

MAGNETIC FIELD PROPERTIES OF THE ISABELLE PROJECT SUPERCONDUCTING DIPOLE MAGNETS*

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Summary

A series of prototype superconducting dipole magnets have been constructed and tested as part of the ISABELLE Project research and development program. Results of magnetic field measurements are presented with emphasis placed on the DC and AC components of the main field. Magnetization and the effects of the magnetic fields at the ends of the magnet are displayed.

In this paper we report on the magnetic field shape of the dipole magnets being constructed at BNL as part of the research and development program for the dipole magnets which will be installed in the ISABELLE storage ring. Although the main thrust of the magnet development to date has been in the area of magnet training and mechanical stability¹, it is nonetheless important to examine the field shape within these dipoles and make comparisons with the tolerances which are imposed on the quality of the field in order to insure the successful operation of the machine.

The field analysis is based on the decomposition of the field into its harmonic components such that

$$B_y = B_0 (1 + b_1 x + b_2 x^2 + b_3 x^3 + \dots)$$

$$B_x = B_0 (a_1 x + a_2 x^2 + a_3 x^3 + \dots)$$

where b_n and a_n express the normal and skew multipole components of the field, with $n = 1$ for quadrupole, $n = 2$ for sextupole, etc.

The measurement system is based on a revolving cylinder² upon which loops have been wound to measure directly particular multipoles on a continuous basis. Currently we are measuring on a routine basis the multipole components b_n and a_n for n from 0 to 5 (dipole to dodecapole). Since these measurements are done in a continuous way we are able to measure these field harmonics while ramping the magnets.

In Fig. 1, we show the transfer function B_0/I for Mk 31, the most recent magnet of this development series. The fall-off of the transfer function at high currents is due to the magnetic field saturation in the 18" iron core which surrounds the superconducting coils. A measured value of 14.13 is obtained for the transfer function in the interval between $I = 1000$ Amps and $I = 2000$ Amps where the effects of magnetization and iron saturation are small. This compares with a value of 14.103 obtained with an NMR device. We estimate the precision of the two measurements to be approximately 1 part in 10^3 and 1 part in 10^4 respectively. The magnet to magnet RMS tolerance for $\delta B_0/B_0$ is 1.7×10^{-4} . In figures 2 through 5 we display the remaining harmonics up to the decapole terms. All results, except the decapole terms, have been corrected for an offset of the measuring device from the magnetic axis of the magnet (defined as the axis of the sextupole). In this case the displacement is 0.75 mm. In all these figures the symbol \square denotes the total integrated DC (0 amp/sec) harmonics (including ends) while $+$, \diamond , and Δ are respectively DC (up) and DC (down) and 8 amp/sec ramp rates at the middle of the magnet (excluding ends).

We note several interesting features. All harmonics except for B_0 , b_2 and b_4 are forbidden and consequently should vanish. In fact all the forbidden DC terms are near zero (note the shaded areas on each plot which correspond to the magnet to magnet rms tolerances³ required for the machine to obtain design luminosity). The only significant departure from zero for a forbidden term, the skew decapole, most likely results from feed down due to measuring coil displacement in a large 14-pole field, b_6 . This pole has not been directly measured and therefore a calculation of the correct decapole term cannot be made. ISABELLE dipoles will have trim coils present to compensate for the allowed terms b_2 and b_4 while the 14-pole will be removed from the final design of the dipole magnet.

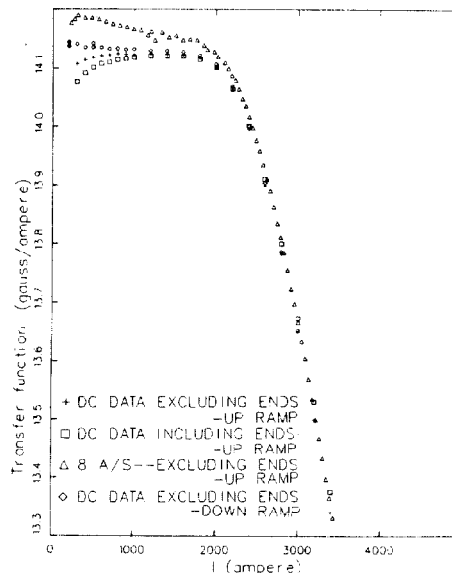


Fig. 1. The measured transfer function B_0/I .

The reconstructed field shape, obtained by summing the measured multipoles through the decapole term, is shown in Fig. 6 at three different current values. The influence of the strong sextupole term is apparent. A similar plot is shown in Fig. 7 but with the allowed harmonics b_2 and b_4 removed in order to illustrate what the shape of the field would be after the sextupole and decapole trim correction coils are powered.

The presence of multipoles induced during the ramping of the magnet is noted in Figs. 2 thru 5. The induced allowed harmonics b_2 and b_4 are believed to originate from interstrand eddy currents generated within the braided coils during ramping of the magnets. The appearance of the induced skew terms in the quadrupole and octupole can be interpreted as an asymmetry between the generated eddy currents in each of the two superconducting coils in the dipole.

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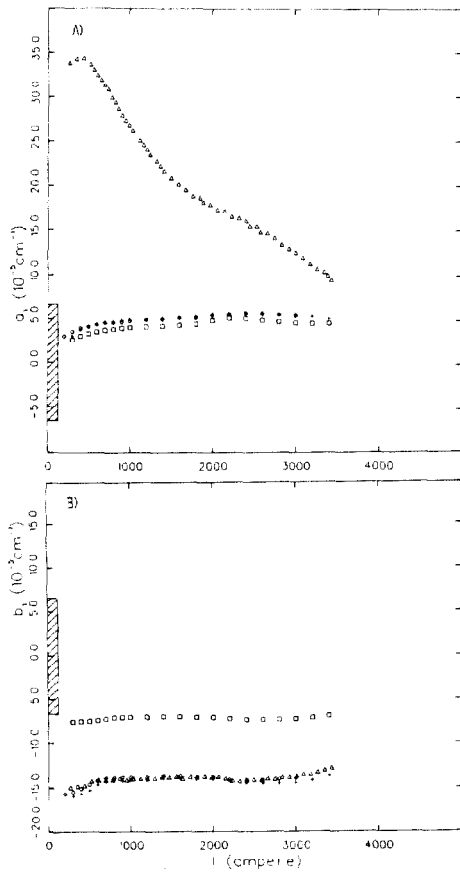


Fig. 2. The magnetic field quadrupole components.

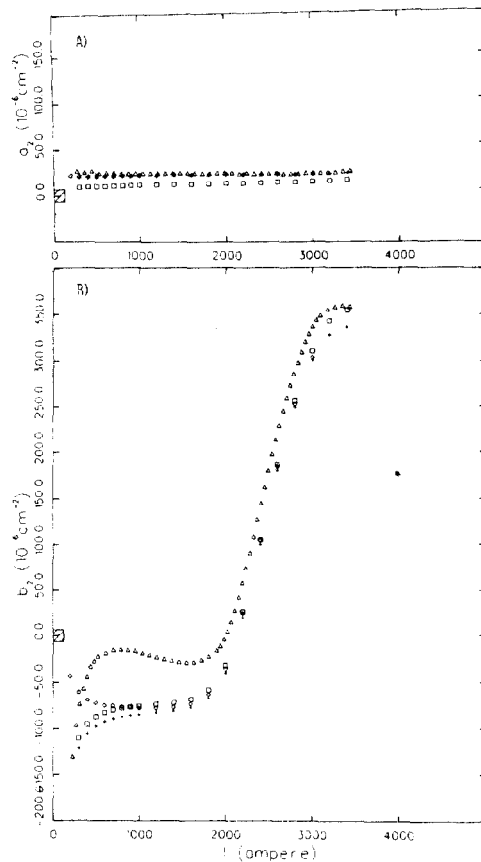


Fig. 3. The magnetic field sextupole components.

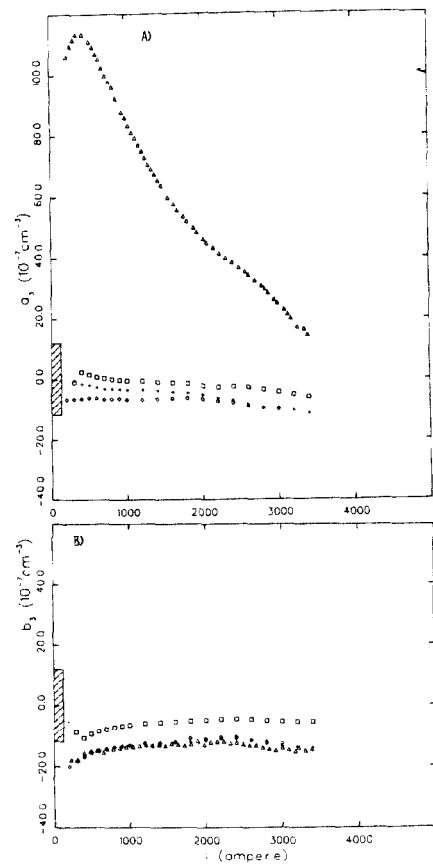


Fig. 4. The magnetic field octupole components.

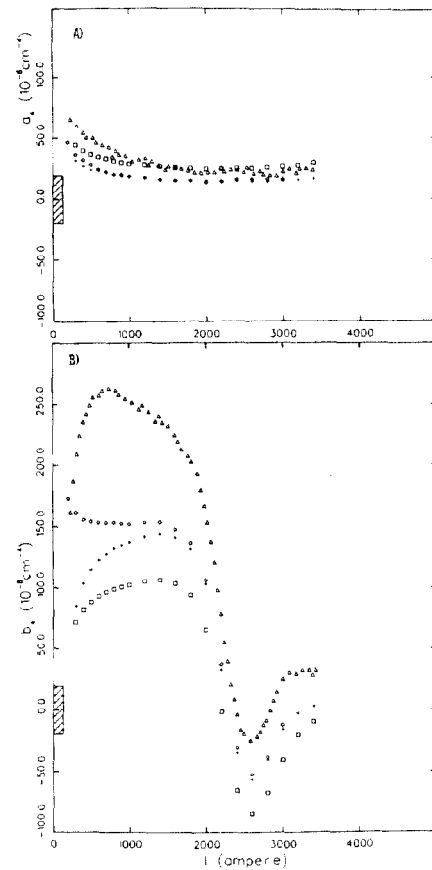


Fig. 5. The magnetic field decapole components.

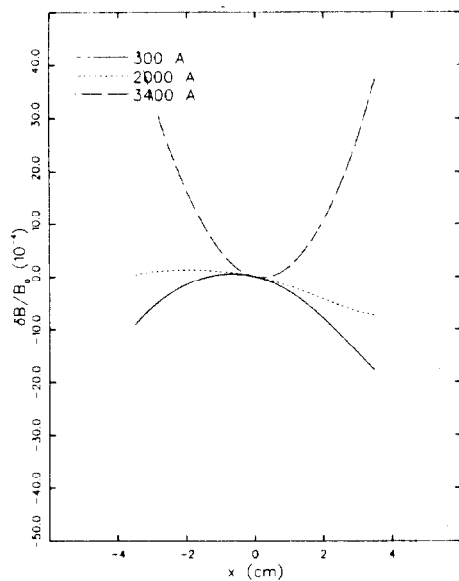


Fig. 6. The reconstructed magnetic field on the x axis.

The induced allowed harmonics could, in principle, be corrected by appropriately powering the trim coils of the magnets. This approach presents formidable difficulties, however, in that it would be necessary for the amplitudes of the induced harmonics to be reproducible from magnet to magnet and that allowances be made for the complicated nature of the time development of these induced harmonics. Further, since no trim coils are anticipated to correct for skew quadrupole and octupole terms, the presence of these induced harmonics places a more serious limitations on the operation of ISABELLE. Consequently, a considerable effort is being made toward reducing this effect. The focus of this effort, currently, is toward increasing the interstrand resistance of the braid which should result in a suppression of the eddy currents within the braid. One quadrupole magnet has been constructed and tested to date which contains a specially prepared high interstrand resistance braid.⁴ The results of this magnet show a significant reduction in the induced harmonics. Dipoles which contain this new braid have been constructed and will be tested in the near future.

The discrepancy between the harmonics obtained at low currents for the two cases, DC (up) and DC (down), are predominately caused by persistent currents in the superconductor which have been induced by the dynamics of the changing magnetic field, \dot{B} . However, unlike the previously discussed case of interstrand eddy currents, these currents are established within the superconducting filaments and persist due to the absence of an internal resistance. This magnetization

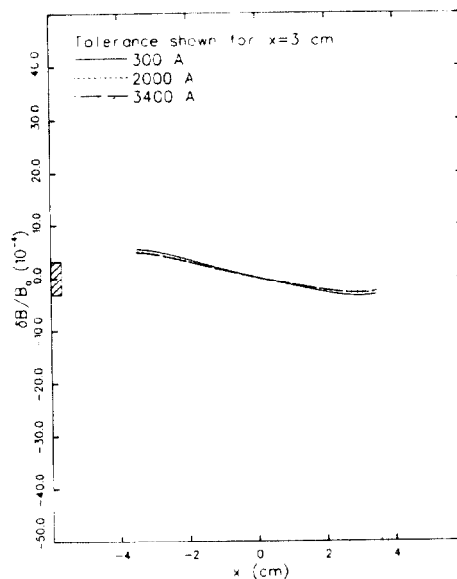


Fig. 7. The reconstructed magnetic field shapes with the terms b_2 and b_4 removed.

effect induces a field at $I = 300$ Amps of $B_0 = 8$ gauss and induces the harmonics $b_2 = 52 \times 10^{-6} \text{ cm}^{-2}$ and $b_4 = 36 \times 10^{-8} \text{ cm}^{-4}$.

Conclusions

In summary, we have reported on the most recent of a series of dipole magnets now being constructed and tested as part of the magnet R&D program for the ISABELLE Project. The principle thrust of this program is now being shifted from the training and mechanical stability of the dipole magnets toward the understanding and control of the magnetic field harmonics, in particular the magnet to magnet reproducibility of the allowed harmonics B_0 , b_2 and b_4 . The appearance of induced harmonics during the ramping of the magnets seriously degrade the quality of the magnetic field and consequently much effort is being directed toward significantly reducing this effect.

References

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