Magnetic Measurement Data of the Injector Synchrotron Dipole Magnets for the 7-GeV Advanced Photon Source*

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Abstract

The magnetic measurement data of the first 34 of the required 68 production magnets for the injector synchrotron are summarized. The magnetic measurement method of the field strength and field shape relative to a reference magnet is described. The standard deviation of the integrated field strength for the 34 magnets is 3.3×10^{-4} and the variation of the integrated field with transverse displacement of ±25 mm is less than 2.5×10^{-4}.

I. INTRODUCTION

The injector synchrotron dipole magnets for the 7-GeV Advanced Photon Source (APS) are to be excited from 0.0447 T to 0.7011 T during a ramp time of 0.25 s. The magnetic length and pole gap are 3.077 m and 40 mm, respectively. The relative tolerance for the integrated field strength is 2×10^{-3} and the tolerances for quadrupole and sextupole coefficients at a radius of 25 mm are 5×10^{-4} and 1.2×10^{-3}, respectively. Detailed descriptions of field shapes of the integrated, 2-D, and end field for the pre-production magnet, including 3-D calculations, are summarized in Ref. [1]. The measured data for the first 34 of the required 68 production magnets are described in this paper.

II. MEASUREMENT

The integrated field strength, not the local field variation, along the beam orbit is an important parameter to be measured. However, since the 2-D "body" field along the magnet axis for a laminated magnet depends on how smoothly the laminations are stacked, the variation of the vertical field and magnet pole gap are measured. In Figure 1, the field variation, measured every 2.5 cm with a Hall probe, and the inverse of the gap along the beam orbit are plotted. Here, the average measured gap of 39.88 mm and the average measured field of 0.7488 T at 1000 A are used for the plot. It is seen that the field variation closely follows that of the gap. It has been identified that the gap variation is due to displacements of the laminations during welding of the bolting fixtures and support steel plates after the lamination stacking. The local field variation in Figure 1 is less than 2×10^{-3} and will not be harmful for the positron beam.

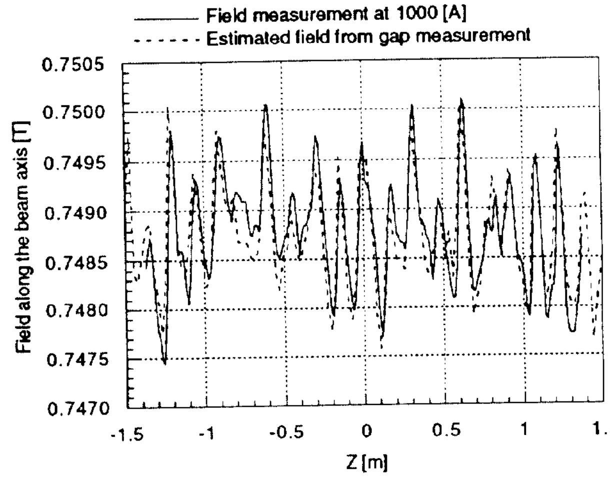

Figure 1. Magnetic field along the beam orbit. The solid line shows the measured field and the dashed line shows the estimated field from the gap measurement.

A general description of the magnetic measurement system is given in Ref. [2]. Two sets of integral coils, one for the reference magnet and one for production magnets, are made by placing two layers of seven printed circuit (PC) coils on an aluminum block along the beam orbit. For measurement of an average magnetic field inside 1.5 m, a short version of the PC coils is placed on top of the full integral coil.

When the magnet current is ramped up and down between 0 A and 1025 A (7.7 GeV) in 120 s, a 0.5-s trigger signal generated by a time-base and gated trigger units is fed into four digital integrators and a digital multimeter. The coil signal from the reference magnet (reference signal) and the bucked signal between the coils for the reference and production magnets are integrated. Then, the integrated data for the reference magnet and the current transducer readings are least-square-fitted to a straight line and the fitting coefficient and the signal form are used to check the measurement condition. The integrated data of the reference and bucked signals are also least-square-fitted to a straight line. The fitting coefficient represents the relative magnetic field strength between the reference and the production magnets. The positioning error of the integrated coil is estimated to be less than 1×10^{-4}, and the repeatability of the fitting coefficient when measured consecutively is better than 2×10^{-5}.

*Work supported by the U.S. Department of Energy, Office of Basic Energy Sciences, under Contract No. W-31-109-ENG-38.

The integrated field shape is measured by moving the same integral coils in the transverse direction. When the integral coil in the testing magnet is moving in the transverse direction, the trigger signals are generated from a linear encoder and the integral coil signal is measured using the digital integrators.

The measured data for the 34 magnets are listed in Table 1. Magnet BDP003 is used as the reference. The first two columns after the magnet number in the first column are the relative integrated and 1.5-m average 2-D fields, respectively, and are plotted in Figure 2. Except for the magnets BDP006 and BDP007, the relative field strength varies less than 1×10^{-3}.

Table 1.
Measured data for the 34 production magnets.

Magnet Number	$\frac{\Delta BL}{B_{ref}L}$ [$\times 10^{-4}$]	$\frac{\Delta BL_o}{B_{ref}L_o}$ [$\times 10^{-4}$]	Residual Field [Gauss]	Survey Angle [mrad]	$\frac{\Delta BL}{BL}$ in ±25 mm at 60 A [$\times 10^{-4}$]	$\frac{\Delta BL}{BL}$ in ±25 mm at 300 A [$\times 10^{-4}$]	$\frac{\Delta BL}{BL}$ in ±25 mm at 930 A [$\times 10^{-4}$]	$\frac{\Delta BL}{BL}$ in ±25 mm at 1025 A [$\times 10^{-4}$]
BDP003	0.0	0.0	12.02	0.067	3.0	2.0	1.5	1.5
BDP004	-1.6	0.3	12.24	0.045	1.4	2.0	1.2	1.1
BDP005	0.2	0.1	12.64	-0.171	1.5	1.5	1.0	0.9
BDP006	-13.7	-10.6	12.50	-0.035	1.3	1.8	1.0	1.0
BDP007	-14.8	-11.0	12.90	-0.381	2.2	2.2	1.2	1.0
BDP008	-5.7	-5.3	13.23	-0.027	1.4	1.6	1.0	0.8
BDP009	-5.4	-4.3	12.84	-0.143	1.9	1.6	1.2	1.0
BDP010	-2.3	0.0	12.15	0.156	1.6	1.6	1.1	0.9
BDP011	-3.8	-2.3	12.06	-0.018	1.7	1.5	1.0	0.8
BDP012	-3.6	-2.1	12.21	-0.323	1.8	1.8	1.2	1.0
BDP013	-9.2	-5.7	12.47	-0.065	1.9	2.0	1.3	1.0
BDP014	-3.9	-2.4	12.33	0.046	1.7	1.6	1.1	0.9
BDP015	-1.6	-0.5	12.09	-0.033	1.6	1.5	1.0	0.8
BDP016	-3.6	-3.3	12.65	-0.182	1.3	1.7	1.1	1.0
BDP017	-4.6	-2.8	12.43	0.040	1.3	1.8	1.2	1.0
BDP018	-7.4	-3.0	12.54	-0.139	1.7	1.8	1.2	1.0
BDP019	-1.9	1.8	12.57	0.010	1.9	1.5	1.0	0.8
BDP020	-3.4	-0.7	12.33	-0.095	2.3	2.0	1.4	1.2
BDP021	-7.0	-4.3	12.98	-0.034	2.4	2.1	1.6	1.4
BDP022	-5.1	-1.6	13.35	0.108	2.0	1.9	1.4	1.2
BDP023	-4.9	-1.2	13.15	-0.009	1.9	2.0	1.5	1.3
BDP024	-5.0	-1.7	13.20	0.137	1.5	1.9	1.3	1.2
BDP025	-4.4	-1.4	12.73	-0.059	1.8	1.7	1.3	1.2
BDP026	-3.4	-0.5	12.29	0.104	2.1	1.8	1.2	1.0
BDP027	-3.7	-1.1	12.42	0.032	1.8	1.9	1.5	1.3
BDP028	-1.6	2.7	12.65	-0.042	1.6	2.1	1.4	1.2
BDP029	-4.7	-1.3	12.24	0.458	1.5	1.6	1.0	0.8
BDP030	-1.8	0.2	12.19	0.093	1.9	1.8	1.3	1.1
BDP031	0.4	3.4	13.74	0.091	1.9	1.8	1.2	1.0
BDP032	-4.7	-0.8	11.98	0.090	1.8	2.2	1.5	1.3
BDP033	-2.4	1.6	12.25	0.086	2.0	1.9	1.3	1.1
BDP034	-5.0	-2.1	12.52	0.052	2.5	2.1	1.5	1.3
BDP035	-1.5	0.9	11.91	0.007	2.4	2.2	1.5	1.3
BDP036	-3.7	-0.1	12.42	-0.035	1.6	1.9	1.4	1.2
Average	-4.3±3.3	-1.7±3.1	12.54±0.4		1.8±0.4	1.8±0.2	1.2±0.2	1.1±0.2

($\Delta BL_o/B_{ref}L_o$ in the third column is the 2-D average field with L_o = 1.5 m.)

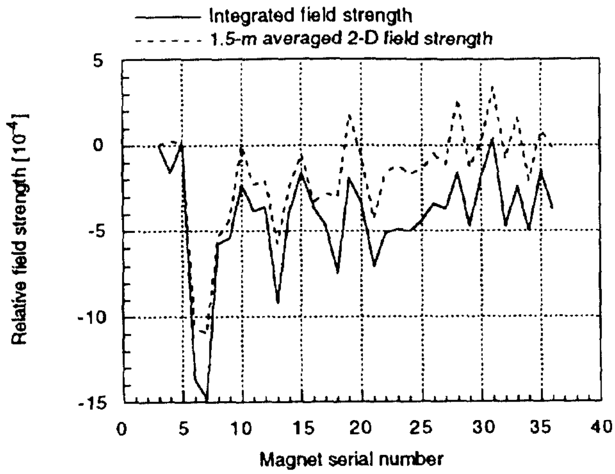

Figure 2. Variation of relative magnetic field strength.

The survey angles in the fourth column in Table 1 are the differences between the angles at the survey reference positions and the average angles for 20 measurements along the magnet length, which are also plotted in Figure 3. The angles vary within ±0.5 mrad along the longitudinal positions. There seems to be a systematic tendency in fabrication procedure that at the negative z end, all but a few of the magnets twist to the same direction.

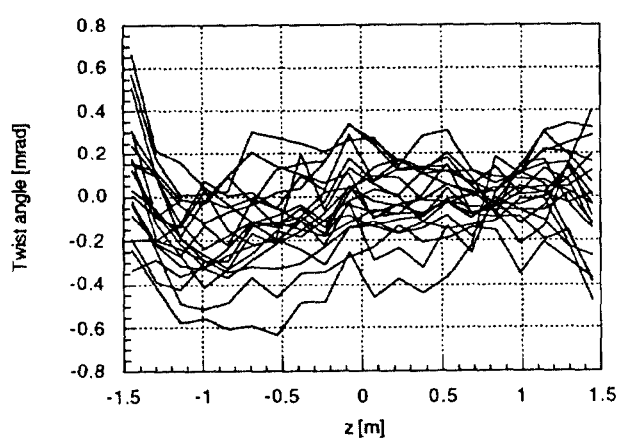

Figure 3. Twist angles along the magnets relative to the survey reference positions for the 20 magnets.

The last four columns in Table 1 are the data for the integrated field variation with the transverse displacement of ±25 mm at four excitation currents. The data at the injection and extraction currents are plotted in Figure 4. Slightly less field variation at the extraction energy seems to be due to a slight field saturation at the pole shims. The field variations for the two currents are less than 2.5×10^{-4}.

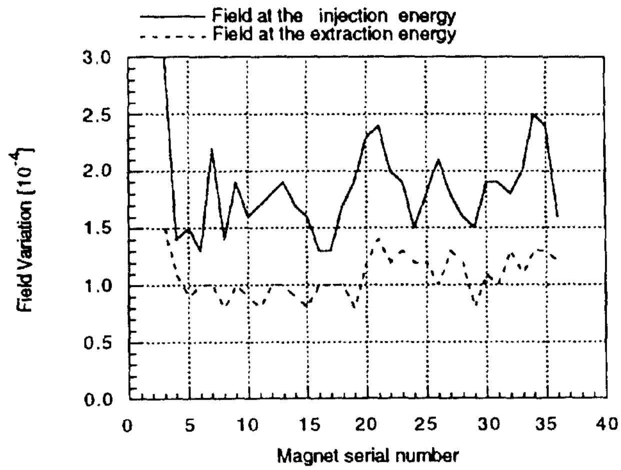

Figure 4. Integrated field variation with the transverse displacement of ±25 mm.

III. CONCLUSION

For the 68 required production magnets for the injector synchrotron of the 7-GeV APS, measured data for 34 magnets show that one standard deviation of the integrated field strength is 3.3×10^{-4} and the integrated field quality with transverse displacement of ±25 mm is better than 2.5×10^{-4}. The tendency of the integrated field strength to vary from magnet to magnet seems to be decreasing as magnet production continues.

IV. REFERENCES

[1] K. Kim, S. H. Kim, K. Thompson, and L. Turner, "Design and Tests of the Injector Synchrotron Magnets for the 7-GeV Advanced Photon Source," these proceedings.

[2] S. H. Kim, K. Kim, C. Doose, and R. Hogrefe "Magnet Measurement Facility for the 7-GeV Advanced Photon Source," these proceedings.