Fermilab

TS-SSC 91-243
12/11/91
J. Strait

# Shell Azimuthal Stress Change with Excitation in DCA312

In a previous note[1] I presented an analysis of axial shell stress changes with with excitation in the first two long 50 mm magnets at Fermilab. In this note I present the data from an array of gauges measuring azimuthal stress as a function of angle from the yoke parting plane. At 1297 mm (51 inches) from the return end of the yoke there is an array of 5 gauges that measure the azimuthal strain at 5 different angles. Although the figure in [1] shows these as being in the same quadrant as the axial array, in fact they are in different quadrants. (I believe that the axial array is in Quadrant I and the azimuthal array is in Quadrant II; however, this is unimportant for the analysis below.) The azimuthal array was mounted first to measure stresses during shell welding[2] and a compensating gauge is included as part of the array. This gauge is mounted on a simple tab welded to the shell and therefore is not suitable for cryogenic use. This information was not relayed to MTF until after the initial strain gauge runs and quench runs, so the "wrong" compensating gauge was used. Therefore the cooldown data are clearly not correct for these gauges. This was corrected before the data discussed in this note were taken.

These data were taken from the strain gauge run DCA312.CA005, a complete loop to 7040 A and back to zero. The data, analysed as in the previous note, are shown in Table I. Table I(a) - I(f) are the same as in the previous analysis. Table I(g) gives the raw strains for the azimuthal array as reported in the data file. Table I(h) give the strain change relative to the initial I=0 point. In Table I(i) the azimuthal stress is recorded, where correction has been made for the Poisson effect using the axial stress at z=1297 mm given Table I(g), under the assumption that this stress is azimuthally symmetric.

Figures 1-4 plot data from the axial array as in [1]. The peak IxB is about 10% higher than before and the results are basically the same. Figure 5 is a plot of axial and azimuthal strains versus I**2 for the gauges at z=1297 mm. The legend gives the angular distance (in degrees) from the parting plane for the azimuthal gauges and labels the axial gauge (located 28o from the parting plane) as "z". The gauges that are part of the axial array are plotted with a dashed line. The 2 azimuthal gauges in different quadrants but the same angle from the parting plane differ by about 8 microstrain at the highest current. The stresses, with Poisson effects corrected, are plotted in Figure 6. These results are quite similar to those measured in short magnets[3]. The azimuthal stresses for DSA324[3] are shown in Figure 7. That the stress change towards the yoke parting plane is compressive and all stresses are linear in I**2 suggest that the yoke gap remains closed at least to 7 T (or 7.6 T in DSA324). Figure 8 shows the stress change versus angle for the highest current point of the run. The pattern of compressive stress near the vertical and extensive stress towards the horizontal is consistent with an elliptical deflection due the the dominantly horizontal Lorentz force.

REFERENCES

[1] J. Strait, Shell Axial Stress Change with Excitation in DCA311 and DCA312, TS-SSC 91-240, 12/9/91.

[2] J. Strait, DCA312 shell gauge data during welding, TS-SSC 91-179, 9/13/91.

[3] J. Strait, et al., Mechanical behavior of Fermilab-built 1.5 m model SSC collider dipoles, submitted to the 12th International Conference on Magnet Technology (MT12), Leningrad, USSR, 1-5 July, 1991.

DISTRIBUTION: W.Boroski, R.Bossert, J.Carson, S.Delchamps, A.Devred, J.DiMarco, W.Koska, J.Kuzminski, M.J.Lamm, P.O.Mazur, T.Nicol, D.Orris, E.G.Pewitt, M.Wake

# Table I

dca312 shell ca005

DCA312.CA005 07-DEC-1991

strain gauge run to 7100A 4.35K test cycle #1

Axial array at theta = 28o

(a)

| K001 Ibefore | K117 Iafter | K087 I(1.9) | K088 a(1.9) | K089 I(7.8) | K090 a(7.8) | K091 I(18) | K092 a(18) | K094 I(31) | K095 a(31) | K096 I(51) | K097 a(51) | K099 I(79) | K100 a(79) | K102 I(285) | K103 a(285) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 38.4 | 38.8 | 6.4 | 5.3 | 3.1 | 5.1 | -49.8 | 2.9 | -2.5 | -0.5 | -7.2 | 10.3 | -8.9 | 1.9 | -11.9 | -14.2 |
| 1577.8 | 1578.0 | 6.3 | 5.3 | 4.7 | 6.1 | -47.6 | 1.8 | 0.2 | -1.6 | -3.5 | 9.2 | -6.2 | 0.9 | -8.6 | -15.2 |
| 2222.9 | 2223.0 | 6.4 | 4.8 | 5.7 | 5.6 | -46.0 | 1.3 | 2.3 | -2.6 | -0.8 | 7.7 | -3.0 | -0.2 | -6.5 | -17.4 |
| 2719.6 | 2719.6 | 5.3 | 3.2 | 5.7 | 3.4 | -44.9 | -1.4 | 4.4 | -4.3 | 2.4 | 5.5 | -1.4 | -3.4 | -3.8 | -19.5 |
| 3141.9 | 3141.9 | 4.2 | 1.6 | 6.3 | 2.9 | -43.3 | -2.4 | 7.1 | -4.8 | 7.3 | 6.1 | 1.3 | -4.5 | -0.2 | -19.0 |
| 3514.1 | 3514.0 | 5.3 | 1.6 | 7.4 | 2.4 | -41.7 | -3.0 | 9.8 | -5.3 | 10.5 | 5.0 | 5.6 | -4.5 | 3.1 | -20.6 |
| 3861.4 | 3861.2 | 4.2 | 0.5 | 8.0 | 1.8 | -39.0 | -3.0 | 12.5 | -5.9 | 13.2 | 2.9 | 8.8 | -5.0 | 6.8 | -20.6 |
| 4159.3 | 4159.4 | 4.7 | 0.5 | 9.0 | 2.4 | -36.9 | -4.1 | 15.7 | -6.4 | 17.4 | 2.9 | 11.5 | -6.6 | 8.9 | -21.7 |
| 4456.3 | 4456.1 | 4.7 | -1.1 | 9.0 | 1.3 | -34.7 | -4.6 | 18.9 | -6.9 | 21.8 | 1.8 | 14.7 | -7.7 | 12.7 | -21.7 |
| 4953.0 | 4952.9 | 4.7 | -2.2 | 10.6 | 0.2 | -30.4 | -5.7 | 23.2 | -8.0 | 28.2 | -0.4 | 21.1 | -8.7 | 18.0 | -23.8 |
| 5449.4 | 5449.4 | 4.8 | -3.2 | 11.7 | -0.3 | -27.3 | -7.8 | 29.0 | -9.6 | 35.7 | -2.0 | 27.0 | -11.5 | 25.0 | -24.9 |
| 5846.5 | 5846.3 | 5.3 | -3.3 | 13.3 | -1.4 | -23.5 | -8.4 | 33.9 | -10.1 | 41.6 | -4.1 | 32.8 | -12.5 | 29.8 | -26.0 |
| 6441.8 | 6441.7 | 4.2 | -5.9 | 14.4 | -1.9 | -18.6 | -10.5 | 39.8 | -12.8 | 50.1 | -7.3 | 40.9 | -15.2 | 38.3 | -27.0 |
| 6641.3 | 6640.7 | 5.3 | -5.4 | 14.9 | -3.0 | -17.0 | -11.6 | 42.4 | -12.2 | 54.4 | -6.2 | 44.1 | -16.2 | 41.5 | -27.6 |
| 7037.1 | 7037.1 | 4.7 | -6.4 | 15.4 | -3.5 | -13.3 | -11.6 | 47.3 | -12.8 | 60.9 | -8.4 | 50.5 | -17.8 | 46.9 | -28.1 |
| 6441.4 | 6441.3 | 4.8 | -5.3 | 14.4 | -2.4 | -19.7 | -10.5 | 39.8 | -11.7 | 50.2 | -5.7 | 40.4 | -15.7 | 39.4 | -27.6 |
| 5449.4 | 5449.3 | 5.3 | -3.2 | 12.2 | 0.2 | -27.2 | -7.3 | 28.5 | -8.5 | 34.0 | -2.0 | 27.0 | -10.8 | 26.5 | -24.9 |
| 4456.1 | 4456.1 | 5.3 | -1.1 | 7.9 | 1.3 | -35.3 | -4.6 | 18.4 | -5.9 | 20.7 | 2.9 | 15.2 | -6.6 | 14.3 | -22.2 |
| 3860.9 | 3860.9 | 5.3 | 0.5 | 7.9 | 2.9 | -39.0 | -3.0 | 12.5 | -4.8 | 13.2 | 4.0 | 8.7 | -4.5 | 7.9 | -21.1 |
| 3141.8 | 3141.7 | 5.8 | 2.6 | 6.8 | 3.4 | -42.3 | -0.3 | 8.2 | -3.2 | 6.7 | 6.0 | 2.9 | -2.9 | 1.4 | -19.0 |
| 2223.3 | 2223.2 | 5.8 | 3.7 | 5.8 | 5.1 | -46.0 | 0.7 | 3.3 | -1.6 | 0.3 | 8.7 | -3.0 | -0.8 | -3.9 | -16.3 |
| -2.0 | -2.1 | 6.4 | 6.4 | 4.2 | 6.1 | -49.2 | 2.9 | -2.0 | -1.1 | -6.7 | 9.8 | -8.4 | 1.9 | -10.3 | -14.2 |

(b)

| | | Δμe(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 | 0.2 | -0.1 | 1.6 | 2.2 | 2.7 | 3.7 | 2.7 | 3.3 | 2.5 | 0.0 | 1.0 | -1.1 | -1.1 | -1.1 | -1.0 | -1.0 |
| 4.9 | 0.1 | 0.0 | 2.6 | 3.8 | 4.8 | 6.4 | 5.9 | 5.4 | 4.9 | -0.5 | 0.5 | -1.6 | -2.1 | -2.6 | -2.1 | -3.2 |
| 7.4 | 0.0 | -1.1 | 2.6 | 4.9 | 6.9 | 9.6 | 7.5 | 8.1 | 7.4 | -2.1 | -1.7 | -4.3 | -3.8 | -4.8 | -5.3 | -5.3 |
| 9.9 | 0.0 | -2.2 | 3.2 | 6.5 | 9.6 | 14.5 | 10.2 | 11.7 | 9.9 | -3.7 | -2.2 | -5.3 | -4.3 | -4.2 | -6.4 | -4.8 |
| 12.3 | -0.1 | -1.1 | 4.3 | 8.1 | 12.3 | 17.7 | 14.5 | 15.0 | 12.3 | -3.7 | -2.7 | -5.9 | -4.8 | -5.3 | -6.4 | -6.4 |
| 14.9 | -0.2 | -2.2 | 4.9 | 10.8 | 15.0 | 20.4 | 17.7 | 18.7 | 14.9 | -4.8 | -3.3 | -5.9 | -5.4 | -7.4 | -6.9 | -6.4 |
| 17.3 | 0.1 | -1.7 | 5.9 | 12.9 | 18.2 | 24.6 | 20.4 | 20.8 | 17.3 | -4.8 | -2.7 | -7.0 | -5.9 | -7.4 | -8.5 | -7.5 |
| 19.9 | -0.2 | -1.7 | 5.9 | 15.1 | 21.4 | 29.0 | 23.6 | 24.6 | 19.9 | -6.4 | -3.8 | -7.5 | -6.4 | -8.5 | -9.6 | -7.5 |
| 24.5 | -0.1 | -1.7 | 7.5 | 19.4 | 25.7 | 35.4 | 30.0 | 29.9 | 24.5 | -7.5 | -4.9 | -8.6 | -7.5 | -10.7 | -10.6 | -9.6 |
| 29.7 | 0.0 | -1.6 | 8.6 | 22.5 | 31.5 | 42.9 | 35.9 | 36.9 | 29.7 | -8.5 | -5.4 | -10.7 | -9.1 | -12.3 | -13.4 | -10.7 |
| 34.2 | -0.2 | -1.1 | 10.2 | 26.3 | 36.4 | 48.8 | 41.7 | 41.7 | 34.2 | -8.6 | -6.5 | -11.3 | -9.6 | -14.4 | -14.4 | -11.8 |
| 41.5 | -0.1 | -2.2 | 11.3 | 31.2 | 42.3 | 57.3 | 49.8 | 50.2 | 41.5 | -11.2 | -7.0 | -13.4 | -12.3 | -17.6 | -17.1 | -12.8 |
| 44.1 | -0.6 | -1.1 | 11.8 | 32.8 | 44.9 | 61.6 | 53.0 | 53.4 | 44.1 | -10.7 | -8.1 | -14.5 | -11.7 | -16.5 | -18.1 | -13.4 |
| 49.5 | 0.0 | -1.7 | 12.3 | 36.5 | 49.8 | 68.1 | 59.4 | 58.8 | 49.5 | -11.7 | -8.6 | -14.5 | -12.3 | -18.7 | -19.7 | -13.9 |
| 41.5 | -0.1 | -1.6 | 11.3 | 30.1 | 42.3 | 57.4 | 49.3 | 51.3 | 41.5 | -10.6 | -7.5 | -13.4 | -11.2 | -16.0 | -17.6 | -13.4 |
| 29.7 | -0.1 | -1.1 | 9.1 | 22.6 | 31.0 | 41.2 | 35.9 | 38.4 | 29.7 | -8.5 | -4.9 | -10.2 | -8.0 | -12.3 | -12.7 | -10.7 |
| 19.9 | 0.0 | -1.1 | 4.8 | 14.5 | 20.9 | 27.9 | 24.1 | 26.2 | 19.9 | -6.4 | -3.8 | -7.5 | -5.4 | -7.4 | -8.5 | -8.0 |
| 14.9 | 0.0 | -1.1 | 4.8 | 10.8 | 15.0 | 20.4 | 17.6 | 19.8 | 14.9 | -4.8 | -2.2 | -5.9 | -4.3 | -6.3 | -6.4 | -6.9 |
| 9.9 | -0.1 | -0.6 | 3.7 | 7.5 | 10.7 | 13.9 | 11.8 | 13.3 | 9.9 | -2.7 | -1.7 | -3.2 | -2.7 | -4.3 | -4.8 | -4.8 |
| 4.9 | -0.1 | -0.6 | 2.7 | 3.8 | 5.8 | 7.5 | 5.9 | 8.0 | 4.9 | -1.6 | 0.0 | -2.2 | -1.1 | -1.6 | -2.7 | -2.1 |
| 0.0 | -0.1 | 0.0 | 1.1 | 0.6 | 0.5 | 0.5 | 0.5 | 1.6 | 0.0 | 1.1 | 1.0 | 0.0 | -0.6 | -0.5 | 0.0 | 0.0 |

# Table I

dca312 shell ca005

(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)

| | | Δstress(z) (MPa) | | | | | | | 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 | | -0.02 | 0.43 | 0.43 | 0.54 | 0.77 | 0.55 | 0.68 | -0.01 | 0.34 | -0.10 | -0.07 | 0.00 | -0.04 | 0.00 |
| 4.9 | | -0.03 | 0.63 | 0.76 | 0.95 | 1.28 | 1.20 | 1.01 | -0.11 | 0.29 | -0.10 | -0.15 | -0.15 | -0.08 | -0.36 |
| 7.4 | | -0.39 | 0.48 | 0.82 | 1.31 | 1.86 | 1.34 | 1.48 | -0.55 | -0.21 | -0.64 | -0.39 | -0.44 | -0.69 | -0.65 |
| 9.9 | | -0.75 | 0.58 | 1.12 | 1.89 | 3.01 | 1.88 | 2.33 | -0.99 | -0.28 | -0.76 | -0.32 | 0.03 | -0.76 | -0.29 |
| 12.3 | | -0.50 | 0.79 | 1.44 | 2.47 | 3.66 | 2.86 | 2.98 | -0.92 | -0.32 | -0.79 | -0.25 | 0.00 | -0.47 | -0.43 |
| 14.9 | | -0.83 | 0.89 | 2.05 | 3.04 | 4.14 | 3.56 | 3.82 | -1.24 | -0.42 | -0.61 | -0.20 | -0.29 | -0.36 | -0.18 |
| 17.3 | | -0.71 | 1.16 | 2.46 | 3.74 | 5.09 | 4.06 | 4.22 | -1.21 | -0.21 | -0.71 | -0.10 | 0.00 | -0.54 | -0.29 |
| 19.9 | | -0.82 | 1.08 | 2.92 | 4.43 | 6.02 | 4.71 | 5.08 | -1.57 | -0.46 | -0.68 | 0.00 | 0.05 | -0.57 | -0.03 |
| 24.5 | | -0.90 | 1.37 | 3.83 | 5.33 | 7.32 | 6.10 | 6.15 | -1.82 | -0.60 | -0.63 | 0.05 | -0.02 | -0.36 | -0.14 |
| 29.7 | | -0.94 | 1.59 | 4.39 | 6.54 | 8.92 | 7.25 | 7.66 | -2.04 | -0.64 | -0.90 | 0.08 | 0.13 | -0.60 | 0.08 |
| 34.2 | | -0.84 | 1.88 | 5.21 | 7.62 | 10.12 | 8.50 | 8.68 | -2.03 | -0.78 | -0.78 | 0.30 | 0.05 | -0.43 | 0.16 |
| 41.5 | | -1.26 | 2.09 | 6.18 | 8.78 | 11.83 | 10.16 | 10.55 | -2.70 | -0.82 | -0.92 | 0.09 | -0.09 | -0.49 | 0.51 |
| 44.1 | | -0.98 | 2.13 | 6.47 | 9.42 | 12.89 | 10.82 | 11.23 | -2.51 | -1.04 | -1.06 | 0.40 | 0.45 | -0.50 | 0.60 |
| 49.5 | | -1.19 | 2.21 | 7.31 | 10.49 | 14.21 | 12.17 | 12.43 | -2.78 | -1.12 | -0.81 | 0.60 | 0.39 | -0.43 | 0.85 |
| 41.5 | | -1.09 | 2.06 | 5.93 | 8.86 | 11.97 | 10.01 | 10.75 | -2.52 | -0.93 | -0.99 | 0.34 | 0.28 | -0.64 | 0.45 |
| 29.7 | | -0.83 | 1.74 | 4.44 | 6.51 | 8.53 | 7.30 | 8.00 | -2.01 | -0.49 | -0.78 | 0.30 | 0.01 | -0.44 | 0.19 |
| 19.9 | | -0.69 | 0.83 | 2.79 | 4.39 | 5.84 | 4.90 | 5.41 | -1.53 | -0.54 | -0.72 | 0.20 | 0.22 | -0.29 | -0.03 |
| 14.9 | | -0.58 | 0.94 | 2.05 | 3.12 | 4.21 | 3.57 | 4.03 | -1.17 | -0.17 | -0.61 | 0.05 | -0.04 | -0.25 | -0.22 |
| 9.9 | | -0.32 | 0.73 | 1.49 | 2.25 | 2.87 | 2.36 | 2.70 | -0.66 | -0.13 | -0.22 | 0.12 | -0.03 | -0.29 | -0.18 |
| 4.9 | | -0.25 | 0.61 | 0.71 | 1.24 | 1.60 | 1.16 | 1.68 | -0.40 | 0.18 | -0.24 | 0.15 | 0.15 | -0.21 | 0.07 |
| 0.0 | | 0.08 | 0.32 | 0.14 | 0.07 | 0.08 | 0.11 | 0.36 | 0.25 | 0.30 | 0.04 | -0.10 | -0.08 | 0.03 | 0.11 |

# Table I

dca312 shell ca005

(e)

| | | ΔF(z) (N) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| I**2 | z(mm) | 47 | 197 | 447 | 797 | 1297 | 1997 | 7247 |
| 0.0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2.5 | | -119 | 2252 | 2216 | 2809 | 3994 | 2844 | 3555 |
| 4.9 | | -178 | 3259 | 3935 | 4942 | 6660 | 6246 | 5262 |
| 7.4 | | -2050 | 2477 | 4278 | 6826 | 9671 | 7004 | 7715 |
| 9.9 | | -3923 | 3010 | 5819 | 9848 | 15691 | 9813 | 12159 |
| 12.3 | | -2619 | 4136 | 7502 | 12871 | 19092 | 14909 | 15502 |
| 14.9 | | -4314 | 4634 | 10702 | 15857 | 21546 | 18524 | 19887 |
| 17.3 | | -3721 | 6032 | 12799 | 19472 | 26523 | 21155 | 21984 |
| 19.9 | | -4290 | 5641 | 15229 | 23086 | 31347 | 24556 | 26488 |
| 24.5 | | -4681 | 7146 | 19934 | 27791 | 38149 | 31785 | 32022 |
| 29.7 | | -4918 | 8272 | 22861 | 34096 | 46469 | 37782 | 39927 |
| 34.2 | | -4361 | 9777 | 27151 | 39726 | 52715 | 44300 | 45225 |
| 41.5 | | -6589 | 10903 | 32212 | 45758 | 61651 | 52940 | 54943 |
| 44.1 | | -5108 | 11105 | 33717 | 49053 | 67138 | 56377 | 58522 |
| 49.5 | | -6175 | 11519 | 38102 | 54646 | 74059 | 63393 | 64744 |
| 41.5 | | -5665 | 10725 | 30908 | 46149 | 62338 | 52170 | 56033 |
| 29.7 | | -4326 | 9043 | 23157 | 33895 | 44454 | 38031 | 41705 |
| 19.9 | | -3579 | 4338 | 14518 | 22849 | 30434 | 25540 | 28206 |
| 14.9 | | -3010 | 4906 | 10702 | 16248 | 21937 | 18583 | 21012 |
| 9.9 | | -1671 | 3781 | 7751 | 11721 | 14945 | 12278 | 14056 |
| 4.9 | | -1280 | 3200 | 3721 | 6483 | 8320 | 6032 | 8734 |
| 0.0 | | 391 | 1659 | 711 | 379 | 415 | 593 | 1896 |

(f)

| | | ΔF(z)/F(Lorentz) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| I**2 | z(mm) | 47 | 197 | 447 | 797 | 1297 | 1997 | 7247 |
| 0.0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2.5 | | -0.02 | 0.36 | 0.36 | 0.45 | 0.65 | 0.46 | 0.57 |
| 4.9 | | -0.01 | 0.27 | 0.32 | 0.40 | 0.54 | 0.51 | 0.43 |
| 7.4 | | -0.11 | 0.13 | 0.23 | 0.37 | 0.53 | 0.38 | 0.42 |
| 9.9 | | -0.16 | 0.12 | 0.24 | 0.40 | 0.64 | 0.40 | 0.50 |
| 12.3 | | -0.09 | 0.13 | 0.24 | 0.42 | 0.62 | 0.49 | 0.51 |
| 14.9 | | -0.12 | 0.13 | 0.29 | 0.43 | 0.58 | 0.50 | 0.54 |
| 17.3 | | -0.09 | 0.14 | 0.30 | 0.45 | 0.62 | 0.49 | 0.51 |
| 19.9 | | -0.09 | 0.11 | 0.31 | 0.47 | 0.64 | 0.50 | 0.54 |
| 24.5 | | -0.08 | 0.12 | 0.33 | 0.46 | 0.63 | 0.52 | 0.53 |
| 29.7 | | -0.07 | 0.11 | 0.31 | 0.46 | 0.63 | 0.51 | 0.54 |
| 34.2 | | -0.05 | 0.12 | 0.32 | 0.47 | 0.62 | 0.52 | 0.53 |
| 41.5 | | -0.06 | 0.11 | 0.31 | 0.44 | 0.60 | 0.51 | 0.53 |
| 44.1 | | -0.05 | 0.10 | 0.31 | 0.45 | 0.61 | 0.51 | 0.53 |
| 49.5 | | -0.05 | 0.09 | 0.31 | 0.44 | 0.60 | 0.52 | 0.53 |
| 41.5 | | -0.05 | 0.10 | 0.30 | 0.45 | 0.60 | 0.51 | 0.54 |
| 29.7 | | -0.06 | 0.12 | 0.31 | 0.46 | 0.60 | 0.52 | 0.57 |
| 19.9 | | -0.07 | 0.09 | 0.29 | 0.46 | 0.62 | 0.52 | 0.57 |
| 14.9 | | -0.08 | 0.13 | 0.29 | 0.44 | 0.59 | 0.50 | 0.57 |
| 9.9 | | -0.07 | 0.15 | 0.32 | 0.48 | 0.61 | 0.50 | 0.57 |
| 4.9 | | -0.10 | 0.26 | 0.30 | 0.53 | 0.68 | 0.49 | 0.71 |
| 0.0 | | ##### | #### | #### | #### | #### | #### | #### |

# Table I

dca312 shell ca005

(g)

azimuthal array at z = 51

| K104 a(17o) | K105 a(28o) | K106 a(36o) | K108 a(61o) | K109 a(90o) |
|---|---|---|---|---|
| -23.5 | -34.5 | -31.4 | -28.0 | -35.4 |
| -26.2 | -34.5 | -31.9 | -26.9 | -33.3 |
| -27.8 | -35.0 | -32.0 | -25.3 | -30.1 |
| -32.6 | -39.2 | -35.7 | -26.9 | -31.2 |
| -35.8 | -39.2 | -34.1 | -23.2 | -25.3 |
| -35.2 | -37.7 | -32.5 | -21.6 | -22.7 |
| -37.3 | -37.7 | -32.5 | -20.0 | -20.5 |
| -40.5 | -39.2 | -34.1 | -20.0 | -19.4 |
| -42.7 | -39.8 | -33.5 | -18.4 | -16.8 |
| -45.9 | -40.3 | -33.5 | -16.3 | -14.1 |
| -50.1 | -41.4 | -34.1 | -15.7 | -14.1 |
| -53.9 | -43.0 | -35.2 | -14.1 | -13.6 |
| -58.6 | -44.6 | -36.2 | -13.1 | -13.6 |
| -60.8 | -45.6 | -35.7 | -12.0 | -11.4 |
| -64.0 | -45.6 | -36.7 | -11.5 | -8.8 |
| -59.2 | -45.1 | -36.2 | -13.0 | -13.6 |
| -50.1 | -41.3 | -33.5 | -14.6 | -13.5 |
| -42.2 | -38.2 | -32.0 | -17.3 | -16.2 |
| -37.4 | -37.2 | -32.0 | -19.5 | -19.4 |
| -33.1 | -36.6 | -31.4 | -22.1 | -24.2 |
| -29.4 | -35.6 | -32.5 | -26.9 | -31.2 |
| -23.0 | -33.4 | -31.4 | -28.0 | -34.9 |

(h)

| | Δμe(a) | | | | |
|---|---|---|---|---|---|
| I**2 | 17 | 28 | 38 | 61 | 90 |
| 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2.5 | -2.7 | 0.0 | -0.5 | 1.1 | 2.1 |
| 4.9 | -4.3 | -0.5 | -0.6 | 2.7 | 5.3 |
| 7.4 | -9.1 | -4.7 | -4.3 | 1.1 | 4.2 |
| 9.9 | -12.3 | -4.7 | -2.7 | 4.8 | 10.1 |
| 12.3 | -11.7 | -3.2 | -1.1 | 6.4 | 12.7 |
| 14.9 | -13.8 | -3.2 | -1.1 | 8.0 | 14.9 |
| 17.3 | -17.0 | -4.7 | -2.7 | 8.0 | 16.0 |
| 19.9 | -19.2 | -5.3 | -2.1 | 9.6 | 18.6 |
| 24.5 | -22.4 | -5.8 | -2.1 | 11.7 | 21.3 |
| 29.7 | -26.6 | -6.9 | -2.7 | 12.3 | 21.3 |
| 34.2 | -30.4 | -8.5 | -3.8 | 13.9 | 21.8 |
| 41.5 | -35.1 | -10.1 | -4.8 | 14.9 | 21.8 |
| 44.1 | -37.3 | -11.1 | -4.3 | 16.0 | 24.0 |
| 49.5 | -40.5 | -11.1 | -5.3 | 16.5 | 26.6 |
| 41.5 | -35.7 | -10.6 | -4.8 | 15.0 | 21.8 |
| 29.7 | -26.6 | -6.8 | -2.1 | 13.4 | 21.9 |
| 19.9 | -18.7 | -3.7 | -0.6 | 10.7 | 19.2 |
| 14.9 | -13.9 | -2.7 | -0.6 | 8.5 | 16.0 |
| 9.9 | -9.6 | -2.1 | 0.0 | 5.9 | 11.2 |
| 4.9 | -5.9 | -1.1 | -1.1 | 1.1 | 4.2 |
| 0.0 | 0.5 | 1.1 | 0.0 | 0.0 | 0.5 |

(i)

| | Δstress(a) | | (MPa) | | |
|---|---|---|---|---|---|
| I**2 | 17 | 28 | 38 | 61 | 90 |
| 0.0 | 0 | 0 | 0 | 0 | 0 |
| 2.5 | -0.33 | 0.23 | 0.13 | 0.46 | 0.66 |
| 4.9 | -0.51 | 0.28 | 0.26 | 0.94 | 1.48 |
| 7.4 | -1.33 | -0.42 | -0.33 | 0.78 | 1.43 |
| 9.9 | -1.64 | -0.07 | 0.34 | 1.90 | 2.99 |
| 12.3 | -1.32 | 0.44 | 0.87 | 2.42 | 3.73 |
| 14.9 | -1.62 | 0.58 | 1.01 | 2.90 | 4.32 |
| 17.3 | -1.99 | 0.55 | 0.97 | 3.18 | 4.84 |
| 19.9 | -2.17 | 0.71 | 1.37 | 3.79 | 5.66 |
| 24.5 | -2.44 | 1.00 | 1.76 | 4.62 | 6.61 |
| 29.7 | -2.83 | 1.25 | 2.12 | 5.22 | 7.08 |
| 34.2 | -3.26 | 1.28 | 2.25 | 5.91 | 7.55 |
| 41.5 | -3.72 | 1.46 | 2.56 | 6.63 | 8.06 |
| 44.1 | -3.86 | 1.57 | 2.98 | 7.18 | 8.83 |
| 49.5 | -4.12 | 1.97 | 3.17 | 7.68 | 9.77 |
| 41.5 | -3.80 | 1.40 | 2.60 | 6.69 | 8.10 |
| 29.7 | -2.95 | 1.15 | 2.13 | 5.33 | 7.09 |
| 19.9 | -2.12 | 0.99 | 1.63 | 3.97 | 5.73 |
| 14.9 | -1.61 | 0.70 | 1.14 | 3.02 | 4.58 |
| 9.9 | -1.13 | 0.43 | 0.86 | 2.08 | 3.18 |
| 4.9 | -0.74 | 0.25 | 0.25 | 0.71 | 1.35 |
| 0.0 | 0.13 | 0.25 | 0.02 | 0.02 | 0.13 |

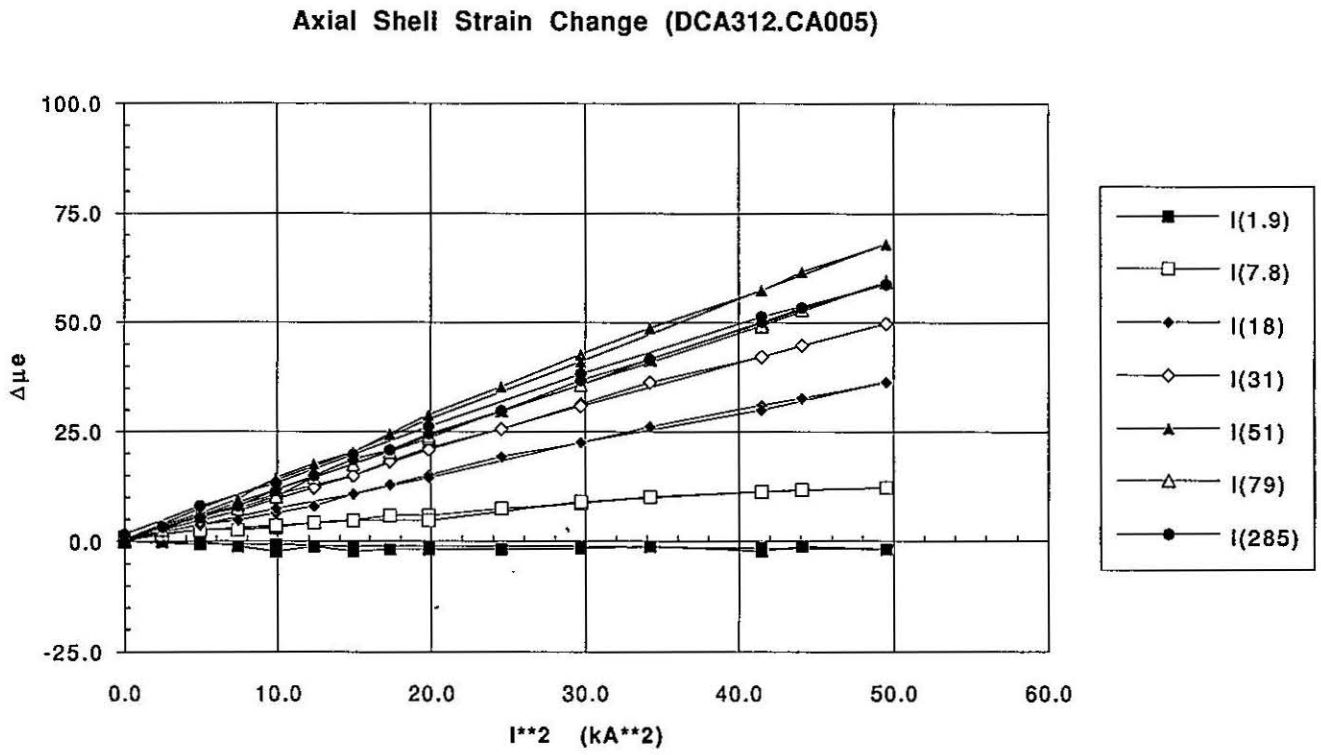


Figure 1

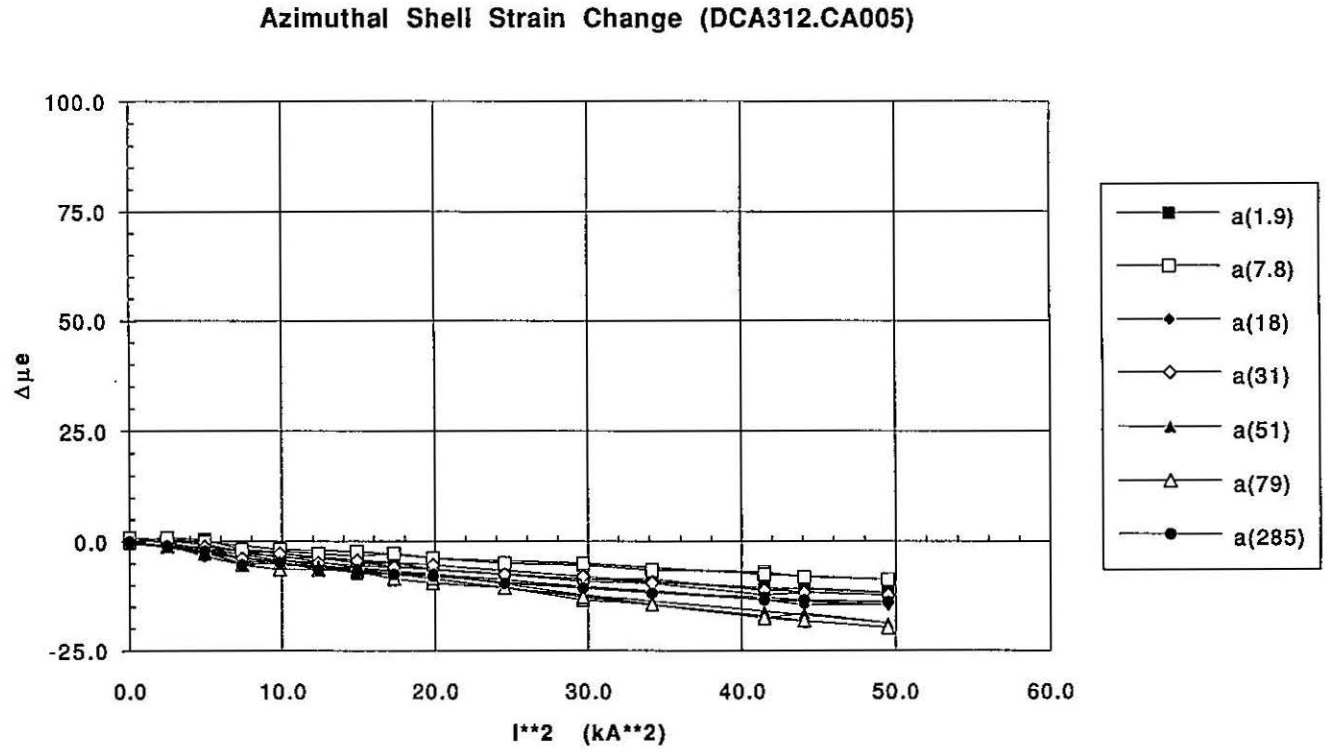


Figure 2

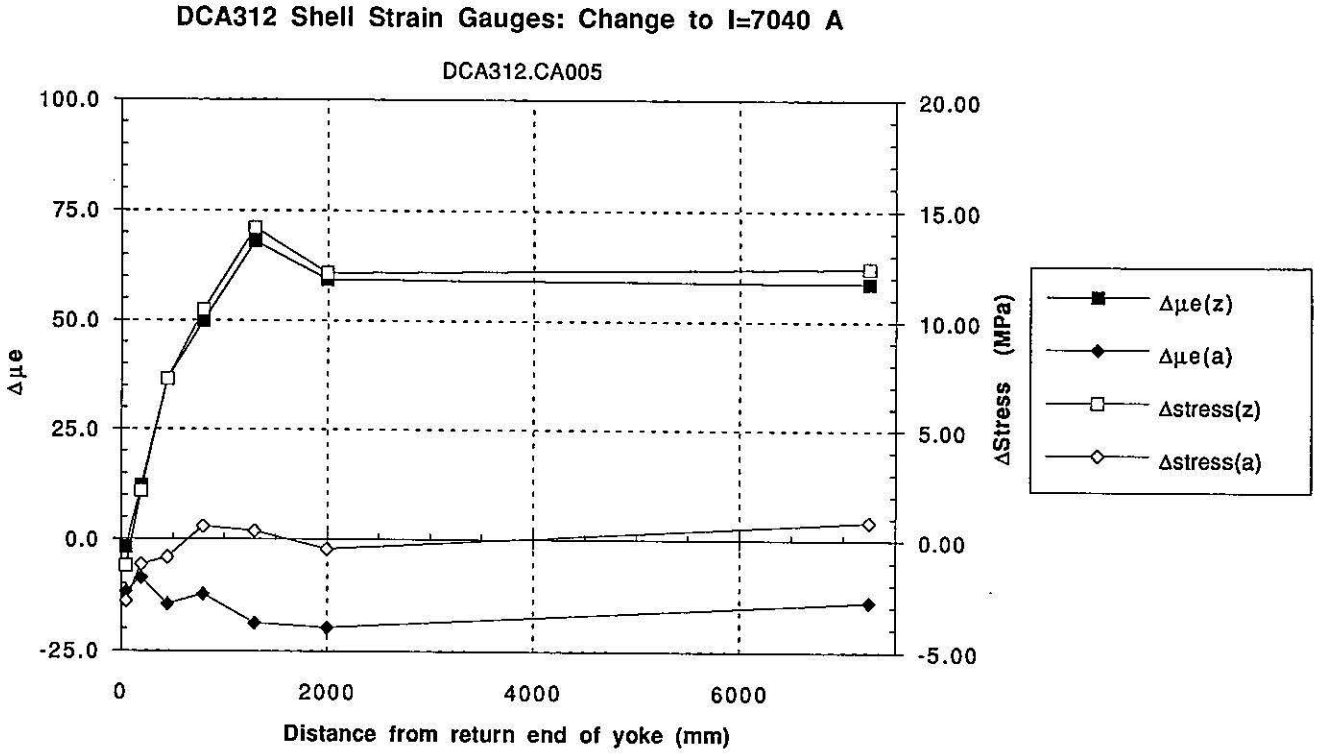


Figure 3

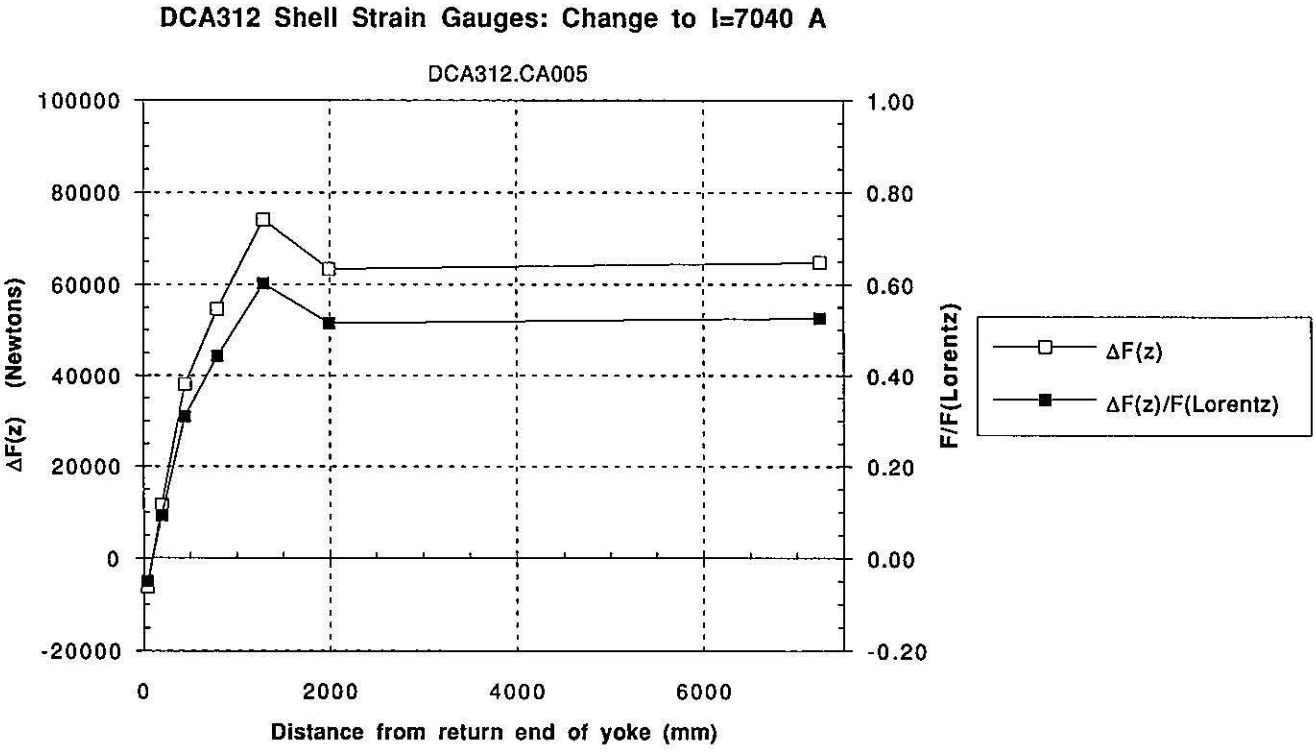


Figure 4

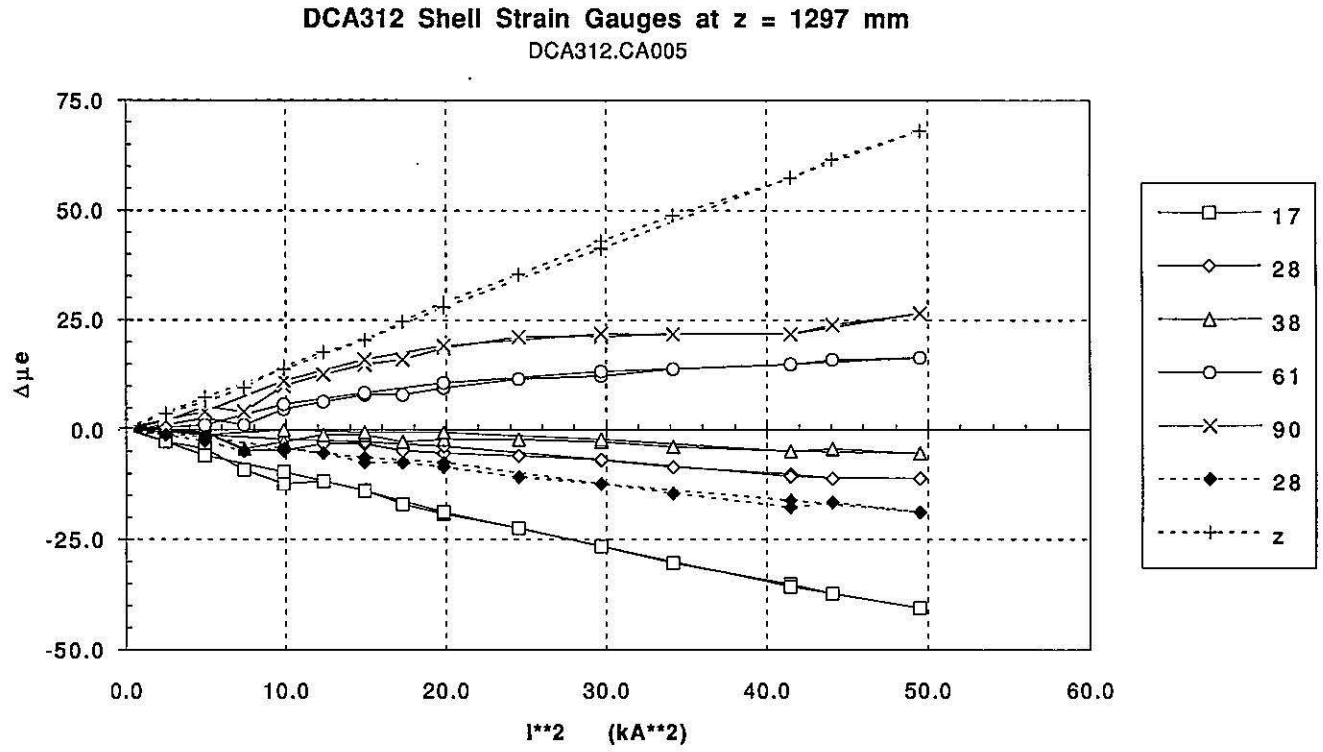


Figure 5

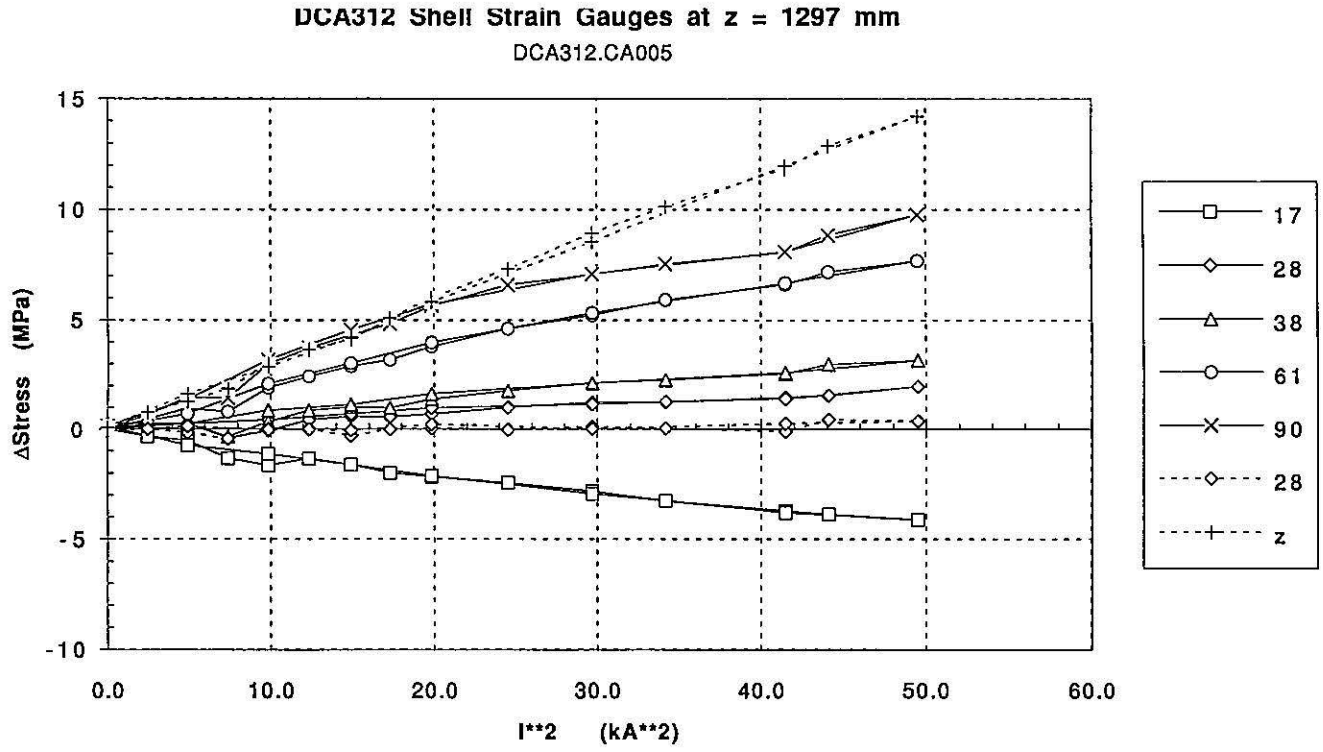


Figure 6

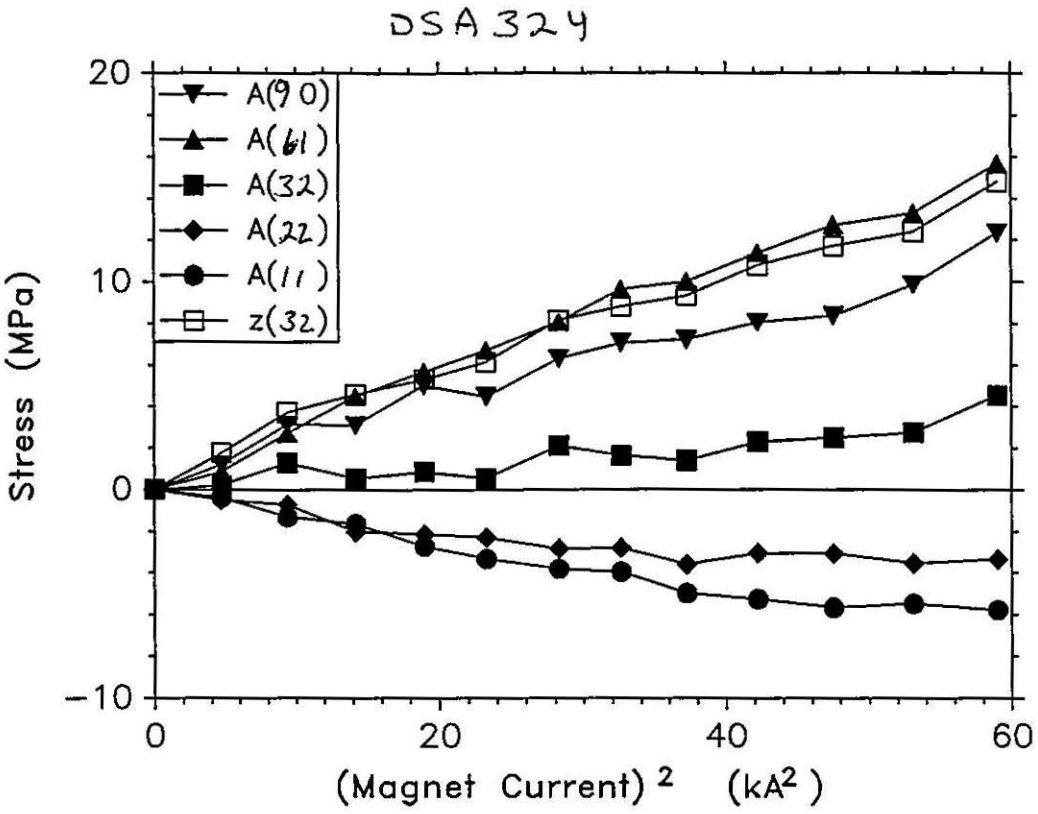


Figure 7

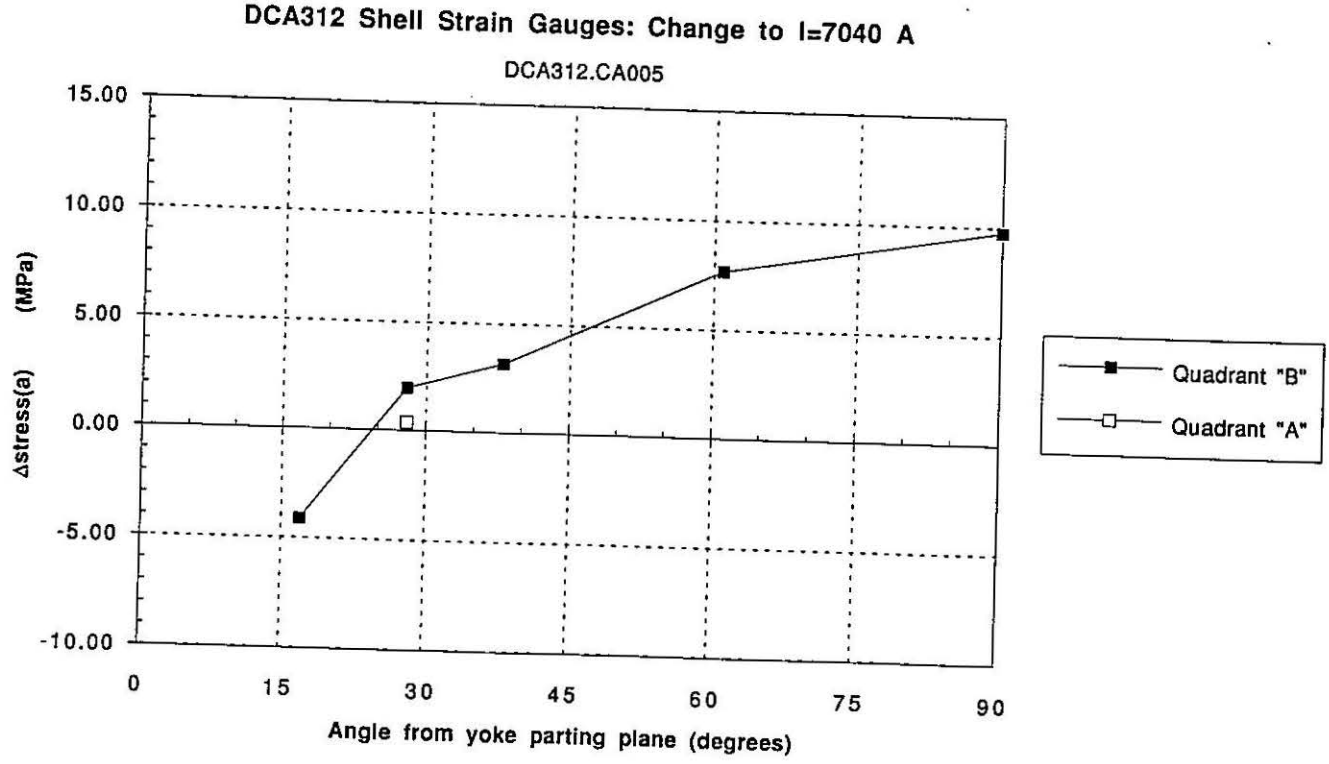


Figure 8