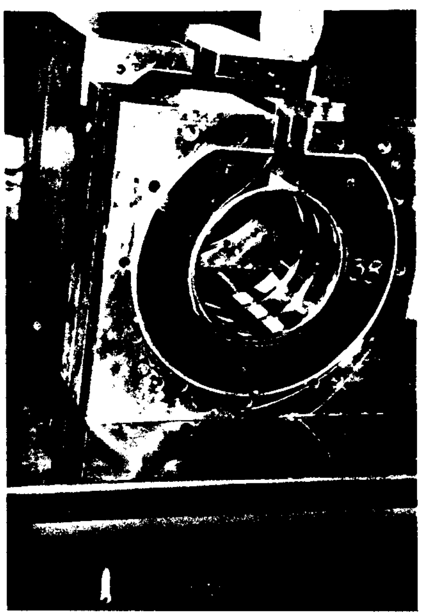

Fig. 4. Ferrite cores in Al holders.

at 30–50 Torr during the transfer. As soon as the transfer is completed and the filling funnel is nearly full, the potting tank is pressurized to five atmospheres, which initiates dissolution of any bubbles containing gas to dissolved gas in the liquid phase.

Pressure is maintained on the curing rubber for 48 hours, then the pressure is reduced to atmospheric for the remaining five days. All cures are seven days at room temperature: elevated-temperature curing can cause shrinkage separation voids with the aluminum container—the expansion coefficient of the rubber is ten times that of aluminum.

A similar technique is used in encapsulating the ferrite cores in their holders (Fig. 4).

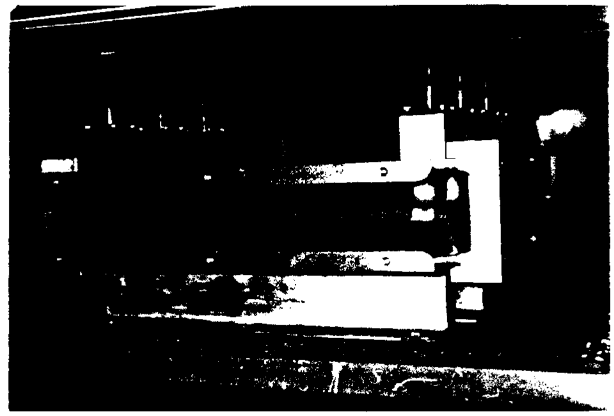

Fig. 5. SLAC-designed kicker magnet.

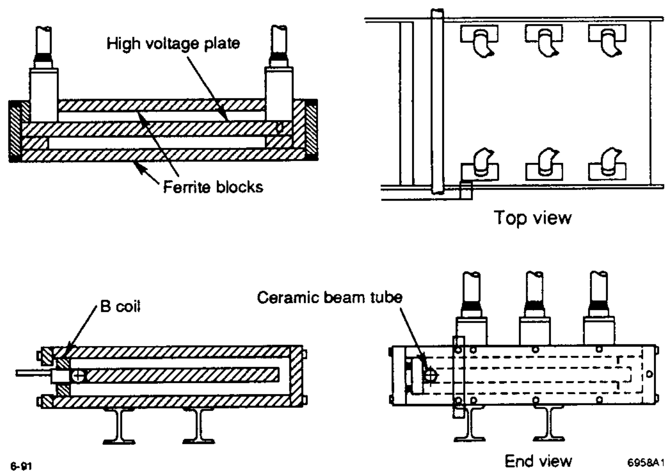

Fig. 6. SLAC-style kicker magnet.

FURTHER CONSIDERATIONS

During operation of the kicker magnets in SLC's damping rings, a heat input of some 200 W comes from the ceramic vacuum pipe in the magnet (from eddy-current and image-current heating of its inner Kovar lining). At shut-down, the loss of this heat source led to temperature cycling of the magnet assembly. Expansion differences between the rubber insulation and the aluminum structure were exacerbated by the radiation-hardening of the rubber caused by exposure to lost or missteered beam.

This effect is minimized at SLAC by having electrical heaters that are thermostatically-controlled arranged on the magnets to keep the temperature at operating levels, even during shut-down periods.

FUTURE DIRECTIONS

There are alternatives to the high-voltage-gradient design of the Fermi-style magnet. For single-bunch beams, the positron damping ring at SLAC can operate using a lumped magnet, as shown in Figs. 5 and 6. Here the thickness of the insulation is substantial, with low-voltage gradient, and the weak point is the interface between the ferrite and the silicone rubber. Techniques similar to those described above are used to pot these magnets.

At high beam intensities such as obtain at SLC, even small beam losses cause high radiation doses close to the beam-line, where the kicker insulation is. Despite local shielding, this may prove to be the lifetime-determining factor for the kicker magnets, and experiments are under way to enhance the radiation resistance of silicone rubber. A well-known technique is to add inorganic filler to the polymer, and mixtures of RTV and alumina are being studied at SLAC. These have the advantage that the high dielectric constant of alumina gives a mixture with a dielectric constant up to twice the value of 3.0 obtained with GE615. The insulation thickness can then be doubled for the same magnet impedance, giving a reduction of two in the voltage gradient.

As a major change from the high-voltage-gradient design of the Fermi-style kicker, SLAC is developing an epoxy-resin insulated design of kicker with a much lower gradient [3]. In addition to reducing the problem of corona breakdown, the new design is expected to be much less susceptible to radiation damage.

ACKNOWLEDGMENT

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