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DSS6 Retest With Shims Between Collars And Yoke

C. Goodzeit and P. Wanderer

April 4, 1988

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SUMMARY.

Following the initial successful test of DSS6, the collared coil was reassembled the same way as the 17m magnets DD12 and DD14. (Shims filled the gap between the collars and yoke; the shell surrounding the yoke was welded.) The reassembled magnet, DSS6R, was tested to check that the magnet performance was not affected by the reassembly. No retraining was required to reach the quench current values achieved by DSS6, the highest being 7.5T at 3.5K. (Since only the central 6" were uncollared during the reassembly, there was a chance the magnet remembered its previous training.) Later, the magnet trained to an 8.0T plateau in two quenches.

When magnets are energized, the azimuthal prestress decreases. In DSS6R, the decrease was only half that seen in DSS6. Two aspects of the multipole data were of interest: The reassembly eliminated a 0.5 unit variation of the skew quadrupole seen at high current in DSS6. The change in sextupole with time was found to be remarkably small.

AZIMUTHAL AND END PLATE STRAIN GAUGE SUMMARY

The only azimuthal coil gauges that were available for the DSS6 retest were the original inner coil gauges from the first test. These beams were made by machining on a milling machine and therefore had a slight initial curvature. We have since learned that the beams must be free from initial stresses and as flat as possible to achieve accurate results and, therefore, all beams are now fabricated by the EDM process. The improvement in beam calibrations by using the EDM process can be shown by reference to Figures 1 and 2 which are the liquid helium temperature calibrations of the original beams used in DSS6 and the newer EDM'd beams that are used in DD015. It can be seen that the EDM'd beams have a much tighter calibration group. On the basis of this comparison it, is thought that DSS6 beam 70901-8 has the best calibration since it falls nicely in the group of beams for DD015. Thus, this beam will be used for stress comparison results between the initial test and the retest.

A comparison of the coil stresses and end force changes between the initial test of this magnet in October 1987 and the present test is shown in Table I. The most noticeable difference was in the change in the inner coil stress when the magnet was powered to 7000 A. Using gauge #70901-8 as representing the most reliable data, the Lorentz force change was only about half of what is was in the previous test. There were less differences in the end force change and cool down prestress loss. However, the direction of these changes were consistent with the effect of the shell shrinkage clamping the collared coil in the yoke.

A detailed comparison of the inner coil stress vs. current response is shown in Figure 3 with the gauge #70901-8 normalized to the same starting stress. The lesser response to the azimuthal Lorentz force during the retest could be attributed in part to the stiffening effect on the collared coil of being clamped in the yoke. Since the horizontal component of the Lorentz force is about 4000 lbs/in at 6.6 T, the collared coil assembly would be expected to have an *outward radial deflection* at the *midplane* (i.e., *the collared coil would become egg shaped*) if the collars were not clamped in the yoke as in the initial test of this magnet. A preliminary finite element analysis of the effect of this horizontal load on the deflection of collars indicated that the Lorentz force loading would produce a horizontal collar deflection of about .002 inch. In order to estimate this effect on the polar stress of the inner coil, a finite element analysis was made of an inner coil subjected to a horizontal displacement of .002 inch at the midplane. The result of this analysis is shown in Figure 4. In order to deflect the coil the .002 inches at the mid plane, internal forces are present which produce a combined bending moment and direct tensile force at the pole. In this case, the average stress at the pole from the coil shape change is 1686 psi in tension which would cause a reduction of this amount in the compressive prestress. Thus, by the principle of superposition, *this effect would be present if the coil undergoes an egg shaped deformation* under the action of the Lorentz force and therefore, more compressive prestress is lost if the collared coil is allowed to deflect in this manner.

The other effect that could produce less of a change in coil stress from the azimuthal Lorentz force for the case of the retested magnet is the closure of the midplane gap between the yoke halves as the magnetic field increases in the iron. The effect has been calculated by Morgan[1] and found to be about 2700 lbs. per inch pulling the two halves of the yoke together. If this force is applied to the ~1.54 sq. inches of coil area, the effect would be an increase in average compressive stress of about 1750 psi. Thus, if these two effects were taken into consideration they could account for about a 3000 psi difference in the Lorentz force effects in the two magnet tests.

The other detailed comparison between the two tests is the end force change as shown in Figure 5 and amounts to about 400 lbs. less end force as seen by the end plates at 7000 A in the retest. Since the DSS magnets coils are approximately 9 times stiffer in the axial direction that the full length dipole coils most of the axial Lorentz force is taken up by the coils rather than being transmitted to the end plates. Thus, we may see a more significant difference in the long magnet axial response with the clamped collared coil type of construction as embodied in magnets DD012 and DD014 than was seen in DSS6. (Note: Data for strain gauges mounted on the S.S. shell have been discussed elsewhere[1].)

QUENCH RESULTS.

When DSS6 was tested, little training was needed to reach the short-sample limits at 4.5K, 4.0K, and 3.5K (Fig. 6). Also, no retraining was needed after the thermal cycle. During the reassembly, the only part of the coil which was uncollared was a 6″ section in the center which contained the strain gauge collar pack. Thus, the DSS6R quench plot (Fig. 7), which looks even better than that of DSS6, is probably due the good "memory" of the collared coil[2,3].

In order to have some test of training in DSS6R, the helium temperature was lowered to 3.0K, 0.5K below the lowest temperature used in testing DSS6. The magnet required 2 quenches to train from the plateau field at 3.5K, 7.5T, to plateau at 3.0K, 8.0T.

MULTIPOLES.

A complete set of multipoles from DSS6R, compared with those of DSS6, are given in a separate report[4]. Within tenths of a unit, the results are the same, with two exceptions (Fig. 8):

(1) The sextupoles of the magnets differ slightly. Due to the shims, there is a small gap between the upper and lower halves of the yoke. The sextupole would be the first term affected by this symmetric change in magnet construction.

(2) In DSS6, the skew quadrupole increased 0.5 unit between 2T and 6.2T, with most of the increase coming above 5T[5]. The change with current is absent in DSS6R. A reasonable supposition is that the shims prevent the small motion of the collared coil in the yoke which could have produced the change in DSS6. (The quadrupole terms change approximately 0.4 units per mil of displacement of the collared coil.)

With DSS6R, two improvements in the measurement of sextupole with time were implemented. First, the measurement of the central 30″ was made with an improved measuring coil. (The Litz wire in the tangential coil was replaced with solid wire, reducing pickup.) Second, the magnet was quenched before the AC cycle in order to obtain a reproducible history. The results (Fig. 9) indicate remarkably little variation in both the magnet and the measuring coil system with time, after the initial measurement at t=0. The time between measurements was 228 seconds with the first measurement thought to have been made within a few seconds of the time the magnet reached 320A. The change in the measured value of b_2 over the hour of data-taking was a few hundredths of a unit. This is much smaller than measurements on two previous DSS magnets, which were NOT preceded by a quench. These showed changes in b_2 in the range 0.3 to 1 unit over an hour. The history-dependence of these measurements precludes making direct comparisons between the different magnets. The conductor in DSS6 was cable SI49 (SC353) and SO72 (SC348), with 5 micron filaments, double-extruded, from Oxford.

Footnotes

[1] R Schermer, memo dated 2/11/88.

[2] P. Wanderer, "Quench Performance and Multipoles of DSS6", report AD/SSC/Tech. Note. No. 66 (SSC-N-416).

[3] The variation in quench current at 4.0 K before the thermal cycle has been traced to a variation in helium temperature.

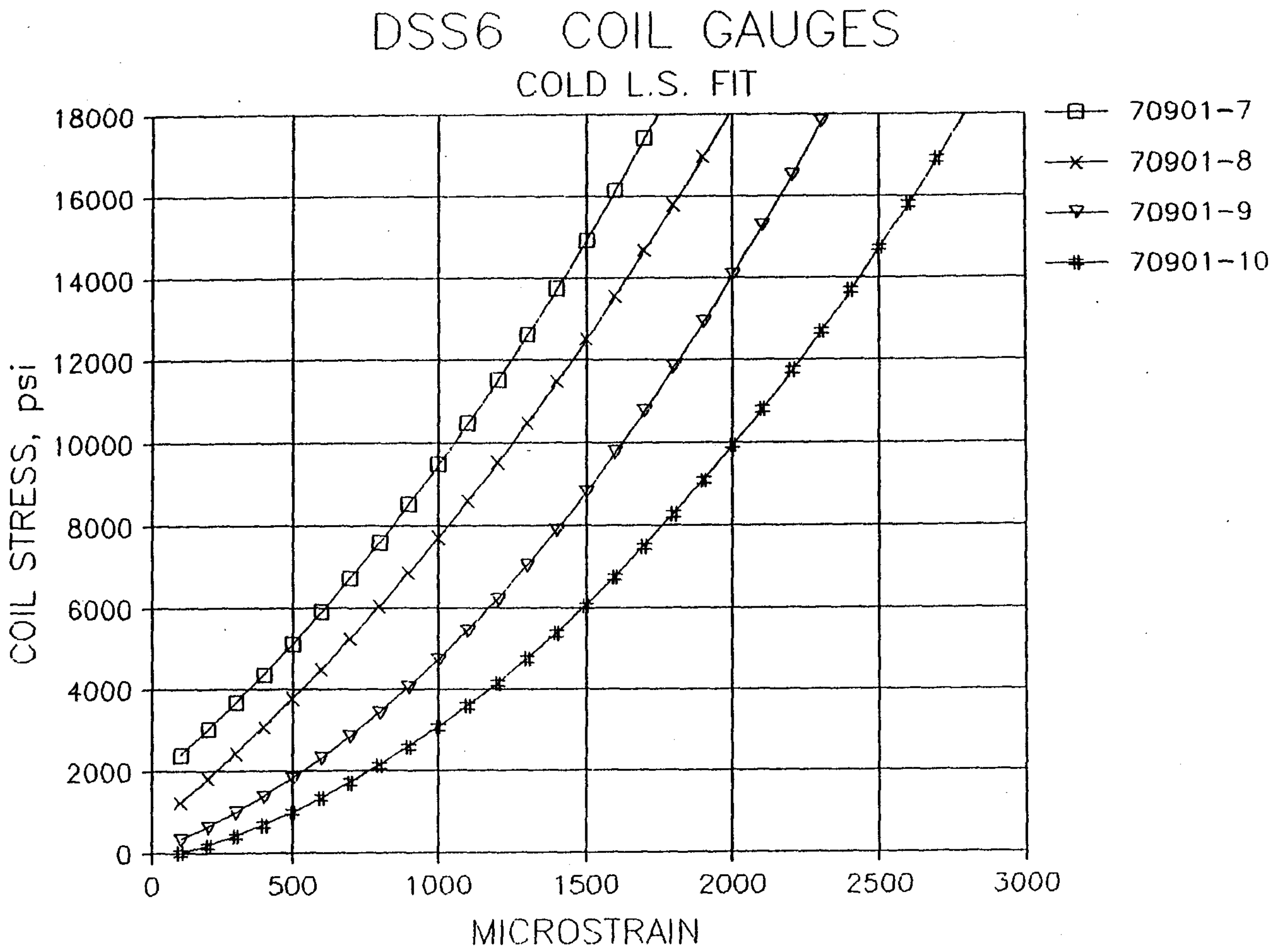
[4] MTG note, to be done

[5] TMG370

TABLE I

INNER COIL STRESS DATA USING GAUGE #70901-8

	INITIAL TEST		RETEST WITH SHIMS			
	RUN1	RUN2*	RUN1	RUN2	RUN3	RUN4
LOSS OF INNER COIL STRESS @ 7000A, PSI	6417		3322	3306	3452	3324
INCREASE IN END FORCE @ 7000A, LBS.	1491	1465	743	1145	821	1470
DELTA END FORCE @ 0 AMPS	-15		-118			
INNER COIL COOLDOWN LOSS, PSI	-2279		-1798	-2052		



DSS6 COIL GAUGES
COLD L.S. FIT
COIL STRESS, psi
MICROSTRAIN
70901-7
70901-8
70901-9
70901-10
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
500
1000
1500
2000
2500
3000

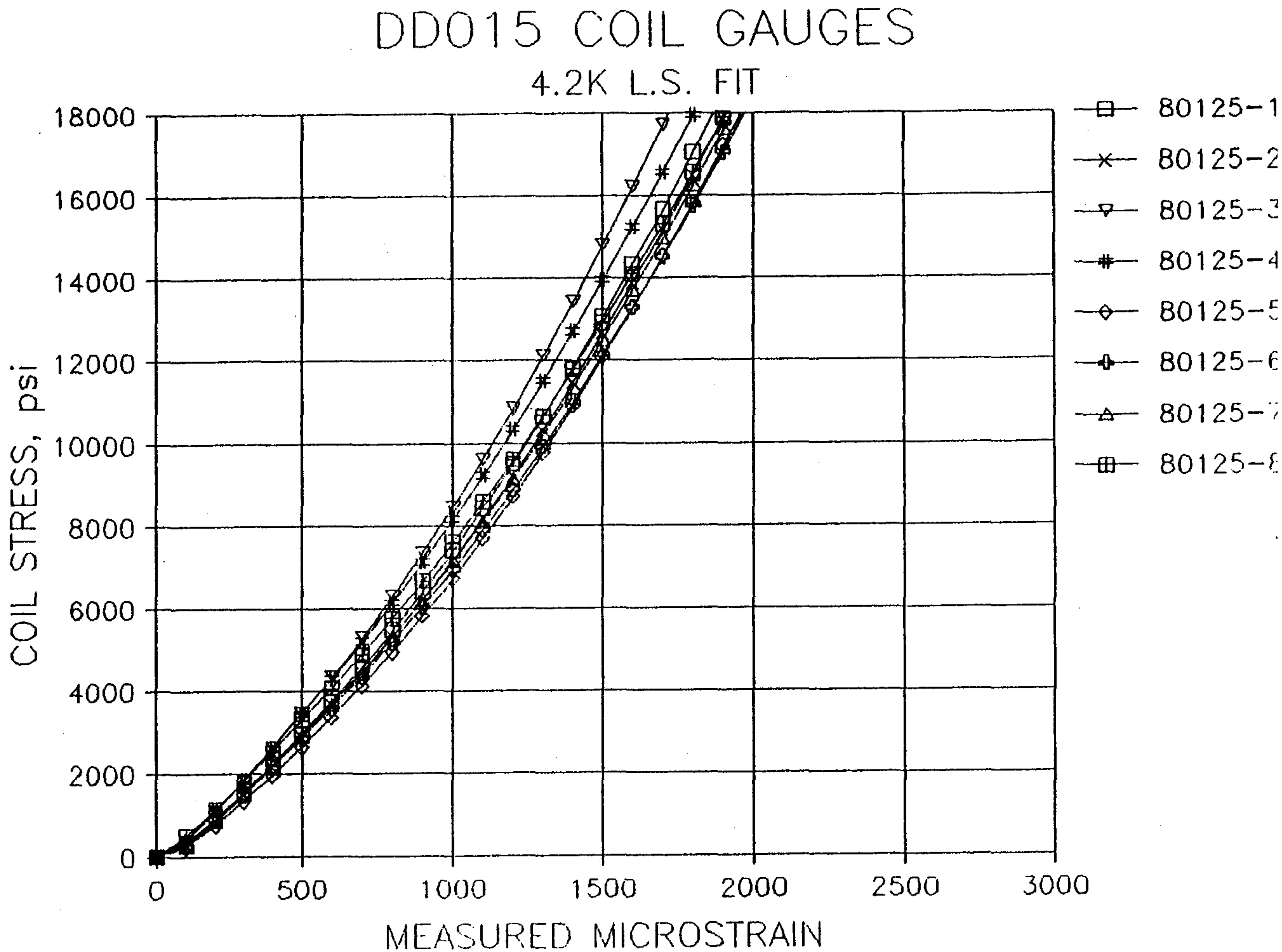
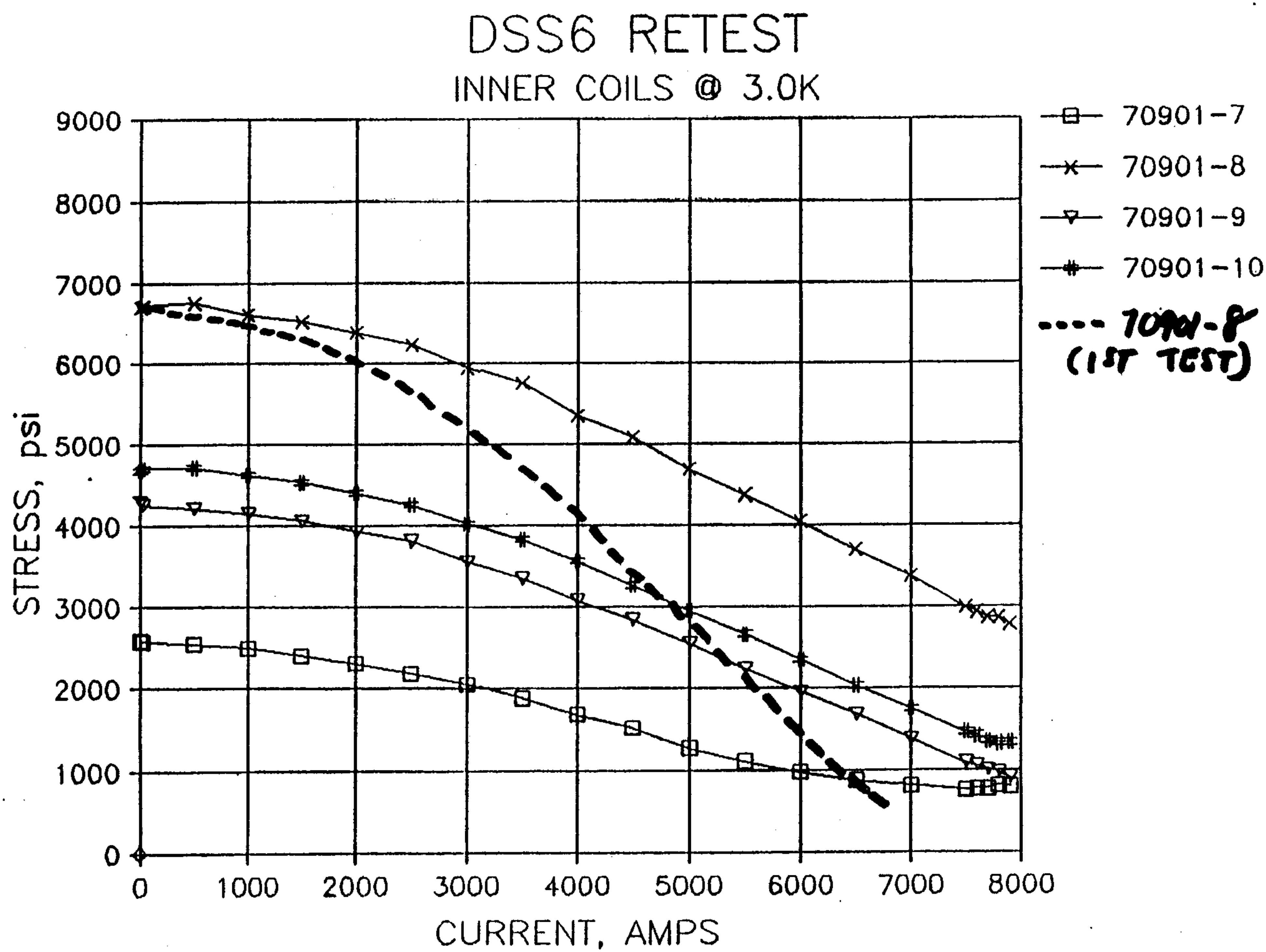
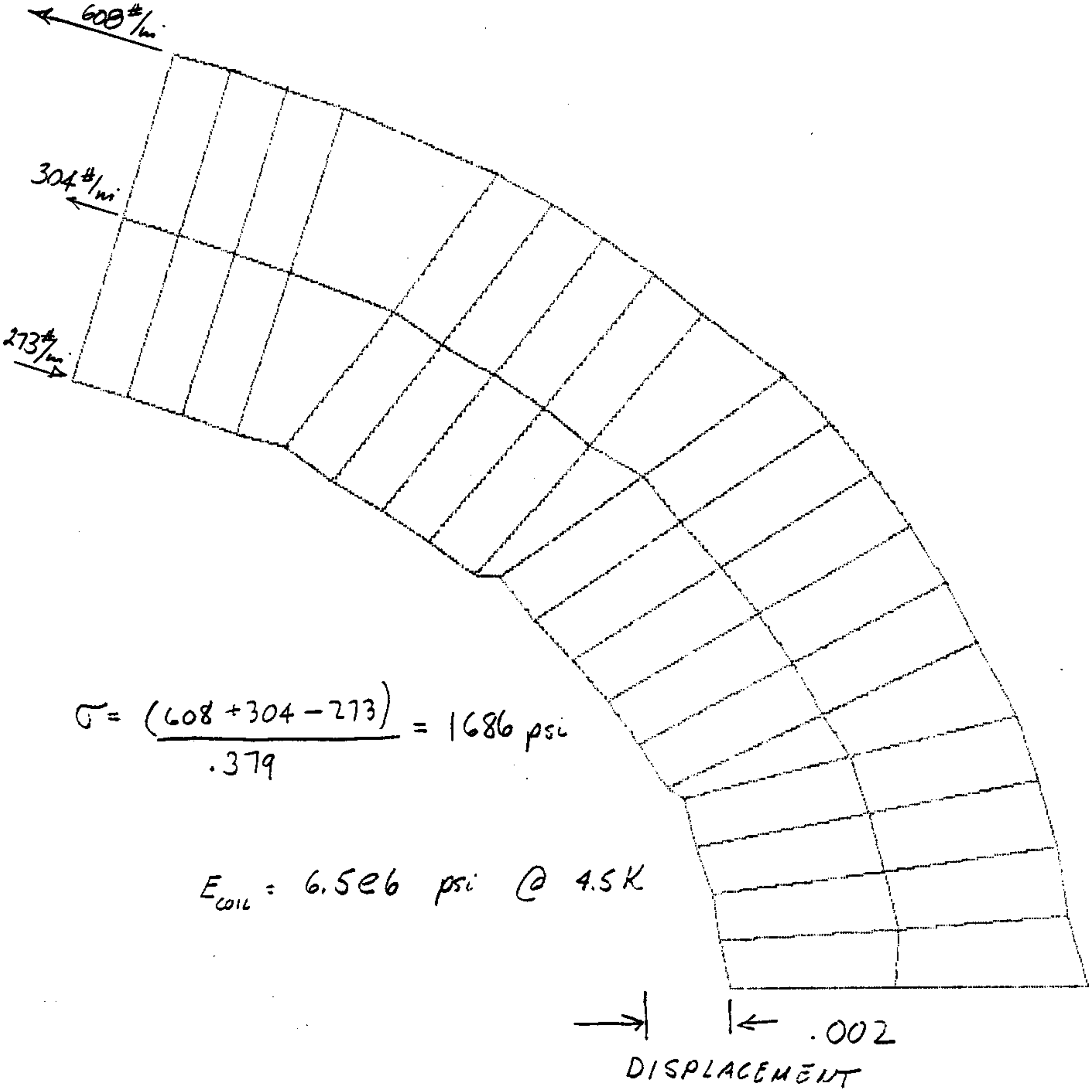

DD015 COIL GAUGES
4.2K L.S. FIT
COIL STRESS, psi
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
500
1000
1500
2000
2500
3000
MEASURED MICROSTRAIN
80125-1
80125-2
80125-3
80125-4
80125-5
80125-6
80125-7
80125-8

Fig. 2

Fig. 3


DSS6 RETEST
INNER COILS @ 3.0K
STRESS, psi
CURRENT, AMPS
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
70901-7
70901-8
70901-9
70901-10
70901-8 (1ST TEST)



$$\sigma = \frac{(608 + 304 - 273)}{.379} = 1686 \text{ psi}$$

$$E_{coil} = 6.5e6 \text{ psi @ } 4.5K$$

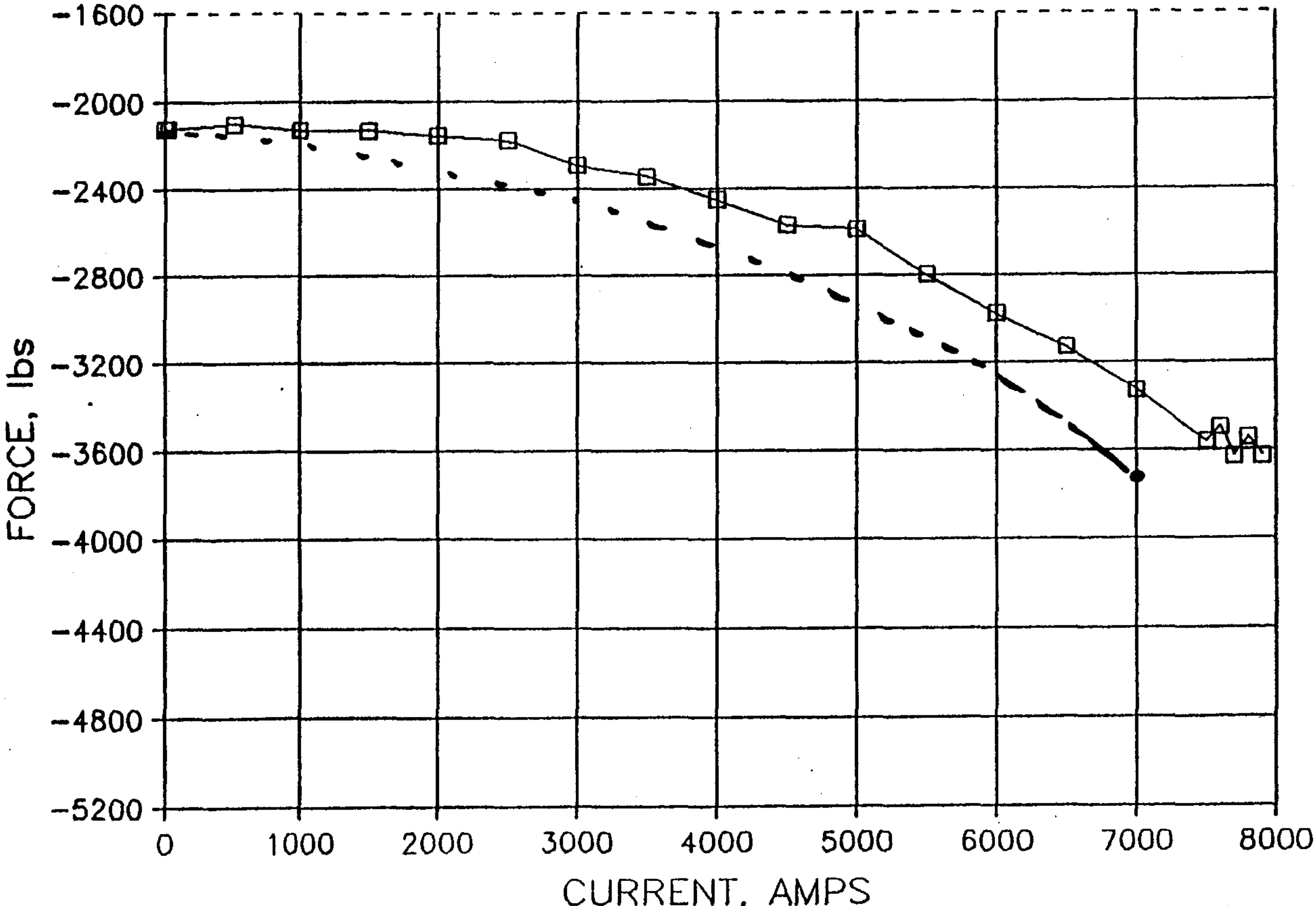
C358A INNER COIL
C358A INNER COIL
@

Fig. 4

---- (1ST TEST)

DSS6 RETEST

END FORCE vs CURRENT (@ 3.0K)



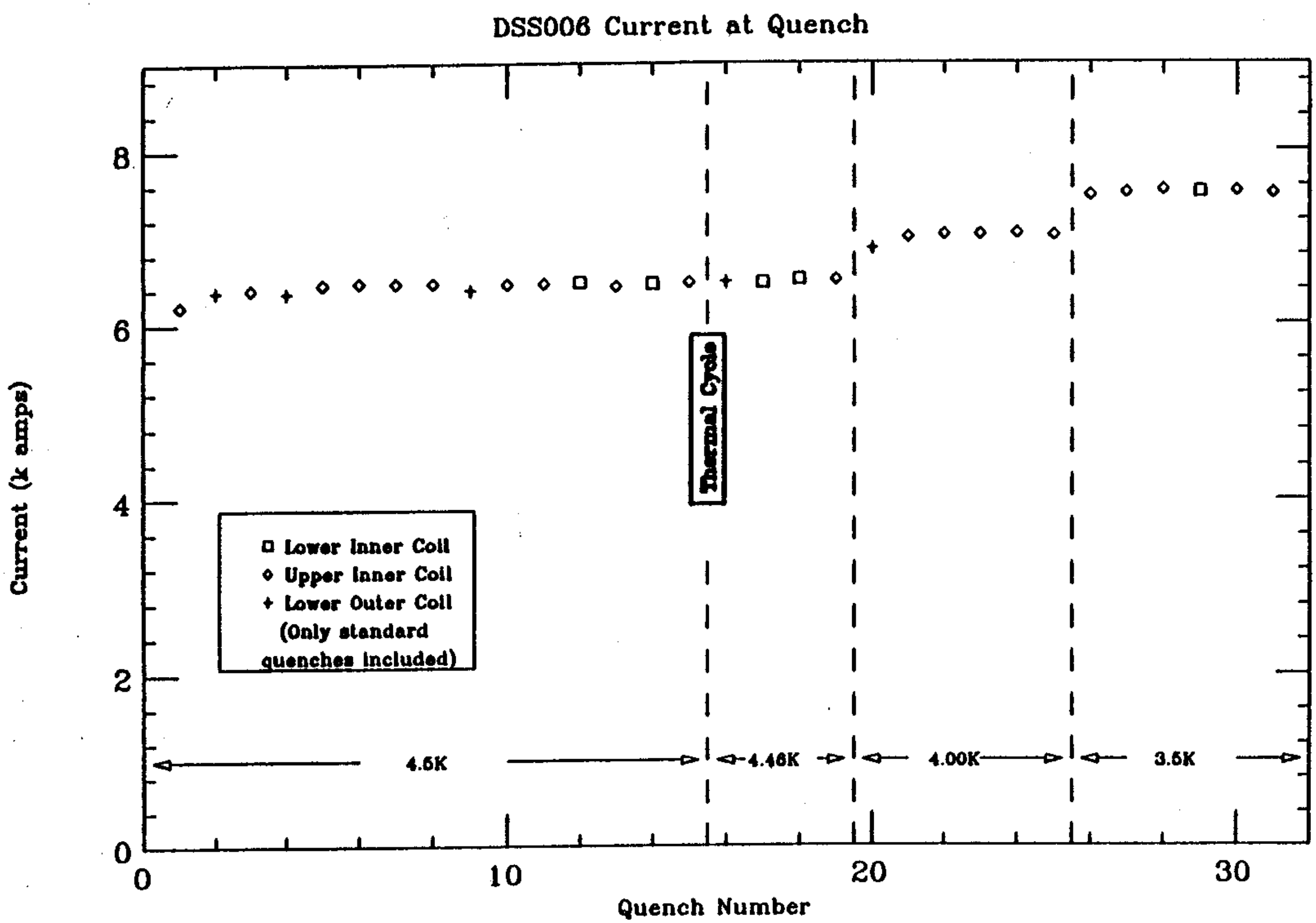
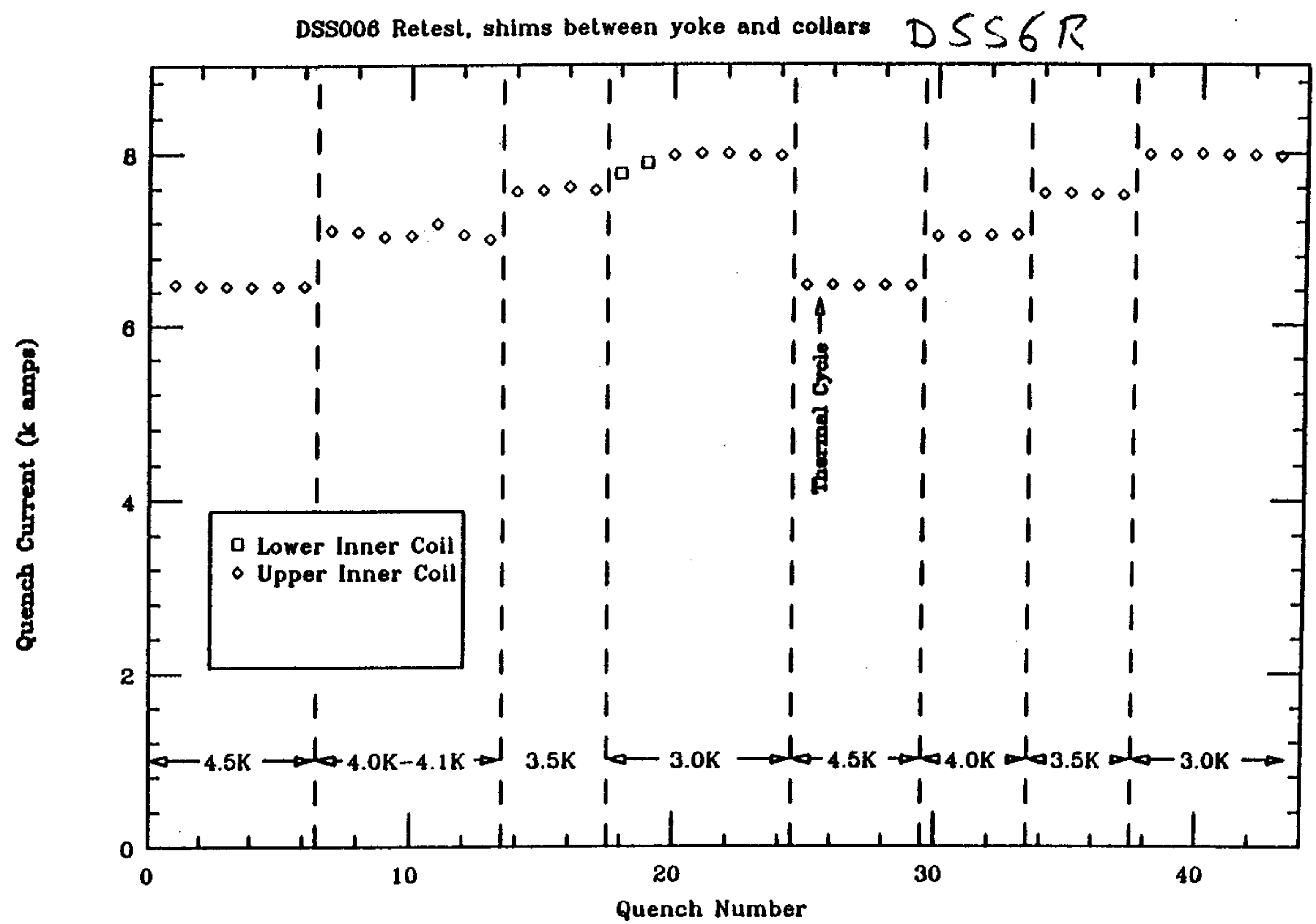

DSS006 Current at Quench
Current (k amps)
Quench Number
0
2
4
6
8
0
10
20
30
Thermal Cycle
4.5K
4.46K
4.00K
3.5K
Lower Inner Coil
Upper Inner Coil
Lower Outer Coil
(Only standard
quenches included)

Fig. 6



DSS006 Retest, shims between yoke and collars
DSS6R
Lower Inner Coil
Upper Inner Coil
Thermal Cycle
4.5K
4.0K–4.1K
3.5K
3.0K
4.5K
4.0K
3.5K
3.0K
Quench Current (k amps)
Quench Number
0
2
4
6
8
0
10
20
30
40

Fig. 7

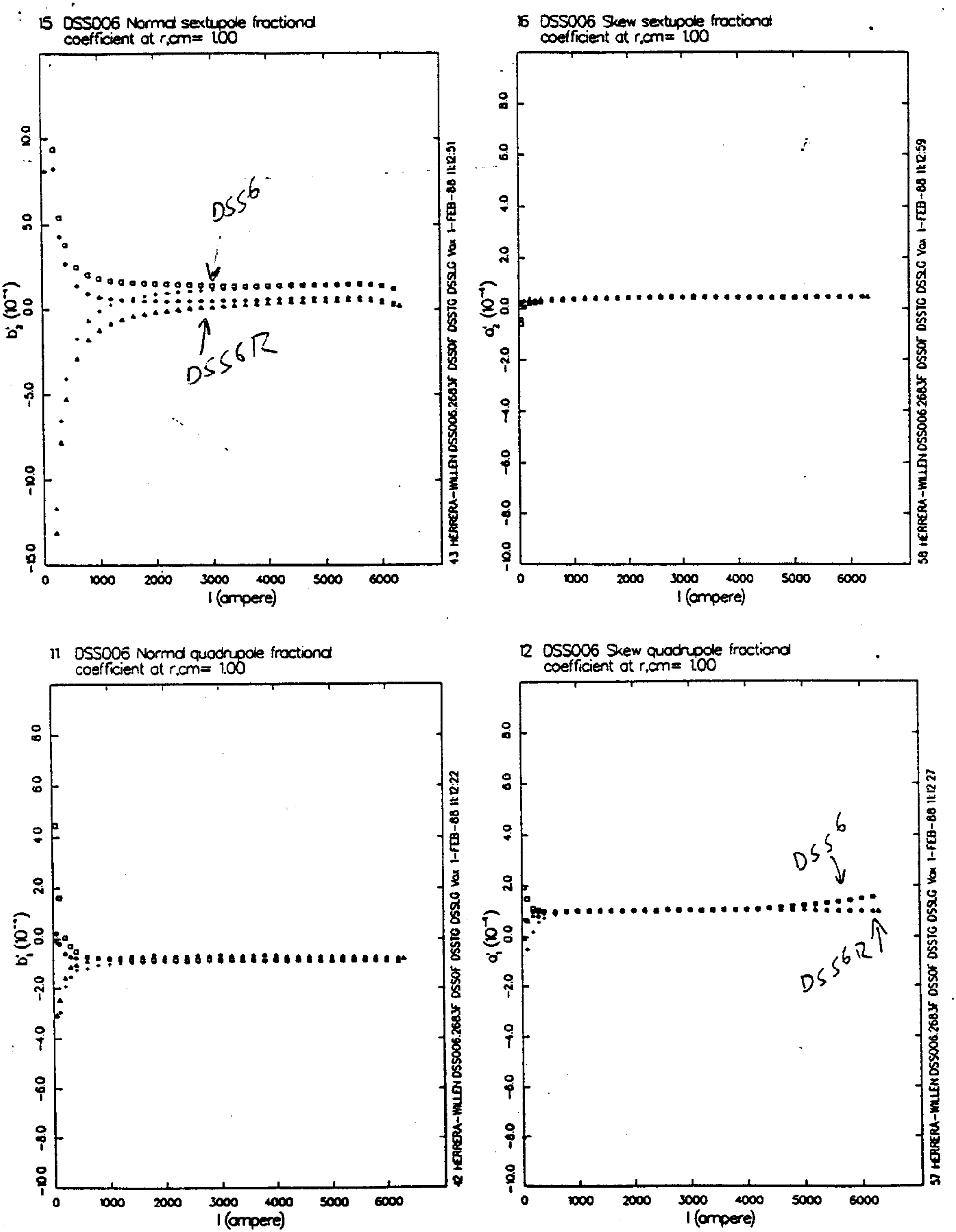

15 DSS006 Normal sextupole fractional coefficient at r,cm= 1.00
b'2 (10^-4)
I (ampere)
DSS6
DSS6R
43 HERRERA-WILLEN DSS006.2683F DSS0F DSSTG DSSLG Vax 1-FEB-88 11:12:51
16 DSS006 Skew sextupole fractional coefficient at r,cm= 1.00
a'2 (10^-4)
I (ampere)
58 HERRERA-WILLEN DSS006.2683F DSS0F DSSTG DSSLG Vax 1-FEB-88 11:12:59
11 DSS006 Normal quadrupole fractional coefficient at r,cm= 1.00
b'1 (10^-4)
I (ampere)
42 HERRERA-WILLEN DSS006.2683F DSS0F DSSTG DSSLG Vax 1-FEB-88 11:12:22
12 DSS006 Skew quadrupole fractional coefficient at r,cm= 1.00
a'1 (10^-4)
I (ampere)
DSS6
DSS6R
57 HERRERA-WILLEN DSS006.2683F DSS0F DSSTG DSSLG Vax 1-FEB-88 11:12:27

Fig. 8

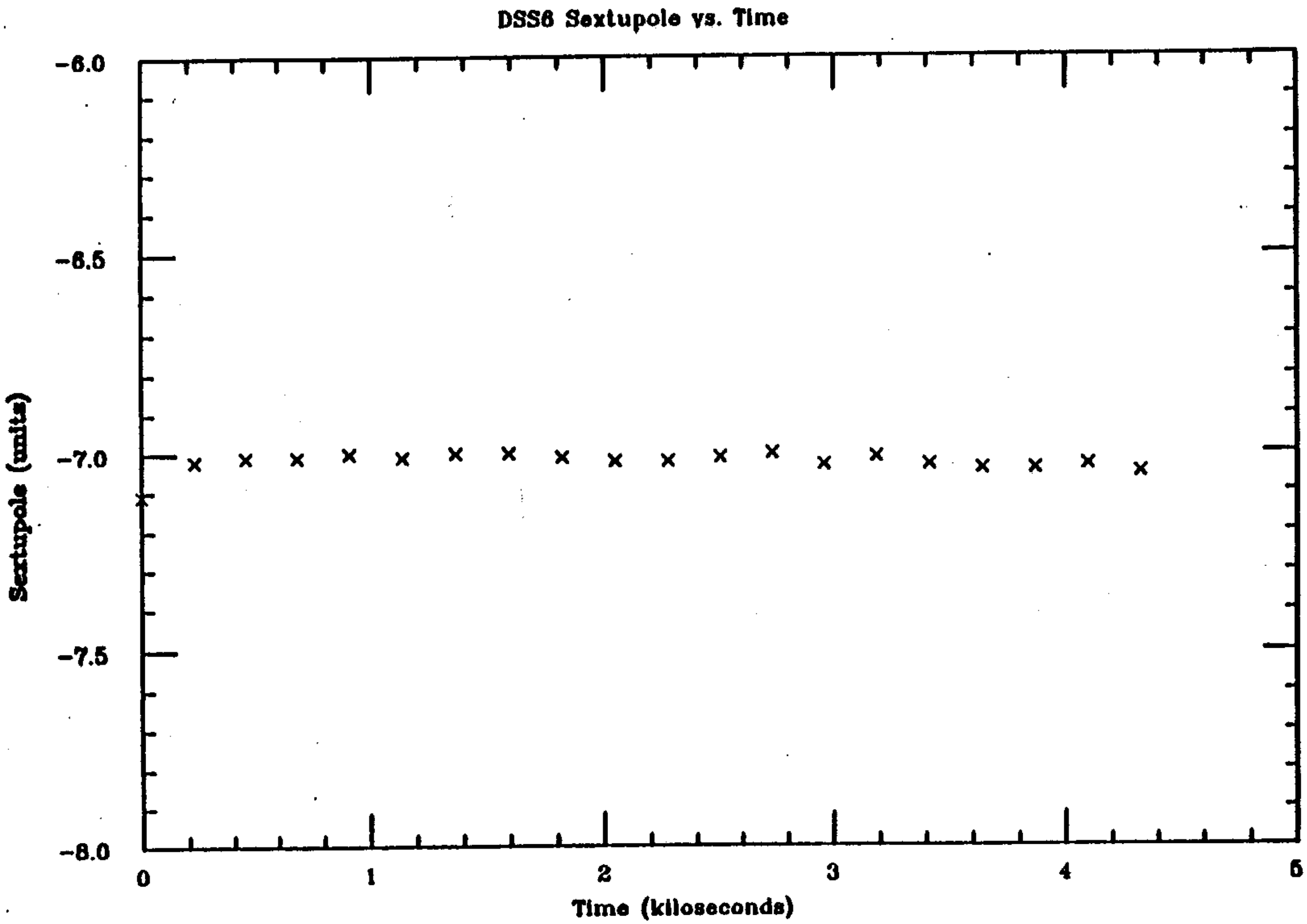


Fig. 9

History: Quench (6.5kA), cycle to 5.3kA, wait 8 min. at 25A idle current, ramp to 320A, hold constant current, measure. (4.5K, 8A/sec ramps, cable SI49, 5 micron filaments)

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