Magnetic Measurements of the Storage Ring Quadrupole Magnets for the 7-GeV Advanced Photon Source*

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Abstract

The pre-production quadrupole magnet for the Advanced Photon Source (APS) storage ring has been tested. The multipole coefficients meet the tolerance requirements. The field-gradient integrals are measured relative to a reference quadrupole. By using two laser beam units, the magnetic and geometrical axes of the magnet are aligned within 0.2 mrad. The dependencies of the sextupole coefficient and the magnetic center on the excitation current are corrected by shunting the magnetic potentials of the top and bottom yokes.

I. INTRODUCTION

The APS storage ring (SR) requires 400 normal quadrupole magnets, consisting of five families with three different magnetic lengths [1]. The quadrupoles are conventional resistive magnets; each of them is excited by an independent DC power supply. All the magnets have the same 2-D geometry and bore radius of 40 mm.

In spite of the conventional nature of the quadrupole, the design of the magnet cross section is severely restricted for the accomodation of the vacuum chamber as shown in Fig. 1. The top and bottom halves of the magnet are not connected with flux-return yoke; they are connected mechanically with aluminum spacers between the halves. Each of the top and bottom halves consists of two welded quadrants stacked with 1.5-mm-thick laminations.

In order to maximize the excitation efficiency, the pole bases are asymmetrically widened 22 mm towards the vertical plane of the magnet as shown in Fig. 1. The magnet has pole-end bevels of 9.6 mm x 17.4 mm and pole chamfers of 16.5 mm [2]. The shims at both edges of the hyperbolic pole face have 6-mm-straight contours perpendicular to each other, and are used as the reference directions for stacking the laminations.

Listed in Table 1 are the design parameters for the five-family quadrupoles, Q1, Q2, Q3, Q4 and Q5, and excitation efficiencies measured for an 0.8-m pre-production magnet at the corresponding operating currents. By asymmetrically widening the poles, the efficiency for the 7-Gev operation is better than 96.5%.

Table 1
Parameters for the 400 quadrupole magnets

	Q1	Q2	Q3	Q4	Q5
# mag	80	80	80	80	80
L (m)	0.50	0.80	0.50	0.50	0.60
B' (T/m)	-10.843	15.792	-10.585	-18.902	18.248
B'L (T)	-5.421	12.634	-5.293	-9.451	10.949
I (A)	215	312	210	386	370
e (%)	100	99.5	100	96.5	97.3
I (A)[a]	230	350	225	442	419
e (%)[a]	100	98.3	100	92.5	94.2

[a] for 7.5-Gev Operation

II. MAGNETIC MEASUREMENTS

A. *Measurement Methods*

Field-gradient integrals and multipole coefficients are measured using a rotating coil technique. The probe coil consists of a "radial" integral coil and a 0.4-m-long "tangential" coil on the same cylinder [3]. The latter measures the 2-D "body" multipole coefficients averaged over a 0.4-m axial length of the magnet.

Using a laser beam unit, the rotating coil axis is aligned to the magnetic axis by adjusting the magnet position and minimizing the dipole component of the harmonic analysis. Prior to this procedure, the geometrical axis of the quadrupole is aligned to the axis of two air-bearings as in the following method. A second laser beam unit is installed and aligned with the air-bearing axis. A photo-quadrant detector is placed at the geometrical axis of the magnet aperture. By detecting the beam position along the aperture axis, the magnet is aligned. Since the rotating coil cylinder is supported by the two air-bearings, the coil rotates at the air-bearing axis. This procedure not only ensures parallelism between the geometrical and magnetic axes within ±0.2 mrad, but it also enables measurement of the offset of the two axes.

The field-gradient integrals are also measured relative to a reference quadrupole with a measurement reproducibility of $\pm 1\times10^{-4}$. Figure 2 shows the cross sections of the gradient-coil probes: one on the reference magnet and one on the testing magnet. A probe consists of two flat printed-circuit coils. The probe in the reference magnet is fixed at the geometric or magnetic center supported by a G-10 plate. The probe in the

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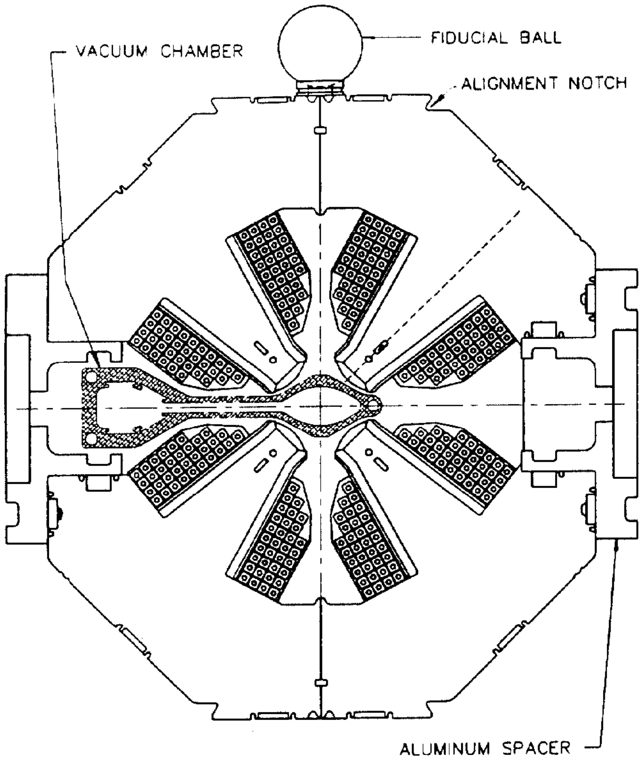

Figure 1. Cross section of the quadrupole and the vacuum chamber. The magnet aperture diameter is 80 mm. A Taylor-Hopson ball and alignment notch for the measurements of magnetic axis and roll angle are shown.

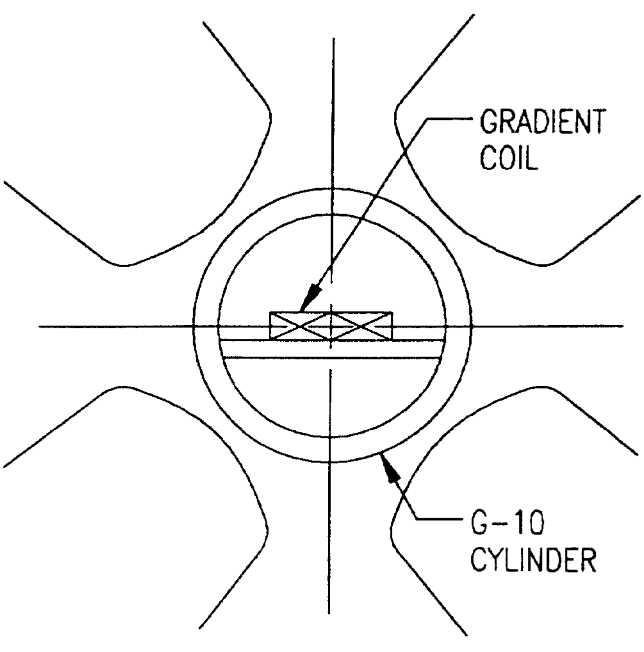

Figure 2. Cross section of the probe for the field- gradient measurements in the testing magnet.

testing magnet is installed in a G-10 cylinder. Since the measurement is conducted after the rotating coil measurements, the probe in the testing magnet is located along the magnetic axis.

B. Multipole Coefficients

Shown in Fig. 3 are the normal multipole coefficients for the pre-production magnet at four excitation currents. The coefficients, measured at an aperture radius of 35 mm, are calculated at 25 mm. The magnitudes of the coefficients are well within the tolerance of the SR random multipole allowed errors, 2.5×10^{-4}. The measured values of the first two allowable coefficients after the main quadrupole field, b5 (duodecapole) and b9, are -0.1×10^{-4} and -0.45×10^{-4}, respectively. The 2-D calculations for the two coefficients agree with the measurements better than 0.05×10^{-4} at a 25-mm radius.

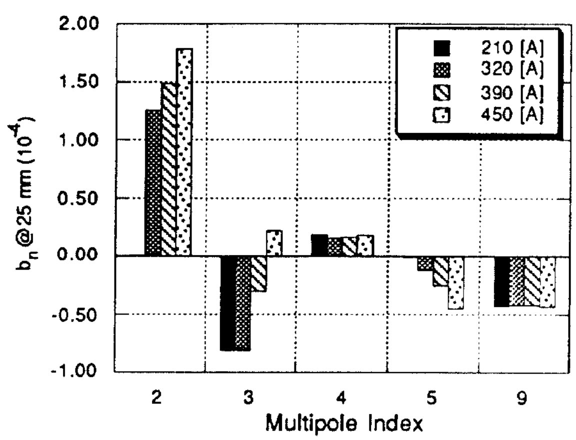

Figure 3. Multipole coefficients at four excitation currents (b2 = sextupole coefficient).

C. Ambient Field

Since the top and bottom yokes are not connected magnetically, ambient field (mainly the Earth field) affects the sextupole and dipole coefficients of the magnet. Plotted in Fig. 4 are variations of the sextupole coefficient: with and without shunts of the magnetic scalar potential between the top and bottom yoke, and with three external fields using a Helmholz coil to compensate for the Earth field. The coefficient b2 varies 4 $\times10^{-4}$ between 100 and 450 A without shunts. By shunting with five 1.5-mm-thick and 76-mm-wide straps on both sides of the magnet, the variation of b2 is corrected to within 1×10^{-4}. Similarly, it was corrected by applying magnetic fields of 0.4 and 0.8 G.

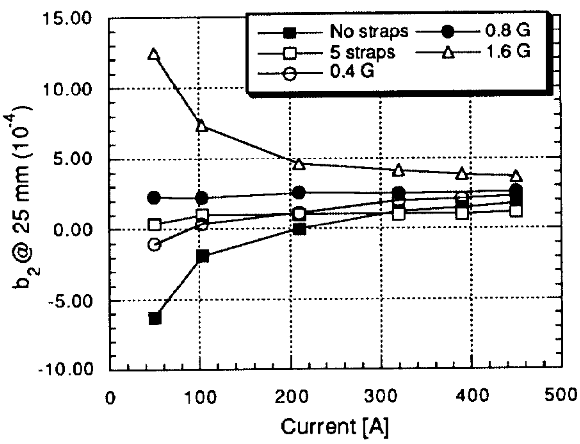

Figure 4. Sextupole coefficients of the quadrupole with no 0.8 and 1.6 G.

Plotted in Fig. 5 are the data for offsets of the magnetic center due to the ambient field. When the yokes are shunted or the ambient field is compensated, the offset in the x-direction does not depend on the magnet excitation currents. As expected, the offset in the y-direction, which is due to a horizontal field, does not depend on the ambient fields.

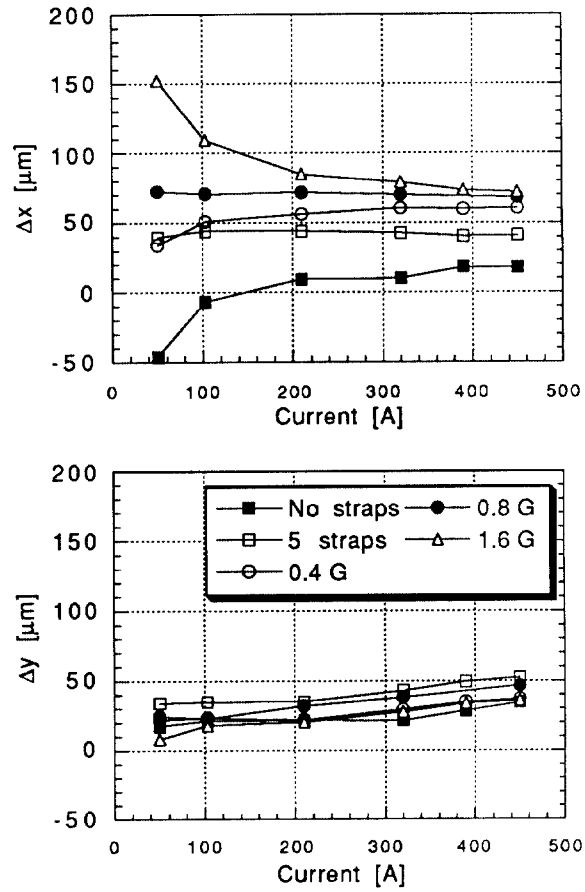

Figure 5. The offsets of the magnetic center in the x- and y-directions due to ambient field.

III. CONCLUSIONS

The restrictions of the design geometry due to the vacuum chamber have been overcomed by widening the pole asymmetrically, and an excitation efficiency better than 96.5% has been achieved. The multipole coefficients are measured at the magnetic axis, which is parallel to the geometrical axis of the magnet within ±0.2 mrad. The coefficients are less than 2.5×10^{-4} in magnitude and meet the tolerance requirements. Using two sets of gradient coils, the field-gradient integrals are measured relative to a reference quadrupole to within 1×10^{-4}. The sextupole coefficient and the magnetic axis, which depend on the ambient field, are stabilized by shunting the top and bottom yokes.

IV. REFERENCES

[1] "7-Gev Advanced Photon Source Conceptual Design Report," Argonne National Laboratory, ANL-87-15, 1987.

[2] S. H. Kim, K. M. Thompson, E. L. Black and J. M. Jagger, "Fabrication and Tests of Prototype Quadrupole Magnets for the Storage Ring of the Advanced Photon Source," *Conference Record of the 1991 IEEE Particle Accelerator Conference*, Vol. 4, pp. 2375-2377, 1991.

[3] S. H. Kim, K. Kim, C. Doose, R. Hogrefe and R. Merl, "Magnetic Measurement Facility for the 7-Gev Advance Photon Source," these proceedings.