Fermilab

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J. Strait

DCA313 Shell Strain Gauge Data with Excitation

In this note I present an analysis of the shell stress changes with excitation in DCA313. The data are from the file DCA313.CA005, a complete strain gauge run to 7030 A and back to 0 after the initial quench series. The analysis is identical to that presented earlier[1,2] for DCA311 and DCA312, except that here the azimuthal array of gauges is in the same quadrant as the axial array. The data are displayed in Tables I(a) - I(i); a complete explanation of the analysis may be found in [1] and [2].

The data are quite similar to the previous two magnets and only a few plots will be shown here. All strains, axial and azimuthal, are linear in I**2 up to the highest currents measured. There is very little hysteresis and the net strain change around the excitation loop is typically about +/-1 microstrain. (See Tables I(b) and I(h).) The axial array of gauges is 28 degrees from the yoke parting plane. Figure 1 shows the axial and azimuthal strain and force changes to 7030 A as a function of axial position for this array. The axial forces dominate, as in the previous magnets. Figure 2 compares the axial force, normalized to the total Lorentz force, among the three magnets. At most points a greater fraction of the Lorentz force is transfered to the shell in DCA313 than in DCA311 or DCA312, but the general features of the data are very similar among the three magnets.

Figure 3 shows the azimuthal stress change to 7030 A versus angle from the yoke parting plane for the azimuthal array, located 1297 mm from the return end of the yoke. The data are compared with those from DCA312. (DCA311 did not have an azimuthal array.) As before the stress changes are quite small -- a maximum of 10 MPa -- compared with the estimated shell prestress of >300 MPa. The stress is slightly compressive near the parting plane and modestly extensive far from the parting plane, as expected for a horizontally elliptical deflection of the cold mass.

REFERENCES

[1] J. Strait, DCA311-312 shell axial stress with excitation, TS-SSC 91-240, 12/9/91.

[2] J. Strait, DCA312 shell azimuthal stress with excitation, TS-SSC 91-243, 12/11/91.

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Table I

DCA313.CA005 06-JAN-1992

(a)

SG Run to 7100A - after plateau - 4.35 K 1st TC

Axial array at theta = 28o

K001 Ibefore	K128 Iafter	K099 I(1.9)	K100 a(1.9)	K101 I(7.8)	K102 a(7.8)	K103 I(18)	K104 a(18)	K106 I(31)	K107 a(31)	K108 I(51)	K109 a(51)	K111 I(79)	K112 a(79)	K114 I(285)	K115 a(285)
32.5	32.9	-2.5	-0.7	-2.6	-0.3	-5.9	-3.6	-5.1	-4.6	-8.0	-4.2	-7.4	-4.7	-10.6	-7.6
1571.7	1571.6	-3.0	-1.8	-0.4	-1.4	-2.2	-4.2	-1.4	-5.1	-3.1	-4.8	-4.2	-6.9	-6.9	-8.7
2216.5	2216.6	-3.0	-1.8	1.7	-0.3	0.5	-4.7	1.8	-6.7	0.6	-6.3	0.6	-7.4	-3.7	-9.3
2240.9	2240.9	-2.5	-1.8	1.7	-2.0	0.5	-4.7	2.3	-6.2	2.2	-5.8	0.6	-6.9	-3.1	-8.7
2712.6	2712.7	-1.4	-0.2	5.0	-0.9	3.2	-5.7	4.5	-7.7	6.0	-6.3	4.3	-9.0	0.1	-9.3
3134.7	3134.6	-1.9	-1.8	5.5	-3.0	5.4	-7.4	8.2	-8.8	9.2	-6.9	8.7	-9.0	3.3	-10.9
3506.8	3506.6	-2.4	-2.9	6.5	-4.1	9.1	-7.4	12.0	-8.8	15.0	-8.4	13.0	-9.5	6.0	-11.3
3853.8	3853.7	-3.0	-3.4	7.6	-5.1	11.3	-7.9	14.2	-9.9	19.4	-6.8	17.2	-10.6	9.2	-12.4
4449.1	4449.0	-3.5	-3.9	11.3	-5.7	17.1	-9.5	21.1	-11.5	27.4	-10.0	25.8	-12.2	16.1	-12.5
4945.7	4945.8	-4.6	-6.6	12.4	-9.4	22.5	-11.1	27.0	-13.1	35.9	-10.5	33.3	-13.3	22.6	-14.6
5442.1	5442.0	-4.1	-6.1	17.8	-8.9	27.9	-12.7	33.4	-14.7	44.0	-12.1	41.9	-14.3	28.4	-16.2
5838.6	5838.6	-4.6	-7.7	19.4	-11.0	32.7	-13.3	39.8	-15.2	52.0	-12.1	49.4	-14.9	34.4	-17.3
6433.8	6434.1	-4.6	-8.2	24.2	-12.1	36.4	-17.6	45.7	-19.5	59.5	-15.3	61.2	-16.5	43.4	-17.8
7029.8	7029.6	-5.2	-9.8	27.9	-14.8	42.9	-19.2	52.6	-21.7	69.6	-16.4	72.4	-18.1	52.6	-19.4
6433.8	6434.0	-4.1	-8.2	23.6	-12.6	35.9	-17.0	44.6	-19.5	58.4	-14.8	60.6	-16.5	44.5	-18.8
5838.7	5838.8	-3.5	-6.6	20.4	-10.5	32.2	-13.3	39.3	-15.2	50.4	-11.0	49.4	-14.9	37.0	-16.7
4945.5	4945.6	-4.1	-5.5	14.6	-7.3	21.9	-10.6	27.5	-12.1	34.3	-9.5	34.4	-12.2	24.7	-15.1
3853.4	3853.5	-3.5	-3.9	7.6	-5.1	11.8	-7.4	15.7	-8.8	18.8	-6.9	17.7	-10.1	11.9	-11.9
3134.0	3134.3	-2.5	-1.2	5.5	-3.5	5.8	-6.3	9.3	-8.3	10.2	-6.3	8.7	-9.0	5.4	-10.3
2215.9	2216.2	-3.0	-1.8	1.2	-1.9	0.5	-5.7	1.8	-7.2	0.1	-6.8	0.6	-7.4	-2.0	-9.8
-2.0	-2.0	-3.5	-1.8	-3.1	-0.9	-5.4	-3.7	-4.1	-4.6	-8.5	-4.7	-7.4	-5.8	-8.0	-7.7

(b)

Quadrant I

		Δμe(z)				z				Δμe(a)						
I**2	ΔI	I(1.9)	I(7.8)	I(18)	I(31)	I(51)	I(79)	I(285)	I**2	a(1.9)	a(7.8)	a(18)	a(31)	a(51)	a(79)	a(285)
0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2.5	-0.1	-0.5	2.2	3.7	3.7	4.9	3.2	3.7	2.5	-1.1	-1.1	-0.6	-0.5	-0.6	-2.2	-1.1
4.9	0.1	-0.5	4.3	6.4	6.9	8.6	8.0	6.9	4.9	-1.1	0.0	-1.1	-2.1	-2.1	-2.7	-1.7
5.0	0.0	0.0	4.3	6.4	7.4	10.2	8.0	7.5	5.0	-1.1	-1.7	-1.1	-1.6	-1.6	-2.2	-1.1
7.4	0.1	1.1	7.6	9.1	9.6	14.0	11.7	10.7	7.4	0.5	-0.6	-2.1	-3.1	-2.1	-4.3	-1.7
9.8	-0.1	0.6	8.1	11.3	13.3	17.2	16.1	13.9	9.8	-1.1	-2.7	-3.8	-4.2	-2.7	-4.3	-3.3
12.3	-0.2	0.1	9.1	15.0	17.1	23.0	20.4	16.6	12.3	-2.2	-3.8	-3.8	-4.2	-4.2	-4.8	-3.7
14.9	-0.1	-0.5	10.2	17.2	19.3	27.4	24.6	19.8	14.9	-2.7	-4.8	-4.3	-5.3	-2.6	-5.9	-4.8
19.8	-0.1	-1.0	13.9	23.0	26.2	35.4	33.2	26.7	19.8	-3.2	-5.4	-5.9	-6.9	-5.8	-7.5	-4.9
24.5	0.1	-2.1	15.0	28.4	32.1	43.9	40.7	33.2	24.5	-5.9	-9.1	-7.5	-8.5	-6.3	-8.6	-7.0
29.6	-0.1	-1.6	20.4	33.8	38.5	52.0	49.3	39.0	29.6	-5.4	-8.6	-9.1	-10.1	-7.9	-9.6	-8.6
34.1	0.0	-2.1	22.0	38.6	44.9	60.0	56.8	45.0	34.1	-7.0	-10.7	-9.7	-10.6	-7.9	-10.2	-9.7
41.4	0.3	-2.1	26.8	42.3	50.8	67.5	68.6	54.0	41.4	-7.5	-11.8	-14.0	-14.9	-11.1	-11.8	-10.2
49.4	-0.2	-2.7	30.5	48.8	57.7	77.6	79.8	63.2	49.4	-9.1	-14.5	-15.6	-17.1	-12.2	-13.4	-11.8
41.4	0.2	-1.6	26.2	41.8	49.7	66.4	68.0	55.1	41.4	-7.5	-12.3	-13.4	-14.9	-10.6	-11.8	-11.2
34.1	0.1	-1.0	23.0	38.1	44.4	58.4	56.8	47.6	34.1	-5.9	-10.2	-9.7	-10.6	-6.8	-10.2	-9.1
24.5	0.1	-1.6	17.2	27.8	32.6	42.3	41.8	35.3	24.5	-4.8	-7.0	-7.0	-7.5	-5.3	-7.5	-7.5
14.8	0.1	-1.0	10.2	17.7	20.8	26.8	25.1	22.5	14.8	-3.2	-4.8	-3.8	-4.2	-2.7	-5.4	-4.3
9.8	0.3	0.0	8.1	11.7	14.4	18.2	16.1	16.0	9.8	-0.5	-3.2	-2.7	-3.7	-2.1	-4.3	-2.7
4.9	0.3	-0.5	3.8	6.4	6.9	8.1	8.0	8.6	4.9	-1.1	-1.6	-2.1	-2.6	-2.6	-2.7	-2.2
0.0	0.0	-1.0	-0.5	0.5	1.0	-0.5	0.0	2.6	0.0	-1.1	-0.6	-0.1	0.0	-0.5	-1.1	-0.1

(c)

2.1E+05	Modulus (MPa)
0.3	Poisson ratio
5210	x-sect area of shell (mm**2)
105000	F(Lorentz) at operating current (N)
6.5	Operating current (kA)

(d)

Quadrant I

		Δstress(z) (MPa) z							Δstress(a) (MPa)						
I**2	z(mm)	47	197	447	797	1297	1997	7247	47	197	447	797	1297	1997	7247
0.0		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.5		-0.19	0.43	0.80	0.81	1.07	0.58	0.77	-0.28	-0.10	0.12	0.14	0.20	-0.28	0.00
4.9		-0.19	0.98	1.38	1.43	1.81	1.64	1.45	-0.28	0.29	0.19	-0.01	0.11	-0.07	0.08
5.0		-0.08	0.86	1.38	1.57	2.21	1.67	1.63	-0.25	-0.09	0.19	0.14	0.33	0.05	0.26
7.4		0.28	1.69	1.93	1.97	3.04	2.37	2.32	0.19	0.38	0.14	-0.05	0.48	-0.18	0.34
9.8		0.06	1.66	2.31	2.74	3.73	3.37	2.94	-0.21	-0.06	-0.09	-0.05	0.56	0.12	0.20
12.3		-0.13	1.81	3.15	3.60	4.95	4.31	3.52	-0.49	-0.24	0.16	0.21	0.61	0.30	0.29
14.9		-0.30	1.99	3.62	4.03	6.06	5.19	4.18	-0.65	-0.40	0.20	0.11	1.28	0.34	0.26
19.8		-0.45	2.79	4.83	5.49	7.66	7.04	5.74	-0.80	-0.28	0.23	0.22	1.10	0.56	0.71
24.5		-0.88	2.79	5.95	6.72	9.56	8.67	7.07	-1.49	-1.05	0.23	0.26	1.56	0.82	0.67
29.6		-0.73	4.05	7.07	8.07	11.29	10.56	8.28	-1.34	-0.56	0.24	0.33	1.75	1.18	0.71
34.1		-0.96	4.27	8.12	9.49	13.11	12.22	9.57	-1.74	-0.93	0.43	0.65	2.30	1.56	0.86
41.4		-0.99	5.29	8.67	10.54	14.60	14.80	11.59	-1.85	-0.86	-0.30	0.08	2.08	2.00	1.36
49.4		-1.24	5.95	10.04	11.96	16.82	17.24	13.57	-2.25	-1.22	-0.22	0.05	2.52	2.40	1.63
41.4		-0.88	5.12	8.59	10.29	14.38	14.66	11.77	-1.82	-1.01	-0.20	0.00	2.12	1.96	1.21
34.1		-0.63	4.54	8.00	9.38	12.82	12.22	10.21	-1.41	-0.75	0.39	0.62	2.44	1.56	1.18
24.5		-0.69	3.43	5.85	6.90	9.26	9.00	7.52	-1.20	-0.42	0.30	0.52	1.68	1.15	0.70
14.8		-0.45	1.99	3.77	4.44	5.91	5.34	4.82	-0.80	-0.40	0.34	0.46	1.21	0.48	0.56
9.8		-0.03	1.62	2.48	3.02	4.00	3.37	3.46	-0.11	-0.18	0.18	0.14	0.76	0.12	0.48
4.9		-0.19	0.76	1.31	1.39	1.67	1.64	1.81	-0.28	-0.10	-0.04	-0.12	-0.04	-0.07	0.09
0.0		-0.30	-0.15	0.11	0.23	-0.15	-0.08	0.58	-0.32	-0.17	0.01	0.07	-0.15	-0.25	0.15

(e)

		ΔF(z) (N)						
l**2	z(mm)	47	197	447	797	1297	1997	7247
0.0		0	0	0	0	0	0	0
2.5		-984	2216	4172	4207	5594	3010	3994
4.9		-984	5096	7194	7431	9446	8521	7573
5.0		-391	4492	7194	8201	11519	8699	8497
7.4		1481	8794	10038	10275	15845	12337	12076
9.8		320	8640	12041	14269	19424	17552	15300
12.3		-664	9434	16426	18772	25765	22470	18358
14.9		-1553	10382	18855	20989	31548	27057	21759
19.8		-2323	14553	25160	28597	39892	36680	29901
24.5		-4586	14542	30991	35021	49787	45177	36858
29.6		-3816	21119	36822	42037	58818	55014	43163
34.1		-4978	22269	42297	49444	68299	63689	49882
41.4		-5155	27566	45154	54907	76050	77105	60371
49.4		-6435	30991	52288	62302	87629	89809	70705
41.4		-4563	26677	44774	53604	74924	76394	61319
34.1		-3283	23632	41705	48851	66794	63689	53177
24.5		-3603	17895	30458	35969	48247	46872	39169
14.8		-2323	10382	19626	23157	30802	27827	25137
9.8		-178	8462	12906	15750	20823	17552	18002
4.9		-984	3935	6838	7253	8675	8521	9410
0.0		-1576	-806	557	1185	-770	-391	3046

(f)

		ΔF(z)/F(Lorentz)						
l**2	z(mm)	47	197	447	797	1297	1997	7247
0.0		0	0	0	0	0	0	0
2.5		-0.16	0.36	0.68	0.69	0.91	0.49	0.65
4.9		-0.08	0.42	0.59	0.61	0.77	0.70	0.62
5.0		-0.03	0.36	0.58	0.66	0.92	0.70	0.68
7.4		0.08	0.48	0.55	0.56	0.87	0.67	0.66
9.8		0.01	0.35	0.49	0.58	0.80	0.72	0.63
12.3		-0.02	0.31	0.54	0.61	0.84	0.74	0.60
14.9		-0.04	0.28	0.51	0.57	0.85	0.73	0.59
19.8		-0.05	0.30	0.51	0.58	0.81	0.75	0.61
24.5		-0.08	0.24	0.51	0.58	0.82	0.74	0.61
29.6		-0.05	0.29	0.50	0.57	0.80	0.75	0.59
34.1		-0.06	0.26	0.50	0.58	0.81	0.75	0.59
41.4		-0.05	0.27	0.44	0.53	0.74	0.75	0.59
49.4		-0.05	0.25	0.43	0.51	0.71	0.73	0.58
41.4		-0.04	0.26	0.44	0.52	0.73	0.74	0.60
34.1		-0.04	0.28	0.49	0.58	0.79	0.75	0.63
24.5		-0.06	0.29	0.50	0.59	0.79	0.77	0.64
14.8		-0.06	0.28	0.53	0.63	0.83	0.75	0.68
9.8		-0.01	0.35	0.53	0.65	0.85	0.72	0.74
4.9		-0.08	0.32	0.56	0.59	0.71	0.70	0.77
0.0		#####	####	####	####	####	####	####

(g)

azimuthal array at z = 51

K116 a(17o)	K109 a(28o)	K117 a(36o)	K118 a(61o)	K120 a(90o)
-6.6	-4.2	-4.1	-5.1	-5.5
-9.8	-4.8	-5.2	-6.2	-5.0
-11.4	-6.3	-5.2	-4.6	-2.3
-10.9	-5.8	-4.6	-4.0	-1.8
-14.6	-6.3	-5.7	-4.1	-0.2
-16.2	-6.9	-5.7	-1.9	1.9
-17.8	-8.4	-5.7	-1.3	4.1
-21.5	-6.8	-6.2	-0.3	6.2
-24.1	-10.0	-6.2	1.3	10.5
-28.9	-10.5	-6.7	1.3	11.0
-31.0	-12.1	-5.7	4.5	13.7
-34.3	-12.1	-6.2	5.0	14.2
-39.0	-15.3	-6.2	6.1	14.2
-43.8	-16.4	-6.7	7.2	19.0
-39.6	-14.8	-6.2	6.6	15.8
-34.8	-11.0	-6.2	4.5	13.7
-29.5	-9.5	-6.2	1.8	12.0
-21.5	-6.9	-5.2	0.8	7.3
-16.2	-6.3	-5.7	-2.4	2.0
-12.4	-6.8	-6.2	-5.1	-2.8
-7.2	-4.7	-5.2	-6.2	-6.1

(h)

	Δμe(a)				
I**2	17	28	38	61	90
0.0	0.0	0.0	0.0	0.0	0.0
2.5	-3.2	-0.6	-1.1	-1.1	0.5
4.9	-4.8	-2.1	-1.1	0.5	3.2
5.0	-4.3	-1.6	-0.5	1.1	3.7
7.4	-8.0	-2.1	-1.6	1.0	5.3
9.8	-9.6	-2.7	-1.6	3.2	7.4
12.3	-11.2	-4.2	-1.6	3.8	9.6
14.9	-14.9	-2.6	-2.1	4.8	11.7
19.8	-17.5	-5.8	-2.1	6.4	16.0
24.5	-22.3	-6.3	-2.6	6.4	16.5
29.6	-24.4	-7.9	-1.6	9.6	19.2
34.1	-27.7	-7.9	-2.1	10.1	19.7
41.4	-32.4	-11.1	-2.1	11.2	19.7
49.4	-37.2	-12.2	-2.6	12.3	24.5
41.4	-33.0	-10.6	-2.1	11.7	21.3
34.1	-28.2	-6.8	-2.1	9.6	19.2
24.5	-22.9	-5.3	-2.1	6.9	17.5
14.8	-14.9	-2.7	-1.1	5.9	12.8
9.8	-9.6	-2.1	-1.6	2.7	7.5
4.9	-5.8	-2.6	-2.1	0.0	2.7
0.0	-0.6	-0.5	-1.1	-1.1	-0.6

(i)

	Δstress(a)		(MPa)		
l**2	17	28	38	61	90
0.0	0	0	0	0	0
2.5	-0.34	0.20	0.09	0.09	0.43
4.9	-0.45	0.11	0.32	0.65	1.21
5.0	-0.23	0.33	0.56	0.89	1.43
7.4	-0.74	0.48	0.58	1.12	2.01
9.8	-0.87	0.56	0.79	1.78	2.65
12.3	-0.83	0.61	1.15	2.27	3.47
14.9	-1.27	1.28	1.38	2.81	4.24
19.8	-1.33	1.10	1.86	3.62	5.61
24.5	-1.75	1.56	2.33	4.19	6.28
29.6	-1.66	1.75	3.06	5.37	7.36
34.1	-1.80	2.30	3.50	6.02	8.01
41.4	-2.33	2.08	3.94	6.70	8.46
49.4	-2.65	2.52	4.51	7.59	10.12
41.4	-2.52	2.12	3.88	6.74	8.72
34.1	-1.99	2.44	3.41	5.83	7.82
24.5	-1.96	1.68	2.34	4.21	6.40
14.8	-1.31	1.21	1.55	2.99	4.42
9.8	-0.79	0.76	0.87	1.76	2.75
4.9	-0.70	-0.04	0.06	0.50	1.06
0.0	-0.17	-0.15	-0.27	-0.27	-0.17

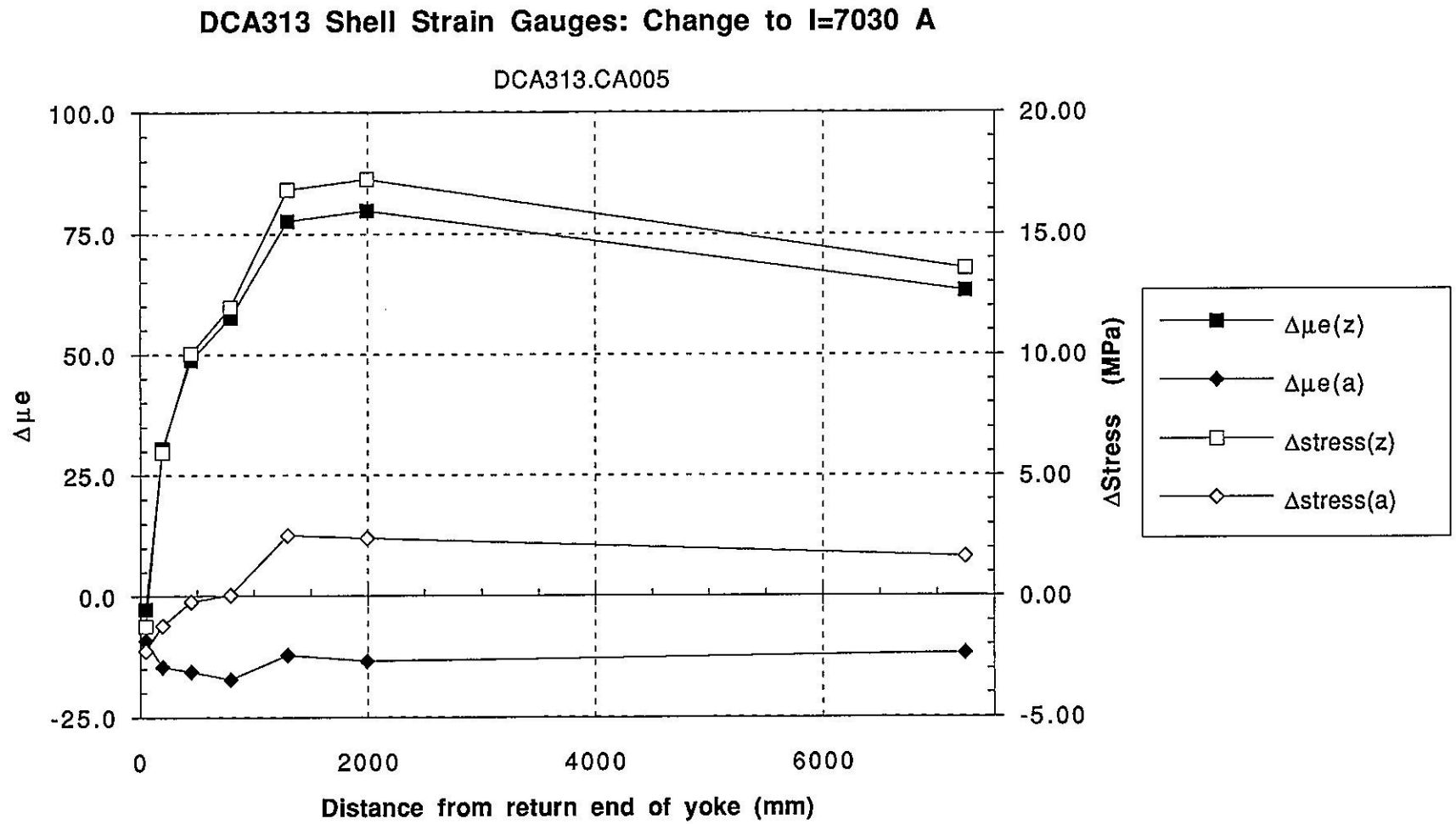
DCA313 Shell Strain Gauges: Change to I=7030 A
DCA313.CA005
100.0
75.0
50.0
25.0
0.0
-25.0
Δμe
20.00
15.00
10.00
5.00
0.00
-5.00
ΔStress (MPa)
0
2000
4000
6000
Distance from return end of yoke (mm)
Δμe(z)
Δμe(a)
Δstress(z)
Δstress(a)

Figure 1

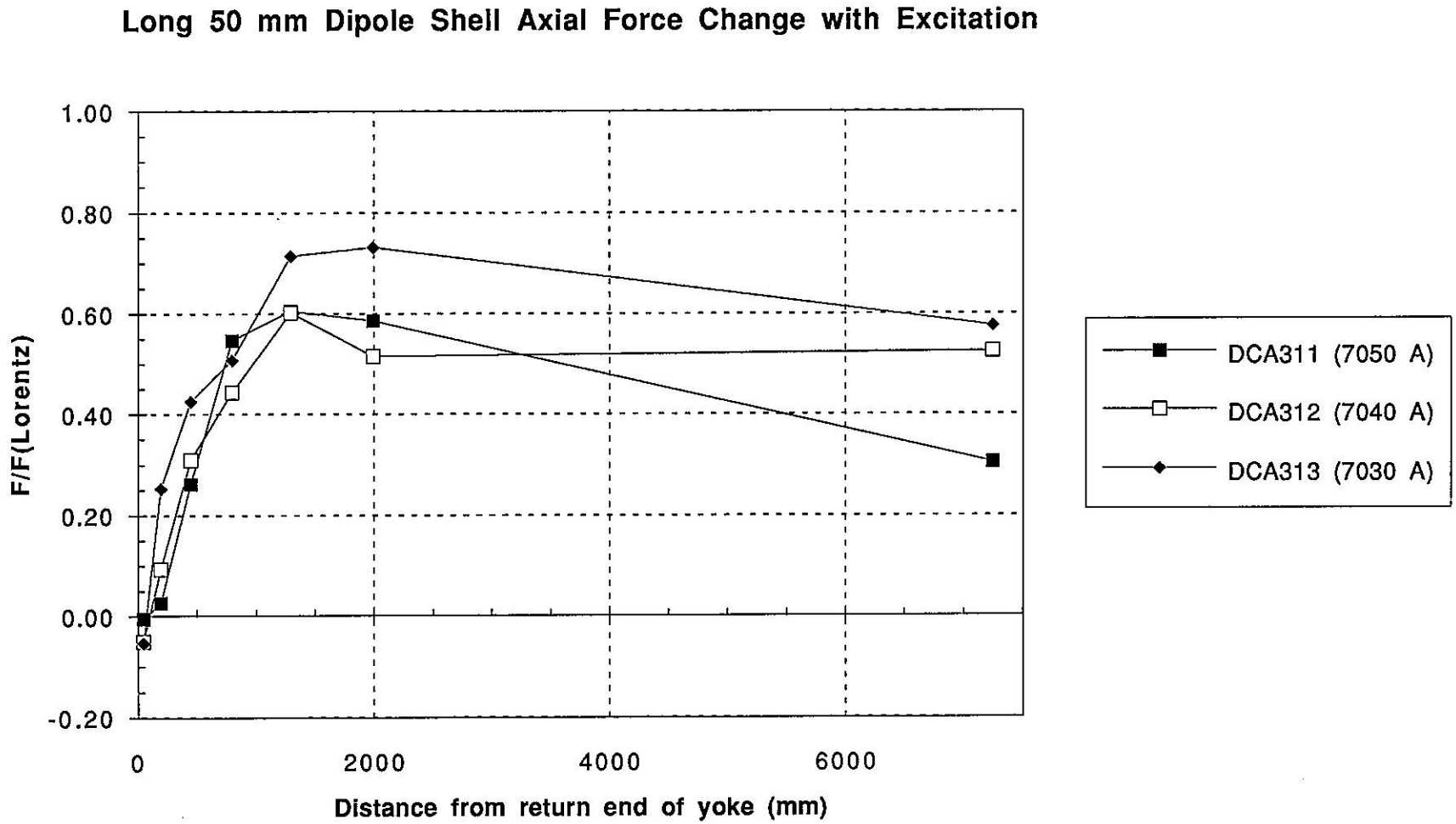
Long 50 mm Dipole Shell Axial Force Change with Excitation
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
F/F(Lorentz)
0
2000
4000
6000
Distance from return end of yoke (mm)
DCA311 (7050 A)
DCA312 (7040 A)
DCA313 (7030 A)

Figure2

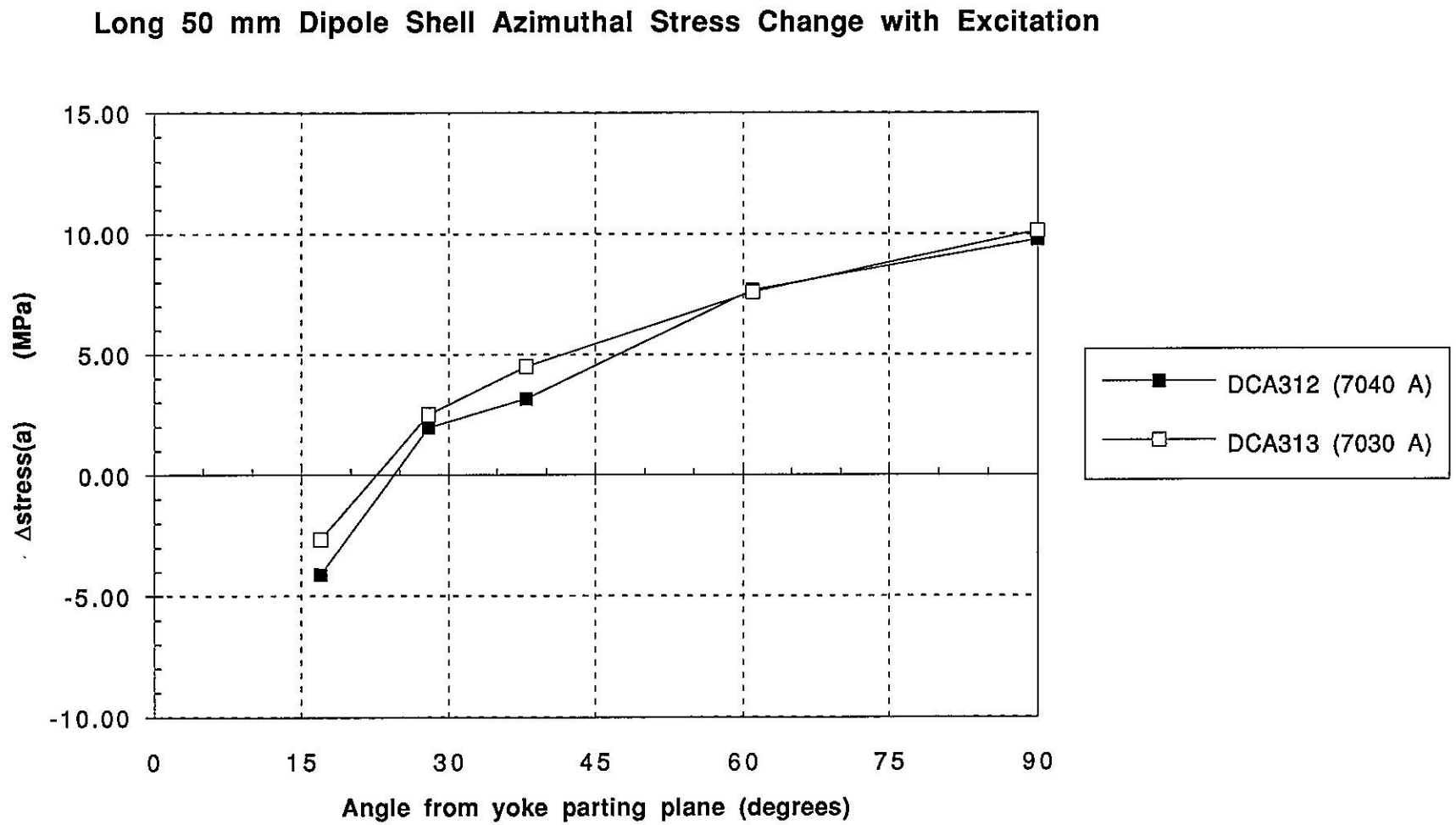
Long 50 mm Dipole Shell Azimuthal Stress Change with Excitation
15.00
10.00
5.00
0.00
-5.00
-10.00
Δstress(a) (MPa)
0
15
30
45
60
75
90
Angle from yoke parting plane (degrees)
DCA312 (7040 A)
DCA313 (7030 A)

Figure 3

ATTACH TO TS-SSC-92-010
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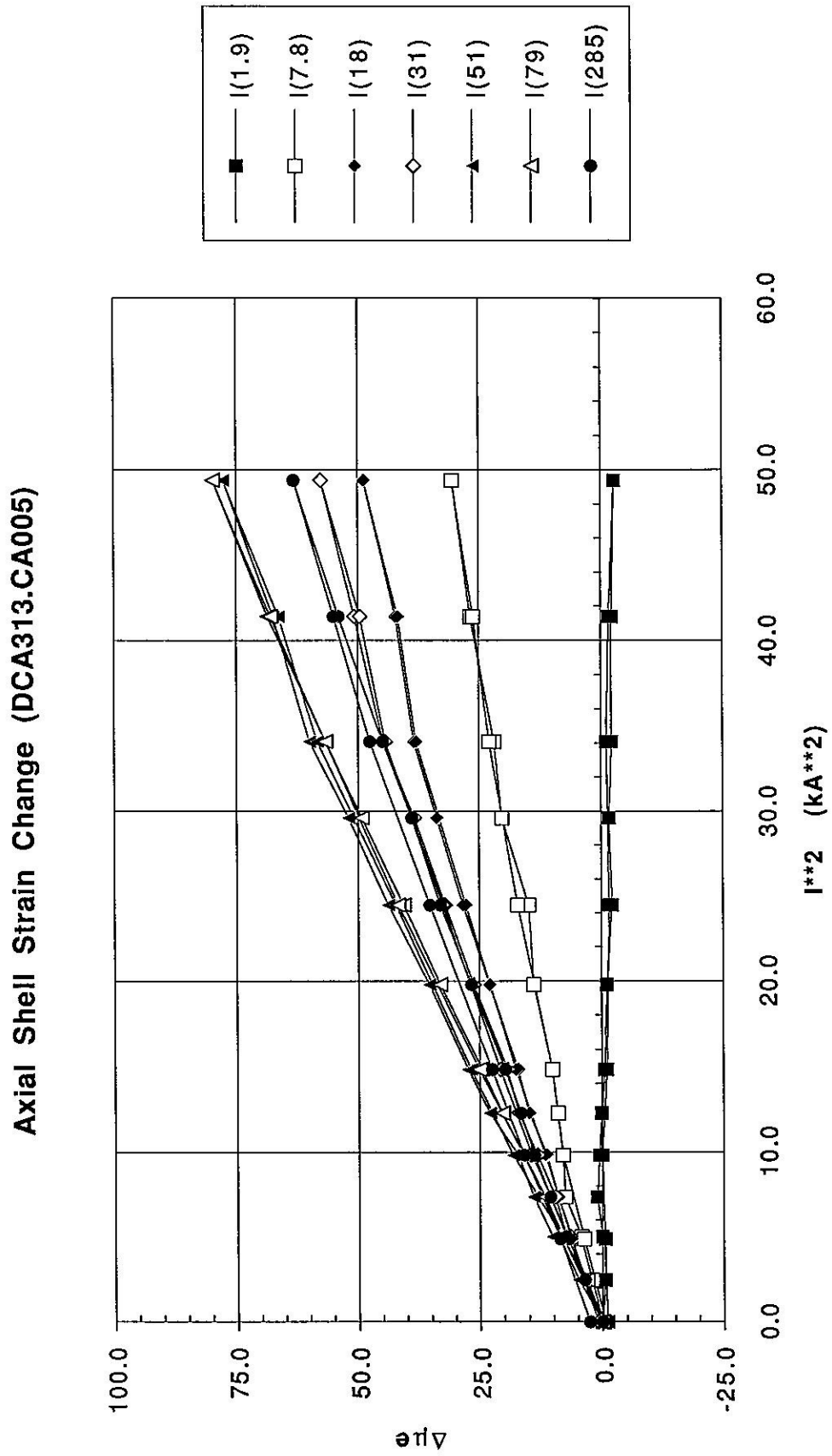
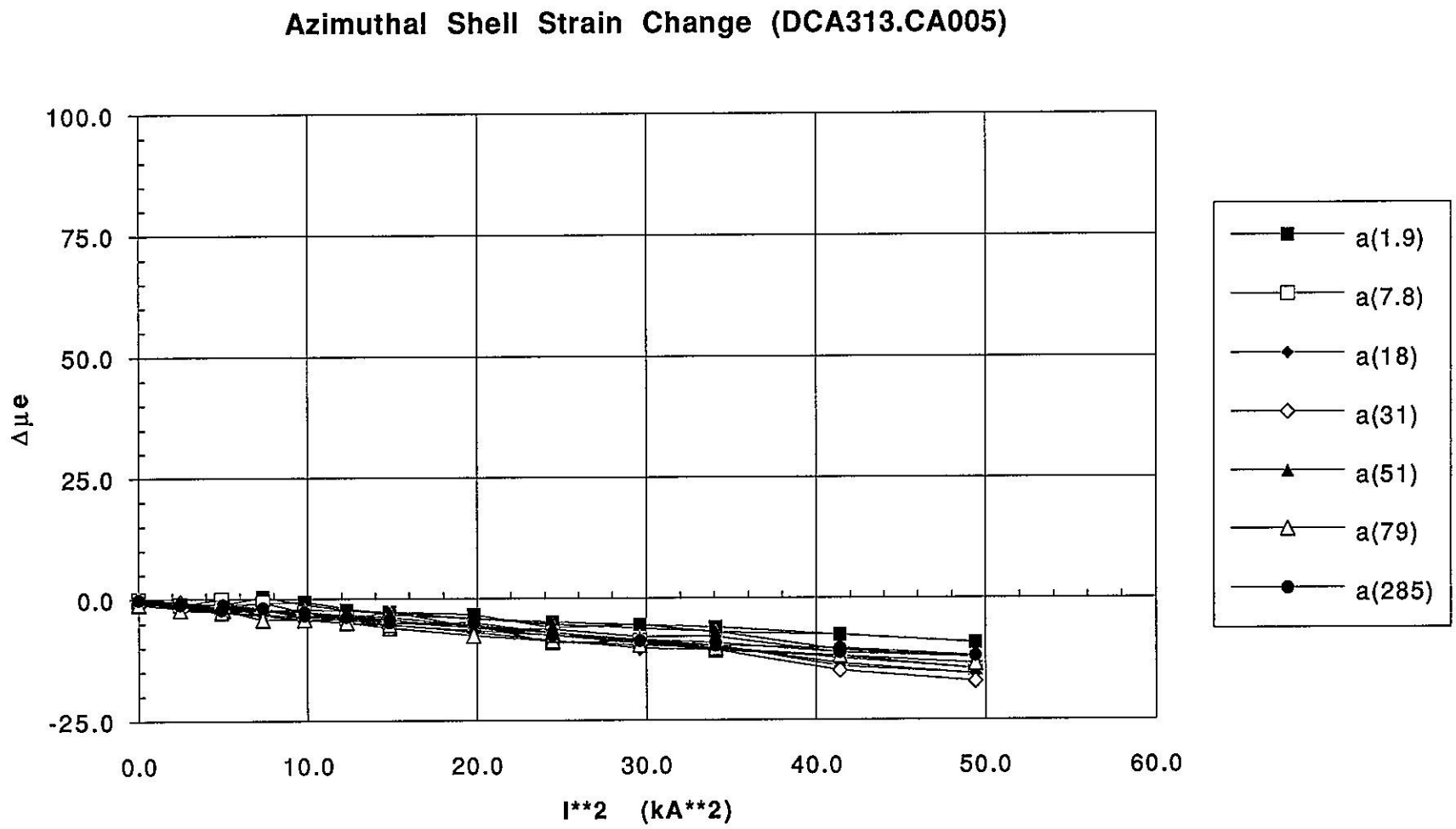
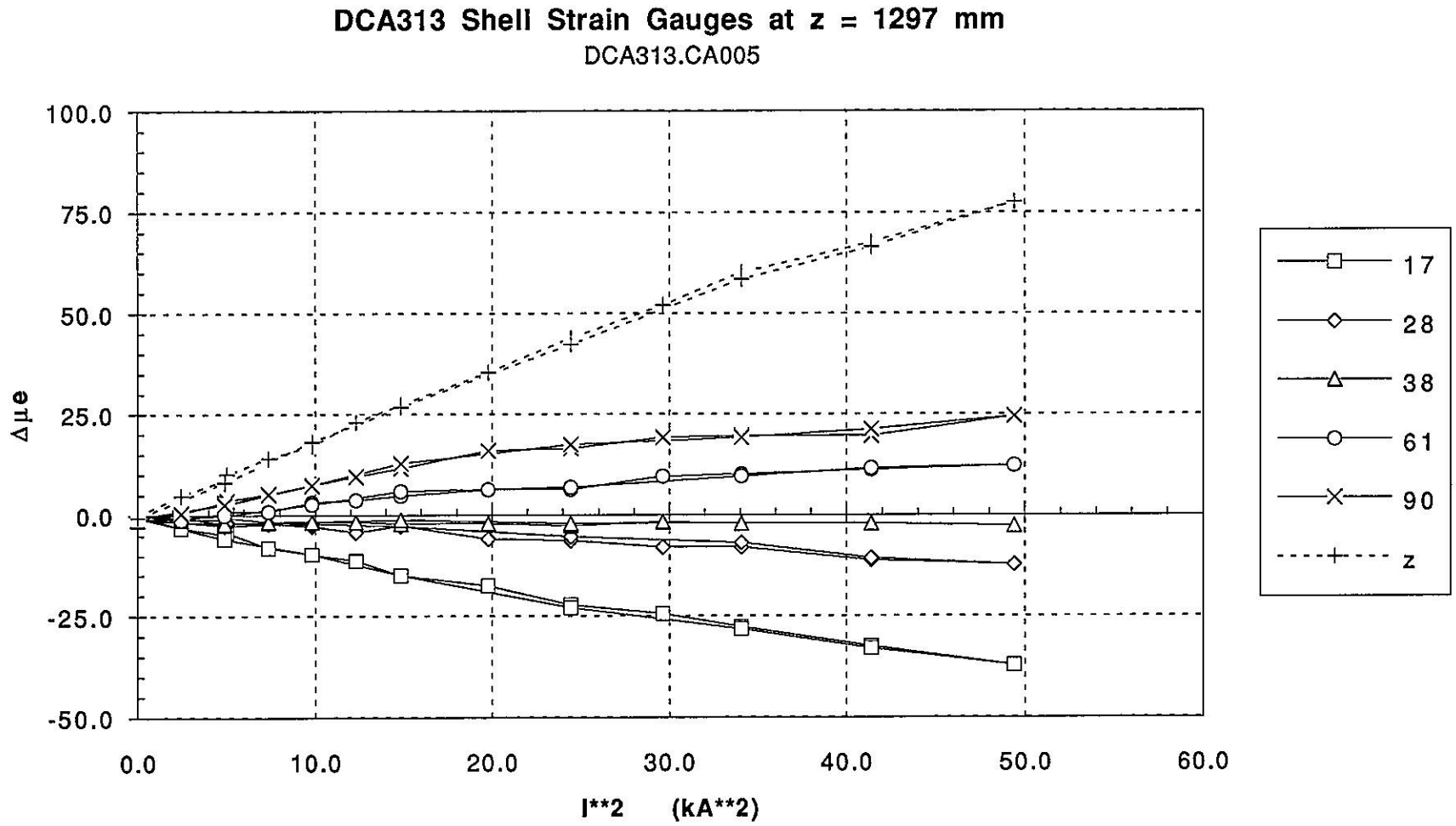
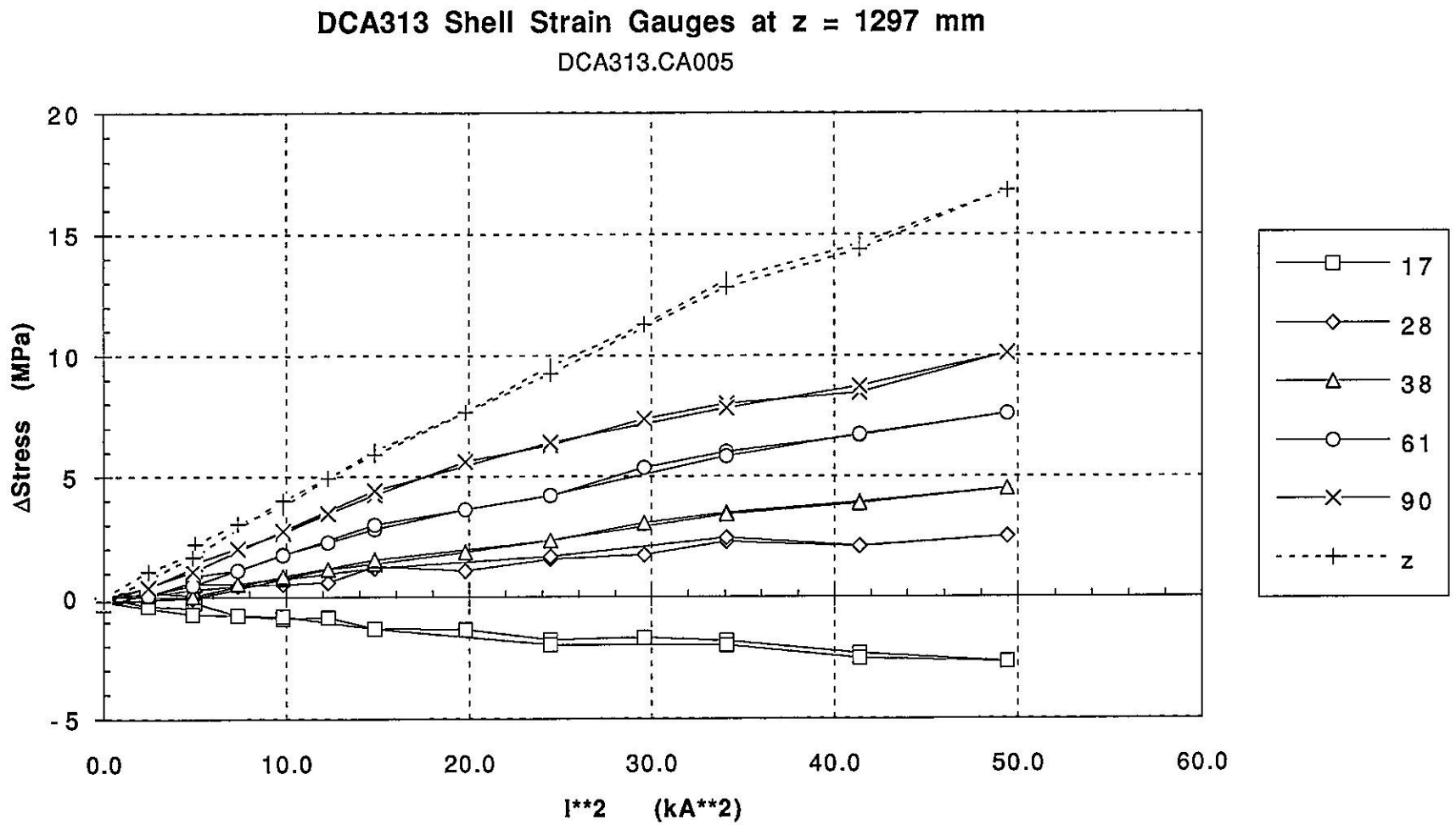



Azimuthal Shell Strain Change (DCA313.CA005)
100.0
75.0
50.0
25.0
0.0
-25.0
Δμe
0.0
10.0
20.0
30.0
40.0
50.0
60.0
I**2 (kA**2)
a(1.9)
a(7.8)
a(18)
a(31)
a(51)
a(79)
a(285)


DCA313 Shell Strain Gauges at z = 1297 mm
DCA313.CA005
100.0
75.0
50.0
25.0
0.0
-25.0
-50.0
Δμe
0.0
10.0
20.0
30.0
40.0
50.0
60.0
I**2 (kA**2)
17
28
38
61
90
z


DCA313 Shell Strain Gauges at z = 1297 mm
DCA313.CA005
ΔStress (MPa)
20
15
10
5
0
-5
0.0
10.0
20.0
30.0
40.0
50.0
60.0
I**2 (kA**2)
17
28
38
61
90
z