CORRECTION OF MAGNETIZATION SEXTUPOLE AND DECAPOLE IN A 5 CENTIMETER BORE SSC DIPOLE USING PASSIVE SUPERCONDUCTOR

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Abstract

Higher multipoles due to magnetization of the superconductor in four and five centimeter bore Superconducting Super Collider (SSC) superconducting dipole magnets have been observed. The use of passive superconductor to correct out the magnetization sextupole has been demonstrated on two dipoles built by the Lawrence Berkeley Laboratory (LBL). This reports shows how passive correction can be applied to the five centimeter SSC dipoles to remove sextupole and decapole caused by magnetization of the dipole superconductor. Two passive superconductor corrector options will be presented. The change in magnetization sextupole and decapole due to flux creep decay of the superconductor during injection can be partially compensated for using the passive superconductor.

I. INTRODUCTION

Sextupole, decapole and other higher multipoles can be of serious concern during injection into the SSC. Magnetization of the superconductor is a major contributor to the symmetric field error (normal sextupole, decapole and so on) in the SSC dipoles methods of correcting out the magnetization sextupole in the SSC dipoles. These methods are: 1) using filament diameters which are larger in one or more blocks of the SSC dipole, and 2) adding pieces of passive superconductor to the inside bore of the SSC dipole coil. Of concern is whether or not the decay in the Magnetization sextupole can be eliminated.

II. SEXTUPOLE CORRECTION BY CHANGING THE SIZE OF THE FILAMENTS IN VARIOUS PARTS OF THE DIPOLE COIL

H. C. Brown, Fermi National Accelerator Laboratory[1], suggested that magnetization sextupole could be controlled by somehow optimizing the superconductor filament diameter in various blocks or layers of the dipole. In order to investigate this technique, a conductor by conductor analysis of magnetization sextupole and decapole was done for the SSC 50 millimeter bore dipole DX-201 shown in Fig. 1. The following pattern emerged: block 1 and block 4 contribute positive magnetization sextupole at injection while blocks 2, 3 and 6 contribute strong negative magnetization sextupole. Block 5, which is in the lowest field region of the coil, contributes a small positive or negative sextupole depending on the injection field. The inner layer contributes a net negative magnetization sextupole and a positive decapole at injection. The outer layer contributes a net negative sextupole and a small negative decapole.

One cannot correct the magnetization sextupole by playing the inner and outer layers against each other because both contribute a negative sextupole. Block 1 (the inner block closest to the midplane) contributes by far the largest positive magnetization sextupole at injection so magnetization sextupole can be eliminated in the dipole at injection by increasing the block 1 filament diameter. The DX-201 dipole has 6 micron filaments and a copper to superconductor ratio of 1.5 in the inner cable; the outer cable has 6 micron filaments and a copper to superconductor ratio of 1.8. Increasing the filament diameter in block 1 to 14 microns reduces the magnetization sextupole in the DX-201 dipole by over an order of magnitude at injection. In addition, the magnetization dipole is also reduced. Figure 2 shows the uncorrected magnetization sextupole and decapole for the DX-201 magnet with 6 micron filaments. Figure 3 shows the magnetization sextupole and decapole for the DX-201 magnet with 14 micron filaments in block 1. In Figs. 2 and 3, the magnet cycle goes from 6.6 T to 0.25 T and back up to 6.6 T. (There are 6 micron filaments in all other

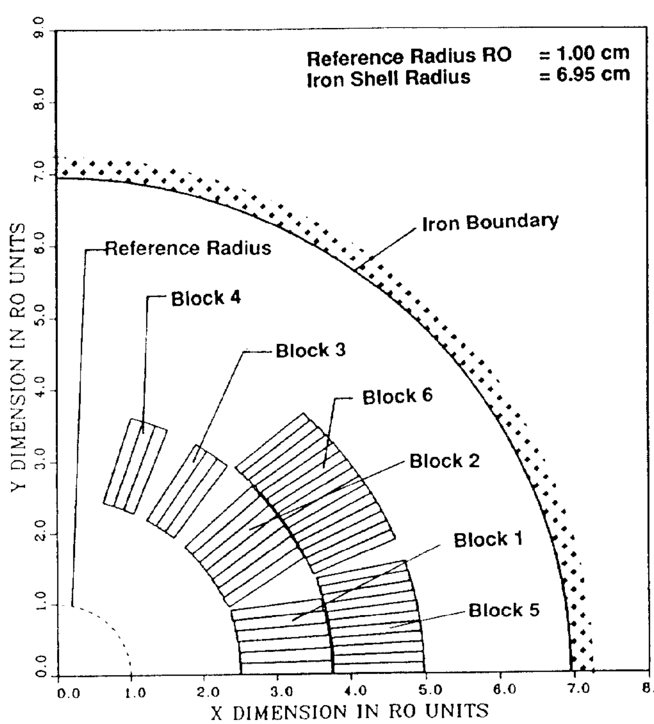

Fig. 1. A quarter section of the DX-201 SSC 50 mm bore dipole magnet.

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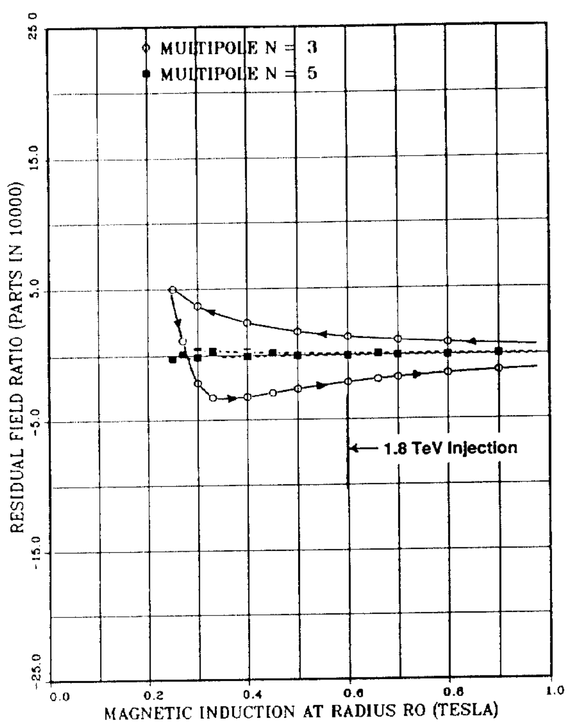

Fig. 2. The magnetization sextupole and decapole ratios at R = 10 mm for the DX-201 dipole magnet without passive correctors (with 6 micron filaments in all coil blocks). The cycle goes from 6.6 T to 0.25 T, then up.

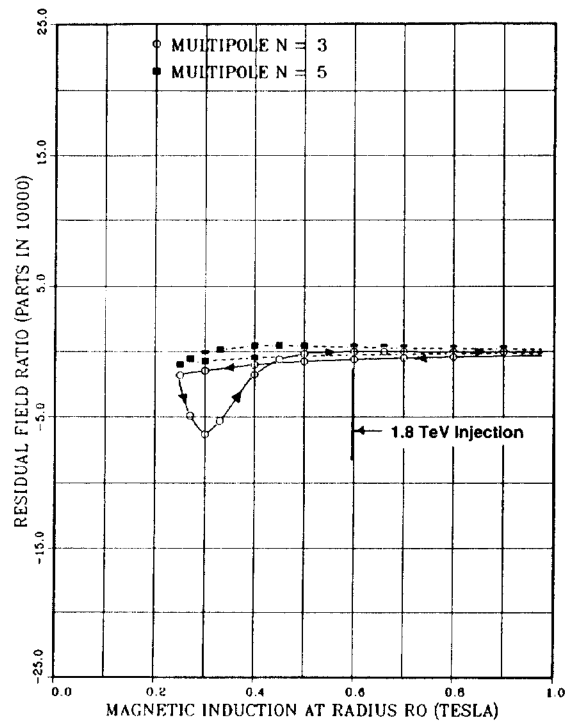

Fig. 3. The magnetization sextupole and decapole ratios at R = 10 mm for the DX-201 dipole magnet with 14 micron filaments in block 1 (6 micron filaments are in all other blocks). The cycle goes from 6.6 T to 0.25 T, then up.

blocks.) The two major disadvantages of this approach are: 1) the magnetization decapole is increased a factor of three or four, and 2) there must be two extra cable joints in each magnet.

III. SEXTUPOLE AND DECAPOLE CORRECTION BY ADDING SUPERCONDUCTOR ON TO THE DIPOLE INNER BORE

This method of passive superconductor correction is not new. The basic idea was presented Brown and Fisk in 1984.[2] Both Fermi Lab[3] and LBL[4] have tested the concept in 40 and 50 millimeter dipole magnets and have found that correction can be achieved using this method.

Passive superconductor inside the dipole bore works best when the correction superconductor filaments are 1.4 to 1.7 times larger than the filaments in the inner cable superconductor.[5] Since the passive superconductor carries no transport current, the copper to superconductor ratio in the corrector superconductor can be made as low as possible provided the superconductor critical current density is as high as the critical current density of the dipole conductor (2750 Amm^{-1} at 5T and 4.2 K) and the filament spacing is greater than 1 micron (to avoid proximity coupling).[6]

Figure 4 shows the DX-201 dipole with 1.62 mm thick correctors on its inner bore. The filament diameter of the correctors is 12 microns and the copper to superconductor ratio is 1.0. (The dipole cables have 6 micron filaments.) Figure 5 shows the magnetization sextupole and decapole as a function of central magnetic induction. When one compares Fig. 5 with Fig. 2, one can see that the magnetization sextupole has been reduced over an order of magnitude over a range of injection energies from 1 TeV on up. The magnetization decapole has been reduced by a factor of 3.[5]

The corrected dipole shown in Fig. 4 requires 2.72 percent more superconductor than the uncorrected dipole. The placement of the conductor in the correctors is not a critical issue.[7] Magnetic force is not an issue since the correctors carry no transport current. One can reduce the amount of superconductor needed to correct the magnetization sextupole and the radial space needed for the correction provided one is willing to increase the filament diameter in the corrector conductor. In the LBL experiments, the corrector filaments were four times larger than the filaments in the coil conductors; successful correction was achieved.

IV. FLUX CREEP DECAY WITH CORRECTION

Experiments at LBL suggest that the passive superconductor correction can get rid of two thirds of the sextupole flux creep.[4] This ratio appears to hold even if the highest field in the dipole is reduced to half of the normal

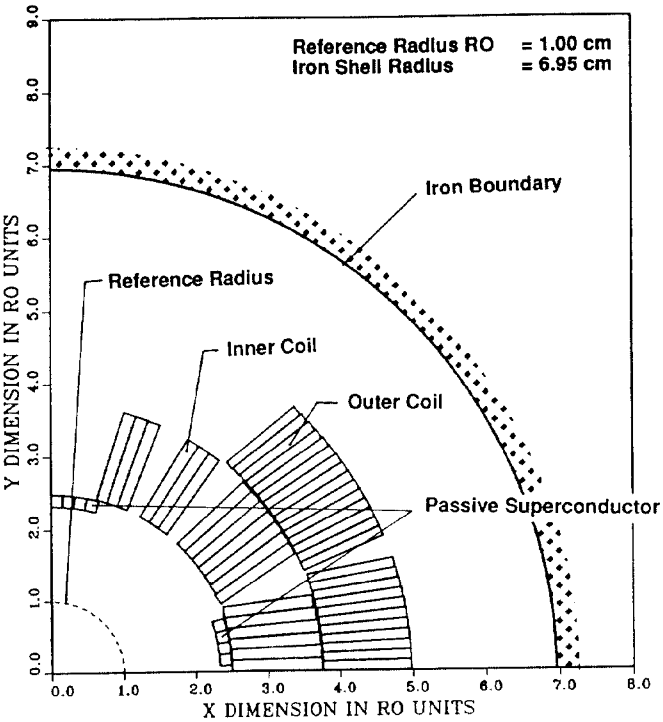

Fig. 4. A quarter section of the DX-201 SSC 50 mm bore dipole magnet with passive superconductor correctors on the inner coil bore.

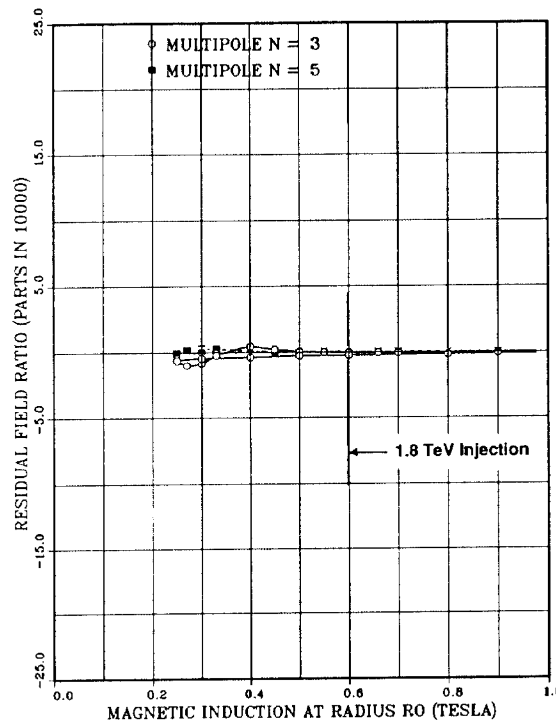

Fig. 5. The magnetization sextupole and decapole ratios at R = 10 mm for the DX-201 dipole with passive correctors with 12 micron filaments (with 6 micron filament in all coil blocks). The cycle goes from 6.6 T to 0.25 T, then up.

value of 6.6 T. Passive correctors by themselves may not be able to get rid of two thirds of the flux creep in a full length SSC magnet.

Experiments with YBCO high T_c superconductor suggest that the flux creep can be entirely eliminated by operating the superconductor in the penetration region of the hysterias loop.[8] Altering the magnet charge cycle can have an effect on flux creep.[9]

V. SUMMARY

Both methods of passive superconductor correction will reduce magnetization sextupole at injection at 1 TeV or above by an order of magnitude or more over a wide range of operating temperatures. Increasing the diameter of the filament in block 1 increases the magnetization decapole at injection while the separate passive superconductor method reduces magnetization decapole. Both methods of correction reduce the magnetization sextupole whether the field is rising or falling. If either method of passive sextupole correction is combined with an altered field cycle, a reduction of flux creep decay of the sextupole should be achieved.

VI. REFERENCES

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