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MAGNETIC PROPERTIES OF THE ALS BOOSTER SYNCHROTRON ENGINEERING MODEL MAGNETS*

R. Keller, M. I. Green, E. Hoyer, Y. M. Koo**, K. Luchini, S. Marks, J. Milburn, and D. H. Nelson
Lawrence Berkeley Laboratory, 1 Cyclotron Road, Berkeley, CA 94720

Abstract

The Advanced Light Source (ALS) at Lawrence Berkeley Laboratory is designed to be a third-generation electron storage ring producing high-brightness VUV and X-ray radiation from wiggler and undulator insertion devices. Engineering models of all lattice magnets that are to be installed in the storage ring and its booster synchrotron have been built and are being tested to verify their performance. This paper is concerned with the magnets that form the booster lattice: dipoles, quadrupoles, sextupoles, and corrector dipoles (steerers). After a brief outline of measurement techniques and equipment, the major design parameters of these magnets are listed. Measured effective lengths and multipole field errors are then given for each type. All engineering models meet the specifications, and tracking studies including the measured systematic field errors show acceptable performance of the booster synchrotron; hence the designs are qualified for production.

Introduction

The Advanced Light Source (ALS), currently under construction at the Lawrence Berkeley Laboratory, consists of three major accelerator systems: a 50 MeV linac; a 1 Hz, 1.5 GeV booster synchrotron; and a storage ring optimized for operation at 1.5 GeV. Engineering models for most of the magnets for the two rings have been built to verify their performance. In this paper we describe the field analysis of the magnets that comprise the booster synchrotron lattice: dipoles, quadrupoles, sextupoles, and corrector dipoles (steerers).

Both, ac and dc magnetic measurements were performed with the dipole; the ac measurements are discussed elsewhere in more detail [1]. All the other magnets to date have only been measured under dc conditions. The main qualities assessed are: fundamental strength, effective length, and higher-order multipole field errors. The measurement equipment includes static point coils and static, curved integral coils for the dipole, rotating integral coils for quadrupole and sextupole, and Hall probes. As an example, the rotating coil used to measure the sextupole is shown in Fig. 1. It can be used to measure the sextupole field or, with its two sets of windings in series opposition (bucked mode), to measure the higher-order multipoles while suppressing the quadrupole and sextupole field components.

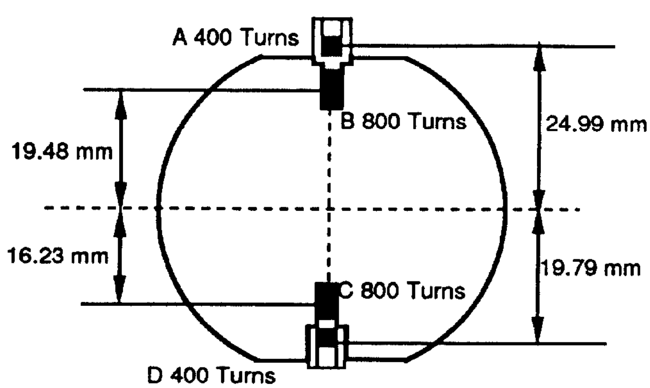

Figure 1. Cross-sectional layout of the rotating integral coil used to measure the sextupole. Packets A and D form one coil, and packets B and C the other.

Design Parameters of the Magnets

The main design parameters of the magnets are listed in Tables 1 - 4. Note that the booster injection energy is 50 MeV and the extraction energy is 1.5 GeV; the excitation currents for all magnets will be ramped accordingly. The current waveform for the dipoles will be a free-running ramp with 1 Hz repetition frequency; due to power supply constraints, however, the ac measurements were actually performed with either a 2 Hz free-running ramp or a dc-biased 10 Hz sine waveform.

Table 1. Major Parameters of the Dipole

Type	H-type, curved, zero gradient, parallel end plates
Bend angle (deg)	15
Radius of curvature (m)	4.0107
Magnetic flux density, extraction (T)	1.248
Magnetic length (m)	1.050
Gap height (mm)	44.0
Horizontal good-field width (mm)	±30
Vertical good-field height (mm)	±18
Field uniformity, apart from fringe-fields	$\pm 1.0 \times 10^{-3}$
Maximum current (A)	746
Current waveform	(see text above)

Table 2. Major Parameters of the Quadrupole

Type	Closed yoke, symmetrical in hor. and vert. directions
Maximum gradient (T/m)	15.0
Magnetic flux density, extraction (T)	0.488
Magnetic length (m), QF	0.3
Magnetic length (m), QD	0.2
Pole inscribed radius (mm)	32.5
Good-field radius (mm)	30
Maximum current (A)	398
Current waveform	tracking dipole excitation

Table 3. Major Parameters of the Sextupole

Type	Closed yoke, symmetrical in hor. and vert. directions
Maximum Sextupole strength (T/m^2)	75
Magnetic flux density, extraction (T)	0.082
Magnetic length (m)	0.1
Pole inscribed radius (mm)	35
Good-field radius (mm)	30
Maximum current (A)	5.8
Current waveform	tracking dipole excitation

Table 4. Major Parameters of the Corrector Dipole

Type	C-type
Bend angle (deg)	0.115
Maximum magnetic flux density (T)	0.1
Magnetic length (m)	0.1
Gap height (mm)	75
Good-field radius (mm)	30
Maximum current (A)	5
Current waveform	tracking dipole excitation

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**Permanent address: Pohang Light Source Project, Pohang Institute of Science and Technology, Pohang, Korea 790-330.

Dipole

Effective Length

The effective length of the dipole was evaluated in two ways; conventionally by dividing the line integral of the flux density along the magnet by the local flux density at the magnet center, and by using a new differential method [2]. With the latter, relative length differences are measured as a function of the magnet excitation. The results have to be combined with a known value for one condition, in order to derive absolute values, but the relative accuracy of this new method is noticeably better than what can be achieved conventionally. Effective length values are displayed in Fig. 2 as a function of the magnet excitation. Up to 1.0 T flux density, the mean value is $L_{eff} = 1.047 \pm 0.001$ m; at extraction condition it is reduced to 1.045 m, due to saturation. As a consequence, the production magnet cores of this type will be built 5 mm longer than the engineering model.

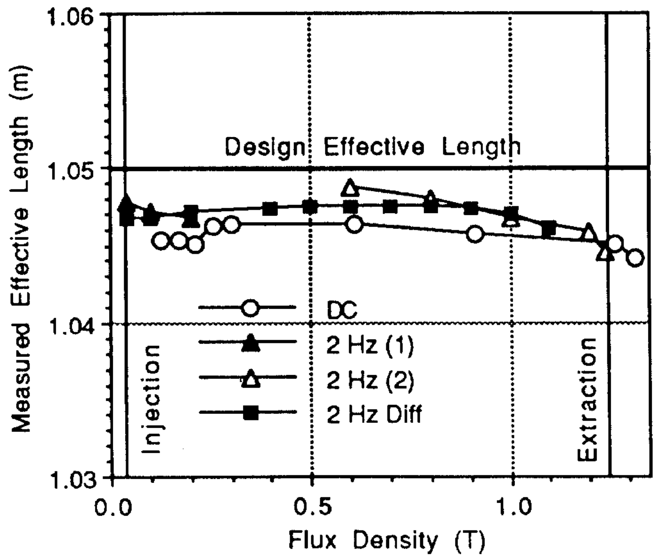

Figure 2. Effective length of the dipole for dc and 2 Hz ac conditions."2 Hz (1)" and "2 Hz (2)" represent data from two runs spanning different flux density ranges. These and the dc data were obtained with the conventional method. The "2 Hz Diff" data were acquired with the new differential method.

Multipole Errors

Under dc conditions, only integrated field uniformity data were taken and fitted by approximation polynomials of 2nd and 4th order, allowing a multipole analysis up to the decapole. With ac excitation, integrated and local flux densities were measured, the latter ones with and without a vacuum chamber segment installed in the gap. Results are displayed in Figs. 3 and 4. The sextupole values in Fig. 3 are normalized to the beam rigidity $B\rho$:

$$m = \frac{1}{B\rho}\frac{d^2\Phi}{dx^2} = \frac{2b_3}{B\rho}$$

with $B = 1.248$ T at 1.5 GeV; $\rho = 4.0107$ m; and $\Phi = \int B_y(x)\, ds$. $b_3 = \Phi / x^2$ is the sextupole coefficient of the approximation polynomials.

A comparison between integrated and local sextupole strengths (the latter ones are not shown here) shows that the finite integrated sextupole strength of the dipole, as found in Fig. 3, is caused by end geometry, rather than by imperfect pole contours. Only above 1.0 T does the local sextupole strength become finite, due to saturation effects.

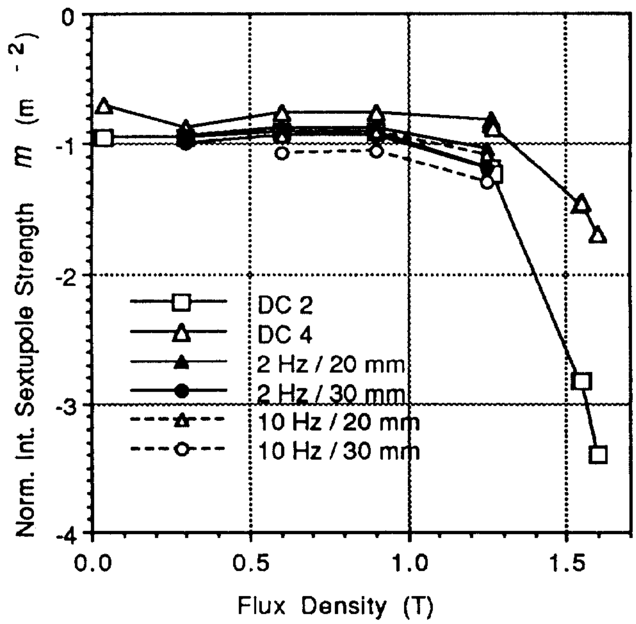

Figure 3. Dipole, integrated sextupole strengths for dc and ac conditions. DC2, from 2nd order polynomial. DC4, from 4th order polynomial. The difference between these two curves indicates that higher-order multipoles are contained in the field. 2 Hz and 10 Hz ac data were taken at the central and two equidistant transverse x-positions, as given by the listed distances in mm.

Fig. 4 shows integrated flux densities at mid range excitation, generated by each individual multipole component up to the decapole at the transverse position x = 30 mm in the horizontal mid plane of the magnet.

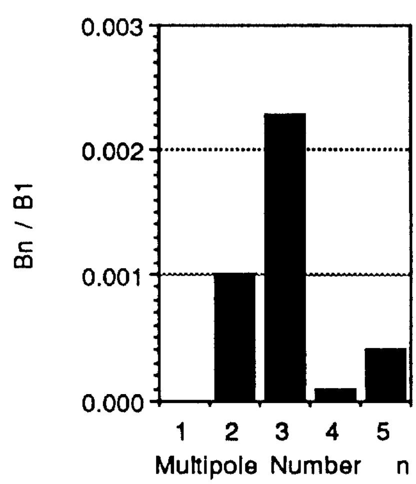

Figure 4 Dipole, integrated dc multipole strengths at x = 30 mm, given in units of the fundamental, $\int B_y\, ds = 0.63$ Tm.

Quadrupole

Two quadrupole types, one focusing in the horizontal plane (QF, 0.3 m design effective length) and one defocusing (QD, 0.2 m) will be installed in the booster synchrotron. Because the designs are different in the magnet lengths only, measurements were performed with a QF engineering model. The measured effective length is $L_{eff,QF}$ = 0.2874 m. This means that the effective length of the shorter type will be $L_{eff,QD}$ = 0.1874 m. Therefore, the gradient values will have to be increased from 15 T/m to 15.66 T/m for QF and to 16.01 T/m for QD, to meet the design specifications. An example of the multipole analysis at mid range excitation is shown in Fig. 5. The data are normalized to a radius of 30 mm.

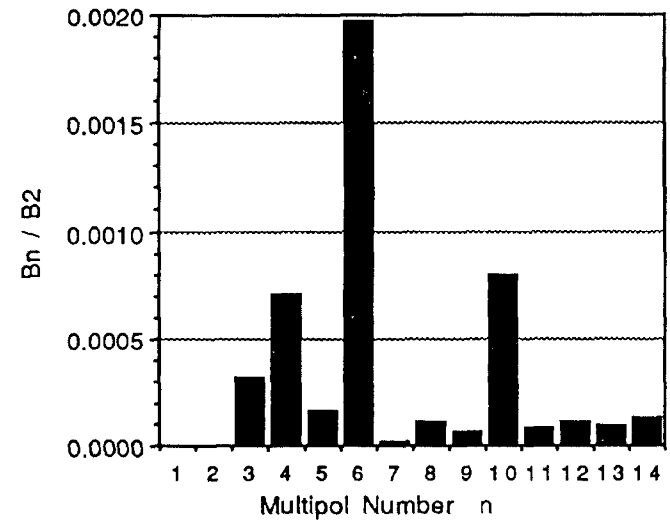

Figure 5. Quadrupole QF, integrated dc multipole strengths at x = 30 mm, given in units of the fundamental, $\int B_2\, ds$ = 0.065 Tm.

Sextupole

The mid range sextupole field errors, normalized to a radius of 30 mm, are displayed in Fig. 6.

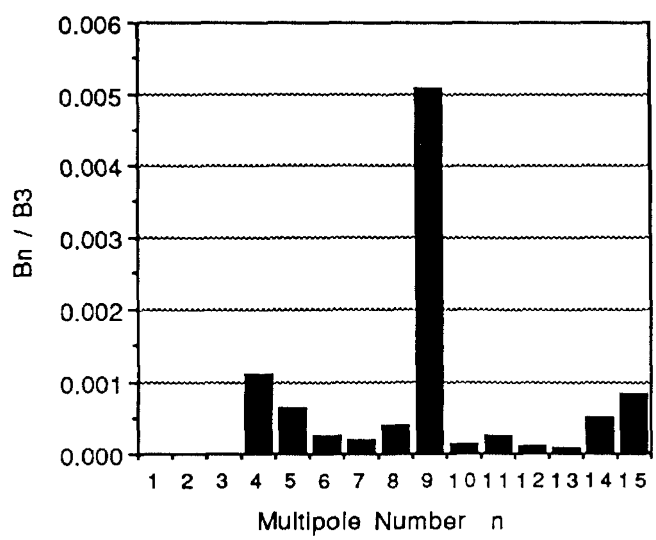

Figure 6. Sextupole, integrated dc multipole strengths at x = 30 mm, given in units of the fundamental, $\int B_3\, ds$ = 0.00248 Tm.

Corrector Dipole

The corrector dipole was measured by a Hall probe scanned in the longitudinal direction, at 5 different transverse positions. The effective length, 120.8 mm, was determined by numerically integrating the measured flux density values. The multipole analysis, see Fig. 7, was performed using the coefficients of a 4^{th}-order interpolation polynomial fitted to the calculated integrated flux density values.

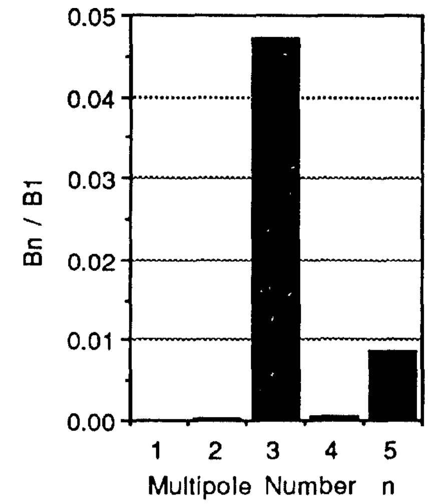

Figure 7. Corrector dipole, integrated dc multipole strengths at x = 30 mm, given in units of the fundamental, $\int B_1\, ds$ = 0.00904 Tm.

Conclusion

The magnetic properties of the ALS booster synchrotron engineering model magnets were measured and analyzed in terms of higher multipoles. The measurement system provided sufficient sensitivity to assess the systematic field errors; all magnets meet their specifications. Tracking studies performed with these data [3] showed acceptable performance of the booster synchrotron and permitted qualification of all magnet designs for production.

Acknowledgements

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References

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[2] D. H. Nelson, to be published. See also in Ref. [1].

[3] C. H. Kim, H. Nishimura, "Dynamic Aperture of the ALS Booster Synchrotron," presented at this IEEE Particle Accelerator Conf., Chicago, Ill., March 20-23, 1989.