

Persistent Current Effects in BSCCO Common Coil Dipoles

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Abstract—A series of one-meter long racetrack-shaped windings has been fabricated from BSCCO tape conductors obtained from four manufacturers. Two coils were built from each conductor type and tested in the "common coil" dipole configuration in liquid helium. The effect of the remnant magnetization currents was determined by measuring the residual dipole and sextupole fields after cycling the magnets to progressively higher currents. Two coil sets have been measured and the results are compared to those obtained from a Nb₃Sn ribbon magnet of the same geometry.

Index Terms—Common Coil Magnets, remnant fields, HTS BSSCO-2223 tape conductor

I. INTRODUCTION

Common coil dipoles in which the windings are powered in such a way that regions of opposite polarity occur in the same magnet are ideally suited to collider applications [1,2]. The fact that the minimum-bending radius of the superconductor can be made quite large in such a design means that relatively brittle materials can be used in their construction. High Temperature Superconductors (HTS) in general have limited flexibility so that the common coil approach provides a natural way of exploiting the potential of these materials. This combination of a novel magnet design and a new type of conductor makes it difficult to estimate the effect of persistent currents on the magnetic field distribution. Direct measurements were made on the residual fields of two magnets made from BSCCO-2223 tape produced by different suppliers, Intermagnetic General Corporation (IGC) and American Superconductor Corporation (ASC). A common coil dipole wound from Nb₃Sn tape was also measured. Additional magnets in this series will be tested for remnant fields as they become available.

II. MAGNET CONSTRUCTION DETAILS

The coils were wound on a flat table with conductor and insulation feeding from separate pay-off spools. The tension was controlled using torque motors with most of the force applied to the Kapton insulating ribbon. As each half turn was positioned it was held in place by a clamping bar

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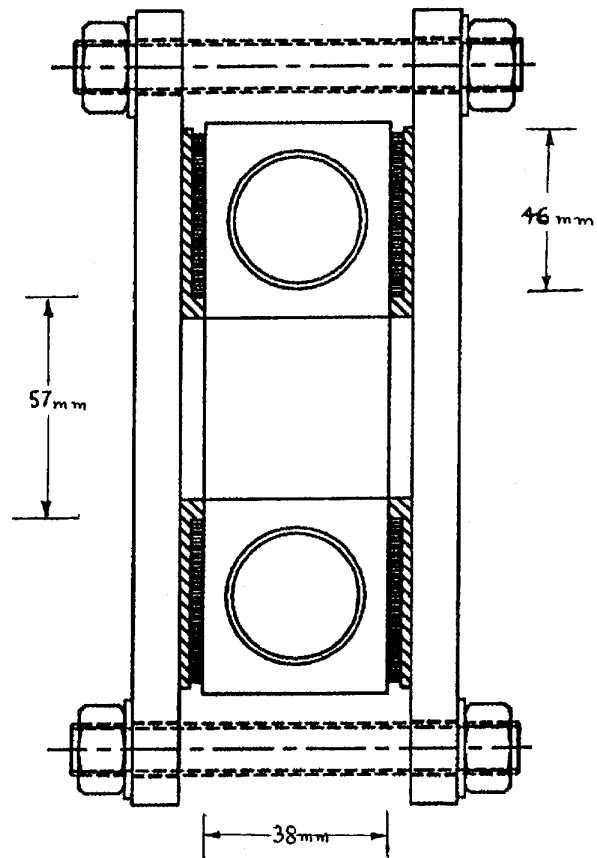


Fig. 1. Test configuration of the racetrack coils in "common-coil" form.

while the next half turn was wound. Joints between sections of ribbon were formed as needed in the end regions by overlap soldering. Voltage taps were provided by inserting thin copper foils into the coils at the beginning and end of each conductor length and on either side of any unusual sections that appeared during winding. Finished coils were coated with epoxy and heat cured to form quite rigid and easy to handle structures. A common coil magnet was assembled from two racetrack coils in an aluminum fixture clamped by brass bolts as shown in Fig. 1. The separation between coils is 38 mm and an access hole of 32 mm is available for the magnetic measuring probe. Four sets of BSCCO-2223 coils are being fabricated with conductor from different sources. The windings have the same overall dimensions except for the thickness, which is determined by the width of the ribbon.

The number of turns in each set varies due to conductor thickness. Details of the windings are summarized in Table I.

TABLE I
RACETRACK COIL PARAMETERS

Conductor Type	Dimensions, mm	Turns/Coil	Status
Nb ₃ Sn	0.2 x 3.2	168	Tested
IGC	0.25 x 3.3	147	Tested
ASC	0.18 x 3.1	221	Tested
NST	0.20 x 3.2	220	Under construction
VAC	0.23 x 3.4	170	Under construction

After testing in their self field in the fixture shown in Fig. 1 the coils will be measured as inserts in a high field NbTi test magnet.[3]

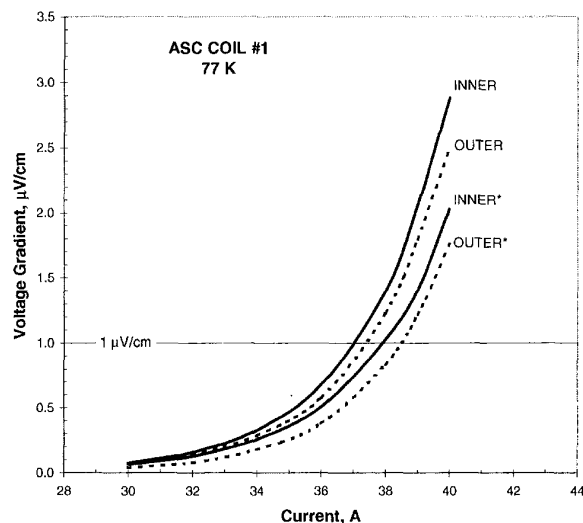


Fig. 2. The average voltage gradient across the inner and outer sections of ASC Coil # 1 as a function of current measured in liquid nitrogen. The curves marked with a star are for the case where only half the magnet is powered.

III. RACETRACK COIL PERFORMANCE

The first pair of HTS racetrack coils was made from 2223 ribbon produced by IGC. This conductor was received over two years ago and had quite low current carrying ability. The performance of this set of coils was limited to 110 amps at 4.2 K. The ASC windings were a significant improvement and could be operated at currents as high as 300 amps despite the smaller cross sectional area of the conductor. Each of the ASC coils was wound from two 210 m lengths of conductor. In Fig. 2 the 77 K voltage-current characteristics are shown for the inner and outer sections of Coil # 1 when powered as either a single winding or part of a common coil magnet. It is obvious from this diagram that all sections of the winding exhibit approximately the same effective resistivity

independent of their position in the coil and the local magnetic field distribution. The current at which the average voltage gradient along the conductor equals 1 $\mu\text{V}/\text{cm}$ is the same to within about 1 amp for the whole magnet or any individual section and is approximately one half of the zero field value. The situation in liquid helium is similar as shown in Fig. 3 where the voltage gradient characteristics of the whole magnet are compared to the two sections of one of the racetrack coils. Again at an average gradient of 1 $\mu\text{V}/\text{cm}$ the current is almost the same but the voltage gradient in the outer section is increasing more rapidly than the inner and ultimately it is this section which limits the magnet performance. At lower effective resistance most of the voltage appears to be across the inner turns but the smaller gradients are more difficult to measure accurately due to the large inductive voltages arising from power supply ripple.

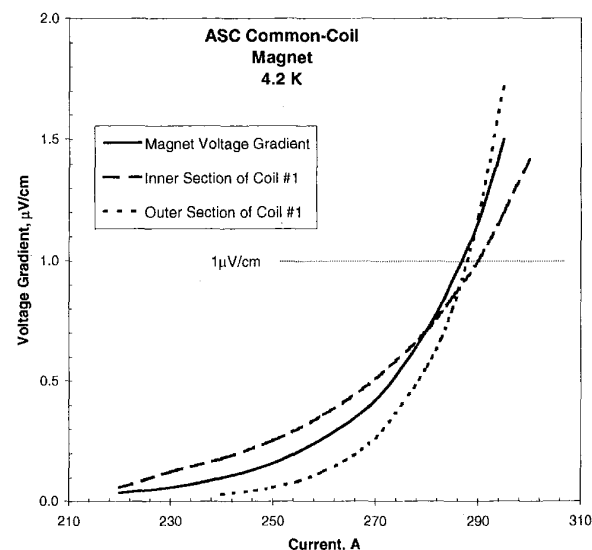


Fig. 3. The average voltage gradient across the whole magnet compared with the inner and outer sections of Coil # 1 measured in liquid helium.

IV. MAGNETIC MEASUREMENTS

The effect of conductor magnetization was characterized by measuring the trapped field at zero current after energizing the magnet to progressively higher currents. The remnant dipole and sextupole fields were measured since they are by far the largest and most important components. The technique used employs Hall probes mounted in a G-10 cylinder, which can be rotated in one of the magnet apertures. Fig. 4 shows the arrangement of the three Siemens type SBV 604 Hall plates. As the cylinder is rotated each unit produces a signal proportional to the tangential component of the field. By reading the values at discrete angular increments and performing a fourier analysis, the various harmonics can be resolved. If the three probes are carefully adjusted to the same sensitivity and connected in series the output is proportional to the sextupole component only and the array has three times the sensitivity of a single plate. An example is shown in Fig. 5 where the output of the three Hall array is

plotted against angle for a sextupole field of about 2 gauss in the bottom portion of the figure, while the top shows a single probe output proportional to the trapped dipole field with approximately equal amounts of dipole and sextupole field.

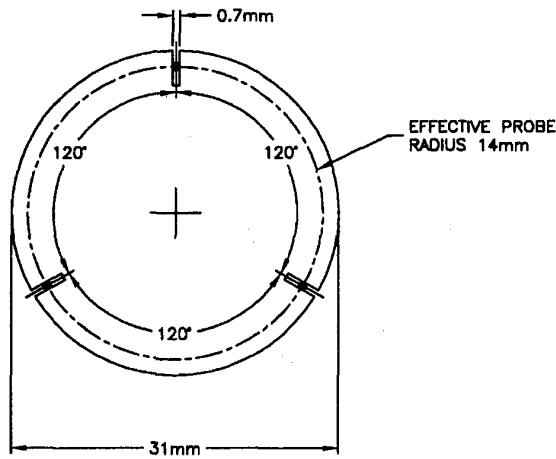


Fig. 4. The arrangement of Hall plates in the probe used to measure residual fields.

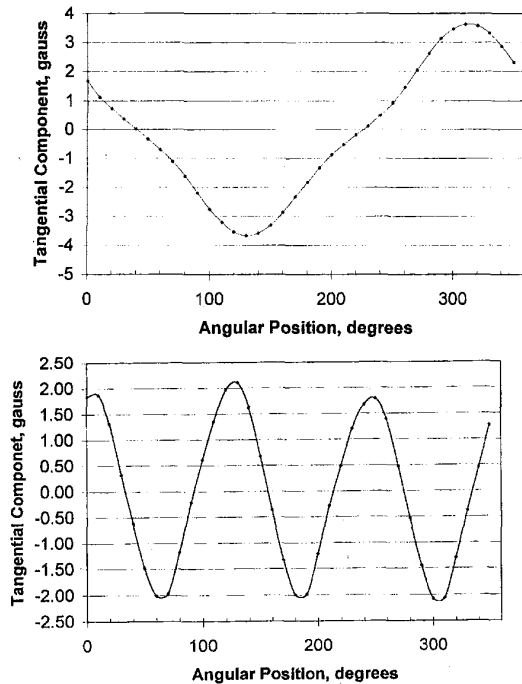


Fig. 5. Typical output data from a single rotation of the magnetic measuring probe, (top) a single Hall plate for dipole determination and (bottom) the three Hall plate assembly for sextupole measurement.

The residual dipole field for the three magnets tested to date is given as a function of the maximum energizing current density in Fig. 6. This current density is calculated by multiplying the peak current by the number of turns per unit area to normalize for the difference in conductor size. The Nb₃Sn coil shows a small reversible region with no

measurable trapped dipole field and then an increasing amount of residual field which is opposite in sign to the energizing field. Both HTS magnets, however, produce remnant fields even for low current excursions. The residual fields start out in the same direction as the applied field but soon reverse in sign, and in the case of the ASC coil, become significantly larger than the trapped field in the Nb₃Sn magnet. The residual sextupole field is shown in Fig. 7. As in the dipole case the Nb₃Sn magnet shows an initial region of very little trapped field and then a maximum of about two gauss of negative sextupole. The HTS coils again trap field at very low currents and have a positive remnant sextupole, which peaks and then in the case of the ASC magnet becomes negative. These residual fields seem quite stable with no observable change over a 17-hr period. The two HTS magnets were also measured in liquid nitrogen where the trapped field pattern was found to scale with current so that remnant fields were approximately one seventh of their 4.2 K values.

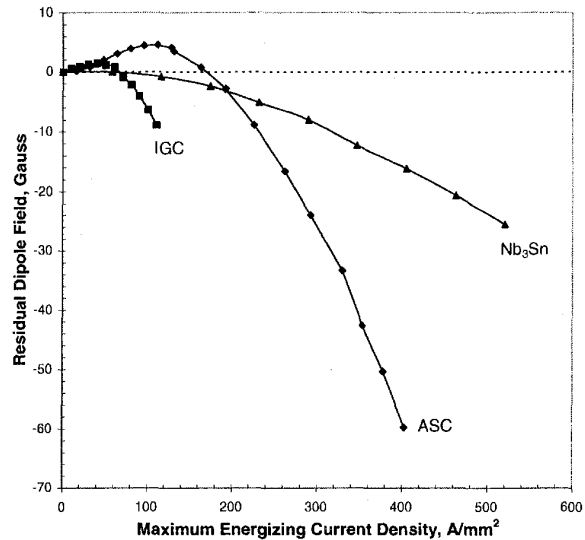


Fig. 6. The trapped dipole field plotted against maximum energizing current density for the IGC and ASC HTS magnet and the Nb₃Sn coils.

V. CONCLUSIONS

The fact that the trapped field harmonics are opposite in sign to the applied field in the Nb₃Sn magnet is attributed to the unusual geometry of the common coil design. Why the residual field of the HTS magnets is positive at low excitation and then changes sign is not obvious. The Nb₃Sn ribbon is made by diffusing tin into a niobium sheet and would be expected to exhibit large magnetization currents. Both of the HTS conductors are at least nominally composed of discrete filaments so the large remnant fields are somewhat unexpected. Additional measurements on the rest of the magnets in this series will, hopefully, make the situation easier to understand.

ACKNOWLEDGEMENT

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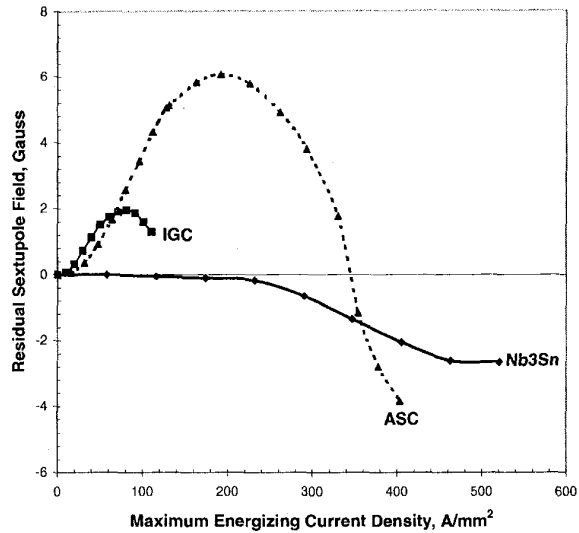


Fig. 7. The remnant sextupole field as a function of the peak current density for all three common coil magnets.