Fermilab

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From: Jim Strait

Subject: Collar keying of DSA325

In this note I summarize the collar keying procedure used for DSA325. Both inner and outer coils were molded with the mold components (key inserts, sizing bars, mold stop bars, etc.) at their nominal sizes and no additional molding shims were used. (This magnet is the first to have the outer coils molded with the design size key inserts.) Five mils of non-adhesive Kapton was placed between the inner coil pole turn and the pole cap to increase the prestress above that in DSA321-323[1-5]. No outer coil pole shim was used.

Collaring experiments done with DSA322[4,5] have shown that with EDMed lower collaring tooling the keys can be inserted by hand ("square key method") if the tooling is closed 4 mils beyond the nominal stop, and that with laminated lower tooling the keys can be started by about 50 mils (for "tapered key method" insertion) if the tooling is closed 6 mils less than the nominal stop. The keys are 190 mils deep and have a 10:1 wedge angle, suggesting that with laminated tooling a stop about 10 mils beyond the nominal would be required for key insertion without force.

A first collar keying attempt was made with the goal of inserting the keys without force. Initially the same shim (4 mils) was placed between the upper tooling and the upper platen as had been successfully used on DSA322 with EDMed lower tooling. The amount of collar closure was monitored by reaching into the press with a sample key and trying to insert it into the collars at the lead end. With the press closed until no lower tooling - upper platen gaps existed, full key insertion was not possible. The press shim was then increased in 2 mils increments up to 10 mils. At this point the test key could still be inserted only a little more than half way. To limit the number of compressions of the coils to high stress and until the apparent discrepancy between the expected and the observed tooling behavior was understood, the attempt to do a "square key method" insertion was abandoned. The strain gauge data from these four keying attempts are displayed in Table I and Figure 1.

A key insertion method intermediate between the successful "square" and "tapered" key assemblies of DSA322 was tried. In the "tapered key method" assembly of DSA322 the inner coil stress when the keys were started was 2.6 kpsi lower than the final value, and in the "square key method" assembly the the inner coil stress before key insertion was 4.6 kpsi higher than the final stress. For DSA325 no press-tooling shims were used resulting in a compression of 6 mils more than that used for the "tapered key" assembly of DSA322 and a compression less than the "square key" assembly by an amount unknown due to the switch from EDMed to laminated tooling.

Feeler gauge measurements indicated that the press was fully closed at 7000 pump psi. To verify full closure, the vertical hydraulic pressure was increased to 8500 psi. To quantify better the amount of "zero force" key insertion possible at this point, the side cylinders were energized to 65 psi (65 lbs./in.), the pressure delivered with the regulator set to "zero," and data were recorded from the linear potentiometers connected to the side bars. The side hydraulic pressure was then increased in 500 psi steps until no change in the amount of key insertion was observed. The linear potentiometer data[6], shown in Figure 2, indicate that at zero force the keys were about 80 mils out and that full insertion occurred at 1500 lbs./in. The vertical load was then reduced to 4000 pump psi, the side load was reduced to zero, and the vertical load was reduced to zero. Visual inspection of the collared coil confirmed the full insertion of the keys.

The strain gauge data are displayed in Table II and Figure 3. The final prestresses are 11.7 and 11.8 kpsi in the inner and outer coils respectively. These are 1.2 and 5.0 kpsi lower than before key insertion and 2.8 and 7.1 kpsi lower than the peak stresses. Figure 4 shows the coil stress versus vertical hydraulic pressure before key insertion. Shown also is the expected slope[7] of 2.56 coil psi per pump psi if the press load is fully balanced by the coil and the pole and mid-plane stresses are equal. Figure 5 shows the slope $d\sigma(\text{coil})/dP(\text{press})$ versus press pressure. Even after the press is nominally closed (7000 pump psi) about 20% of the press load is still transferred to the coil. This is not understood.

The conclusions of this collaring exercise are:

1) The final inner coil stress is towards the high end of the desired range. Since this includes a 5 mil Kapton pole shim, the inner coils need to be molded 3-5 mils larger than these coils. In molding the next short inner coils (for DSA327) the mold cavity will be increased by 5 mils.

2) The final outer coil stress is higher than is needed, implying that the outer coils should be molded several mils smaller than these coils. The outer coils for DSA327 will be molded with the cavity decreased by 3 mils.

3) An "optimized" tapered key insertion may be defined as one in which the stress before key insertion equals the final stress. To achieve such an assembly requires that the press be closed somewhat less than was done in this case but more than was done for DSA322[5]. A shim of 2-3 mils between the lower tooling and the upper platen might meet this criterion.

4) That the keys were 80 mils out at "zero" side load implies that 8 mils more closure would be required for "square key" insertion. This is less than the greatest compression tried (Fig. 1). Perhaps the discrepancy results from occasional small mis-registrations between the laminated tooling and collars that could be overcome with a load of 65 lbs./in. but not by hand. The peak coil stresses with an 8 mil tooling shim (Fig. 1 and Table I) were only 0.2 and 0.3 kpsi higher in the inner and outer coils than the peak during the final key insertion.

References

[1] J. Strait, DSA321 Collaring and Yoking: Strain Gauge Data, TS-SSC 91-026, 2/5/91.
[2] S. Delchamps, DSA323 Collar Keying Data, TS-SSC 91-036 2/22/91.
[3] R. Bossert, Magnet DSA321 - Construction Summary, TS-SSC 91-040, 3/5/91.
[4] J. Strait, Second Collaring of DSA322, TS-SSC 91-049, 3/15/91.
[5] J. Strait, Development of Collar Keying Procedures, TS-SSC 91-060, 4/4/91.
[6] R.E. Sims, private communication.
[7] J. Strait, DSA322 Assembly Experiment Plan, TS-SSC 91-048, Version 7, 3/22/91.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1				CORRECTED AVERAGING FORMULAS 11-20-90									
2													
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				A082	Active	Inner	1	2.03	350.039	37.1	2.0E+00	4.71E-03	0.00000
6				A083	Active	Inner	2	2.03	350.609	-4.2	2.0E+00	7.25E-03	0.00000
7				C062	Comp.	Inner	1&2	2.03	350.114				
8				A087	Active	Inner	3	2.03	349.607	45.6	2.2E+00	6.20E-03	0.00000
9				A088	Active	Inner	4	2.03	349.787	25.3	3.9E+00	6.46E-03	0.00000
10				C063	Comp.	Inner	3&4	2.03	349.735				
11				A075	Active	Outer	1	2.03	349.910	-81.1	3.7E+00	6.74E-03	0.00000
12				A079	Active	Outer	2	2.03	349.916	19.5	1.2E+00	5.82E-03	0.00000
13				C058	Comp.	Outer	1	2.03	349.622				
14				C059	Comp.	Outer	2	2.03	349.768				
15				A080	Active	Outer	3	2.03	349.903	-130.9	4.2E+00	6.73E-03	0.00000
16				A081	Active	Outer	4	2.03	349.771	35.4	1.6E+00	5.99E-03	0.00000
17				C060	Comp.	Outer	3	2.03	349.349				
18				C061	Comp.	Outer	4	2.03	350.097				
19													
20													
21	Upper Tooling					Hydraulic Pressure		Average Coil Stress			d(Stress)/dPv		
22		Shim	Seq #	Date	Press	Vertical	Horizontal	Inner	Outer	All	Inner	Outer	All
23		4 mil	1	4/2/91	0	0	0	44	-2	21			
24			2	4/4/91	0	0	0	46	-2	22			
25			3	4/4/91	0	750	0	799	899	849	1.00	1.20	1.10
26			4	4/4/91	0	2000	0	2606	3012	2809	1.45	1.69	1.57
27			5	4-4-9/1	0	4000	0	6605	7788	7196	2.00	2.39	2.19
28			6	4/4/91	0	6000	0	11420	14464	12942	2.41	3.34	2.87
29			7	4/4/91	0	7000	0	13505	17804	15654	2.09	3.34	2.71
30			8	4/4/91	0	8000	0	14677	19449	17063	1.17	1.64	1.41
31		6 mil	9	4/4/91	0	0	0	205	199	202	1.81	2.41	2.11
32			10	4/4/91	0	750	0	1261	1393	1327	1.41	1.59	1.50
33			11	4/4/91	0	2000	0	3276	3786	3531	1.61	1.91	1.76
34			12	4/4/91	0	4000	0	7069	8638	7854	1.90	2.43	2.16
35			13	4/4/91	0	6000	0	11400	14588	12994			
36			14	4/4/91	0	7000	0	13351	17378	15364			
37			15	4/4/91	0	8000	0	14510	19173	16842			
38		8 mil	16	4/4/91	0	0	0	129	17	73			
39			17	4/4/91	0	750	0	1363	1470	1416			
40			18	4/4/91	0	2000	0	3457	3980	3719			
41			19	4-4-9/1	0	4000	0	7182	8768	7975			
42			20	4/4/91	0	6000	0	11409	14541	12975			
43			21	4/4/91	0	7000	0	13441	17530	15485			
44			22	4/4/91	0	8000	0	14753	19176	16964			
45		10 mil	23	4/4/91	0	0	0	128	20	74			
46			24	4/4/91	0	800	0	1514	1630	1572			
47			25	4/4/91	0	2000	0	3488	4019	3753			
48			26	4/4/91	0	4000	0	7190	9042	8116			
49			27	4/4/91	0	6000	0	11340	14582	12961			
50			28	4/4/91	0	7000	0	13452	17751	15601			
51			29	4/4/91	0	8000	0	15201	20104	17652			
52			30	4/4/91	0	8580	0	15865	20930	18398			
53			31	4/4/91	0	0	0	144	32	88			
54			32	1/1/04	0	0	0	0	0	0			
55			33	1/1/04	0	0	0	0	0	0			
56			34	1/1/04	0	0	0	0	0	0			
57			35	1/1/04	0	0	0	0	0	0			
58			36	1/1/04	0	0	0	0	0	0			
59			37	1/1/04	0	0	0	0	0	0			
60			38	1/1/04	0	0	0	0	0	0			

Table I

	A	B	C	D	E	F	G	H	I	J	K	L	M
1				CORRECTED AVERAGING FORMULAS 11-20-90									
2													
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				A082	Active	Inner	1	2.03	350.039	37.1	2.0E+00	4.71E-03	0.00000
6				A083	Active	Inner	2	2.03	350.609	-4.2	2.0E+00	7.25E-03	0.00000
7				C062	Comp.	Inner	1&2	2.03	350.114				
8				A087	Active	Inner	3	2.03	349.607	45.6	2.2E+00	6.20E-03	0.00000
9				A088	Active	Inner	4	2.03	349.787	25.3	3.9E+00	6.46E-03	0.00000
10				C063	Comp.	Inner	3&4	2.03	349.735				
11				A075	Active	Outer	1	2.03	349.910	-81.1	3.7E+00	6.74E-03	0.00000
12				A079	Active	Outer	2	2.03	349.916	19.5	1.2E+00	5.82E-03	0.00000
13				C058	Comp.	Outer	1	2.03	349.622				
14				C059	Comp.	Outer	2	2.03	349.768				
15				A080	Active	Outer	3	2.03	349.903	-130.9	4.2E+00	6.73E-03	0.00000
16				A081	Active	Outer	4	2.03	349.771	35.4	1.6E+00	5.99E-03	0.00000
17				C060	Comp.	Outer	3	2.03	349.349				
18				C061	Comp.	Outer	4	2.03	350.097				
19													
20													
21						Hydraulic Pressure		Average Coil Stress			d(Stress)/dPv		
22			Seq #	Date	Press	Vertical	Horizontal	Inner	Outer	All	Inner	Outer	All
23			1	4/8/91	Collaring(84	0	0	109	30	70			
24			2	4/8/91	Collaring(84	790	0	2457	2762	2610	2.97	3.46	3.22
25			3	4/8/91	Collaring(84	2000	0	3896	4305	4101	1.19	1.27	1.23
26			4	4/8/91	Collaring(84	4000	0	8058	9519	8789	2.08	2.61	2.34
27			5	4/8/91	Collaring(84	6000	0	11817	14579	13198	1.88	2.53	2.20
28			6	4/8/91	Collaring(84	7000	0	12478	15762	14120	0.66	1.18	0.92
29			7	4/8/91	Collaring(84	8000	0	12917	16578	14748	0.44	0.82	0.63
30			8	4/8/91	Collaring(84	8500	0	13016	16885	14950	0.20	0.61	0.40
31			9	4/8/91	Collaring(84	8500	0	12909	16754	14831	#DIV/0!	#DIV/0!	#DIV/0!
32			10	4/8/91	Collaring(84	8485	65	12927	16804	14865	-1.20	-3.35	-2.28
33			11	4/8/91	Collaring(84	8471	500	13310	17466	15388	-27.38	-47.29	-37.33
34			12	4/8/91	Collaring(84	8462	1000	13894	18224	16059	-64.88	-84.21	-74.54
35			13	4/8/91	Collaring(84	8444	1500	14352	18761	16557			
36			14	4/8/91	Collaring(84	8432	2000	14553	18877	16715			
37			15	4/8/91	Collaring(84	4000	2000	14003	16668	15336			
38			16	4/8/91	Collaring(84	4111	0	13406	16301	14854			
39			17	4/8/91	Collaring(84	0	0	11714	11768	11741			
40			18	4/8/91	0	0	0	#NUM!	#NUM!	#NUM!			
41			19	4/8/91	0	0	0	#NUM!	#NUM!	#NUM!			
42			20	4/8/91	0	0	0	#NUM!	#NUM!	#NUM!			
43			21	4/8/91	0	0	0	#NUM!	#NUM!	#NUM!			
44			22	4/8/91	0	0	0	#NUM!	#NUM!	#NUM!			
45			23	4/8/91	0	0	0	#NUM!	#NUM!	#NUM!			
46			24	4/8/91	0	0	0	#NUM!	#NUM!	#NUM!			
47			25	4/8/91	0	0	0	#NUM!	#NUM!	#NUM!			
48			26	4/8/91	0	0	0	#NUM!	#NUM!	#NUM!			
49			27	4/8/91	0	0	0	#NUM!	#NUM!	#NUM!			
50			28	4/8/91	0	0	0	#NUM!	#NUM!	#NUM!			
51			29	4/8/91	0	0	0	#NUM!	#NUM!	#NUM!			
52			30	4/8/91	0	0	0	#NUM!	#NUM!	#NUM!			
53			31	4/8/91	0	0	0	#NUM!	#NUM!	#NUM!			
54			32	1/1/04	0	0	0	0	0	0			
55			33	1/1/04	0	0	0	0	0	0			
56			34	1/1/04	0	0	0	0	0	0			
57			35	1/1/04	0	0	0	0	0	0			
58			36	1/1/04	0	0	0	0	0	0			
59			37	1/1/04	0	0	0	0	0	0			
60			38	1/1/04	0	0	0	0	0	0			

Table II

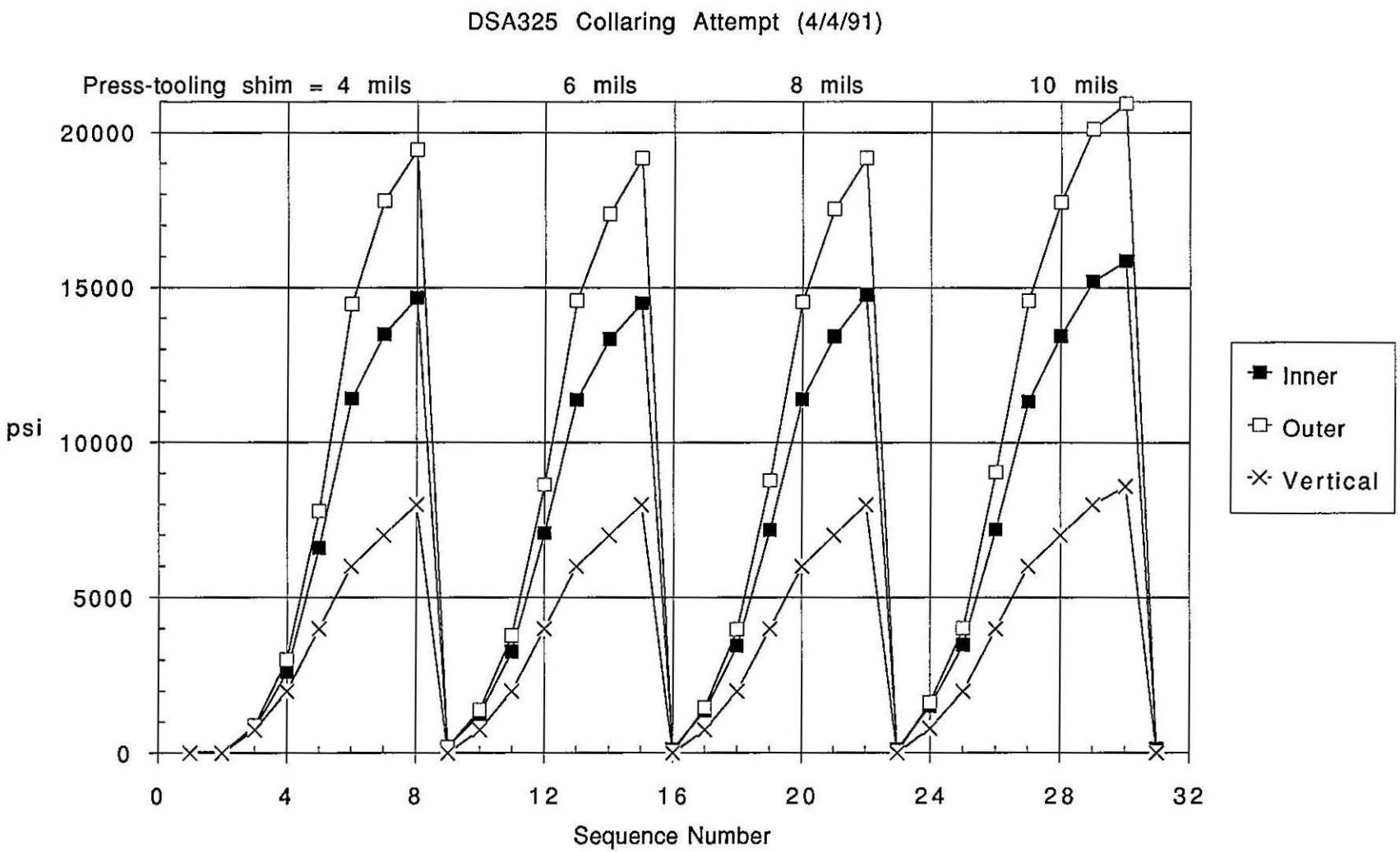
DSA325 Collaring Attempt (4/4/91)
Press-tooling shim = 4 mils
6 mils
8 mils
10 mils
20000
15000
10000
5000
0
psi
0
4
8
12
16
20
24
28
32
Sequence Number
Inner
Outer
Vertical

Figure 1

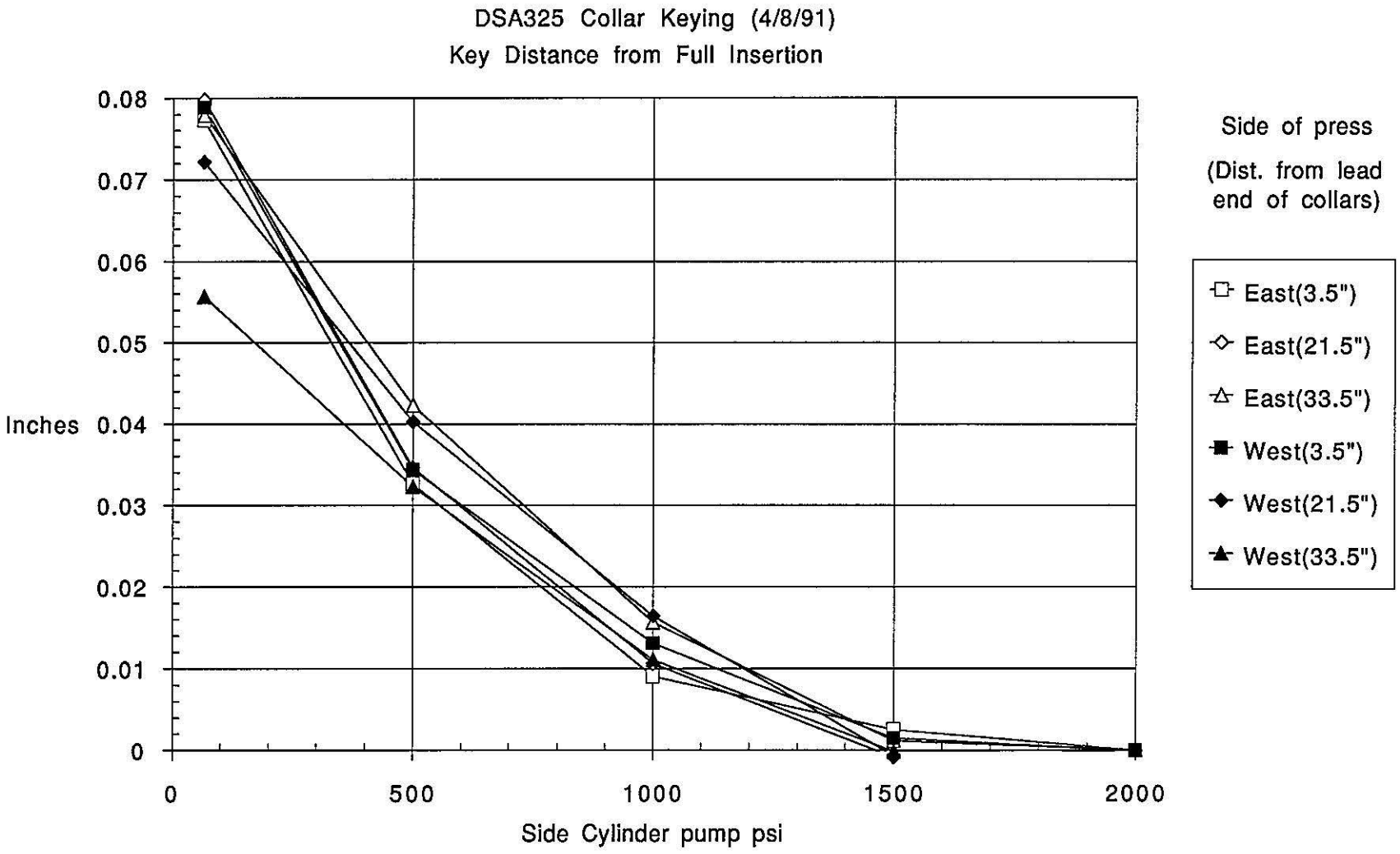
DSA325 Collar Keying (4/8/91)
Key Distance from Full Insertion
Inches
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
500
1000
1500
2000
Side Cylinder pump psi
Side of press
(Dist. from lead end of collars)
East(3.5")
East(21.5")
East(33.5")
West(3.5")
West(21.5")
West(33.5")

Figure 2

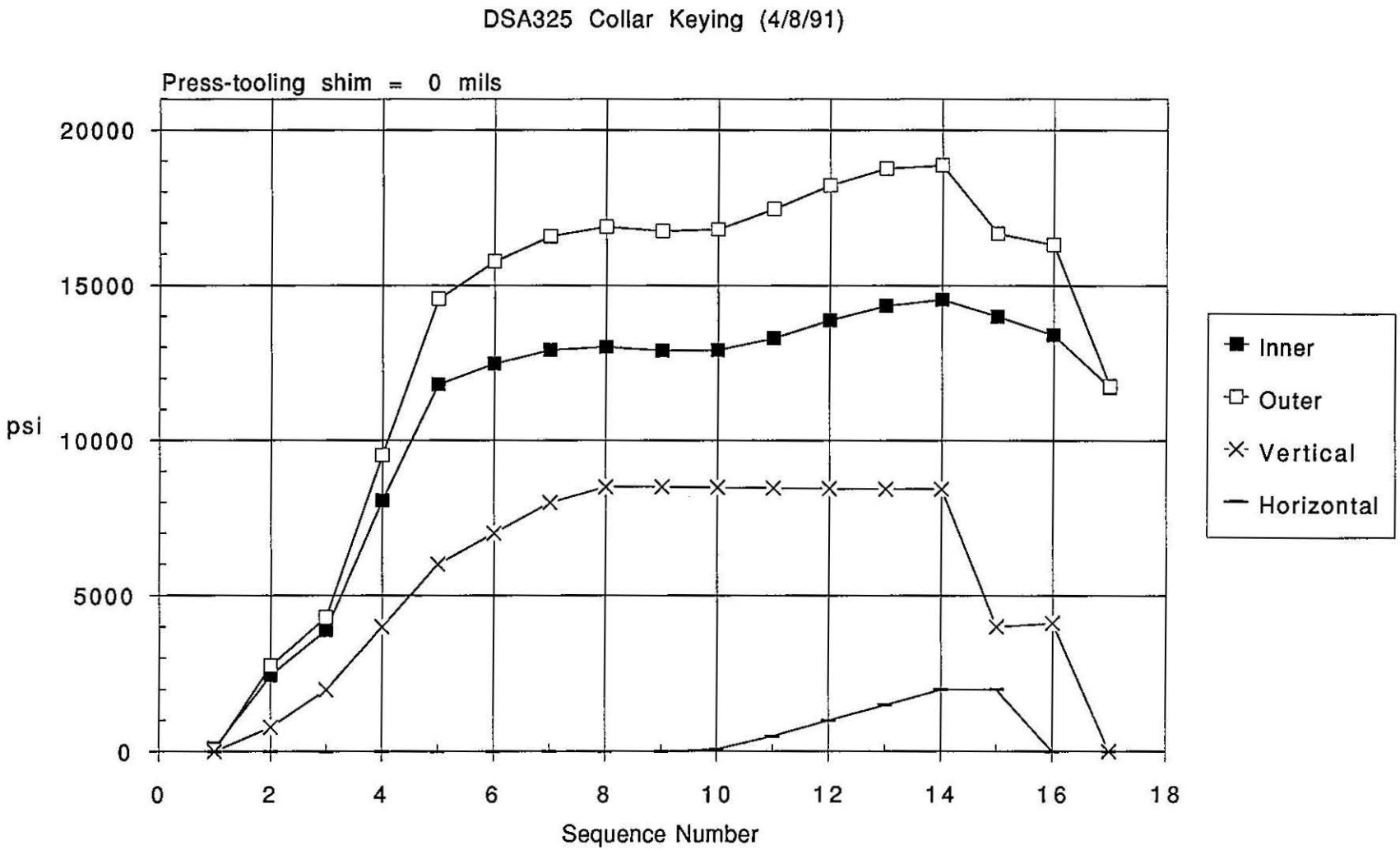
DSA325 Collar Keying (4/8/91)
Press-tooling shim = 0 mils
20000
15000
10000
5000
0
psi
0
2
4
6
8
10
12
14
16
18
Sequence Number
Inner
Outer
Vertical
Horizontal

Figure 3

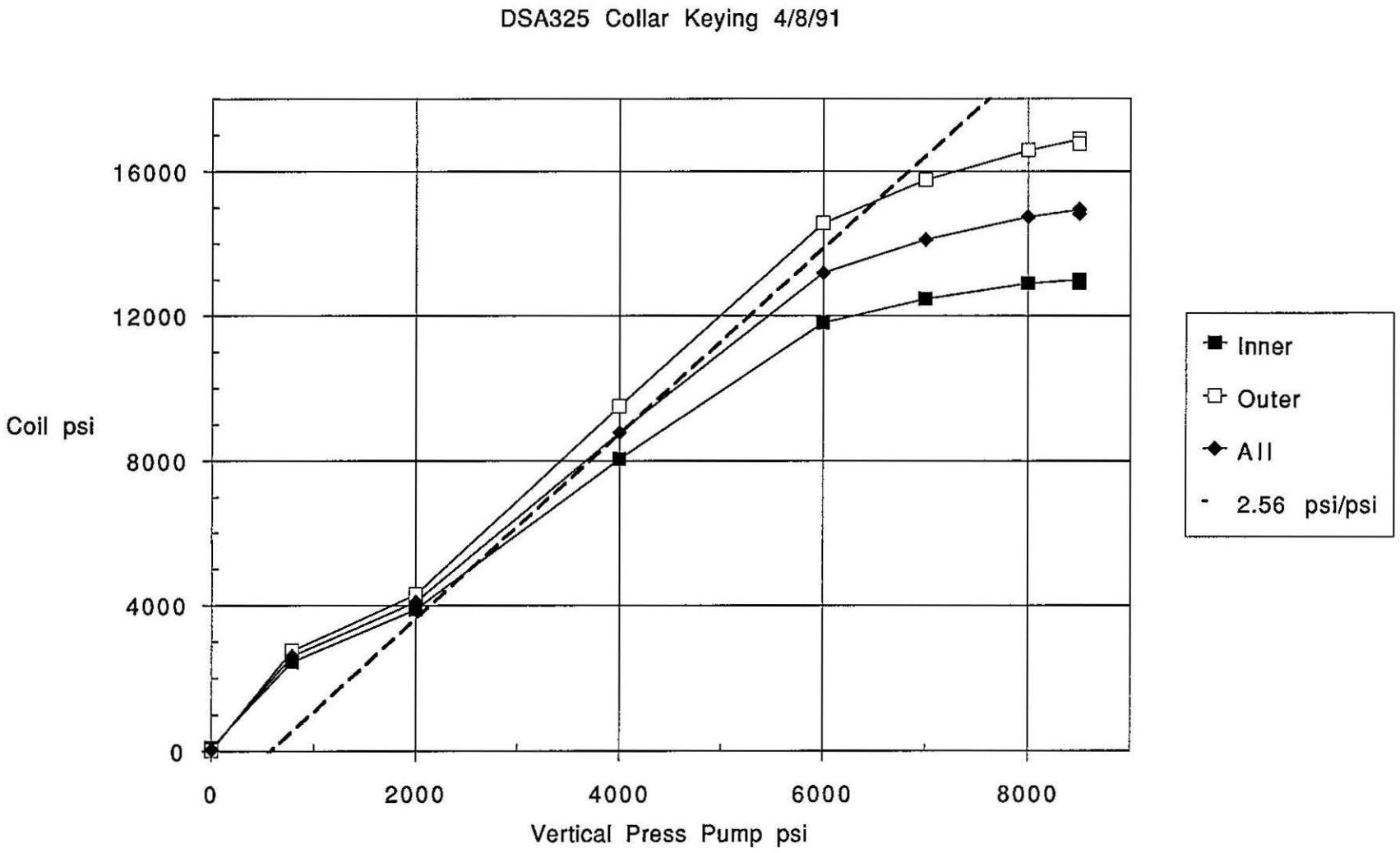
DSA325 Collar Keying 4/8/91
Coil psi
16000
12000
8000
4000
0
0
2000
4000
6000
8000
Vertical Press Pump psi
Inner
Outer
All
2.56 psi/psi

Figure 4

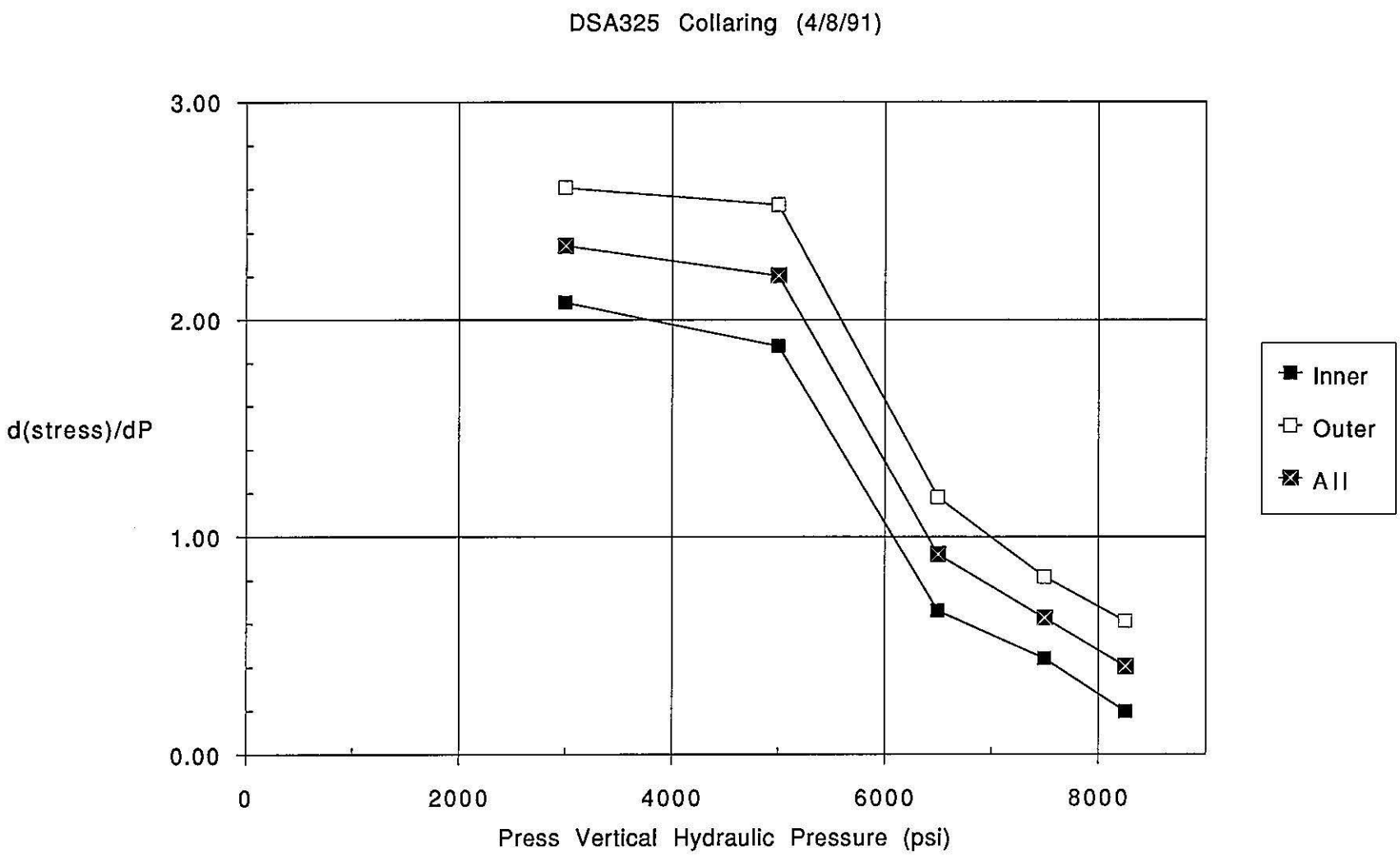
DSA325 Collaring (4/8/91)
3.00
2.00
1.00
0.00
d(stress)/dP
0
2000
4000
6000
8000
Press Vertical Hydraulic Pressure (psi)
Inner
Outer
All

Figure 5