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MAGNETIC FIELD DECAY IN MODEL SSC DIPOLES*

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Abstract

We have observed that some of our model SSC dipoles have long time constant decays of the magnetic field harmonics with amplitudes large enough to result in significant beam loss, if they are not corrected. The magnets were run at constant current at the SSC injection field level of 0.3 tesla for one hour and changes in the magnetic field were observed. One explanation for the observed field decay is time dependent superconductor magnetization. Data are presented on how the decay changes with previous flux history. Similar magnets with different Nb-Ti filament spacings and matrix materials have different long time constant field decay. A theoretical model using proximity coupling for the observed field decay is discussed.

Introduction

The quality of the magnetic field in the model SSC dipoles has been a major concern in that circulating beam can be lost if field imperfections exceed approximately 10^{-4} of the dipole field, especially at the injection field of 0.33 tesla or 1 TeV. Incorporated in the magnet test program has been an extensive magnetic field measurements program at all field levels. Because of magnetization currents flowing in the superconducting filaments, the exact field distribution depends on the path taken to reach a given field. We have been careful to follow a standard excitation path. An example is shown in Fig. 1, with the complete excitation and measurement cycle being from zero field to 6.6 tesla and then decreasing to zero.

Generally, it was found that the magnetic field nonuniformities repeated quite well, but sometimes there were differences that were unexpected. These differences were traced to different delay times between the magnet excitation and magnetic field measurement; since no decay was expected, there was no standard delay time. In some magnets, when we looked for field decay with time, we found it. Several magnets with different superconductor designs were tested for magnetic field decay and some of that data is presented here. The largest effect is seen in the normal sextupole component, although it also appears in the other multipoles allowed in a dipole. In this paper, we will focus on the sextupole.

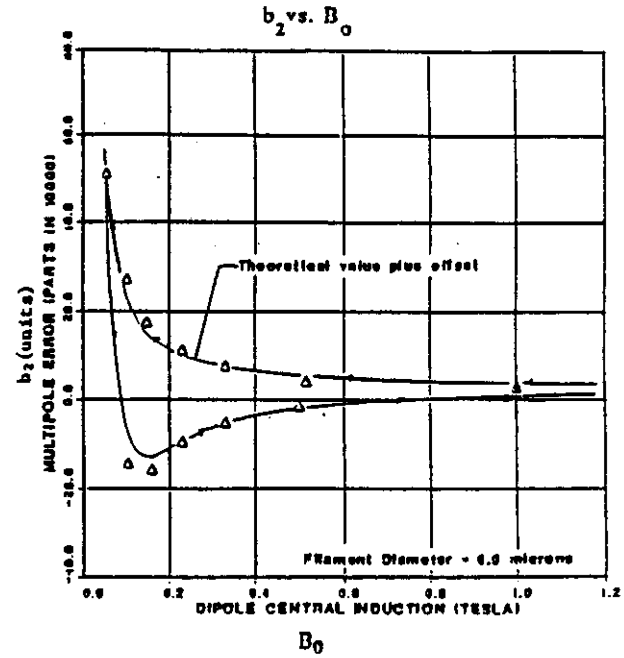

Fig. 1. Normal Sextupole Term

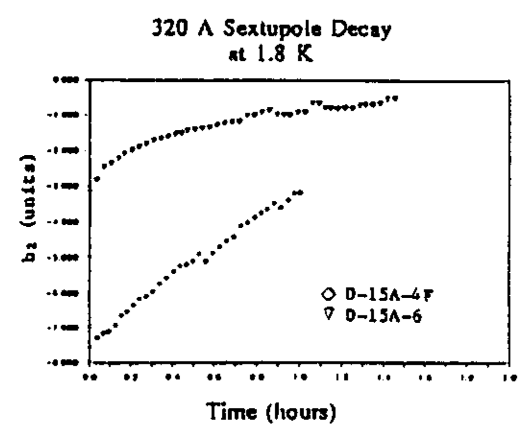

Fig. 2. Example of Sextupole Decay. Two Different Conductors at 1.8K.

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Figure 2 shows how the sextupole, b_2, decays with time for two different magnets at a temperature of 1.8K. Differences in values between 1.8K and 4.3K values are explained by the greater J_c at 1.8K. Figure 3 shows the effect of different excitation times. In the cycle case, the magnet is ramped to 6600 A at 16 A/S, back to 50 A, and up to 320 A at the same rate for a total of about 15 minutes before the decay measurements begin. When this cycle is interrupted to make magnetic measurements on the upramp and downramp, the time is increased to about 120 minutes. Figure 4 shows that the decapole also changes with time. Figure 5 shows the injection field decays for five different magnets at 4.3 K. The magnets are almost identical except for their superconductors, which are listed in Table I.

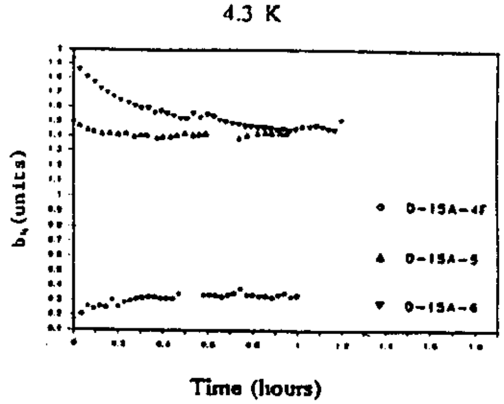

Fig. 4. 320 A 10-Pole Decay

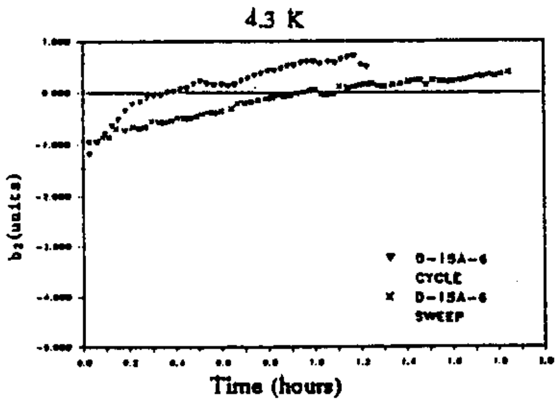

Fig. 3. 320 A Sextupole Decay

Cycle = 15 min. 0A → 320 A decay

Sweep = 120 min. 0A → 320 A decay

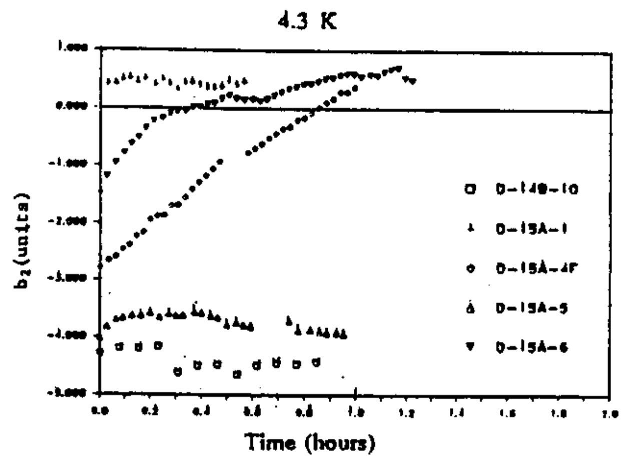

Fig. 5. 320 A Sextupole Decay in 5 Magnets

Table 1. A Comparison of the Superconductor in Five LBL Dipoles in Which Long Time Constant Field Decay Was Measured.

Magnet —>	D-14B-10	D-15A-1	D-15A-4F	D-15A-5	D-15A-6
Inner Layer					
Number of Strands in Cable	23	23	23	23	23
Strand Diameter (mm)	0.808	0.808	0.808	0.808	0.808
Normal Metal to S/C Ratio	1.4	1.4	1.26	1.3	~1.35
Filament Diameter (μm)	5.0	5.0	4.7	6.0	5.3
Filament Spacing (μm)	1.4	1.4	0.4*	1.5	0.53
Material Between Filaments	Cu	Cu	Cu*	Cu	Cu-Mn**
J_c at 5 T and 4.2 K (A mm^{-2})	2600	2600	2600	~ 2700	~2700
Strand Twist Pitch (twists per in.)	1.0	1.0	2.0	2.0	2.7
Cable Twist Pitch (twists per in.)	0.1	1.6	2.0	1.6	2.2
Outer Layer					
Number of Strands in Cable	30	30	30	30	30
Strand Diameter (mm)	0.648	0.648	0.648	0.648	0.648
Normal Metal to S/C Ratio	1.7	1.7	1.76	1.8	~1.35
Filament Diameter (μm)	5.0	5.0	4.7	6.0	4.3
Filament Spacing (μm)	1.4	1.4	0.4*	1.5	0.43
Material Between Filaments	Cu	Cu	Cu*	Cu	Cu-Mn**
J_c at 5 T and 4.2 K (A mm^{-2})	2750	2750	2618	~ 2700	~2700
Strand Twist Pitch (twists per in.)	1.0	1.0	2.0	2.0	5.4
Cable Twist Pitch (twists per in.)	1.6	1.6	2.0	1.6	4.9

* This superconductor is quite complex. The conductor consists of 52 μm diameter bundles of superconductor with 0.4 μ spacing between filaments within the bundle. The filaments are not round. The spacing between the filament bundles is about 3.5 μm.

** The filaments are nearly round and uniformly distributed in the conductor with manganese poisoned copper between filaments.

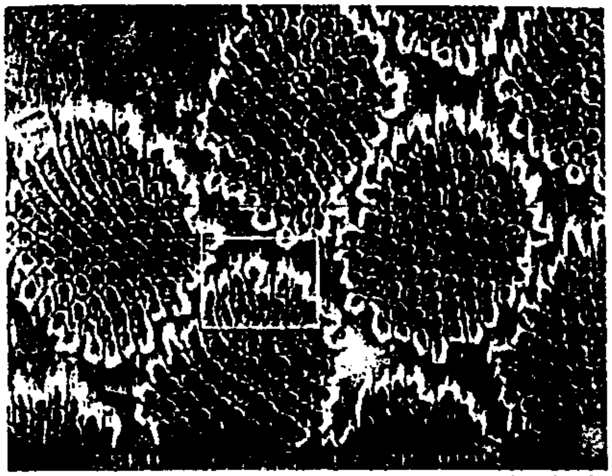

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Fig. 6 Photo - Furakawa

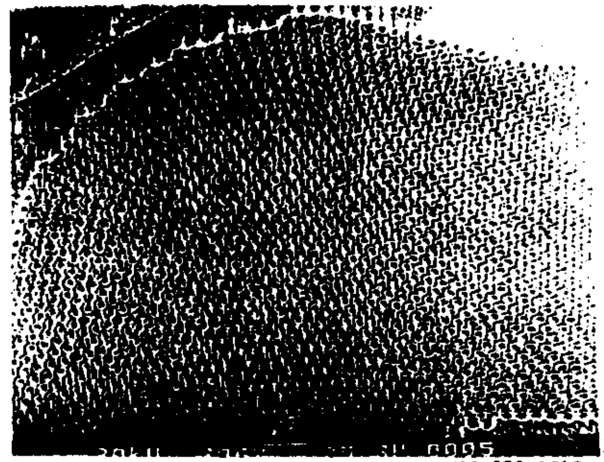

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Fig. 7 Supercon (Mn)

<u>An Explanation for the Observed Field Decay</u>

Long time constant field decays (less than 0.3 units over one hour) were not observed in dipole magnets D14B-10, D-15A-1 and D-15A-5. At 4.3 K, a 3 unit decay of sextupole (from negative to positive) was observed over a period of one hour in dipole magnets D-15A-4F. In magnet D-15A-6 at 4.3 K, a sextupole decay (from negative to positive) of about two units over one hour was observed. In the two magnets where field decay was observed, the field decay was in a direction consistent with a <u>reduction</u> of the superconductor magnetization.

Table 1 compares the superconductor in the five, nearly identical, one-meter long dipole magnets. The superconductor in the inner coils of the magnet has a normal metal-to-superconductor ratio of 1.26 to 1.4 with filament diameters of 4.7 to 6 μm and a critical current density at 5 T and 4.2 K of about 2650 A mm-2. The outer layer has a wider variation of normal metal-to-superconductor ratio (1.35 to 1.8) and filament diameters (4.3 to 6.0 μm), but the critical current density at 5.0 T and 4.2 K is about the same for both layers. The factor which differs between the five magnets is the spacing between the filaments. The magnets which exhibit no sextupole decay have a filament spacing of 1.4 to 1.5 μm, while the magnets which exhibit decay have filament spacings of 0.40 to 0.53 μm. The small filament spacings suggest that sextupole decay is related to proximity coupling[1] between filaments, because a decay in proximity coupling between filaments would result in a <u>decrease</u> in superconductor magnetization.

According to E. W. Collings,[2] one can argue for decay in the proximity coupling currents because the region between filaments behaves like a weakly pinned superconductor. (Proximity coupling is like weak tunneling between filaments). A weakly pinned superconductor will exhibit flux flow which manifests itself as decay in its critical current. The region between filaments is not superconducting in a true sense so it might be reasonable to expect currents flowing in this region to decay with time. To test the hypothesis of proximity coupling as a source for extra magnetization (which then decays away), the SCMAGØ4 computer code[3] was used to estimate the effects of superconductor magnetization (including proximity coupling) on the sextupole at a central induction of 0.33 T (when the magnet has been charged to high field, brought down to 0.05 T then brought back up to 0.33 T).

If one includes the extra magnetization due to proximity coupling measured by Brookhaven National Laboratory for the Furukawa cable used in magnet D-15A-4F,[4] one gets an extra negative sextupole of 3 to 4 units at a central induction of 0.33 T when one calculates the effect of superconductor magnetization on the central field of a SSC dipole using the SCMAGØ4 code. If one dopes the superconductor matrix material to reduce the coherence length in that material, one should reduce the magnetization due to coupling.[5] The addition of manganese to the center copper in the superconductor of magnet D-15A-6 does reduce the coherence length of the copper, and it appears to reduce the proximity coupling between filaments. The decay sextupole component at 0.33 T observed in dipole D-15A-6 is also reduced.

Unfortunately it is difficult to make a direct comparison between magnet D-15A-4F and D-15A-6 because the conductors in the two magnets are quite different in their structure. The conductor in magnet D-15A-4F is complex consisting of many 52 µm diameter bundles of 4.7 µm diameter filaments spaced 0.4 µm apart with copper between the filaments. The bundles of filaments are about 3.5 µm apart, and there is probably no proximity coupling between bundles. If the D-15A-4F magnet conductor had spacings between the filaments of 0.4 µm throughout the conductor (instead of in 52 µm bundles), the proximity coupling magnetization would be at least an order of magnitude more than that measured in the dipole D-15A-4F conductor. The Supercon conductor used in dipole D-15A-6, which has manganese doped copper between filaments, has a uniform filament spacing throughout the conductor, yet the measured proximity coupling magnetization is smaller than that measured in the D-15A-4F superconductor.[5,6] Magnet measurements suggest that the manganese doping does really reduce proximity coupling but not enough to completely eliminate it or the resultant field decay. Calculations using the SCMAGØ4 program suggest that most of the proximity coupling occurs in the outer layer of the magnet (where the filament spacing is smaller and the field is lower), and that there is almost no proximity coupling in the inner layer superconductor.

Conclusions

Slow magnetic field changes have been observed in two SSC model dipole magnets containing fine filament superconductor in which the filament spacing is approximately 0.5 micron. For similar magnets with filament spacings of 1.5 micron, these slow field changes were not significant. An explanation based on proximity coupling and the decay of these currents seems qualitatively correct, but quantative predictions require more detailed magnetization data on the candidate conductors. Doping of the interfilament region copper with 0.5% manganese reduces the proximity effect.

References

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