Harmonics of Magnets with all Kapton and Apical Insulation (Revised)

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This memo summarizes harmonics data for model and full length SSC collider dipole magnets with all kapton (Dupont) and apical (Allied Signal) insulation. (For a summary of insulation schemes in these magnets and the status of the model and full length programs, see Tables 1a, 1b, and 1c.)

Model Magnet Data: Collared coil harmonics have been measured for DSA330, DSA331, DSA332, and DSA333. The results are shown in Table 2a. Yoked harmonics have been measured at room temperature and at 4.2 K for DSA330 and DSA331. The results are shown in Table 2b. The harmonics a7 and b7 aren't shown, because these are set to zero by the mole centering correction algorithm.

Full-Length Magnet Data: Collared coil harmonics have been measured for DCA320, DCA321, DCA322, and DCA323. The results are shown in Table 3a. As usual, a7 and b7 aren't shown.

Harmonics Predictions: M. Wake has been developing a field calculation program [1] which predicts the field shape by summing over the contributions from individual strands. He has calculated fields for collared coils and yoked magnets (the latter assuming an azimuthally symmetric yoke with infinite permeability).

Tables 4a and 4b give the predictions of Wake's program for several pole shimming situations, including no shim (e.g., DCA322), 5 mils in the outer coil only (e.g. DSA330, DCA320, and DCA321), and 10 mils in the outer coil only (e.g. DSA332). Wake also calculates the harmonics in the anomalous case of DSA331, which had a 5 mil pole shim in quadrant 4 of the inner coil.

Discussion:

Allowed Harmonics: Figures 1, 2, and 3 show the measured allowed harmonics for model and full length collared coils compared to the harmonics predicted by the program in Reference 1. The harmonics b2 and b4 are shown in Figures 1 and 2 respectively, and the harmonics b6, b8, and b10 are shown in Figure 3.

Skew Harmonics: J. Strait [2] has applied the work of A. Mohktarani [3] to the calculation of skew harmonics brought about by vertical midplane shifts (odd skew harmonics) and tilting of the midplane (even skew harmonics). Table 2b shows the azimuthal coil size parameters for magnets DCA320-323. (This table is analogous to Table I in Reference 2.) Using the same algorithm as Strait, we calculate the harmonics a1 and a2 for these four collared coils, and show the calculated and measured values in Table 2c. Note that DCA321 and DCA322 have negative values for the predicted skew sextupole. None of the magnets studied in Reference 1 had this property.

distribution: J. DiMarco
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References

1. M. Wake, "Direct Calculations of Magnetic Field from the Measured Strand Positions", TS-SSC 92-056, May, 1992.

2. J. Strait, "DCA311-319 a1 and a2: Predictions from Coil Size Measurements Compared with Measured Values", TS-SSC 92-064, May, 1992.

3. A. Mohktarani, "Effect of Manufacturing Errors on Harmonics in 5 cm SSC Magnets", TS-SSC 91-058, Jan, 1991.

4. M. Wake, "50 mm Short Coils Update", TS-SSC 92-060, May, 1992.

5. R. Bossert, "Cable Insulation for SSC 50 mm Magnets 1992", TS-SSC 92-066, June, 1992.

Insulation Type	Inner Coils	Outer Coils
Kapton I	50% overlap H-film, butt wrap LT-film Scotch 2290 adhesive on one side of films	50% overlap H-film, 50% overlap LT-film Scotch 2290 adhesive on one side of films
Kapton II	Same as Kapton I, but with adhesive on both sides of films	Same as Kapton I, but with adhesive on both sides of films
Apical I	50% overlap NP-film, butt wrap NP-film Cryorad adhesive on both sides of films	50% overlap NP-film, 50% overlap NP-film Cryorad adhesive on both sides of films
Apical II	67% overlap NP-film Cryorad adhesive on one side of films	50% overlap NP-film, 50% overlap NP-film Cryorad adhesive on one side of films

Table 1a. Insulation Styles used on SSC Dipoles with all Kapton and Apical insulated Cable (References 4 and 5)

Magnet Name	Insulation Scheme (see Table 1a)	Inner Pole Shim (mils)	Outer Pole Shim (mils)	Completion Status as of 6/16/92
DSA330	Kapton I (like DCA320, 321)	0	5	disassembled to collared coil; ship to SSCL
DSA331	Apical II	0 (5 mils on quadrant IV)	0	in cold test at Lab 2
DSA332	Kapton I (like DCA320,321)	0	10	ready for headering at Lab 2
DSA333	Kapton II	2	4	keyed; ready for collared coil mole
DSA334	Apical I (like DCA322, 323)	?	?	coil winding delayed by parts

Table 1b. Model SSC Dipoles with all Kapton or Apical Insulation (References 4 and 5)

Magnet Name	Insulation Scheme (See Table 1a)	Inner Pole Shim (mils)	Outer Pole Shim (mils)	Completion Status as of 6/16/92
DCA320	Kapton I	0	5	In final assembly
DCA321	Kapton I	0	5	In final assembly
DCA322	Apical I	0	0	yoking in progress
DCA323	Apical I	0	0	keyed

Table 1c. Full Length SSC Dipoles with all Kapton or Apical Insulation (References 4 and 5)

Harmonic	DSA330* (Kapton I)	DSA331** (Apical II)	DSA332*** (Kapton I)	DSA333** (Kapton II)
b2	-1.986 ± .062	-1.167 ± .078	0.520 ± .056	0.644 ± .053
b4	0.865 ± .058	0.808 ± .046	0.702 ± .026	0.699 ± .031
b6	0.040 ± .011	0.032 ± .028	0.011 ± .011	0.043 ± .010
b8	0.092 ± .003	0.095 ± .017	0.096 ± .007	0.097 ± .006
b10	0.022 ± .004	0.032 ± .022	0.025 ± .004	0.025 ± .005
b1	0.204 ± .223	1.085 ± .114	-0.701 ± .143	0.012 ± .205
b3	-0.015 ± .033	-0.073 ± .102	0.009 ± .056	-0.081 ± .045
b5	-0.040 ± .013	-0.004 ± .072	0.001 ± .008	0.002 ± .022
b9	0.001 ± .004	-0.019 ± .024	0.002 ± .004	0.007 ± .011
a1	1.694 ± .062	-0.700 ± .050	1.686 ± .154	0.753 ± .175
a2	0.655 ± .056	0.871 ± .070	-0.041 ± .030	0.311 ± .073
a3	-0.050 ±.056	-0.084 ± .243	0.102 ± .059	0.017 ± .036
a4	-0.006 ± .039	-0.110 ± .084	0.021 ± .019	0.049 ± .025
a5	0.010 ± .017	-0.030 ± .021	0.011 ± .009	0.002 ± .018
a6	-0.004 ± .008	0.006 ± .034	-0.001 ± .010	0.004 ± .006
a8	0.019 ± .008	0.006 ± .033	0.010 ± .007	0.008 ± .008
a9	-0.004 ± .005	0.006 ± .015	0.001 ± .007	-0.005 ± .004
a10	0.003 ± .002	0.014 ± .014	0.004 ± .005	-0.004 ± .007

Table 2a. Collared Coil Harmonics for Model Magnets with all-Kapton and Apical Insulation.

* Values taken with mole centered at -12" relative to magnet center. Uncertainties calculated as RMS of five values taken at magnet center. (24" mole device.)

** Values taken with mole centered at -9" relative to magnet center. Uncertainties calculated as RMS of four values taken at +8" relative to magnet center. (24" mole device.)

*** Values taken with mole centered at -9" relative to magnet center. Uncertainties calculated as RMS of five values taken at -9" relative to magnet center. (24" mole device.)

Harmonic	DSA330* (Room Temp) (Kapton I)	DSA330** (4.2 K) (Kapton I)	DSA331* (Room Temp) (Apical II)	DSA331** (4.2 K) (Apical II)
b2	3.886 ± .080	3.09	3.835 ± .034	3.311
b4	0.697 ± .038	0.63	0.624 ± .020	0.624
b6	0.045 ± .019	0.01	0.049 ± .006	0.033
b8	0.075 ± .005	0.06	0.073 ± .007	0.071
b10	0.018 ± .002	0.02	0.018 ± .004	0.017
b1	0.224 ± .152		1.015 ± .075	1.012
b3	0.069 ± .050		-0.067 ± .032	
b5	-0.004 ± .038		0.018 ± .018	
b9	-0.001 ± .004		-0.004 ± .005	
a1	1.235 ± .162	1.27	-1.028 ± .106	-1.445
a2	0.665 ± .050		1.093 ± .032	0.937
a3	-0.010 ±.054		-0.060 ± .024	
a4	0.050 ± .012		-0.029 ± .014	
a5	0.013 ± .015		-0.022 ± .022	
a6	0.003 ± .010		-0.001 ± .005	
a8	0.014 ± .009		0.008 ± .005	
a9	-0.001 ± .006		0.004 ± .006	
a10	0.004 ± .004		0.008 ± .002	

Table 2b. Yoked Harmonics for Model Magnets with all-Kapton Insulation (Room Temperature)

* Values taken with mole centered at -9" relative to magnet center. Uncertainties caculated as RMS of five values taken at -9" relative to magnet center. (24" mole device.)

** Values taken at -9" relative to magnet center with 25 cm t angential coil probe.

	DCA320* (Kapton I)	DCA321* (Kapton I)	DCA322* (Apical I)	DCA323* (Apical I)
b2	-0.692 ± .011 (.285)	-0.007 ± .009 (.199)	-1.131 ± .014 (.197)	-1.092 ± .007 (.346)
b4	0.634 ± .005 (.046)	0.722 ± .008 (.039)	0.624 ± .006 (.041)	0.659 ± .008 (.104)
b6	0.010 ± .003 (.012)	0.024 ± .004 (.013)	0.030 ± .002 (.011)	0.030 ± .001 (.013)
b8	0.097 ± .001 (.005)	0.098 ± .002 (.006)	0.103 ± .003 (.008)	0.099 ± .001 (.007)
b10	0.024 ± .001 (.004)	0.023 ± .001 (.003)	0.024 ± .003 (.003)	0.025 ± .001 (.004)
b1	0.052 ± .027 (.243)	-0.137 ± .064 (.441)	-0.095 ± .036 (.347)	-0.082 ± .033 (.522)
b3	-0.062 ± .008 (.074)	0.012 ± .010 (.081)	0.064 ± .009 (.083)	0.018 ± .011 (.105)
b5	0.007 ± .003 (.024)	<0.001 ± .002 (.020)	0.006 ± .003 (.018)	-0.004 ± .003 (.020)
b9	0.001 ± .001 (.007)	-0.001 ± .001 (.005)	0.002 ± .001 (.005)	0.001 ± .001 (.006)
a1	2.784 ± .048 (0.517)	-0.972 ± .027 (0.779)	-1.042 ± .039 (0.327)	2.360 ± .052 (.616)
a2	0.323 ± .011 (0.251)	-0.068 ± .013 (0.231)	0.115 ± .009 (0.209)	0.015 ± .008 (.387)
a3	0.109 ± .007 (0.083)	-0.004 ± .011 (0.084)	0.022 ± .009 (0.088)	0.136 ± .017 (.110)
a4	0.090 ± .006 (0.049)	0.049 ± .005 (0.047)	0.035 ± .007 (0.051)	0.069 ± .005 (.062)
a5	0.020 ± .004 (0.025)	-0.011 ± .003 (0.015)	0.007 ± .004 (0.019)	0.017 ± .003 (.015)
a6	0.004 ± .003 (0.013)	<0.001 ± .002 (0.009)	0.006 ± .002 (0.013)	0.010 ± .002 (.008)
a8	0.014 ± .001 (0.007)	0.011 ± .002 (0.006)	0.012 ± .001 (0.007)	0.010 ± .001 (.007)
a9	<0.001 ± .001 (0.004)	-0.001 ± .001 (0.005)	-0.001 ± .001 (0.005)	-0.002 ± .002 (.006)
a10	0.004 ± .001 (0.004)	0.004 ± .001 (0.003)	0.002 ± .001 (0.003)	0.003 ± .001 (.004)

Table 3a. Collared Coil Harmonics for Full Length Magnets with all-Kapton and Apical Insulation.

* Values shown are $\alpha \pm \beta$ (χ), where α is the average of 24 measurements taken along the straight section of the magnet, β is the calculated uncertainty in the average due to random errors, and χ is the RMS deviation about α of the 24 measurements. The uncertainty is calculated as $1/\sqrt{24}$ times the RMS deviation about the mean of five (5) measurements taken at a single position along the coil.

Magnet	(QI/III + QII/IV)/2		(QI/III - QII/IV)/2		(Upper - Lower)/2	
	Inner	Outer	Inner	Outer	Inner	Outer
DCA320	0.0057	-0.0114	-0.0002	0.0008	0.0016	0.0014
DCA321	0.0061	-0.0131	-0.0004	0.0002	-0.0013	-0.0012
DCA322	0.0050	-0.0070	-0.0002	0.0003	0.0002	-0.0013
DCA323	0.0065	-0.0099	0.0001	0.0002	0.0011	0.0002

Table 3b. Azimuthal Coil Size Parameters; to be Compared with Table I in Reference 4. (QI/III + QII/IV)/2 has not been corrected for systematic shift in coil sizing data with fully automatic sizing fixture, so that ~3.5 mils should be added to all entries in this column.

Magnet	a1 predicted	a1 measured	a2 predicted	a2 measured
DCA320	2.07	2.78 ± .05	0.50	0.32 ± .01
DCA321	-1.72	-0.97 ± .03	-0.41	-0.07 ± .01
DCA322	-0.57	-1.04 ± .04	-0.13	0.12 ± .01
DCA323	0.99	2.36 ± .05	0.24	0.02 ± .01

Table 3c. Predicted and Measured Skew Quadrupole and Sextupole for Full Length Collared Coils with all Kapton and Apical Insulation

Harmonic	DCA320, DCA321, DSA330 (5 mil shim in outer pole)	DCA322, DCA323 (no pole shims)	DSA331 (5 mil shim in Q4 of inner coil only)	DSA332 (10 mil shim in outer pole)	DSA333 (2 mil shim in inner, 4 mil in outer pole)
b2	-0.928	-2.117	-1.800	0.264	-0.674
b4	0.578	0.570	0.530	0.587	0.513
b6	0.033	0.037	0.042	0.027	0.042
b8	0.087	0.087	0.086	0.087	0.085
b10	0.023	0.023	0.023	0.023	0.023
b1	0.000	0.000	1.691	0.000	0.000
b3	0.000	0.000	-0.084	0.000	0.000
b5	0.000	0.000	0.006	0.000	0.000
b9	0.000	0.000	0.000	0.000	0.000
a1	0.000	0.000	0.277	0.000	0.000
a2	0.000	0.000	no prediction	0.000	0.000
a3	0.000	0.000	0.154	0.000	0.000
a4	0.000	0.000	-0.008	0.000	0.000
a5	0.000	0.000	-0.011	0.000	0.000
a6	0.000	0.000	0.004	0.000	0.000
a8	0.000	0.000	0.000	0.000	0.000
a9	0.000	0.000	-0.001	0.000	0.000

Table 4a. Predicted Harmonics for Model and Full-Length Collared Coils with all Kapton and Apical Insulation (M. Wake, private communication, calculations based on Reference 1)

Harmonic	DSA330 (5 mil shim in outer pole)	DSA331 (5 mil shim in Q4 of inner coil only)
b2	2.548	1.827
b4	0.406	0.369
b6	0.025	0.032
b8	0.066	0.065
b10	0.017	0.178
b1	0.000	1.345
b3	0.000	-0.064
b5	0.000	0.005
b9	0.000	0.000
a1	0.000	0.192
a2	0.000	no prediction
a3	0.000	0.118
a4	0.000	-0.006
a5	0.000	-0.008
a6	0.000	0.003
a8	0.000	0.000
a9	0.000	-0.001

Table 4b. Predicted Harmonics for Model and Full-Length Yoked Magnets with all Kapton and Apical Insulation (M. Wake, private communication, calculations based on Reference 1)

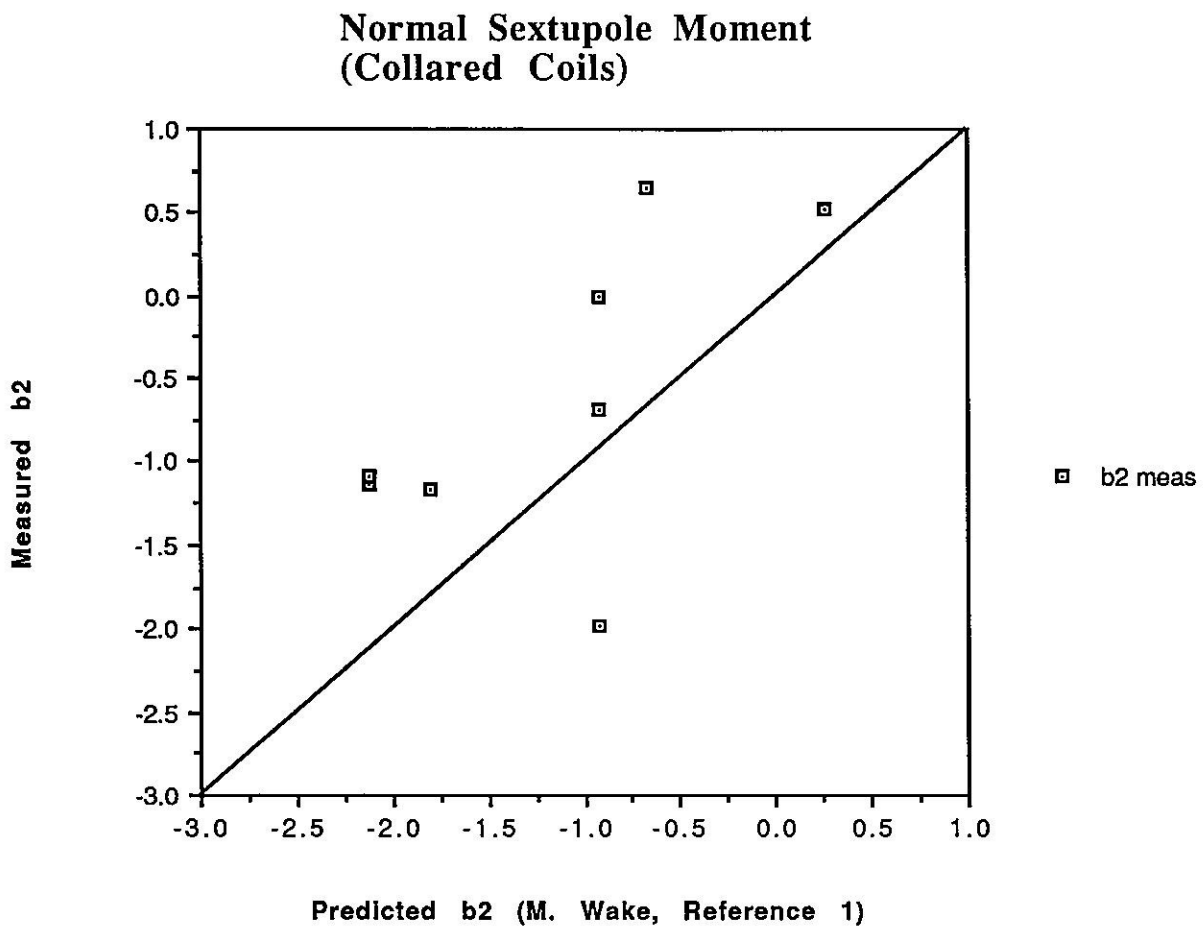
Normal Sextupole Moment
(Collared Coils)
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
Measured b2
-3.0
-2.5
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
Predicted b2 (M. Wake, Reference 1)
b2 meas

FIGURE 1

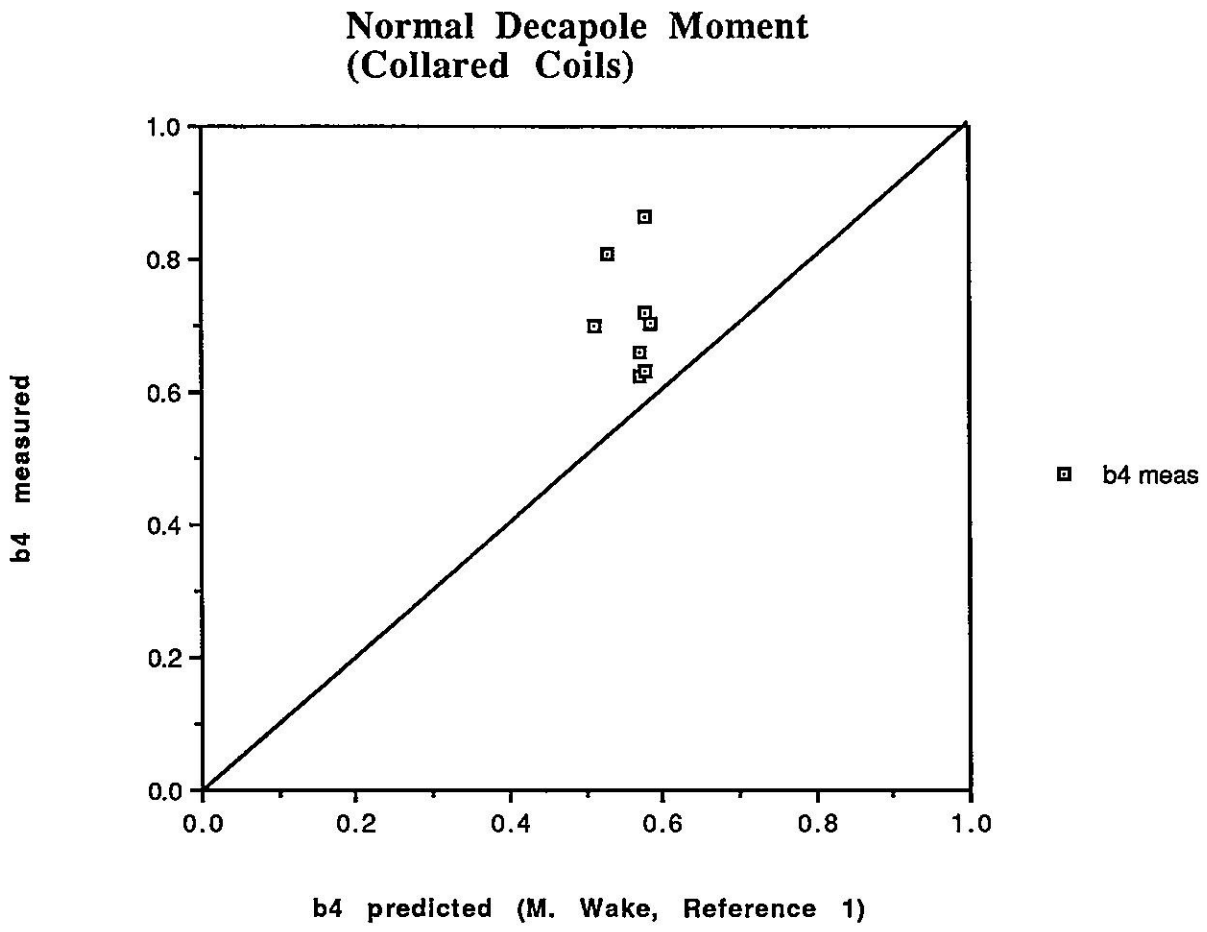
Normal Decapole Moment
(Collared Coils)
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
b4 measured
b4 predicted (M. Wake, Reference 1)
b4 meas

FIGURE 2

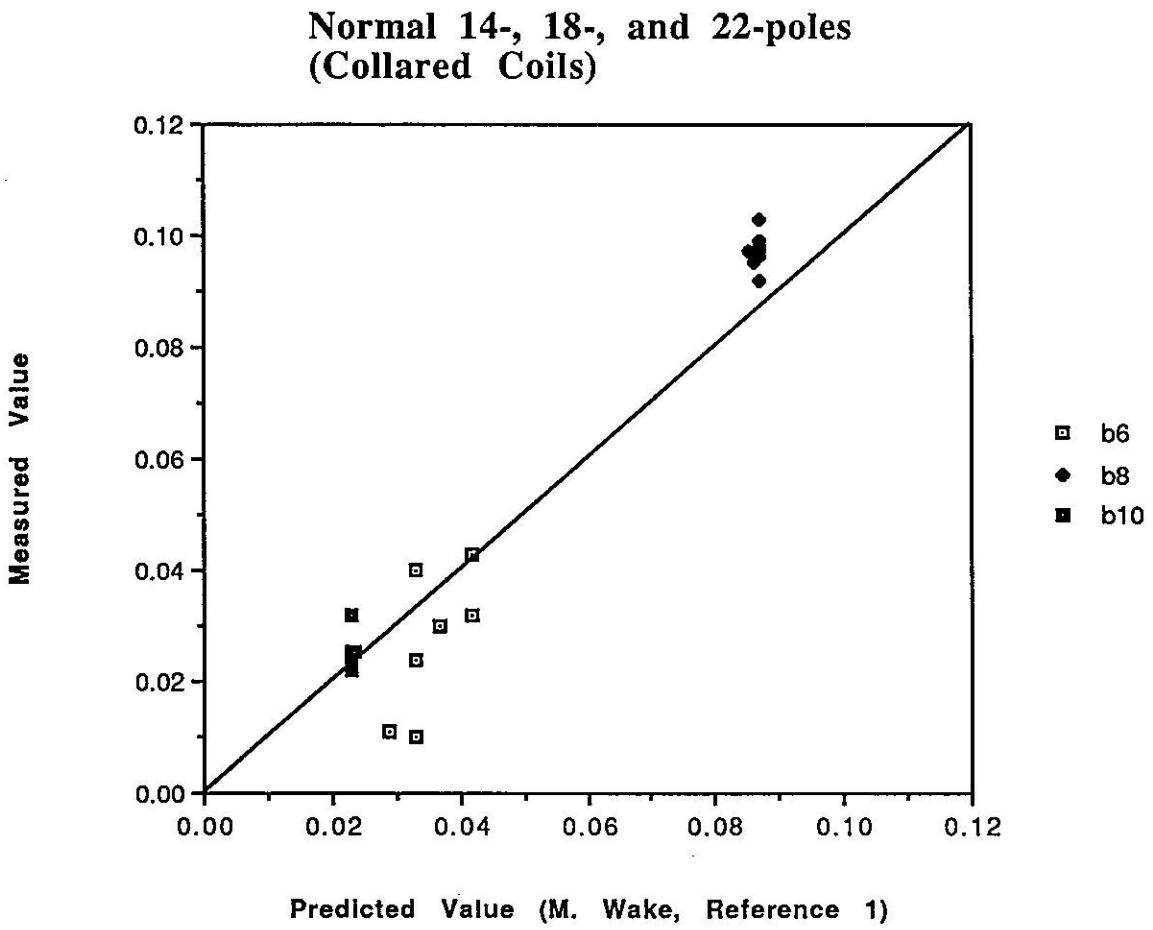
Normal 14-, 18-, and 22-poles
(Collared Coils)
0.12
0.10
0.08
0.06
0.04
0.02
0.00
Measured Value
0.00
0.02
0.04
0.06
0.08
0.10
0.12
Predicted Value (M. Wake, Reference 1)
b6
b8
b10

FIGURE 3