Fermilab

TS-SSC 91-030
2/12/91

To: File

From: Jim Strait

Subject: First collaring of DSA322

DSA322 is a 1.5 m model 50 mm SSC collider dipole magnet which being used for a series of assembly tests. The primary objectives are 1) to determine the correct collaring shims and the correct coil size to achieve simultaneously the correct harmonics and the correct preload, 2) to understand the proper use of the 50 mm collaring tooling in a series of exercises similar to those performed for the 40 mm tooling with DS0312 and 3) to understand coil preloads in the end clamp region and try to find correlations between the end preload and easily measured quantities. The procedure involves multiple assemblies and disassemblies up to the point of collar keying and end clamp installation, but it is not planned to install the yoke and skin or to cold test the coil.

In the first assembly of DSA322 the coil was assembled, as with DSA320 and 321, with no pole shims. This magnet was the first to be keyed in the new 84 inch press using complete 50 mm collaring tooling. The end clamps were not installed. In this note I summarize the strain gauge and harmonics data and discuss briefly some observations from the collaring process.

The coil was keyed in the 84 inch press in IB3 using collaring tooling made from 2 inch EDM cut blocks. The tooling dimensions are the same as those for the laminated tooling to be used for the long magnet assembly; however, some differences may occur due to the less smooth surface of the laminated tooling. The tooling includes features which index the horizontal flats on the lifting point notches of the collars to provide azimuthal alignment. Due to a design oversight, these features were omitted from the upper EDMed tooling used here, although they are included in the laminated tooling. The tooling cavity dimensions are such that, using nominal dimensions for all parts, with the tooling fully closed the upper and lower collar key-ways should overlap enough to allow key insertion with zero clearance.

The DSA322 collared coil was placed in the tooling several inches from the north end of the press and a 5 mil shim was placed between the upper tooling and the press platen. The tooling is 72 inches long, the press platens are 84 inches long and all hydraulic cylinders were active. The collared portion of the coil is 44 inches long, so almost half the press was unopposed by the coil. The press was energized until the tooling was fully closed at between 6000 and 7000 psi in the hydraulic system ("pump psi"). Strain gauge, coil resistances and press gap data were recorded at several intermediate pressures. The lead end of the collared coil could be easily seen and it was observed that the upper collars were rotated significantly with respect to the lower collars such that when the tooling was closed a key could be inserted easily by hand on the left side but just barely started on the right. This makes it clear that the tooling alignment features are necessary on both the upper and lower halves.

The press was left closed for about an hour (lunch time). It was then opened and the tooling shim was increased to 10 mils. The press was closed again and they keys were inserted by energizing the horizontal hydraulic cylinders to 500 psi (500 lbs/inch per side). The vertical and then the horizontal pressure was release and final strain gauge readings were taken.

Strain gauge and press gap data are summarized in Tables I and II and in Figures 1 and 2. See the appendix for details of the analysis of the strain gauges. Several features of the data are worth noting. The press gaps are left-right symmetric within a few mils, but the return end, which is adjacent to the "unsupported" portion of the press, closes much sooner than the lead end. However, the press is fully closed before keying, so the load on the coil is determined by the tooling dimensions and not by the press beam shape. Over the hour at which the coil was maximally compressed during the first attempt, the coil stress decreased by approximately 300 psi in both the inner and outer coils. On the second pressing the stress was distributed somewhat differently between the inner and outer coils but the average stress is almost identical despite the apparent "creep" during the first pressing. During key insertion the inner coil stress dropped and the outer coil stress increased but the average was almost unchanged. The "spring-back" loss (peak minus final coil stress) was considerable: 4.4 kpsi and 8.6 kpsi in the inner and outer coils respectively. The final coil stresses are surprisingly low: 5.8 and 4.7 kpsi.

Figure 3 is a plot of the average (inner + outer) coil stress versus the hydraulic system pressure. The press has a capacity of 250 T/foot at 10 kpsi hydraulic pressure. The sum of the widths of the insulated inner and outer conductors on both sides is 1.95 inches. Therefore if the press load is uniformly balanced by the coil the slope on this plot should be 2.14 coil psi per pump psi. This slope is shown by the dashed line. Both compressions show the expected shape: a linear rise in coil stress which flattens when the tooling closes and no further load is transmitted to the coil. On the second pressing the plateau is at higher stress due to the thicker tooling shim.

Table III contains the measured collar diameters and Figure 4 plots the deflections relative to the design undeflected values. The diameters noted as 53° and 127° were specified in the traveller to be at 45° and 135°, which are in the middle of the lifting fixture cutouts. The measurements were actually made approximately 1/8 inch "above" the feature at approximately 53°, but the actual azimuthal position of the measurement is not known precisely. Because of the "anti-oval" shape of the collars in this region, the diameter measurement is relatively sensitive to the azimuth in this region so the these deflections may be less reliable than those at 0° and 90°. The horizontal measurements were made across the tabs at the horizontal mid-plane.

Table IV compares the measured sextupole and decapole moments in DSA322[1] with DSA32[1] and DSA321[2] and with the calculated values[3]. In making the comparison it must be noted that DSA320 and 322 were measured with the mole at room temperature as collared coils without iron, while DSA321 was measured with the Lab 2 magnetometer and HAL2 systems at 4.2 K as a complete magnet with a yoke. When compensation is make for the presence or absence of iron, the sextupole moments of DSA320 and 321 are quite consistent with each other while DSA322 is dramatically different. There is less internal consistency among the decapole moments, but again DSA322 is quite different from its predecessors. The difference in b_2 is of the sign expected if the pole angles were larger (measured from the mid-plane) in DSA322 than in the previous two magnets. This is qualitatively consistent with the lower prestress.

The coils in DSA322 are close in size to those in DSA321: the inner and outer coils are on the average 1.4 mils and 0.1 mils smaller than those in DSA321. The prestresses are dramatically smaller than 321: 6 and 5 kpsi in the inner and outer coils in DSA322 versus 9 and 13 kpsi in DSA321. This difference, combined with the difference in harmonics, led us to suspect that one or more layers of ground insulation had been inadvertently left out. In disassembling DSA322 it was found that indeed one layer had been omitted in all four quadrants. This was the middle layer covering the entire radially outward surface and the pole of the outer coil. (See Figure 3.) This omission allowed the inner and outer coils to move into cavities 3.4 and 8.4 mils larger in azimuthal extent than the design. The measured spring rates of the DSA322 inner and outer coils are -0.72 mils/kpsi and -0.84 mils/kpsi respectively. Ignoring the elastic properties of the collars, the combined differences in coils sizes and collar cavities predict prestress differences between DSA322 and DSA321 of -3.5 and -7 kpsi in the inner and outer coils respectively. These are quite close to the measured differences of -3 and -8 kpsi.

DSA322 will be assembled a second time with the design ground insulation and no pole shims. On the second assembly laminated upper tooling will be used which will provide better azimuthal alignment between the upper and lower collars. It is hoped that this will reduce the amount of overcompression required for key insertion.

References

[1] S. Delchamps, private communication.

[2] K. Coulter, private communication and T. Jaffery, private communication.

[3] R. Gupta, private communication.

Table I

DSA322 910125

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
21				CORRECTED AVERAGING FORMULAS 11-20-90											
22									From P=0 below					Orig Calib	
23											BNL C3	BNL C2	BNL C1		
24				GAGE NO.	TYPE	COIL	Quadrant	Gage Facto	R0 (Ohms)	FNAL A0	FNAL A1	FNAL A2	FNAL A3	R0 (Ohms)	
25				A009	Active	Inner	1	2.03	349.552	58.9	2.1E+00	7.40E-03	-1.634E-06	349.532	0.020
26				A011	Active	Inner	2	2.03	350.028	-26.0	3.0E+00	6.89E-03	-1.691E-06	350.007	0.021
27				C016	Comp.	Inner	1&2	2.03	349.551					349.521	0.030
28				A013	Active	Inner	3	2.03	350.014	109.6	3.0E+00	6.74E-03	-1.569E-06	350.001	0.013
29				A012	Active	Inner	4	2.03	350.176	6.0	3.4E+00	6.86E-03	-1.742E-06	349.943	0.233
30				C014	Comp.	Inner	3&4	2.03	350.904					350.182	0.722
31				A019	Active	Outer	1	2.03	349.931	-37.2	3.3E+00	6.62E-03	-1.532E-06	349.906	0.025
32				A018	Active	Outer	2	2.03	349.763	36.5	2.7E+00	6.91E-03	-1.543E-06	349.740	0.023
33				C013	Comp.	Outer	1	2.03	349.913					349.891	0.022
34				C012	Comp.	Outer	2	2.03	351.986					350.123	1.863
35				A014	Active	Outer	3	2.03	349.851	12.7	2.8E+00	6.56E-03	-1.468E-06	349.834	0.017
36				A015	Active	Outer	4	2.03	350.092	49.8	2.7E+00	6.83E-03	-1.505E-06	350.072	0.020
37				C008	Comp.	Outer	3	2.03	349.801					349.786	0.015
38				C009	Comp.	Outer	4	2.03	352.286					350.286	2.000
39															
40															
41						Hydraulic Pressure		Average Coil Stress			d(Stress)/dPv				
42			Seq #	Date	Press	Vertical	Horizontal	Inner	Outer	All	Inner	Outer	All		
43			1	1/25/91	Collaring (	0	0	37	15	26				1st Comprssion	
44			2	1/25/91	0	750	0	456	25	241					
45			3	1/25/91	0	1000	0	599	683	641	0.57	2.63	1.60		
46			4	1/25/91	0	3000	0	4521	4102	4311	1.96	1.71	1.84		
47			5	1/25/91	0	5000	0	8419	9215	8817	1.95	2.56	2.25		
48			6	1/25/91	0	6000	0	8824	10608	9716	0.41	1.39	0.90		
49			7	1/25/91	Collaring (	7000	0	9254	11223	10239	0.43	0.62	0.52		
50			8	1/25/91	0	7000	0	8953	10884	9918					
51			9	1/25/91	0	0	0	21	-7	7	1.28	1.56	1.42	2nd Comprssion	
52			10	1/25/91	0	750	0	286	258	272	0.35	0.35	0.35		
53			11	1/25/91	0	3000	0	4493	5052	4773	1.87	2.13	2.00		
54			12	1/25/91	0	5000	0	8018	10061	9039	1.76	2.50	2.13		
55			13	1/25/91	0	6000	0	9606	12492	11049					
56			14	1/25/91	Collaring (	7000	0	10167	12443	11305					
57			15	1/25/91	Collaring (	7000	500	9842	13270	11556					
58			16	1/25/91	0	0	500	5977	4705	5341					
59			17	1/25/91	0	0	0	5814	4666	5240					
60															
61															
62															
63															
64															
65															
66															
67															
68															
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70															
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72															
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77															
78															
79															
80															

Table II
Collaring Press Gaps

Dist. from Lead End of Collared Coil (inches)	Side	Press Pump Pressure (psi) First Pressing 3000	5000	6000	Second Pressing 5000	6000	7000
2	Left	.018	.004	0	.007	.001	0
	Right	.015	.001	0	.005	0	0
22	Left	.015	.003	0	.006	.001	.001
	Right	.013	.002	0	.005	.001	.001
42	Left	.006	0	0	0	0	0
	Right	.006	0	0	0	0	0

Note: the collared coil is 44 inches long.

Table IV
DSA320-322 Harmonics

Magnet	b_2	b_4
DSA320	-2.4	0.57
DSA322	-6.2	0.89
Calculated (w/o iron)	-4.0	0.14
DSA321	2.6	0.35
Calculated (with iron)	0.2	0.07

DSA322 Collared Coil (1st Assembly)
First assembly; measurements made 1/28/91

	--------	Nominal	Diameters	---------	
	5.488	5.3112	5.304	5.304	5.3112

	---------	Measured	Diameters	--------		- Radial	Deflections -	
z(in.)	A(Hor.)	D(53d)	B2(V)	B1(V)	C(127d)	Vert	53deg	Horiz
0	5.489	5.316	5.311	5.311	5.317	0.0035	0.0027	0.0005
2	5.489	5.316	5.311	5.310	5.316	0.0033	0.0024	0.0005
4	5.489	5.316	5.310	5.310	5.316	0.0030	0.0024	0.0005
6	5.490	5.316	5.310	5.311	5.316	0.0033	0.0024	0.0010
8	5.490	5.316	5.311	5.311	5.316	0.0035	0.0024	0.0010
10	5.489	5.316	5.310	5.311	5.316	0.0033	0.0024	0.0005
12	5.489	5.316	5.310	5.310	5.315	0.0030	0.0022	0.0005
14	5.489	5.316	5.310	5.310	5.315	0.0030	0.0022	0.0005
16	5.489	5.316	5.310	5.310	5.315	0.0030	0.0022	0.0005
18	5.489	5.315	5.310	5.310	5.315	0.0030	0.0019	0.0005
20	5.489	5.316	5.310	5.310	5.316	0.0030	0.0024	0.0005
22	5.489	5.315	5.310	5.310	5.316	0.0030	0.0022	0.0005
23	5.489	5.316	5.310	5.310	5.316	0.0030	0.0024	0.0005
24	5.489	5.316	5.310	5.310	5.316	0.0030	0.0024	0.0005
25	5.489	5.316	5.310	5.310	5.316	0.0030	0.0024	0.0005
26	5.489	5.316	5.310	5.310	5.316	0.0030	0.0024	0.0005
27	5.489	5.316	5.310	5.310	5.316	0.0030	0.0024	0.0005
29	5.490	5.316	5.310	5.310	5.316	0.0030	0.0024	0.0010
31	5.490	5.316	5.311	5.310	5.316	0.0033	0.0024	0.0010
33	5.490	5.316	5.311	5.311	5.316	0.0035	0.0024	0.0010
35	5.490	5.318	5.310	5.310	5.316	0.0030	0.0029	0.0010
37	5.489	5.316	5.309	5.309	5.316	0.0025	0.0024	0.0005
39	5.489	5.316	5.309	5.309	5.316	0.0025	0.0024	0.0005
42	5.489	5.316	5.310	5.310	5.316	0.0030	0.0024	0.0005
44	5.489	5.315	5.310	5.310	5.316	0.0030	0.0022	0.0005
Avg	5.489	5.316		5.310		0.0031	0.0024	0.0006
Sigma	0.0004	0.0005		0.0005		0.0002	0.0002	0.0002

Table III

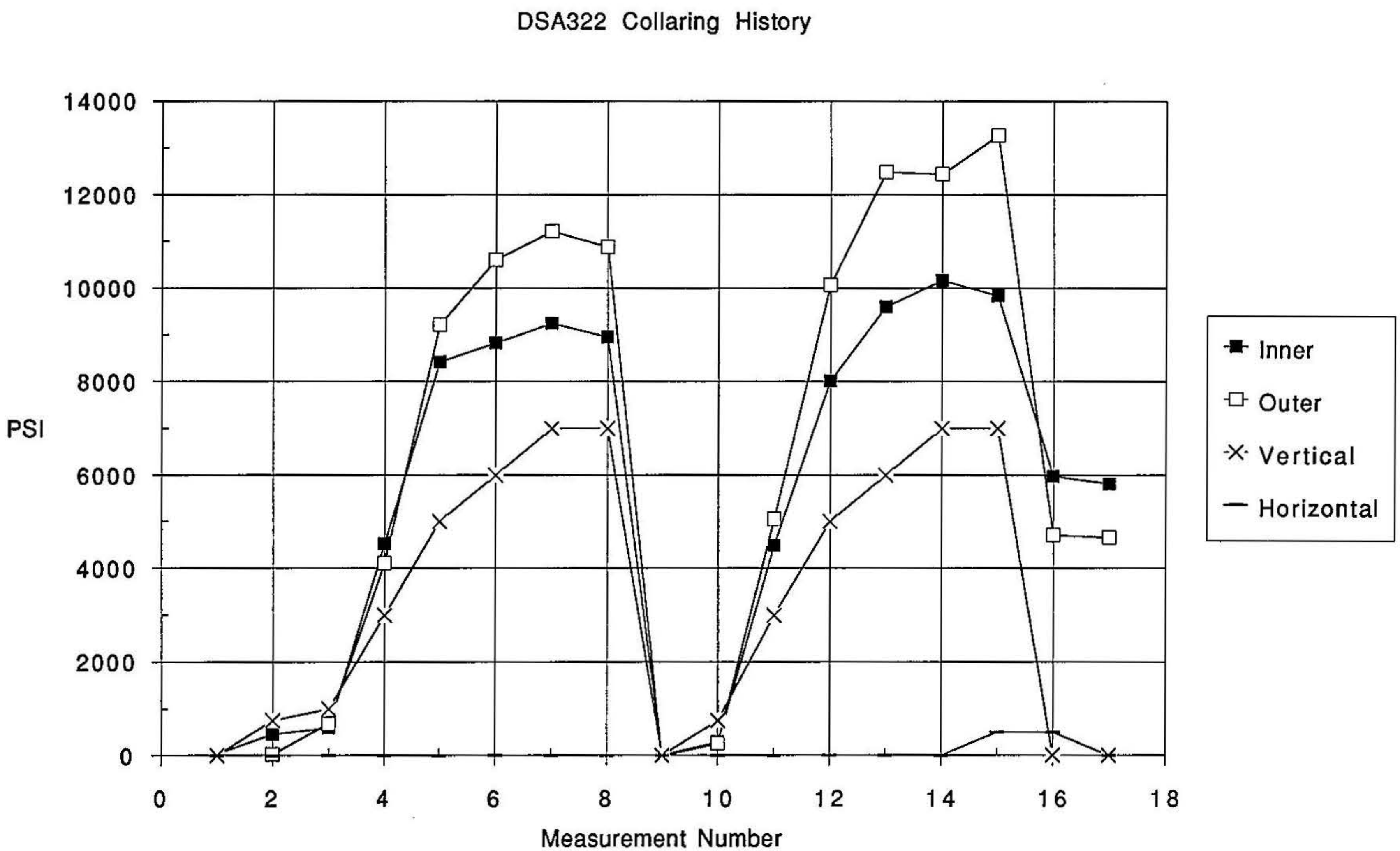

DSA322 Collaring History
PSI
14000
12000
10000
8000
6000
4000
2000
0
0
2
4
6
8
10
12
14
16
18
Measurement Number
Inner
Outer
Vertical
Horizontal

Figure 1

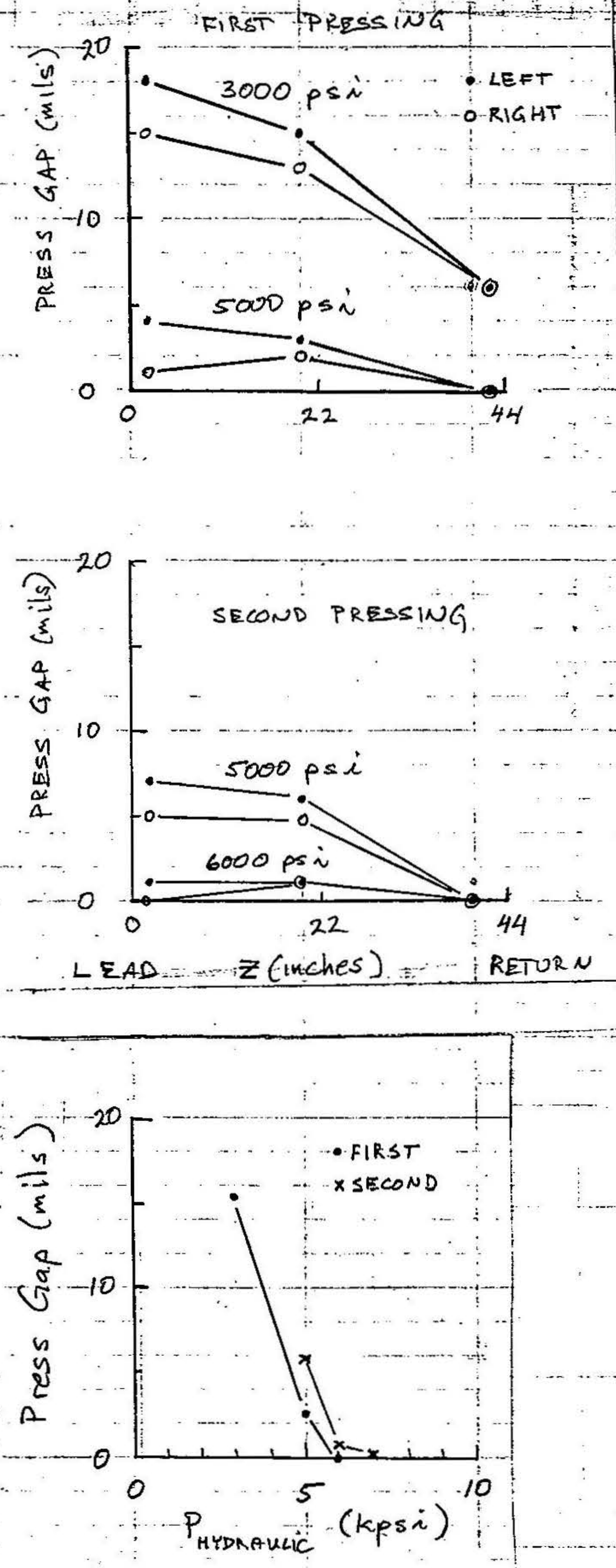

FIRST PRESSING
PRESS GAP (mils)
3000 psi
5000 psi
• LEFT
o RIGHT
20
10
0
0
22
44
SECOND PRESSING
PRESS GAP (mils)
5000 psi
6000 psi
20
10
0
0
22
44
LEAD
Z (inches)
RETURN
Press Gap (mils)
• FIRST
x SECOND
20
10
0
0
5
10
$P_{HYDRAULIC}$ (kpsi)

Figure 2

DSA322 900125 Str vs P graph

DSA322 Collar Keying 1/25/91

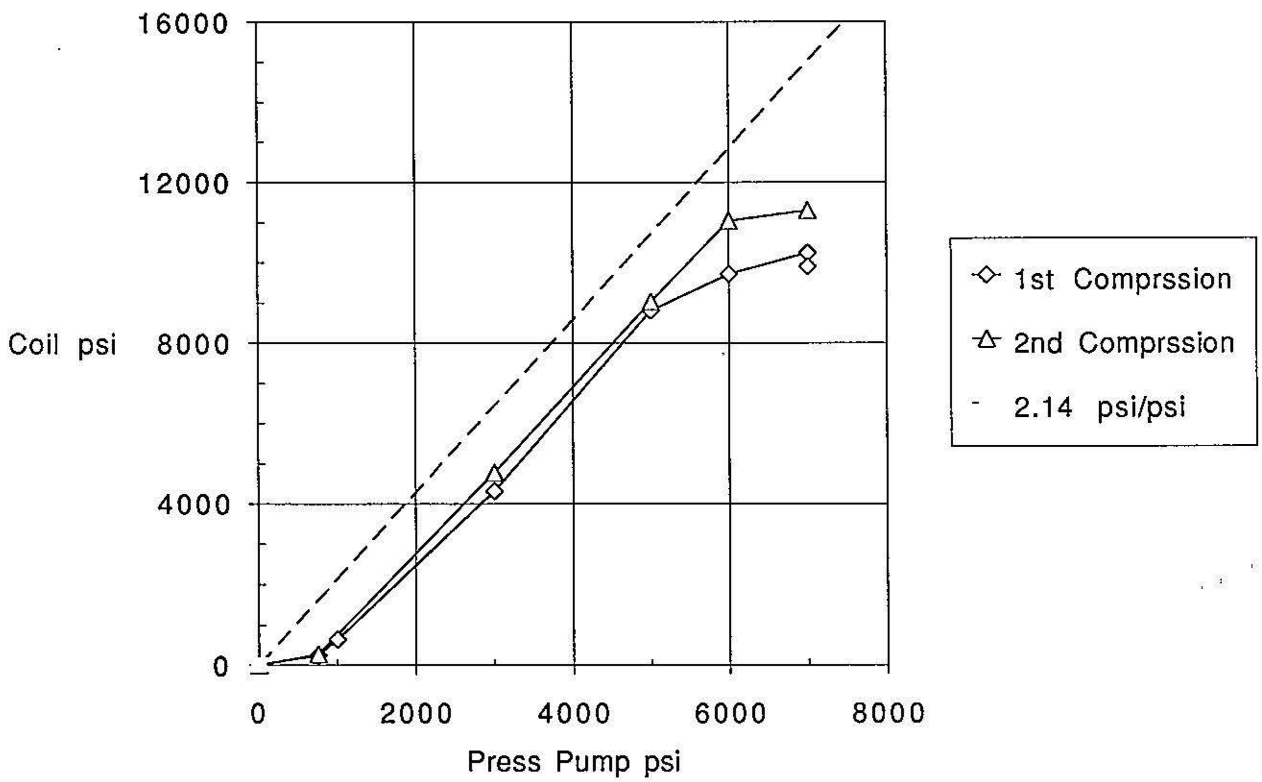
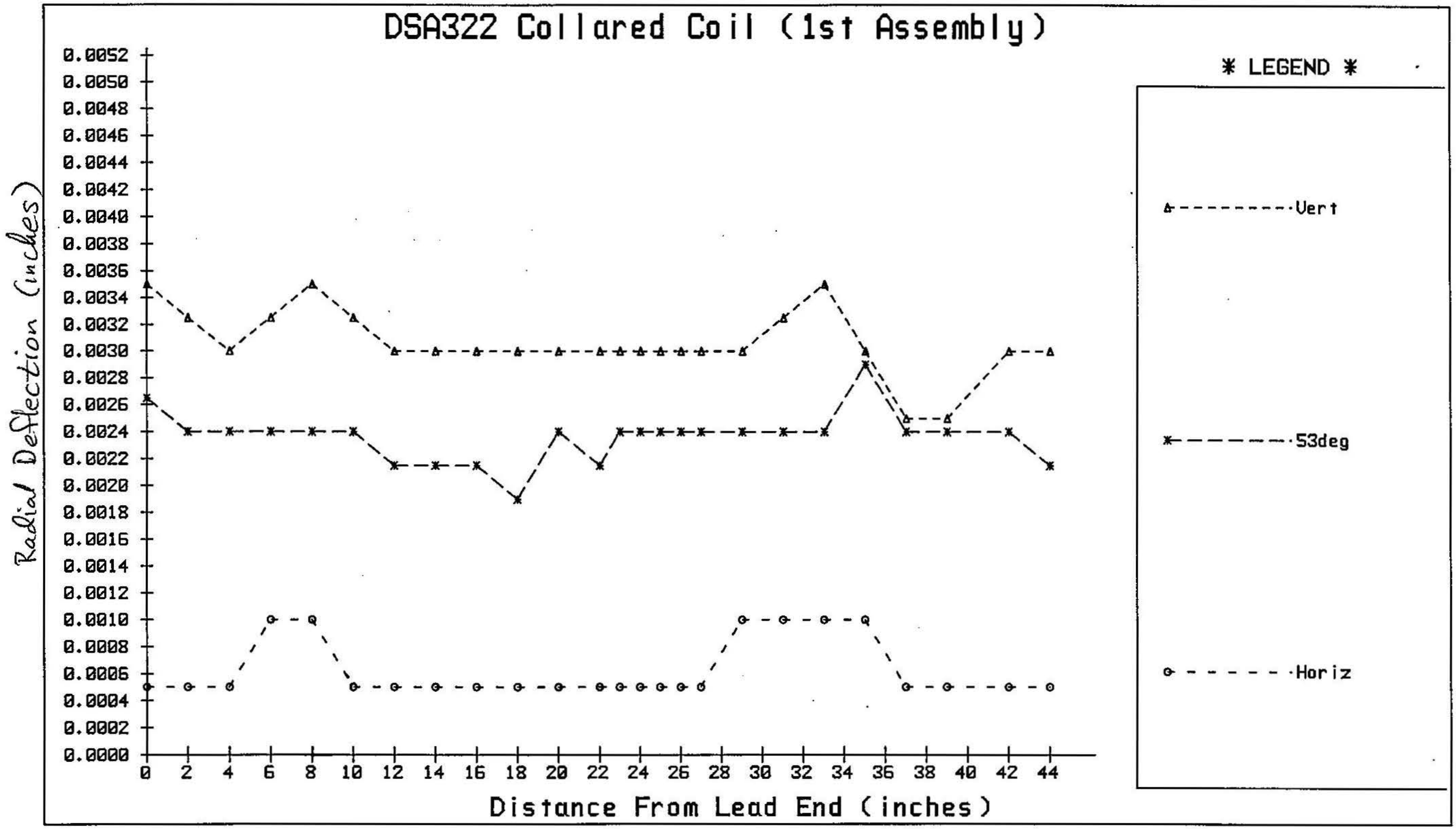


Figure 3



DSA322 Collared Coil (1st Assembly)
Radial Deflection (inches)
0.0052
0.0050
0.0048
0.0046
0.0044
0.0042
0.0040
0.0038
0.0036
0.0034
0.0032
0.0030
0.0028
0.0026
0.0024
0.0022
0.0020
0.0018
0.0016
0.0014
0.0012
0.0010
0.0008
0.0006
0.0004
0.0002
0.0000
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44
Distance From Lead End (inches)
* LEGEND *
Vert
53deg
Horiz

Figure 4

Appendix
Strain Gauge Data Analysis

The resistances of a number of the strain gauges in DSA321, measured on the magnet before the collar keying operation began, disagreed substantially with the calibration values. In two cases (inner coil quadrants 1 and 2 and outer quadrants 1 and 2) good agreement could be gotten if pairs of active gauges were swapped. In these cases all the calibration were also swapped in the Excel spread-sheet used to analyze the data. In three other cases (the active gauge in inner quadrant 4 and the compensating gauges for inner quadrants 3&4 and outer quadrants 3 and 4) no such solution could be found. The source of these discrepancies has not been determined. The identification of which gauges are active and which are compensating seems to be correct since all the active and none of the compensating gauges change with press load. To allow the data to be analyzed, the resistances measured with the coil in the collaring press at zero load were substituted for the original calibrations. The calibrations used for this analysis are shown at the top of Table I and the original calibrations are shown in Table A-I.

Table A-I

DSA322 910125

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1				CORRECTED AVERAGING FORMULAS 11-20-90											
2									"Original" Calibrations						
3											BNL C3	BNL C2	BNL C1		
4				GAGE NO.	TYPE	COIL	Quadrant	Gage Facto	R0 (Ohms)	FNAL A0	FNAL A1	FNAL A2	FNAL A3		
5				A011	Active	Inner	1	2.03	350.007	-26.0	3.0E+00	6.89E-03	-1.691E-06		
6				A009	Active	Inner	2	2.03	349.532	58.9	2.1E+00	7.40E-03	-1.634E-06		
7				C016	Comp.	Inner	1&2	2.03	349.521						
8				A013	Active	Inner	3	2.03	350.001	109.6	3.0E+00	6.74E-03	-1.569E-06		
9				A012	Active	Inner	4	2.03	349.943	6.0	3.4E+00	6.86E-03	-1.742E-06		
10				C014	Comp.	Inner	3&4	2.03	350.182						
11				A018	Active	Outer	1	2.03	349.740	36.5	2.7E+00	6.91E-03	-1.543E-06		
12				A019	Active	Outer	2	2.03	349.906	-37.2	3.3E+00	6.62E-03	-1.532E-06		
13				C013	Comp.	Outer	1	2.03	349.891						
14				C012	Comp.	Outer	2	2.03	350.123						
15				A014	Active	Outer	3	2.03	349.834	12.7	2.8E+00	6.56E-03	-1.468E-06		
16				A015	Active	Outer	4	2.03	350.072	49.8	2.7E+00	6.83E-03	-1.505E-06		
17				C008	Comp.	Outer	3	2.03	349.786						
18				C009	Comp.	Outer	4	2.03	350.286						
19															
20															