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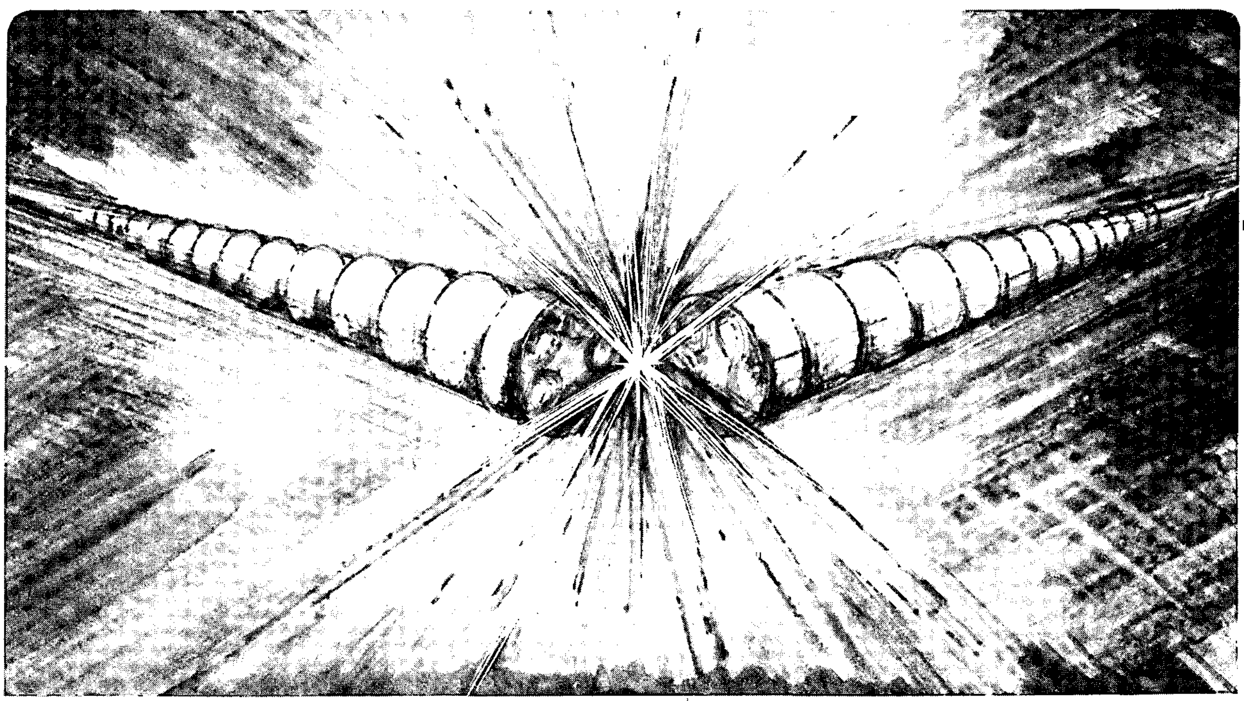

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CORRECTION OF MAGNETIZATION SEXTUPOLE IN ONE-METER LONG DIPOLE MAGNETS USING PASSIVE SUPERCONDUCTOR

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ABSTRACT

The generation of higher multipoles due to the magnetization of the superconductor in the dipoles of the SSC is a problem during injection of the beam into the machine. The use of passive superconductor was proposed some years ago to correct the magnetization sextupole in the dipole magnet. This paper presents the LBL test results in which the magnetization sextupole was greatly reduced in two one-meter long dipole magnets by the use of passive superconductor mounted on the magnet bore tube. The magnetization sextupole was reduced a factor of five on one magnet and a factor of eight on the other magnet using this technique. Magnetization decapole was also reduced by the passive superconductor. The passive superconductor method of correction also reduced the temperature dependence of the magnetization multipoles. In addition, the drift in the magnetization sextupole due to flux creep was also reduced. Passive superconductor correction appears to be a promising method of correcting out the effects of superconductor magnetization in SSC dipoles and quadrupoles.

BACKGROUND

The effect of superconductor magnetization on the quality of the field generated within a superconducting dipole was observed as early as 1970.[1] The effect of superconductor magnetization on field quality has been modeled using complex current doublet theory.[2] The mathematical model has been successfully applied to accelerator dipole and quadrupole magnets.[3]

The computer model has been used to calculate several methods of passive correction for accelerator dipoles. These methods include: passive superconductor,[4,5] ferromagnetic material,[4,6] and oriented permanent magnet material.[4] This paper describes the Lawrence Berkeley Laboratory (LBL) passive superconductor test program. The use of passive superconductors to correct the magnetization sextupole in a dipole magnet is not new. The concept was first described by Brown and Fisk in 1984.[7] Fermilab reported a test of the concept in 1986.[8]

Passive superconductor correction of magnetization multipoles has the following potential advantages for SSC dipole magnets: 1) Passive superconductor correctors are unpowered straight pieces of superconductor mounted within the magnet bore. The pieces are not connected together. 2) Passive superconductor correction corrects the magnetization multipole when the field is falling as well as rising. 3) Passive superconductor correction corrects the field over a wide range of temperatures. 4) It is hoped that passive superconductor correction will eliminate slow changes of magnetization sextupole due to flux creep.[9,10]

This paper describes the passive superconductor correctors which were built and tested in two Lawrence Berkeley Laboratory dipole magnets. The magnets include the LBL D-15-C2 four centimeter bore dipole, and the LBL D-16-B1 five centimeter bore dipole. The D-16-B1 dipole has close-in iron which starts to saturate when the magnet central induction reaches about 3 T.

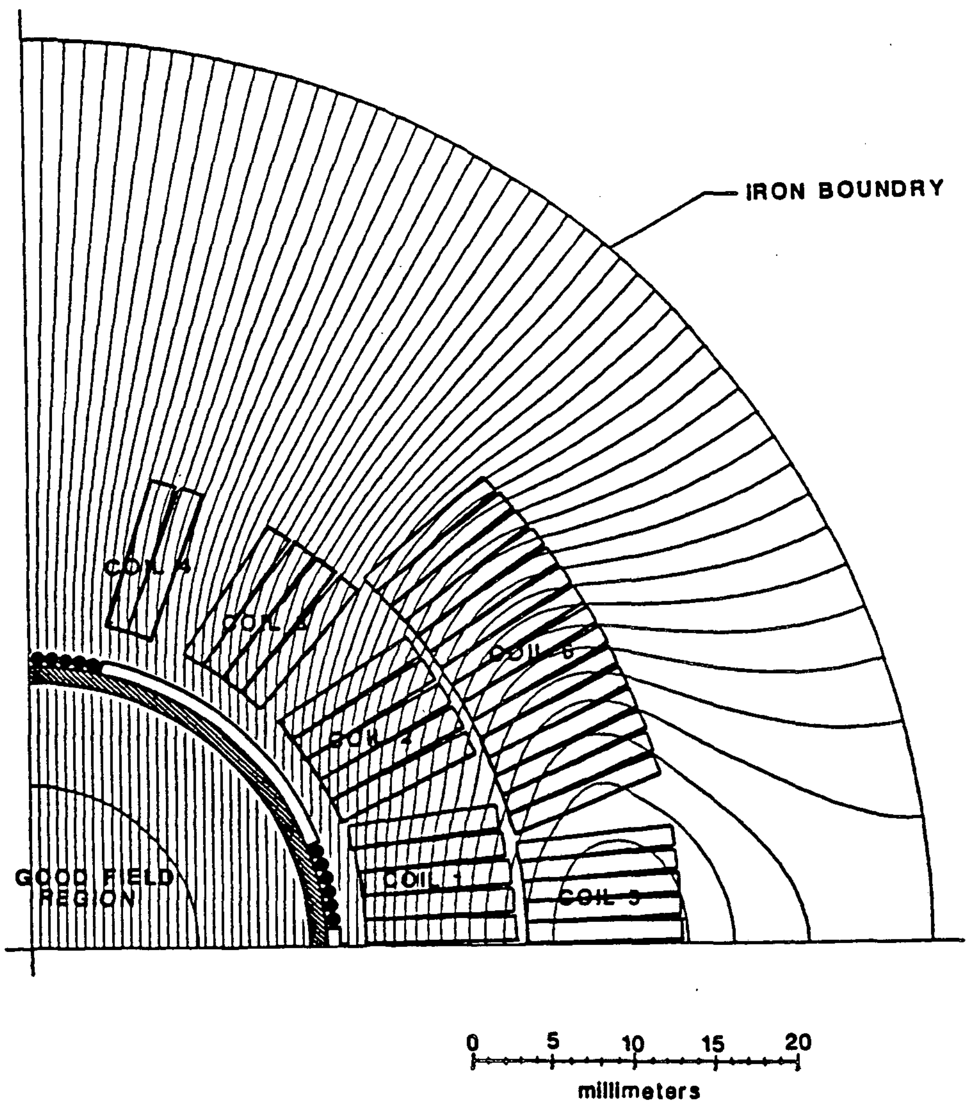


Fig. 1

The D-15-C2 Dipole Coil with its Passive Corrector Installed (Magnetic Flux Lines are Shown)

PASSIVE CORRECTION OF THE D-15-C2 DIPOLE MAGNET

The LBL D-15-C2 dipole is a dipole magnet with NC-9 conductor cross-section (see Figure 1). The inner coil conductor has 5 micron filaments and a copper-to-superconductor ratio of 1.48. The outer coil conductor has 6 micron diameter filaments and a copper-to-superconductor ratio of 1.77. The superconductor used to correct the magnet has 24 micron filaments with a copper-to-superconductor ratio of 1.36.

The corrector for the D-15-C2 dipole is also shown in Figure 1. The corrector is symmetric about the midplane and the poles. Twelve 0.808 mm diameter conductors are located about the midplane and ten 0.808 mm diameter conductors are located at each pole. Forty-four 26-inch long pieces of corrector conductor are mounted on the surface of a 1.362 inch outside diameter stainless steel tube. The amount of superconductor in the corrector represents about 1.6 percent of the superconductor in the D-15-C2 magnet.

Figure 2 shows the measured magnetization sextupole of LBL D-15-C2 dipole as a function of current (the dipole transfer function is 10.3 gauss per ampere) without the passive corrector. Figure 3 shows the measured magnetization sextupole for the LBL D-15-C2 dipole, a function of current with the passive corrector installed. The passive superconductor reduced the magnitude of the magnetization sextupole by a factor of five.

The magnetization sextupole was overcorrected by the passive superconductor corrector. Some of the reasons for the overcorrection of the magnetization sextupole are as follows: 1) The filament diameter of the corrector was 24 microns instead of the 23 microns when the corrector was designed. 2) The average radius of the corrector mounted on the stainless tube is about 0.1 mm smaller than the radius used to design the corrector. 3) The largest effect is caused by an over estimate of the low field critical current density in the magnet conductor. The low field J_c was overestimated by 15 percent. The errors given above account for over 80 percent of the overcorrection observed in the LBL test of dipole D-15-C2.

The decay of the magnetization sextupole was reduced from +1.3 units per decade to about +0.2 units per decade. If the magnetization decay were completely compensated by the superconductor corrector, the decay would have been about -0.25 units per decade. It can be concluded that only 70 percent of the flux creep decay was eliminated by the passive corrector.

PASSIVE CORRECTION OF THE D-16-B1 DIPOLE MAGNET

The D-16-B1 dipole magnet built by LBL has a 5 centimeter bore with the iron against the outer coil (see Figure 4). At low fields, the dipole transfer function is about 13.0 gauss per ampere. The dipole inner coil has 6 micron filaments and a copper-to-superconductor ratio of 1.20. The outer coil has 6 micron filaments and a copper-to-superconductor ratio of 1.66. The same material was used for the D-16-B1 dipole corrector as was used for the D-15-C2 dipole corrector.

Fig. 2

D-15C-2 - COLD MEASUREMENT COMPARISONS
COMPARISON OF 4.3K AND 1.8K BEHAVIOR
DURING 6600 AMP CURRENT SWEEPS

NO PASSIVE CORRECTOR

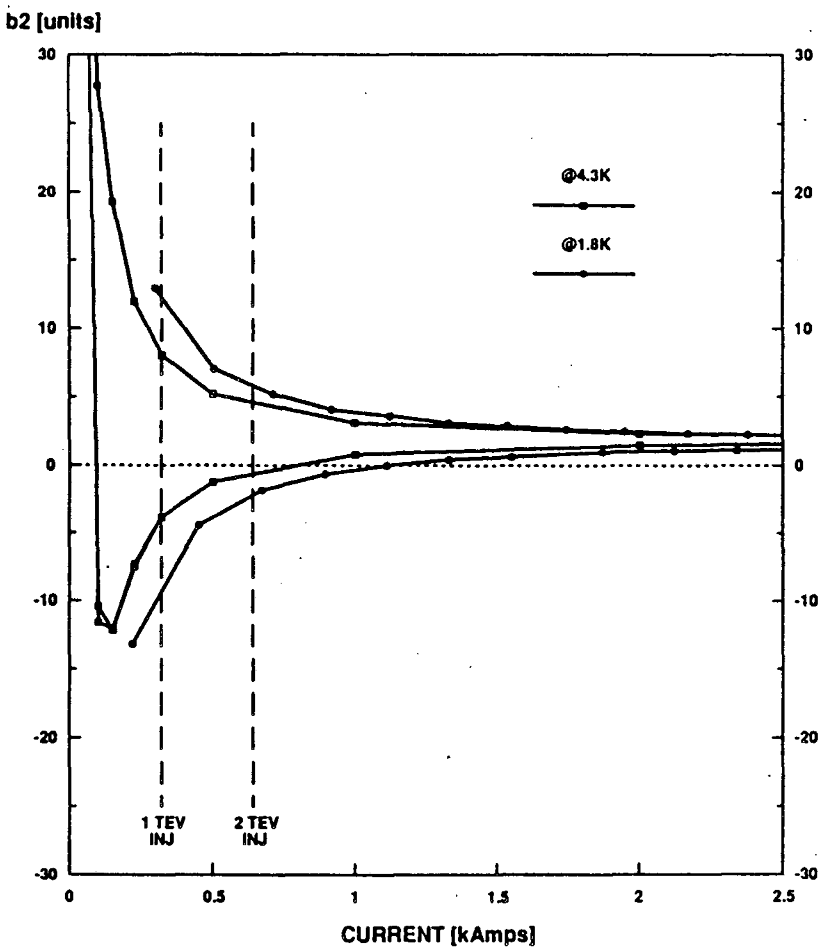


Fig. 3

D-15C-2 - COLD MEASUREMENT COMPARISONS
COMPARISON OF 4.3K AND 1.8K BEHAVIOR
DURING 6600 AMP CURRENT SWEEPS

PASSIVE CORRECTOR IN

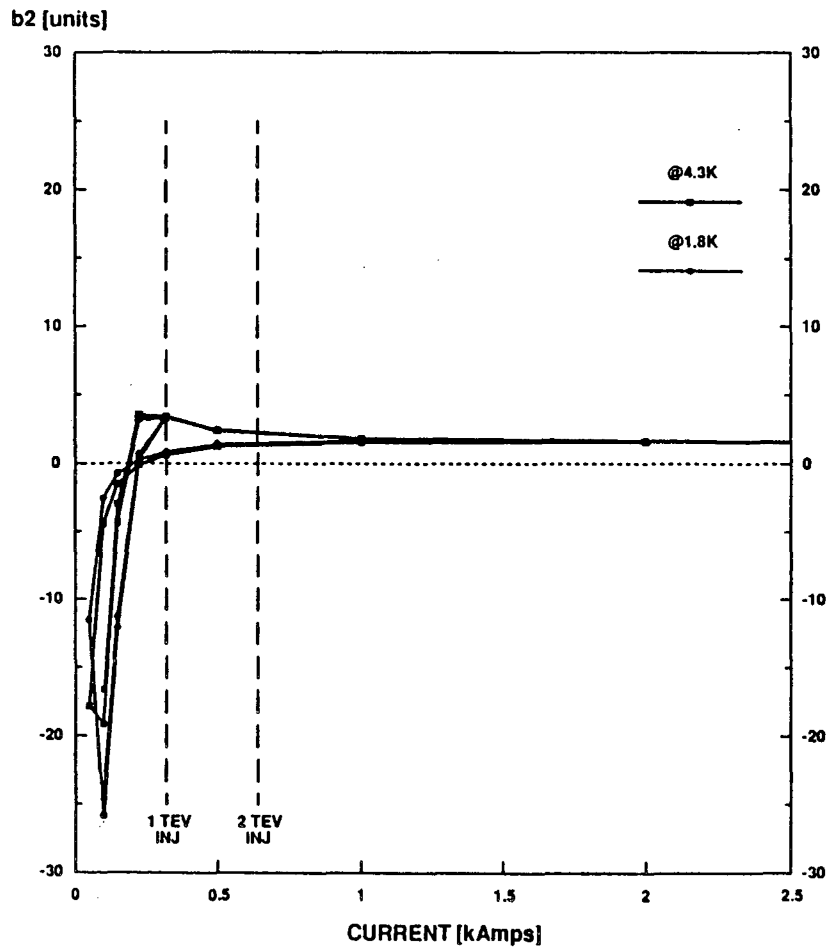


Fig. 4

LBL MAGNET D-16B-1

SUPERCONDUCTING MAGNET CROSS SECTION

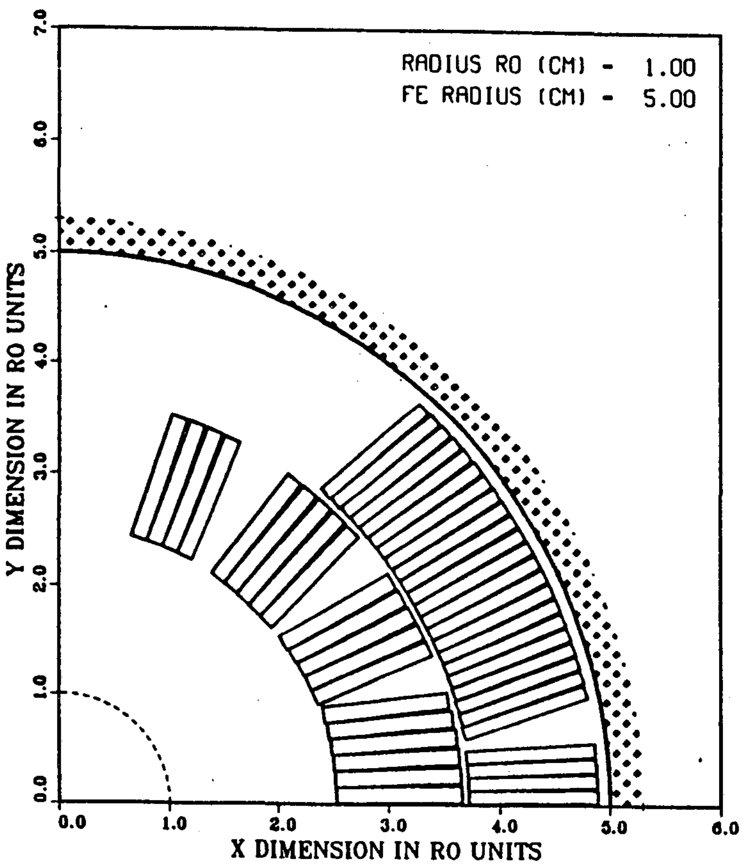
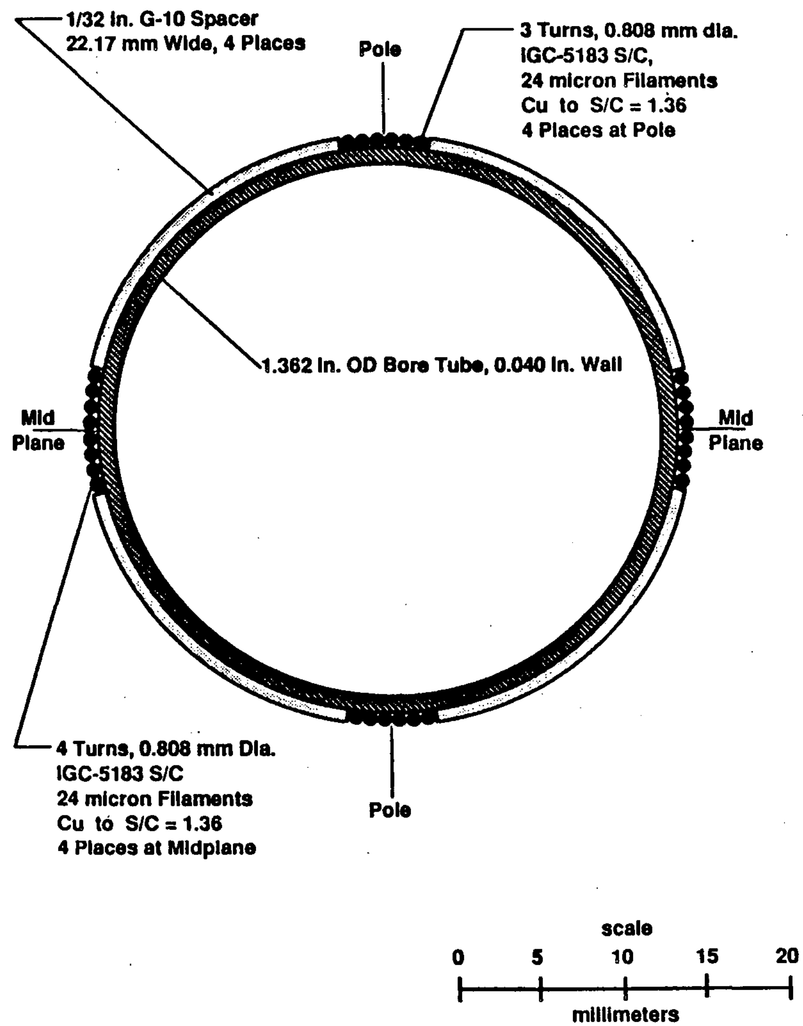


Fig. 5

NEW PASSIVE SUPERCONDUCTOR CORRECTION FOR LBL DIPOLE D-16B-1



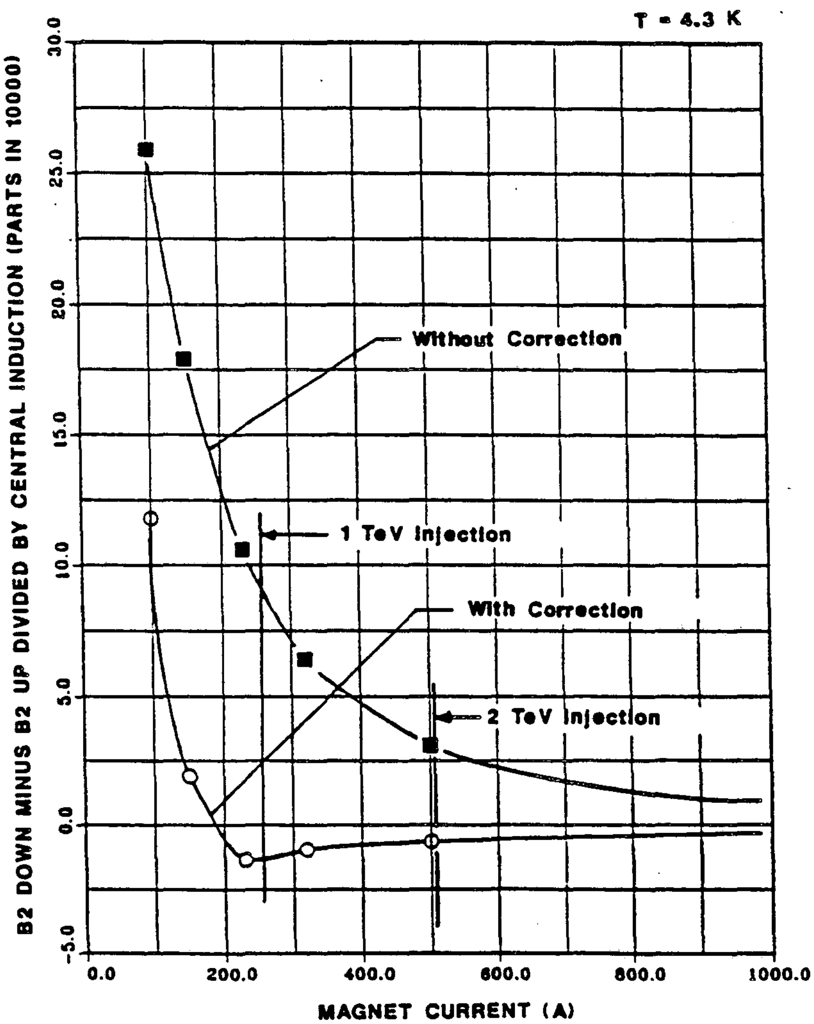
The D-16-B1 corrector is shown in Figure 5. The corrector consists of twenty-eight 26-inch long pieces of corrector conductor mounted on the surface of the 1.362 outside diameter tube. Like the D-15-C2 corrector, the D-16-B1 corrector is symmetric about the midplane and the poles. There are six corrector wires at each pole and there are eight correctors on each side at the midplane. The superconductor in the corrector represents about 0.6 percent of the superconductor in the D-16-B1 magnet.

Figure 6 demonstrates the extent of correction by the D-16-B1 dipole correctors at the center of the magnet. The curve with correction is negative, which indicates that the corrector overcorrected the magnetization sextupole. The magnitude of the magnetization sextupole was reduced by a factor of seven to eight.

The passive corrector reduced the decay of the magnetization sextupole by about 60 percent. Measurements at 1.8K yielded decay rates which are virtually the same as the decay rates at 4.3K. (The decay rate without the corrector is about +1.0 units per decade; the decay rate with the corrector is about +0.3 units per decade.)

Fig. 6

LBL DIPOLE D-16B-1 CENTRAL FIELD
WITH AND WITHOUT PASSIVE CORRECTION



SUMMARY

The passive corrector experiments on the LBL dipoles demonstrated that correction of magnetization sextupole can be done with pieces of passive superconductor. The magnetization sextupole is corrected by the passive superconductor at a temperature of 1.8K as well as 4.3K. A reduction of the magnetization sextupole was achieved when the field was decreasing as well as when the field was increasing. The decay of the magnetization sextupole was not reduced to the same extent that the magnetization sextupole (at the start of the decay) was reduced.

Passive superconductor correction is a viable way of reducing the magnetization sextupole in the SSC dipole magnet. The superconductor in the passive corrector can be less than one percent of the superconductor in the dipole depending on the radial location of the passive correctors with respect to the dipole magnet coil.

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