Fermilab

TS-SSC 90-071
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MEMO TO: R. Bossert, J. Carson, S. Delchamps, N Hassan, S Gourlay, W. Koska, M. Lamm, P. Mantsch, G. Pewitt, R. Rihel, M. Wake

FROM: Jim Strait

SUBJECT: Analysis of DC0302 Collaring Data

Strain gage data were recorded from DC0302 on the first keying attempt. In one 8 foot section of the magnet key insertion failed on one side of the magnet. However, neither of the two strain gage packs were in this region, so the strain gage data remain valid. The location of the unkeyed section is shown in a summary of the press gap measurements supplied by Reid Rihel which is attached as Figure 1. (The first pressing of this coil was done with a 12 mil shim between the upper tooling and the press platen. The gap data recorded in Figure 1 correspond to the final pressing in which the keys were successfully inserted in the offending 8 foot section. In this case a 32 mil shim was used.)

DC0302 has two packs at one-third ("LE") and two-thirds ("RE") of the way from the lead to the return end. Data from the two packs, averaged over the four inner and four outer gages at each location are displayed in Tables Ia and Ib and in Figure 2. Perhaps the most striking feature is the large decrease, particularly in the outer coil, in coil stress from the peak value in the press to the final value. The final values and the "spring-back" losses are summarized in Table II.

The coil stresses are plotted versus press hydraulic pressure in Figure 3. The press capacity is 20 tons/ft per kpsi of hydraulic pressure. The sum of the coil widths is approximately 1.5 inch, so the press capacity is 2.2 coil psi per hydraulic system psi. As long as the tooling remains open essentially all of the press load is balanced by coil stress at the mid-plane. The strain gages measure coil stress at the pole. Due to frictional effects only part of the mid-plane stress is transferred to the pole, typically on the order of 70% in BNL magnets and our short magnets. Over the range $3 \leq P_{HYDRAULIC} \leq 7$ kpsi the data in Figure 4 are reasonably linear and least squares fits have been done. The resultant slopes are tabulated in Table II. Because of different coil sizes and moduli the press load may be more strongly balanced by the inner or outer coil, but the average of the two should show less variation. In fact, the average slopes at the two locations are identical and indicate that 78% of the press load appears at the poles. Thus it appears that the press is operating properly or, alternatively, that the strain gages are giving plausible results.

Once the difficulty with key insertion was overcome and collars were fully keyed, the collared coil diameters were measured. The data are tabulated in Table IIIa. Diameters were measured at positions 12 inches apart except at the strain gage packs where measurements are taken at the centers of the two parts of the pack. The vertical deflection of the collars is proportional to the prestress and gives a cross check on the strain gage measurements. The deflections are tabulated in Table IIIb and plotted in Figure 4. The relation between vertical deflection and prestress can be gotten from data on early BNL magnets[1], which give a slope of 0.56 mils/kpsi, or from ANSYS calculations[2], which give 0.44 mils/kpsi. (The deflection is on the radius.) The average deflection (ignoring the low points at the two ends) is 2.72 mils, which corresponds to an average coil preload of 4.9 kpsi or 6.2 kpsi respectively. The average deflection at the two strain gage packs is 2.9 mils corresponding to 5.2 or 6.7 kpsi. These agree reasonably with the inner-outer coil average prestress of 5.6 kpsi as measured by the strain gages.

References

1. J. Strait, Notes on collared coil mechanics and sextupole moment, Minutes of the MSIM 11-12 July, 1989.

2. J. Cortella, private communication. See also J. Strait, Calculation of Desired Vertical Ovality of SSC Collars, Minutes of the MSIM, October, 1989.

Table Ia

DS0302 LE

	A	B	C	D	E	F	G	H	I	J	K	L	M
1													
2													
3											C3	C2	C1
4				GAGE NO.	TYPE	COIL	Quadrant	Gage Factor	R0 (Ohms)	A0	A1	A2	A3
5				1021	Active	Inner	1	2.02	349.998	-100.8	-8.9E-01	4.76E-03	0.00000
6				1020	Active	Inner	2	2.02	350.019	-43.7	1.3E+00	3.49E-03	0.00000
7				292	Comp.	Inner	1&2	2.02	349.745				
8				1031	Active	Inner	3	2.02	349.805	-162.1	1.5E+00	2.88E-03	0.00000
9				1030	Active	Inner	4	2.02	349.512	49.5	1.7E+00	2.83E-03	0.00000
10				232	Comp.	Inner	3&4	2.02	349.316				
11				1018	Active	Outer	1	2.02	349.661	40.6	1.0E+00	3.13E-03	0.00000
12				1019	Active	Outer	2	2.02	349.928	-15.8	5.1E-01	3.75E-03	0.00000
13				288	Comp.	Outer	1	2.02	349.637				
14				289	Comp.	Outer	2	2.02	349.613				
15				90	Active	Outer	3	2.02	350.758	23.0	1.6E+00	3.89E-03	0.00000
16				94	Active	Outer	4	2.02	350.512	-80.3	7.2E-01	4.50E-03	0.00000
17				280	Comp.	Outer	3	2.02	350.156				
18				293	Comp.	Outer	4	2.02	349.855				
19													
20													
21						Hydraulic Pressure		Average Coil Stress			d(Stress)/dPv		
22			Seq #	Date	Pressure	ss (Vertical)	ss (Horizontal)	Inner Coil (LE)	Outer Coil (LE)	All	Inner	Outer	All
23			1	9/25/90	0	0	0	-21	7	-7			
24			2	9/25/90	0	350	0	82	33	57			Lead End
25			3	9/25/90	0	1000	0	977	410	693	1.38	0.58	0.98
26			4	9/25/90	0	3000	0	3713	2165	2939	1.37	0.88	1.12
27			5	9/25/90	0	4000	0	5155	3611	4383	1.44	1.45	1.44
28			6	9/25/90	0	5000	0	6664	5284	5974	1.51	1.67	1.59
29			7	9/25/90	0	6000	0	8879	7208	8044	2.21	1.92	2.07
30			8	9/25/90	0	7000	0	10222	9216	9719	1.34	2.01	1.68
31			9	9/25/90	0	8000	0	10595	11309	10952	0.37	2.09	1.23
32			10	9/25/90	0	8500	0	10911	11920	11415	0.63	1.22	0.93
33			11	9/25/90	0	8500	500	10891	12285	11588	#DIV/0!	#DIV/0!	#DIV/0!
34			12	9/25/90	0	4500	500	7568	9012	8290	0.83	0.82	0.82
35			13	9/25/90	0	0	0	6645	3662	5154			
36			14	9/25/90	0	0	0	#DIV/0!	#DIV/0!	#DIV/0!			
37			15	9/25/90	0	0	0	#DIV/0!	#DIV/0!	#DIV/0!			
38			16	1/1/04	Ethel	Time:	0	Inner	Outer	#DIV/0!			
39			17	1/1/04	Ethel	Time:	0	Inner	Outer	#DIV/0!			
40			18	1/1/04	Ethel	Time:	0	Inner	Outer	#DIV/0!			

Table Ib

DS0302 RE

	A	B	C	D	E	F	G	H	I	J	K	L	M
1													
2													
3											C3	C2	C1
4				GAGE NO.	TYPE	COIL	Quadrant	Gage Factor	R0 (Ohms)	A0	A1	A2	A3
5				157	Active	Inner	1	2.02	350.272	345.0	3.7E+00	2.26E-03	0.00000
6				155	Active	Inner	2	2.02	350.316	280.9	2.5E+00	2.42E-03	0.00000
7				270	Comp.	Inner	1&2	2.02	350.018				
8				72	Active	Inner	3	2.02	350.112	83.7	3.7E+00	1.44E-03	0.00000
9				75	Active	Inner	4	2.02	350.057	97.2	2.7E+00	1.86E-03	0.00000
10				287	Comp.	Inner	3&4	2.02	349.927				
11				154	Active	Outer	1	2.02	350.058	-26.8	-3.1E-01	4.07E-03	0.00000
12				153	Active	Outer	2	2.02	350.097	-51.6	1.5E+00	3.11E-03	0.00000
13				276	Comp.	Outer	1	2.02	350.953				
14				275	Comp.	Outer	2	2.02	350.026				
15				96	Active	Outer	3	2.02	350.532	-344.8	1.9E+00	3.78E-03	0.00000
16				95	Active	Outer	4	2.02	350.559	24.7	1.8E+00	3.37E-03	0.00000
17				260	Comp.	Outer	3	2.02	350.389				
18				261	Comp.	Outer	4	2.02	350.461				
19													
20													
21						Hydraulic Pressure		Average Coil Stress				d(Stress)/dPv		
22			Seq #	Date	Pressess	(Vertical)	s (Horizontal)	nner Coil (RE)	uter Coil (RE)	All		Inner	Outer	All
23			1	9/25/90	0	0	0	-78	-106	-92				
24			2	9/25/90	0	350	0	321	115	218				Return End
25			3	9/25/90	0	1000	0	747	963	855		0.66	1.31	0.98
26			4	9/25/90	0	3000	0	2830	4049	3440		1.04	1.54	1.29
27			5	9/25/90	0	4000	0	3969	5937	4953		1.14	1.89	1.51
28			6	9/25/90	0	5000	0	5295	8132	6713		1.33	2.19	1.76
29			7	9/25/90	0	6000	0	6575	10351	8463		1.28	2.22	1.75
30			8	9/25/90	0	7000	0	7878	12653	10266		1.30	2.30	1.80
31			9	9/25/90	0	8000	0	8992	14820	11906		1.11	2.17	1.64
32			10	9/25/90	0	8500	0	9757	15953	12855		1.53	2.27	1.90
33			11	9/25/90	0	8500	500	9830	16439	13135		#DIV/0!	#DIV/0!	#DIV/0!
34			12	9/25/90	0	4500	500	8229	12533	10381		0.40	0.98	0.69
35			13	9/25/90	0	0	0	5590	6437	6013				
36			14	9/25/90	0	0	0	#DIV/0!	#DIV/0!	#DIV/0!				
37			15	1/1/04	0	0	0	0	0	0				
38			16	1/1/04	0	0	0	0	0	0				
39			17	1/1/04	0	0	0	0	0	0				
40			18	1/1/04	0	0	0	0	0	0				

Table II

Gage Pack	Final Stress Inner	Outer	Peak-final Inner	Outer	Slope* Inner	Outer	Average
LE	6645	3662	4266	8623	1.67	1.77	1.72
RE	5590	6437	4240	10002	1.27	2.16	1.72
Average	6118	5050	4253	9313	1.47	1.97	1.72

*The slope is from a fit to the data for $3 \leq P_{HYDRAULIC} \leq 7$ kpsi

Table IIIa

SSC COLLARED COIL SERIAL NUMBER: RCM #1 DC 0302

DATE: 10/23/90

INSPECTION PERFORMED BY: SCOTT / STEVE

LEAD END STRAIN GAGE PACK NUMBER IS 17
LEAD END STRAIN GAGE PACK NUMBER IS 18

RETURN END STRAIN GAGE PACK NUMBER IS 40
RETURN END STRAIN GAGE PACK NUMBER IS 41

DIM A HORIZ		DIM B1 VERT		< B-1,B-2 >		DIM B2 VERT	
4.2879	AVERAGE	4.3692	AVERAGE	4.3691	AVERAGE	4.3691	AVERAGE
0.0013	STD DEV	0.0023	STD DEV	0.0021	STD DEV	0.002	STD DEV
0.003	RANGE	0.008	RANGE	0.008	RANGE	0.007	RANGE

POSITION	DIM A HORIZ	DIM A - AVG	DIM B1 VERT	(B-1) - AVG	< B-1,B-2 >	< B > - AVG	DIM B2 VERT	(B-2) - AVG
0	4.290	0.0021	4.365	-0.0042	4.365	-0.0041	4.365	-0.0041
1	4.288	0.0001	4.369	-0.0002	4.370	0.0004	4.370	0.0009
2	4.290	0.0021	4.372	0.0028	4.371	0.0019	4.370	0.0009
3	4.288	0.0001	4.373	0.0038	4.374	0.0044	4.374	0.0049
4	4.290	0.0021	4.368	-0.0012	4.369	-0.0006	4.369	-0.0001
5	4.288	0.0001	4.373	0.0038	4.371	0.0019	4.369	-0.0001
6	4.289	0.0011	4.369	-0.0002	4.369	-0.0006	4.368	-0.0011
7	4.288	0.0001	4.371	0.0018	4.371	0.0019	4.371	0.0019
8	4.291	0.0031	4.371	0.0018	4.370	0.0009	4.369	-0.0001
9	4.287	-0.0009	4.376	0.0068	4.374	0.0044	4.371	0.0019
10	4.287	-0.0009	4.369	-0.0002	4.370	0.0009	4.371	0.0019
11	4.289	0.0011	4.369	-0.0002	4.370	0.0004	4.370	0.0009
12	4.289	0.0011	4.369	-0.0002	4.370	0.0004	4.370	0.0009
13	4.289	0.0011	4.369	-0.0002	4.370	0.0009	4.371	0.0019
14	4.288	0.0001	4.368	-0.0012	4.369	-0.0001	4.370	0.0009
15	4.288	0.0001	4.369	-0.0002	4.370	0.0004	4.370	0.0009
16	4.288	0.0001	4.368	-0.0012	4.368	-0.0011	4.368	-0.0011
17	4.286	-0.0019	4.368	-0.0012	4.368	-0.0011	4.368	-0.0011
18	4.285	-0.0029	4.371	0.0018	4.371	0.0019	4.371	0.0019
19	4.289	0.0011	4.369	-0.0002	4.370	0.0009	4.371	0.0019
20	4.289	0.0011	4.367	-0.0022	4.367	-0.0021	4.367	-0.0021
21	4.288	0.0001	4.367	-0.0022	4.367	-0.0021	4.367	-0.0021
22	4.287	-0.0009	4.371	0.0018	4.371	0.0019	4.371	0.0019
23	4.287	-0.0009	4.370	0.0008	4.371	0.0014	4.371	0.0019
24	4.288	0.0001	4.370	0.0008	4.370	0.0004	4.369	-0.0001
25	4.289	0.0011	4.368	-0.0012	4.368	-0.0016	4.367	-0.0021
26	4.287	-0.0009	4.371	0.0018	4.370	0.0009	4.369	-0.0001
27	4.287	-0.0009	4.373	0.0038	4.373	0.0034	4.372	0.0029
28	4.288	0.0001	4.368	-0.0012	4.369	-0.0006	4.369	-0.0001
CENTER	4.287	-0.0009	4.369	-0.0002	4.370	0.0009	4.371	0.0019
30	4.286	-0.0019	4.368	-0.0012	4.368	-0.0016	4.367	-0.0021
31	4.289	0.0011	4.369	-0.0002	4.369	-0.0006	4.368	-0.0011
32	4.289	0.0011	4.367	-0.0022	4.367	-0.0021	4.367	-0.0021
33	4.286	-0.0019	4.366	-0.0032	4.367	-0.0021	4.368	-0.0011
34	4.286	-0.0019	4.364	-0.0052	4.367	-0.0026	4.369	-0.0001
35	4.286	-0.0019	4.369	-0.0002	4.369	-0.0006	4.368	-0.0011
36	4.287	-0.0009	4.372	0.0028	4.371	0.0014	4.369	-0.0001
37	4.289	0.0011	4.369	-0.0002	4.368	-0.0011	4.367	-0.0021
38	4.287	-0.0009	4.370	0.0008	4.370	0.0009	4.370	0.0009
39	4.289	0.0011	4.371	0.0018	4.371	0.0014	4.370	0.0009
40	4.286	-0.0019	4.370	0.0008	4.371	0.0014	4.371	0.0019
41	4.285	-0.0029	4.370	0.0008	4.370	0.0009	4.370	0.0009
42	4.289	0.0011	4.369	-0.0002	4.369	-0.0001	4.369	-0.0001
43	4.288	0.0001	4.371	0.0018	4.371	0.0019	4.371	0.0019
44	4.289	0.0011	4.370	0.0008	4.370	0.0004	4.369	-0.0001
45	4.289	0.0011	4.367	-0.0022	4.367	-0.0021	4.367	-0.0021
46	4.289	0.0011	4.370	0.0008	4.370	0.0004	4.369	-0.0001
47	4.288	0.0001	4.369	-0.0002	4.369	-0.0001	4.369	-0.0001
48	4.287	-0.0009	4.370	0.0008	4.370	0.0004	4.369	-0.0001
49	4.288	0.0001	4.370	0.0008	4.369	-0.0001	4.368	-0.0011
50	4.287	-0.0009	4.370	0.0008	4.370	0.0009	4.370	0.0009
51	4.287	-0.0009	4.370	0.0008	4.370	0.0004	4.369	-0.0001
52	4.287	-0.0009	4.369	-0.0002	4.370	0.0004	4.370	0.0009
53	4.287	-0.0009	4.369	-0.0002	4.369	-0.0001	4.369	-0.0001
54	4.287	-0.0009	4.370	0.0008	4.371	0.0014	4.371	0.0019
55	4.288	0.0001	4.369	-0.0002	4.369	-0.0001	4.369	-0.0001
56	4.288	0.0001	4.368	-0.0012	4.369	-0.0006	4.369	-0.0001
57	4.287	-0.0009	4.369	-0.0002	4.370	0.0004	4.370	0.0009
58	4.289	0.0011	4.366	-0.0032	4.366	-0.0031	4.366	-0.0031
59	4.289	0.0011	4.360	-0.0092	4.360	-0.0091	4.360	-0.0091

Table III b

COLLAR DIA	2.180
VERT OVALITY	0.002
dr/d(stress)	0.56

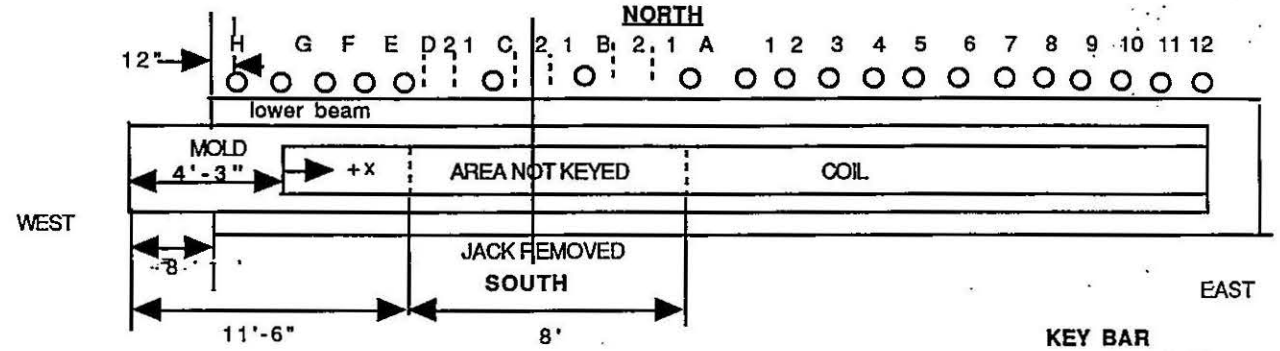
dr(v) (mils)	Coil Str(kpsi)	
2.72	4.86	AVERAGE
0.74	1.33	STD DEV
3.50	6.25	RANGE

POSITION	dr(v) (mils)	Coil Str(kpsi)
0	0.50	0.89
1	2.75	4.91
2	3.50	6.25
3	4.75	8.48
4	2.25	4.02
5	3.50	6.25
6	2.25	4.02
7	3.50	6.25
8	3.00	5.36
9	4.75	8.48
10	3.00	5.36
11	2.75	4.91
12	2.75	4.91
13	3.00	5.36
14	2.50	4.46
15	2.75	4.91
16	2.00	3.57
17	2.00	3.57
18	3.50	6.25
19	3.00	5.36
20	1.50	2.68
21	1.50	2.68
22	3.50	6.25
23	3.25	5.80
24	2.75	4.91
25	1.75	3.12
26	3.00	5.36
27	4.25	7.59
28	2.25	4.02
29	3.00	5.36
30	1.75	3.12
31	2.25	4.02
32	1.50	2.68
33	1.50	2.68
34	1.25	2.23
35	2.25	4.02
36	3.25	5.80
37	2.00	3.57
38	3.00	5.36
39	3.25	5.80
40	3.25	5.80
41	3.00	5.36
42	2.50	4.46
43	3.50	6.25
44	2.75	4.91
45	1.50	2.68
46	2.75	4.91
47	2.50	4.46
48	2.75	4.91
49	2.50	4.46
50	3.00	5.36
51	2.75	4.91
52	2.75	4.91
53	2.50	4.46
54	3.25	5.80
55	2.50	4.46
56	2.25	4.02
57	2.75	4.91
58	1.00	1.79
59	-2.00	-3.57

R.k.Rihel 10-2-90

Real Cold Mass #1 Collaring Gap Measurments

Coil # ARE 1006,1007,2006,2008



GAP MEASURMENTS

+x	#	SOUTH 3000 psi	SOUTH 6000 psi	SOUTH 8500 psi	SOUTH average	NORTH 3000 ps	NORTH 6000 psi	NORTH 8500 psi
-31	H	.000	.000	.000	0	.000	.000	.000
5	G	.004	.000	.000	0	.000	.000	.000
41	F	.018	.007	.000	.005	.030	.018	.010
77	E	.023	.014	.005	.0055	.033	.023	.006
113	D	.045	.033	.023	.020	.038	.024	.017
125	C2	.042	.027	.015	.014	.043	.025	.013
137	C1	.057	.041	.027	.0115	.030	.020	.006
149	C	.042	.024	.012	.006	.028	.006	.000
161	B2	.035	.015	.003	.003	.028	.014	.003
173	B1	.040	.023	.012	.006	.027	.010	.000
185	B	.040	.032	.002	.001	.027	.010	.000
197	A2	.030	.010	.002	.0065	.032	.017	.011
209	A1	.031	.012	.002	.001	.010	.003	.000
221	A	.045	.029	.017	.0085	.000	.000	.000
257	1	.020	.014	.003	.014	.027	.025	.024
293	2	.028	.020	.013	.014	.013	.005	.005
329	3	.023	.023	.013	.010	.016	.009	.007
365	4	.034	.020	.015	.0075	.011	.002	.000
401	5	.042	.035	.025	.0125	.008	.003	.000
437	6	.017	.005	.000	.009	.033	.025	.018
473	7	.011	.000	.000	.0035	.025	.015	.007
509	8	.010	.000	.000	.0135	.041	.035	.027
545	9	.022	.013	.000	..006	.013	.018	.012
581	10	.027	.021	.013	.0065	.012	.004	.000
617	11	.029	.025	.014	.007	.013	.000	.000
653	12	.014	.010	.000	.0045	.026	.013	.009

RCM#1 was keyed the first time in the correct coil position. It did not key. One of the 12' keys had a twist causing it not to key completly. The key was replaced with shorter keys and it was tried again. This time the 12' section keyed but a section 8' long as shown above did not key on the south side of the press. Twist was suspected again, the keys were changed only on the south side and it failed again. A press problem was suspected and the coil was moved 20' east in the press. This try failed also. Finally the keys were removed on both sides of the 8' section positioned correctly in the tooling and it keyed.

KEY BAR PENETRATION

SOUTH

3.628 @ 000 PSI
4.189 @ 1200 PSI

TRAVEL =.561

SAME @ 1500 PSI

SAME @ 1700 PSI

SAME @ 2000 PSI

NORTH

3.633 @ 000 PSI
4.175 @ 1200 PSI

TRAVEL= .542

4.183 @ 1500 PSI

TRAVEL=.550

4.185 @ 1700 PSI

TRAVEL=.552

4.187 @ 1900 PSI

TRAVEL= .554

4.188 @ 2000 PSI

TRAVEL=.555

Figure 1

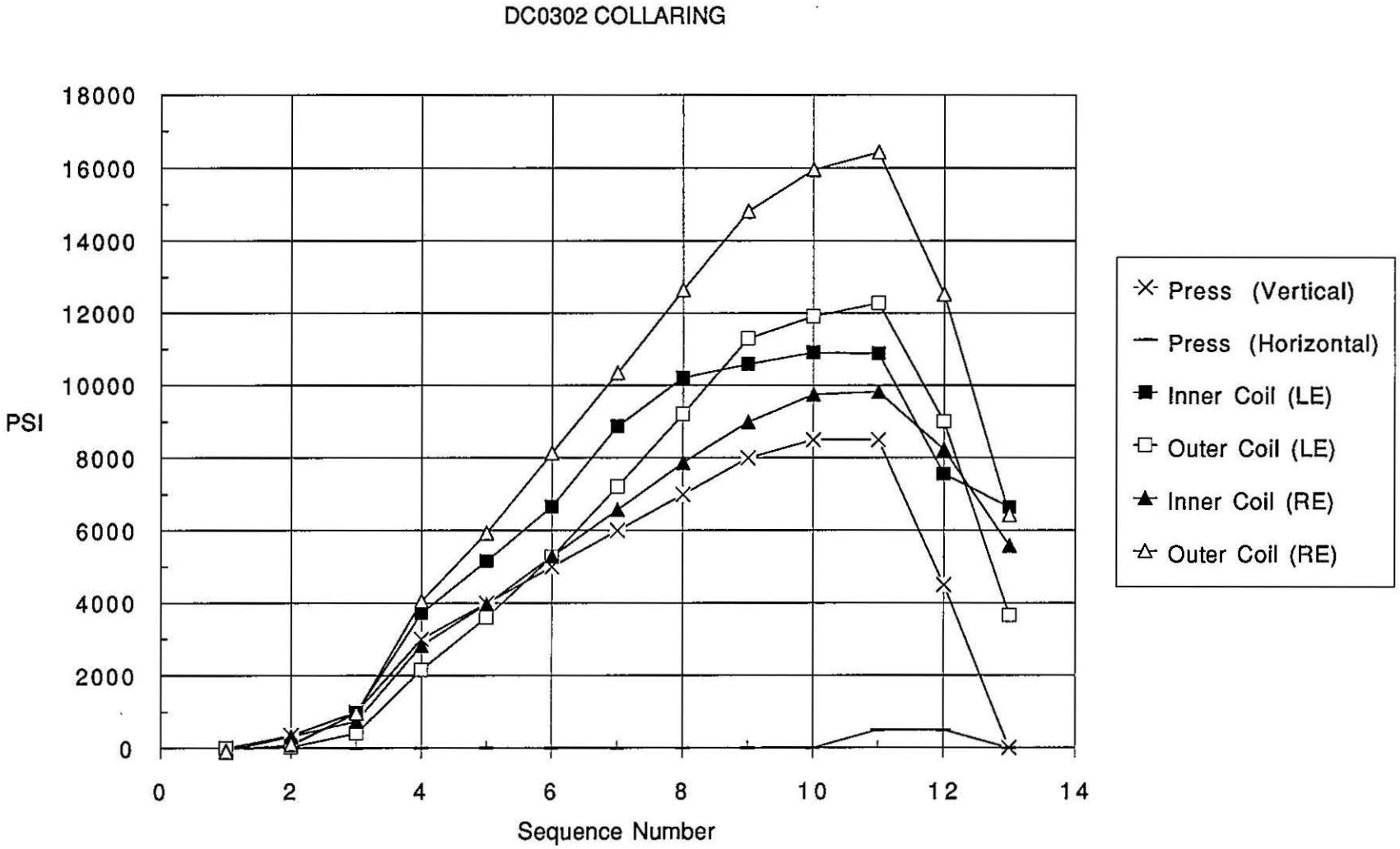

DC0302 COLLARING
PSI
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
2
4
6
8
10
12
14
Sequence Number
Press (Vertical)
Press (Horizontal)
Inner Coil (LE)
Outer Coil (LE)
Inner Coil (RE)
Outer Coil (RE)

Figure 2

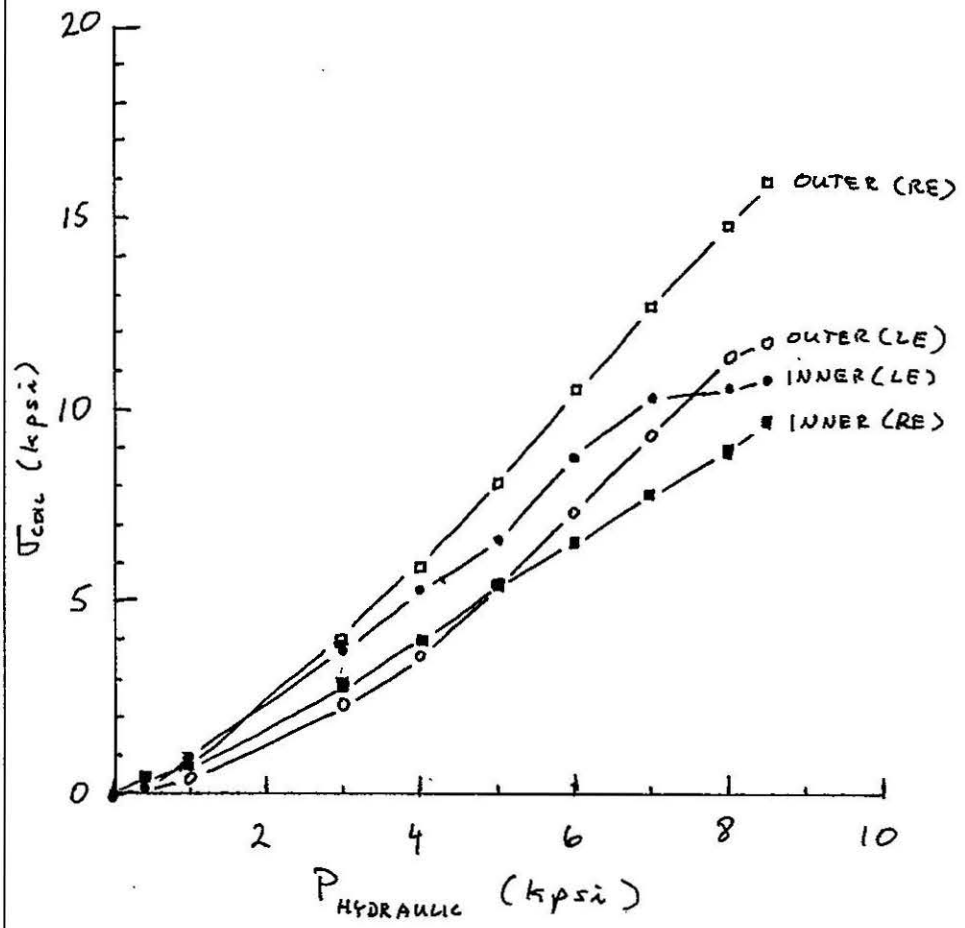

20
15
10
5
0
σ_{coil} (kpsi)
2
4
6
8
10
$P_{HYDRAULIC}$ (kpsi)
OUTER (RE)
OUTER (LE)
INNER (LE)
INNER (RE)

Figure 3

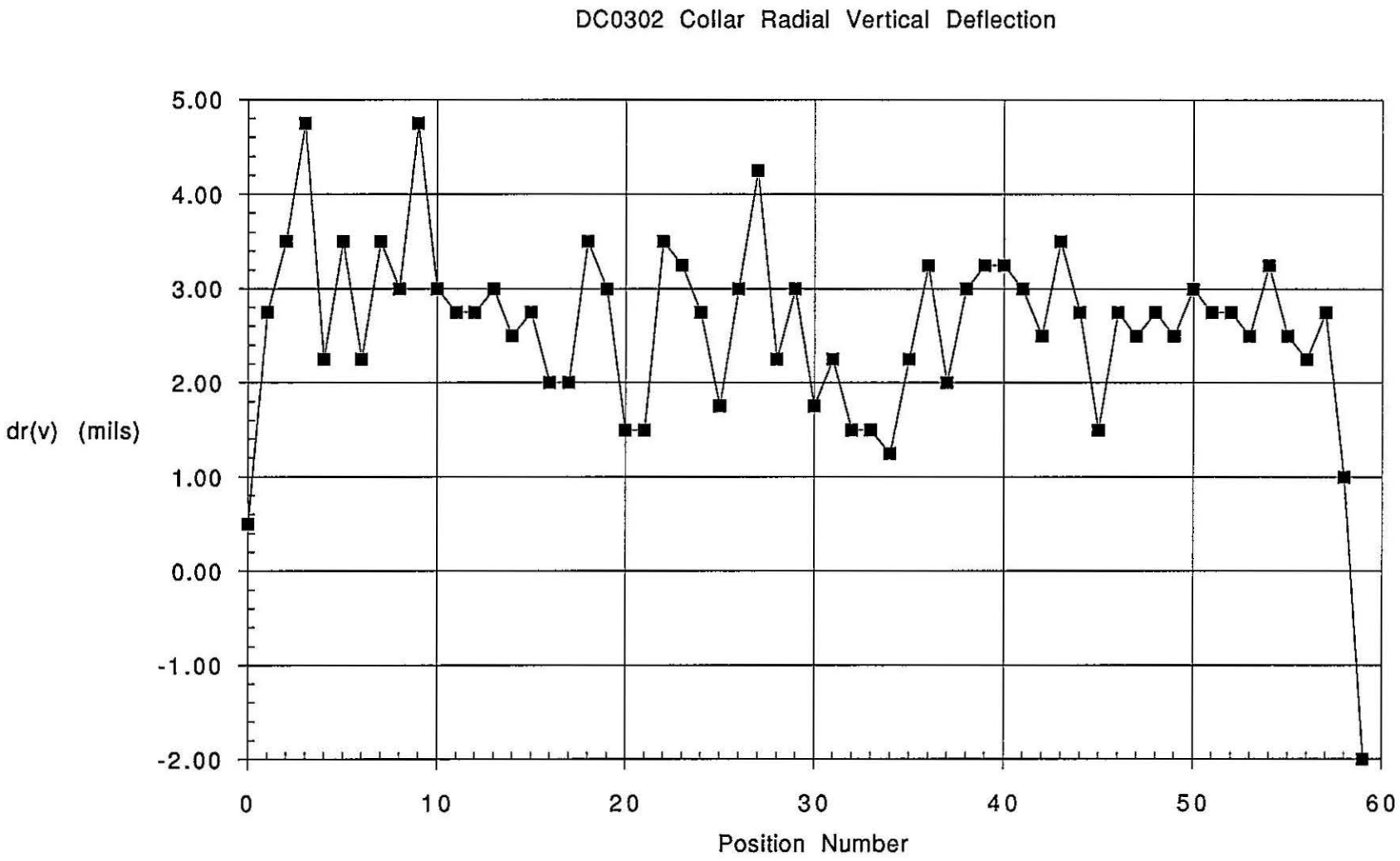

DC0302 Collar Radial Vertical Deflection
dr(v) (mils)
5.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
0
10
20
30
40
50
60
Position Number

Figure 4