Fermilab

TS-SSC 92-064
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DCA311-319 a1 and a2: Predictions from Coil Size Measurements Compared with Measured Values

As is well known, a difference in the size of the upper and lower coils in a magnet results in a vertical displacement of the mid-plane which induces a non-zero skew quadrupole moment, a1. If the upper-right (QI) and lower-left (QIII) quadrants are larger than the upper left (QII) and lower right (QIV) quadrants, then there will be a downward mid-plane displacement on the right and an upward displacement on the left, inducing a non-zero skew sextupole moment. Each of the inner and outer coil sizes can be characterized by the size in each of the four quadrants. The quantity

$$(QI + QII - QIII - QIV) / 4$$

predicts, under the assumptions of equal coil modulus in all four quadrants and no friction, the left-right symmetric component of the mid-plane shift and hence the value of a1, where QI is the measured coil size in quadrant I, etc. Likewise, the quantity

$$(QI + QIII - QII - QIV) / 4$$

predicts the left-right asymmetric component of the mid-plane shift and hence the value of a2.

These values are shown for DCA310-319 in Table I, labeled as (Upper-Lower)/2 and (QI/III-QII/IV)/2 respectively. Also shown are the overall average coil sizes relative to the appropriate master, as measured with the semi-automatic measuring machine, labeled (QI/III+QII/IV)/2. It can be seen that the symmetric component is randomly distributed with a mean consistent with zero and an RMS of 8 microns (0.3 mils) in the inner coils and 15 microns (0.6 mils) in the outer coils. However, the asymmetric component is systematically positive (down on the right, up on the left as viewed from the lead end) by 8-10 microns (0.3-0.4 mils) with an RMS about the mean (sigma) of only 3-5 microns (0.1-0.2 mils). The coil size measurements are histogrammed for DCA311-319 in Figure 1.

Akbar Mokhtarani has calculated the effect of such displacements on the harmonics[1]. The results of these calculations are summarized in Table II. In Table III are the skew harmonics predicted from the measured coil size differences and the calculations. The measured[2] skew harmonics measured at 2 kA at MTF, averaged over the length of the magnet with the measurements at the strain gauge packs removed, are displayed in Table IV. No corrections have been applied for persistent current effects, which may modifiy the geometric skew quadrupole if the upper and lower coil conductors have different low field critical currents. Note also that the cold measurement data are reported as

viewed from the non-lead end. The signs of the even skew moments have been reversed in this analysis to yield values as viewed from the lead end.

The measured versus predicted values of a1 and a2 are plotted in Figures 2 and 3. A line of unit slope is also drawn to guide the eye. The correlation between measured and expected values of a1 is reasonable (correlation coefficient = 0.8). The measured and predicted signs are in all cases the same. The correlation between measured and expected a2 is less striking but clearly present (correlation coefficient = 0.6). The predicted values are all positive and all but one of the measured values are also. The 9-magnet average of predicted and measured a2 is identical. For higher harmonics, however, there is no correlation between the measured values and those predicted from the calculated mid-plane shifts, indicating that these are dominated by other construction variables.

REFERENCES

[1] A. Mokhtarani, Effect of manufacturing errors on harmonics in 5 cm SSC magnets, TS-SSC 91-038, 1/7/91;
A. Mokhtarani, Harmonics from left-right asymmetric mid-plane displacement, TS-SSC 91-146, 7/9/91.

[2] J. DiMarco, Cold axial ave multipoles, private e-mail communication, 4/11/92;
J. DiMarco, Table of DCA318 cold ave mpoles (sg&ends removed, no pcurr corr.), private e-mail communication, 5/20/92.

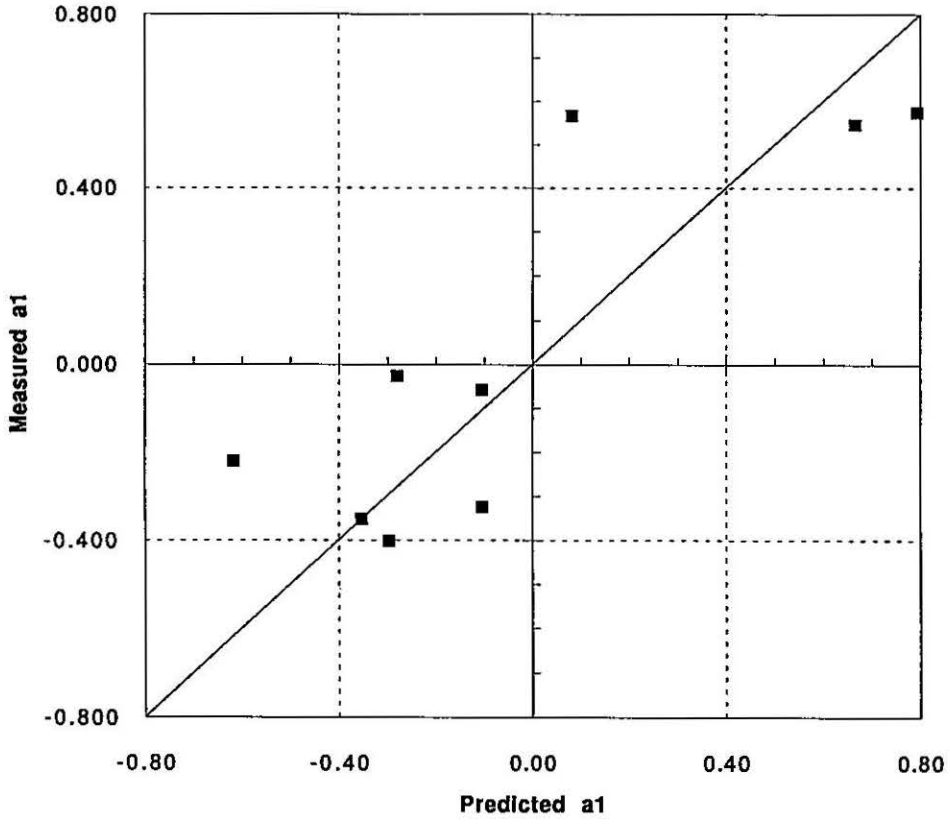

Figure 2

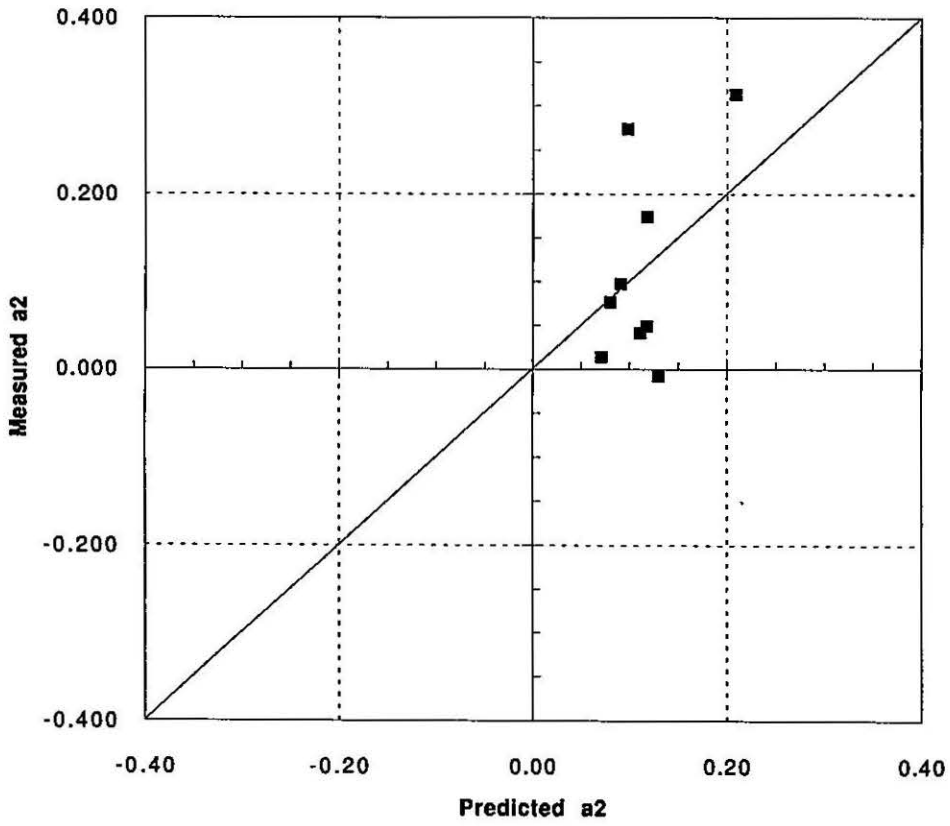

Figure 3

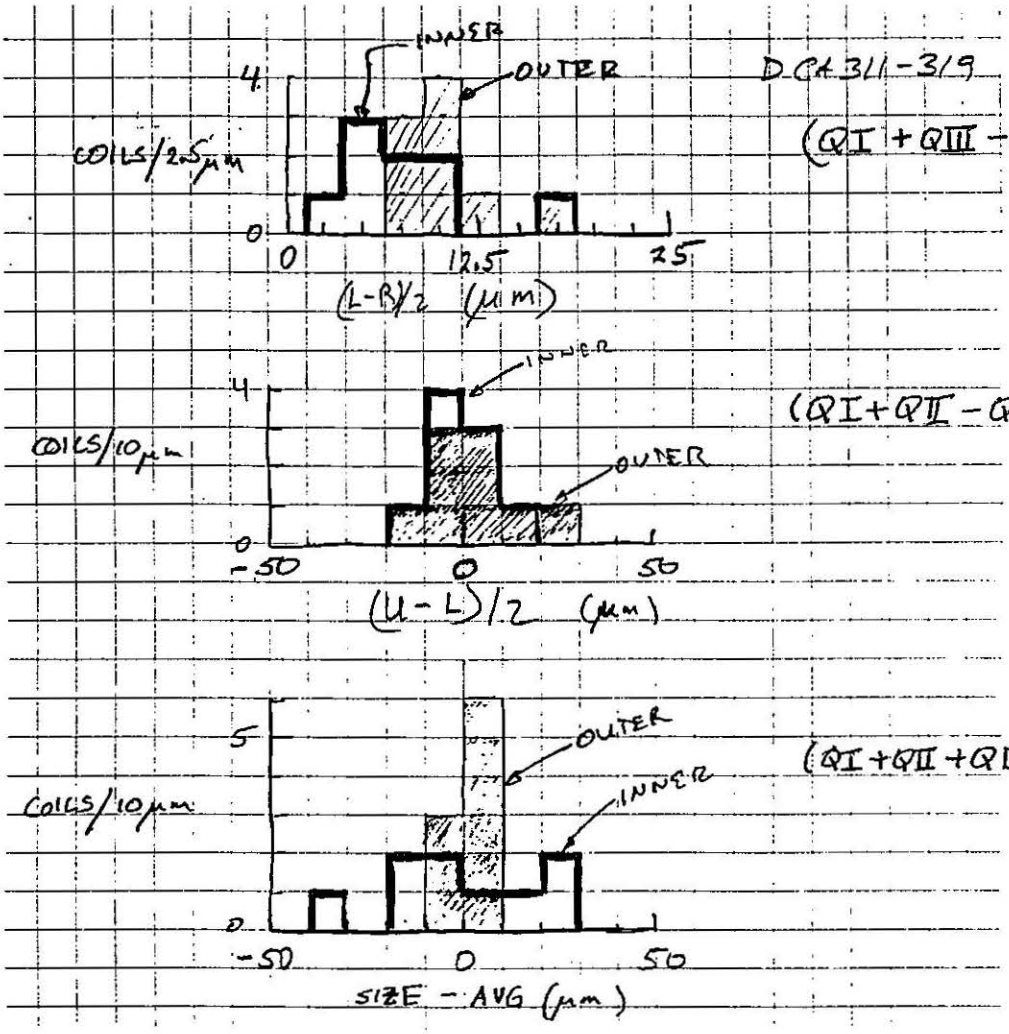
INNER
OUTER
D.C. 311-319
(QI + QIII − QII − QIV)/4
COILS/2.5μm
4
0
0
12.5
25
(L-R)/2 (μm)
INNER
(QI+QII − QIII − QIV)/4
COILS/10μm
OUTER
4
0
-50
0
50
(U-L)/2 (μm)
(QI+QII+QIII+QIV)/4
OUTER
INNER
COILS/10μm
5
0
-50
0
50
SIZE - AVG (μm)

Figure 1

Table I

Magnet	(QI/III + QII/IV)/2 Inner	(QI/III + QII/IV)/2 Outer	(QI/III - QII/IV)/2 Inner	(QI/III - QII/IV)/2 Outer	(Upper - Lower)/2 Inner	(Upper - Lower)/2 Outer
DCA 310 [1]	0.0106	0.0010	0.0002	0.0003	-0.0001	0.0014
DCA 311	0.0099	-0.0030	0.0004	0.0003	0.0005	0.0007
DCA 312	0.0084	-0.0041	0.0004	0.0003	0.0002	0.0009
DCA 313	0.0080	-0.0017	0.0002	0.0004	0.0001	0.0000
DCA 314	0.0085	-0.0019	0.0001	0.0004	-0.0007	-0.0001
DCA 315	0.0093	-0.0020	0.0003	0.0004	-0.0002	0.0001
DCA 316	0.0097	-0.0012	0.0007	0.0005	-0.0002	0.0001
DCA 317	0.0088	-0.0007	0.0002	0.0007	0.0000	-0.0005
DCA 318	0.0083	-0.0017	0.0002	0.0004	-0.0003	-0.0001
DCA 319	0.0088	-0.0013	0.0003	0.0003	-0.0003	-0.0002
DCA 320						
DCA 321						
DCA 322						
DCA 323						
Mean	0.0090	-0.0017	0.00030	0.00040	-0.0001	0.0002
Sigma	0.0008	0.0013	0.0002	0.0001	0.0003	0.0006
RMS	0.0091	0.0021	0.0003	0.0004	0.0003	0.0006

NOTES

[1] All averages include a 5 mil shim placed on the pole of the upper inner coil only.

Table II

	Harmonics per mil (QI/III - QII/IV)/2 Inner	Outer
a0	2.07	1.77
a2	0.199	0.128
a4	0.008	0.003
a6	0.0015	0.0001
a8	0.0003	0.0000

	Harmonics per mil (Upper - Lower)/2 Inner	Outer
a1	0.802	0.561
a3	0.0355	0.0231
a5	0.0319	0.0035
a7	0.0067	0.0002

Table III

Predicted Harmonics from coil size differences

Magnet	(QI/III - QII/IV)/2 a2	a4	a6	a8	(Upper - Lower)/2 a1	a3	a5	a7
DCA 310 [1]	0.08	0.00	0.000	0.000	-1.54	-0.31	0.011	-0.006
DCA 311	0.12	0.00	0.001	0.000	0.79	0.03	0.018	0.003
DCA 312	0.12	0.00	0.001	0.000	0.67	0.03	0.010	0.002
DCA 313	0.08	0.00	0.000	0.000	0.08	0.00	0.003	0.001
DCA 314	0.07	0.00	0.000	0.000	-0.62	-0.03	-0.023	-0.005
DCA 315	0.11	0.00	0.000	0.000	-0.10	0.00	-0.006	-0.001
DCA 316	0.21	0.01	0.001	0.000	-0.10	0.00	-0.006	-0.001
DCA 317	0.13	0.00	0.000	0.000	-0.28	-0.01	-0.002	0.000
DCA 318	0.09	0.00	0.000	0.000	-0.30	-0.01	-0.010	-0.002
DCA 319	0.10	0.00	0.000	0.000	-0.35	-0.02	-0.010	-0.002
DCA 320								
DCA 321								
DCA 322								
DCA 323								
Mean	0.11	0.00	0.001	0.000	-0.02	0.00	-0.003	-0.001
Sigma	0.04	0.00	0.000	0.000	0.47	0.02	0.012	0.002
RMS	0.12	0.00	0.001	0.000	0.44	0.02	0.012	0.002

NOTES

[1] Odd skew harmonics include effect of 5 mil upper inner pole shim

Table IV

Measured Harmonics (Yoked 2 kA)

Magnet	a2	a4	a6	a8	a1	a3	a5	a7
DCA 310								
DCA 311	0.173	0.006	0.006	-0.003	0.575	-0.073	-0.007	0.000
DCA 312	0.049	0.007	0.006	-0.006	0.545	0.041	0.000	-0.001
DCA 313	0.076	0.009	0.009	-0.006	0.566	0.053	0.003	0.000
DCA 314	0.014	0.008	0.012	-0.006	-0.222	-0.009	0.015	0.000
DCA 315	0.042	0.010	0.009	-0.006	-0.059	0.025	0.006	0.000
DCA 316	0.313	0.046	0.016	-0.006	-0.325	-0.013	-0.001	0.000
DCA 317	-0.008	-0.026	0.005	-0.007	-0.027	-0.110	0.005	0.000
DCA 318	0.097	-0.010	0.007	-0.007	-0.403	0.101	0.010	0.000
DCA 319	0.274	0.003	0.007	-0.006	-0.353	-0.033	-0.012	0.000
DCA 320								
DCA 321								
DCA 322								
DCA 323								
Mean	0.11	0.01	0.008	-0.006	0.03	0.00	0.002	0.000
Sigma	0.11	0.02	0.004	0.001	0.42	0.07	0.008	0.000
RMS	0.16	0.02	0.009	0.006	0.39	0.06	0.008	0.000

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