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Masayoshi Wake

Pressure Distribution Effect on Harmonic Components

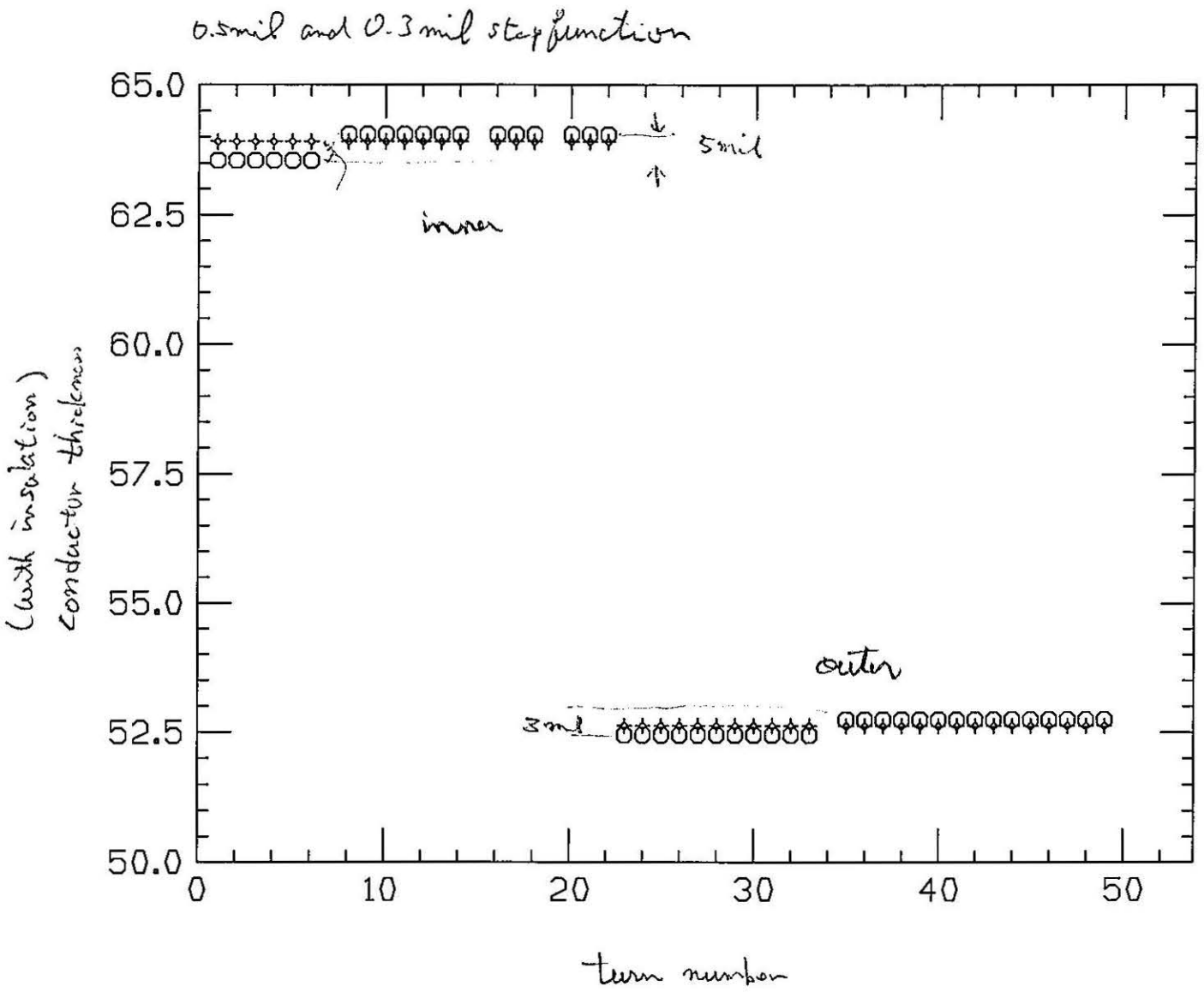
Recent measurement data of harmonics in DCA series ASST magnets show considerably large deviation from design in sextupole component. This is +1.7 units in average. Considering the effect of shimming at the pole is about 1 unit per 5 mil, this is a very large number. Geometrical error exceeding 5 mils is very hard to exist. Ovalization, radius change and other coordinate transformation type deformations all give the same level of change in sextupole. Besides, when we give large enough deformation, decapole moves in negative direction.
One thing we know is there may be a distribution in conductor thickness. Midplane is considered to have more pressure than the pole turn because of friction in the curing die. Attached is the calculation results for 1in the thickness from midplane to pole turn. The difference is +1.4 unit. Decapole changed by +0.1 unit in this deformation. Calculation assuming first blocks are compressed more than other blocks gives even better results. Both are large enough to count for the large deviation of sextupoles.
The cross section measurement currently prepared at SSCL will tell us how the thickness of the conductor is distributed and it is quite possible that the thickness distribution is the main cause of the deviation of harmonics from the design.

*Distribution: R.Bossert, J.Carson, S.Delchamps, W.Koska, T.Jaffery, M.Lamm, G.Pewitt, J.Strait, R.Sims

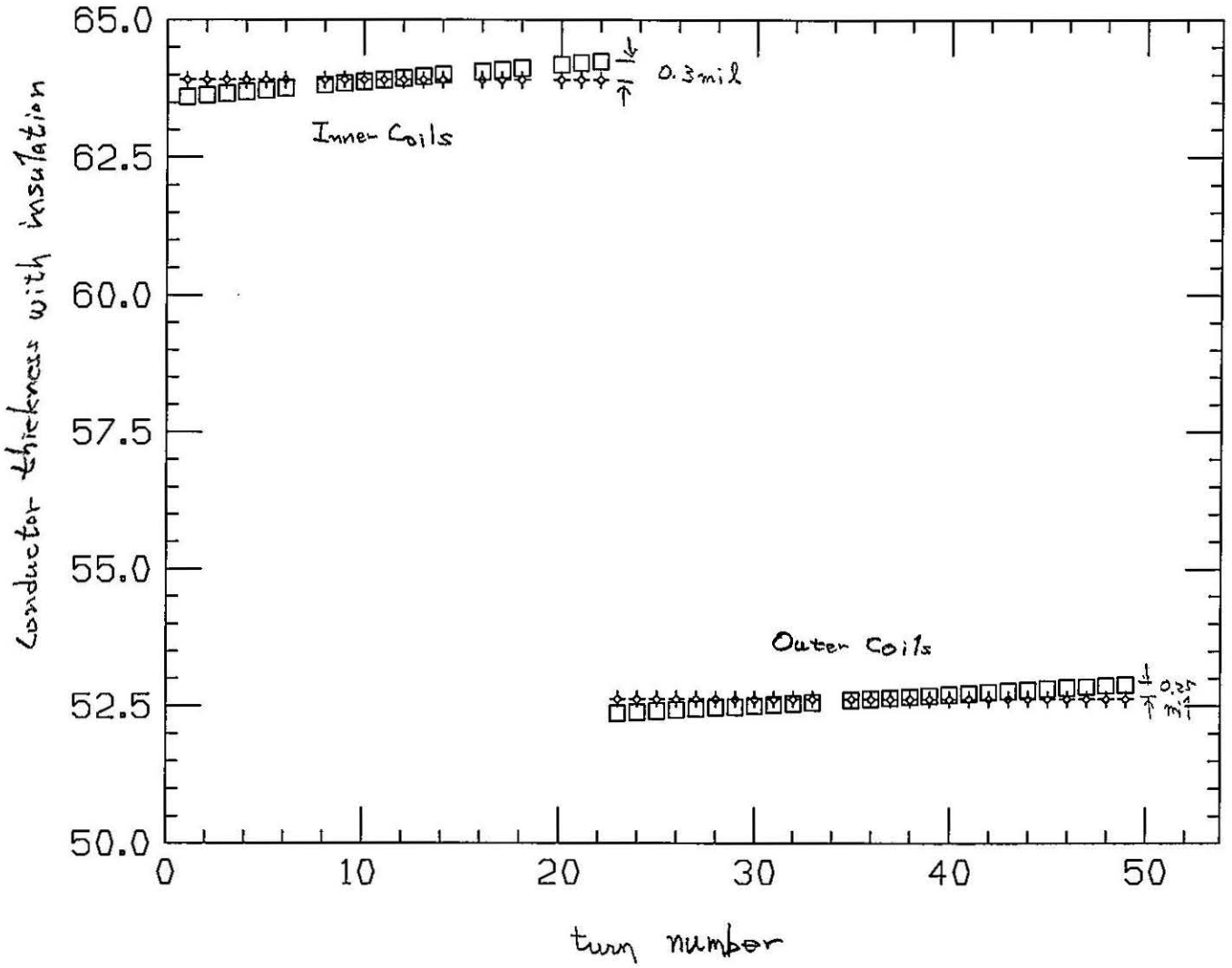
Harmonic Components

Magnet	pole shim	a_1	b_2	b_4	b_6	b_8	b_{10}
DSA321	+0		+3.20	+0.22			
	+0	-2.15	+2.95	+0.33	-0.08	+0.05	+0.02
DSA323	+0	-0.33	+1.50	+0.13	-0.05	+0.05	+0.02
	+0	+0.41	+1.38	+0.22	-0.08	+0.06	+0.02
DSA324	-5		+1.94	+0.04			
	+5	-0.00	+1.76	+0.19	-0.04	+0.05	+0.02
DSA326	+0	+0.96	+2.24	+0.28	-0.03	+0.05	+0.01
	+0	+1.03	+2.19	+0.35	-0.07	+0.06	+0.01
DSA328	+5	+0.04	+0.43	+0.10	-0.03	+0.04	+0.01
	-5	-0.10	+0.07	+0.26	-0.03	+0.06	+0.01
DSA329	-5	-0.05	+1.28	+0.10	-0.03	+0.04	+0.01
	+5	-0.67	+1.80	+0.08	-0.04	+0.05	+0.01
long	+0	+0.58	+1.59	+0.29	-0.04	+0.05	+0.02
ave.	+0	+0.63	+2.30	+0.31	-0.03	+0.05	+0.02
Cal	-5,+5	+0.00	+0.34	-0.08	-0.02	+0.04	+0.02
Cal	+0,+0	+0.00	+0.30	+0.06	-0.04	+0.04	+0.02
Design	+0,+0	+0.00	-0.18	-0.04	+0.00	+0.05	+0.02
Cal	+0,+0	+0.00	+1.58	+0.40	+0.03	+0.07	+0.02
Cal	+0,+5	+0.00	+2.54	+0.41	+0.03	+0.07	+0.02
Cal	+0,+10	+0.00	+3.51	+0.41	+0.02	+0.07	+0.02
DSA330	+0,1/2H+LTs	+1.41	+3.09	+0.63	+0.01	+0.06	+0.02
	+0,1/2H+1/2LTs	+1.27	+3.94	+0.71	+0.04	+0.07	+0.02

Upper rows are cold measurements at 2000A and lower rows are warm measurements at ± 10A. Units are ratio to the dipole component in 10^{-4} at 1cm radius.


0.5mil and 0.3mil step function
65.0
62.5
60.0
57.5
55.0
52.5
50.0
0
10
20
30
40
50
5mil
inner
outer
3mil
(with insulation)
conductor thickness
turn number

1% gradient in conductor thickness



base geometry

Pole	dn	fn	in	out	cn	w/o iron bn	w/ iron bn
0	3.9734485	1.2613871	2.2532790	2.9815567	5.2348356	0.7946897	1.0469671
1	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
2	-0.0015207	0.0016792	-0.0283317	0.0284902	0.0001585	-3.8272529	0.3026977
3	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
4	0.0000474	-0.0000173	0.0015569	-0.0015268	0.0000300	0.1192768	0.0573928
5	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
6	-0.0000214	0.0000000	-0.0000132	-0.0000082	-0.0000214	-0.0537400	-0.0408221
7	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
8	0.0000210	0.0000000	0.0000169	0.0000040	0.0000210	0.0527843	0.0400686
9	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
10	0.0000079	0.0000000	0.0000079	0.0000000	0.0000079	0.0199405	0.0151357

1% gradient in conductor thickness

Pole	dn	fn	in	out	cn	w/o iron bn	w/ iron bn
0	3.9754012	1.2619250	2.2547886	2.9825373	5.2373261	0.7950802	1.0474652
1	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
2	-0.0007973	0.0016984	-0.0278293	0.0287305	0.0009011	-2.0056145	1.7205427
3	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
4	0.0000707	-0.0000172	0.0015675	-0.0015140	0.0000535	0.1779434	0.1022218
5	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
6	-0.0000217	0.0000000	-0.0000136	-0.0000081	-0.0000217	-0.0545864	-0.0414651
7	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
8	0.0000208	0.0000000	0.0000168	0.0000040	0.0000208	0.0522915	0.0396952
9	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
10	0.0000080	0.0000000	0.0000079	0.0000000	0.0000080	0.0199988	0.0151801

0.5mil and 0.3 mil step function

Pole	dn	fn	in	out	cn	w/o iron bn	w/ iron bn
0	3.9750757	1.2618207	2.2546113	2.9822853	5.2368965	0.7950152	1.0473793
1	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
2	-0.0007861	0.0016956	-0.0277689	0.0286784	0.0009096	-1.9774560	1.7368121
3	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
4	0.0001004	-0.0000172	0.0015981	-0.0015148	0.0000832	0.2526957	0.1589597
5	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
6	-0.0000203	0.0000000	-0.0000124	-0.0000079	-0.0000203	-0.0510388	-0.0387716
7	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
8	0.0000208	0.0000000	0.0000168	0.0000040	0.0000208	0.0523679	0.0397531
9	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
10	0.0000079	0.0000000	0.0000079	0.0000000	0.0000079	0.0199556	0.0151473

Thermal contraction(everything shrinked 0.3%)

Pole	dn	fn	in	out	cn	w/o iron bn	w/ iron bn
0	3.9839337	1.2583288	2.2586026	2.9836597	5.2422624	0.7967867	1.0484525
1	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
2	-0.0013337	0.0016667	-0.0282270	0.0285601	0.0003330	-3.3475845	0.6353089
3	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
4	0.0000228	-0.0000172	0.0015489	-0.0015433	0.0000056	0.0571762	0.0106708
5	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
6	-0.0000356	0.0000000	-0.0000276	-0.0000080	-0.0000356	-0.0893437	-0.0679298
7	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
8	0.0000195	0.0000000	0.0000154	0.0000041	0.0000195	0.0488585	0.0371339
9	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
10	0.0000080	0.0000000	0.0000080	0.0000000	0.0000080	0.0201921	0.0153453

Inner pole 1mil shim

Pole	dn	fn	in	out	cn	w/o iron bn	w/ iron bn
0	3.9741757	1.2615352	2.2541542	2.9815567	5.2357111	0.7948352	1.0471421
1	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
2	-0.0014181	0.0016800	-0.0282282	0.0284902	0.0002619	-3.5682642	0.5002627
3	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
4	0.0000342	-0.0000174	0.0015437	-0.0015268	0.0000169	0.0861268	0.0322281
5	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
6	-0.0000196	0.0000000	-0.0000115	-0.0000082	-0.0000196	-0.0493236	-0.0374705
7	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
8	0.0000206	0.0000000	0.0000165	0.0000040	0.0000206	0.0517428	0.0392787
9	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
10	0.0000080	0.0000000	0.0000079	0.0000000	0.0000080	0.0200407	0.0152119

outer pole shim 1mil

Pole	dn	fn	in	out	cn	w/o iron bn	w/ iron bn
0	3.9732549	1.2613097	2.2532790	2.9812858	5.2345648	0.7946510	1.0469129
1	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
2	-0.0015909	0.0016745	-0.0283317	0.0284153	0.0000836	-4.0039372	0.1597670
3	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
4	0.0000415	-0.0000174	0.0015569	-0.0015328	0.0000240	0.1043499	0.0459344
5	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
6	-0.0000216	0.0000000	-0.0000132	-0.0000085	-0.0000217	-0.0544772	-0.0413829
7	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
8	0.0000210	0.0000000	0.0000169	0.0000040	0.0000210	0.0527476	0.0400408
9	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
10	0.0000079	0.0000000	0.0000079	0.0000000	0.0000079	0.0199384	0.0151341