Accelerator Development Department

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CONSTRUCTION AND TEST OF 1.8 m DIPOLE DSS10

C. Goodzeit, B. McDowell, P. Wanderer

April 28, 1988

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SUMMARY.

This magnet is the second tested with shims between the collars and yoke. Principal construction features also include a welded shell, 3/4″-thick split end plates, tapered keys, and improved coil end molding. The cable used for the inner coil had 1.57:1 Cu:SC ratio and 20 micron filaments. The outer coil conductor had 6 micron filaments. During assembly, the coils were subjected to much higher pressures than planned. Also, in the upper coil half, the splice between the inner and outer coils was incorrectly positioned.

When tested at 4.5 K, the magnet trained in three quenches to a plateau quench current of 6.51 kA (about 5% over the value calculated from the short-sample measurement) and did not have to be retrained after a thermal cycle. At 4.0 K it trained quite slowly to higher fields, with the quenches originating simultaneously in the inner and outer layers of the upper half coil. (Normally, quenches originate only in the inner coil.) The multipoles were small.

When the magnet was disassembled after test, the G10 assembly which held the upper coil splice was found to be out of position and cracked along a line of high stress. Presumably this caused the slow training and unusual quench origin seen at 4.0 K. Also, the yoke blocks had moved axially during the test.

STRAIN GAUGE RESULTS

The beam type strain gauge transducers for measuring the azimuthal coil stress were were fabricated by the EDM process. The strain gauge type used for these beams was WK-09-125AD-350 which is compensated at room temperature to match the thermal expansion of stainless steel. Six compensating gauges of the same type were mounted in the strain gauge collar pack. The room temperature and 4.2 K calibrations for the azimuthal gauges are shown Figures 1 & 2. The were no end force or "bullet" type gauges assembled into this magnet.

The collaring of this magnet did not proceed in a straightforward manner. This is explained with reference to Figure 3 which shows the inner coil azimuthal stress and the applied vertical hydraulic pressure during the collaring process which occurred on Feb. 4 & 5. This assembly was with the tapered key collars. The vertical hydraulic pressure was applied to ~4500 psi (Step 1) and then reduced while the side hydraulic pressure (not shown) was raised to ~2000 psi. to engage the tapered keys. (Steps 2-3). However, the keys did not engage because the side hydraulic cylinders bottomed out at the point where the key started to enter the collars. Some shims were prepared to back up the keys and the side pressure was reinstated (Step 4-5); however, the vertical pressure inadvertently remain on during this time and the coils were overcompressed to the 18-20 kpsi range as shown. The side keys were, however, installed and the inner coil prestress remained at the rather high level of ~12,000 psi.The corresponding collaring history fore the outer coils is show in Figure 4.

The first significant measurement with the azimuthal gauges was the loss in compressive stress in the inner and outer coils from room temperature to ~4.4 deg. K. The azimuthal gauge measurements indicated that the inner coils lost 6925 psi while the outer coils lost 2652 psi. Although the stress loss in the outer coils appeared somewhat high but not inconsistent with calculations and measurements on other magnets, the rather large stress loss in the inner coils is not typical since measurements on DSS6 showed a loss about 1800 psi. in the inner coils for the retested magnet and a loss of ~2300 psi in the inner coils for the initial test. It was thought at first that the large cooldown stress measurement change for the inner coils was due to yielding of the inner coil beam transducer during the overpressure phase in the collaring operation. However, this was subsequently shown not to be the case.

Some data was obtained during this test of the change in coil stress with excitation current up to 6400 A. as shown in Figure 6 for the inner coils. The average stress decrease at 6400 A. was 1438 psi. As a comparison, in the retest of DSS6, the average inner coil stress dropped by ~2400 psi. at the same current. The outer coil stress change for this case was 681 psi (there were no outer coil strain gauge transducers in the retest of DSS6).

The azimuthal coil stress was monitored during the warmup and disassembly of this magnet. The average values of the inner and outer coil stresses for this period are shown in Figure 7. The magnet was initially warmed up in the test dewar with warm helium gas in step 1-2. The temperature rose to ~120 deg. F in the dewar during this time. Thus, on Mar. 9, when the magnet had been removed from the dewar and was at ambient temperature, there was a noticeable loss in coil stress attributed to accelerated creep at the high temperature in the dewar. In step 3, a longitudinal cut was made in the shell after which the coil stress drop was noted indicating that the shell was under circumferential tension and still compressing the coils. The loss in prestress shown is consistent with a tensile stress relief in the shell of about 8500 psi. In steps 5-6 the coil was pressed in the collaring press and the collars were removed. It was noticed that the azimuthal coil gauges all drop to zero stress indicating that there had been no yielding in the inner beams due to the high assembly pressure that was present when this magnet was originally collared.

TRAINING

The training data are plotted in Fig. 8 and given in Table I. The magnet had three training quenches before reaching a stable plateau. The quench current was about 5% greater than the value calculated from the short-sample test; typically, this number is 2% to 3%. The magnet did not retrain when thermally cycled to room temperature, but the quench origin did switch to the other half coil. (The cable for both inner coils came from the same reel, so the switch does not violate short-sample expectations.) Overall the magnet trained well, but not as well as DSS6.

At the next step down in temperature, 4.0 K, the magnet trained slowly over seven quenches. Each of the quenches also showed the unusual characteristic of starting at the same time (within a few ms) in the inner and outer layers of the upper half coil (Fig. 9).

At 4.5 K, the outer layer begins to quench about 15 ms after the inner layer (Fig. 10). If the quenches originated in the inner-outer splice they would appear simultaneously in the inner and outer coils. However, the voltage taps only isolated quarter coils, not individual turns, and other sources of the quenches cannot be ruled out. As is noted elsewhere in this report, the splice was found to be out of position when the magnet was disassembled after testing.

MULTIPOLES.

The magnet was assembled with shims which were consistent with the design size (which has a 1 mil tolerance). The multipoles are consistent with values obtained from the previous five magnets in this series. (Care must be exercised in making comparisons with previous DSS magnets, since the earlier magnets were not built with shims between the yoke and collars.) The allowed multipoles (calculated by averaging up and down ramp data from 2 kA through 3 kA) are given in Table II. The transfer function B/I is lower than previous DSS magnets by 1 to 3 parts in a thousand. This could be due to the gap at the yoke midplane but it is also a difference not large compared to the variations seen in the earlier magnets.

The unallowed terms are obtained by choosing currents where the same-n or next-higher-n allowed terms are small and are both positive and negative. (The procedure is discussed in detail in the writeup on DSS6, SSC-N-416.) The procedure also requires a measuring coil with extremely good short-term reproducibility (0.01 units), so only DSS10 and DSS6 appear in the summary of unallowed terms, Table III. The data are consistent with the SSC tolerances, insofar as one can tell from two magnets.

DISASSEMBLY OF DSS-010

This note summarizes the major observations and conclusions obtained from the disassembly of Magnet DSS-010. [Tables of data taken during disassembly are in a separate Note (SSC-MD-196).]

Upon removal of the outer shell of DSS-010 it was noted that the two end blocks at each end were chevroned inward to the center. In other words, the laminations of the end blocks were displaced in such a manner as to cause an offset of approximately 3/16″ of the base of the lamination toward the center of the magnet relative to the top of that lamination. These displacements were found to be caused by installation of the end bonnets over the shimmed and therefore oversized end blocks.

Strain gauges mounted on the 3/4″ end plates indicated very little residual stress in the end plates. Deflection measurements of the end plates gave no indication of residual load.

Collared coil disassembly unearthed a damaged ramp splice in the upper coil. The two halves of the G-10 splice housing were displaced relative to one another by .047″ on the top and .023″ on the bottom. The nylon screws holding the assembly together were deformed in similar fashion. Upon separating the two halves of the top ramp assembly, one of the halves was noticed to be cracked.

Two unfavorable production events could have contributed to this damage. First, during collaring a different location along the collared coil assembly was overstressed due to a hydraulic malfunction. It is unlikely that this was the cause of the ramp damage but it must be considered for completeness. Secondly, because coil assembly was completed before collars were available, a production step in which the ramp is fitted to the ramp collar pack was omitted. It is believed that a poor fit caused the ramp damage.

Finally, the lower inner coil had poor epoxy impregnation at the end. Many voids and cracks were observed and the end of the coil was spongy when subjected to a firm grasp (Photo CN4-110-88).

QUENCH DATA SUMMARY - MAGNET DSS10

BY PW   DATE 2/24/88 PAGE 1

DSS10 (1.8m)

Quench #	File #	I_Q (A)	B/I ②	B_Q (T)	$\dot{I}$ (A/s)	Temp ① (K)	starting coil	Press. (psi) cntrl room	Press. (psi) W&T	Absol. T	Date	Comment
1	5	5416			8	4.467	U1	19.4	18.8		2/24	
2	6	6064			↓	4.460	L1	19.4			↓	
3	7	6383			↓	4.470	L1	19.6	18.5		2/25	
4	8	6532			↓	4.469	U1	19.6			↓	
5	9	6483			↓	4.496	U1	20.5			↓	
6	10	6493			↓	4.48	U1	20.0			↓	
7	11	6526			↓	4.475	U1	20.3			↓	Herb asked to improve temp. stability
8	12	6525			↓	4.476	U1	19.7			↓	"
9	13	6503			0/8	4.459	U1	19.8	18.7		2/26	Strain gauge run
10	14	6537			32	4.468	U1	19.6			"	
			THERMAL CYCLE									
11	17	6510			8	4.477	L1	20.6	19.1		2/29	
12	18	6508				4.479	L1	19.7			"	
13	19	6507				4.474	L1	19.7	18.4		3/2	
14	20	6484				4.479	L1	20.1			↓	Leads voltage high during ramp ③
15	21	6749				3.997	U ④	13.2	11.6		↓	
16	22	6730				3.996	U ④	13.1			↓	
17	23	6847				3.999	U ④	13.0			↓	
18	24	6859				3.997	U ④	13.0	11.6		3/3	
19	85	6887				3.994	U ④	13.0			↓	
20	26	6967				3.991	U ④	13.0			↓	
21	27	7025				3.991	U ④	13.0			↓	

④ Quench starts in UI & UO simultaneously (±1 to 2 ms).
③ Leads did not start quench, however.
① Temp from top thermometer ② Morgan calc.

TABLE 1

L1 = 30
U1 = 20

DSS ALLOWED MULTIPOLE SUMMARY

PW ~~1/3/87~~ 4-28-88

meas. values (corrected for non-design shim in DSS 2,7,6)

	DSS2	7	4	5	6	10	C358 design
b_2	(-2.9)	(-1.3)	2.5	2.0	3.55	-1.80	-.03
b_4	-.51	-.23	.54	.40	.54	.43	-.03
b_6	-.11	-.22	-.07	-.09	-.07	-.20	0
b_8	+.04	.06	.06	.07	+.04	.04	0
b_{10}	-.08	-.07	.07	.08	-.02	.06	.08
b_{12}	-.02	-.01	-.02	-.02	0	-.01	-.01
B/I	10.448	10.443	10.429	10.429	10.438	10.417	10.426

( ) estimates which include up-dn avg @ <I> = 2.5kA/cetur

① (Rm temp) 10.395 x 1.003 = 10.426 (cold)

TABLE II

DSS MAGNETS - UNALLOWED MULTIPOLES

(measurements with coil 33)

multipole	DSS 6	DSS 10	tolerances avg.	tolerances σ's
a_1	.95	.29	.2	3.3 (0.7)
a_2	.41	.11	.1	.6
a_3	.17	-.44	.2	.7
a_4	.02	-.08	.2	.2
a_5	.06	-.05	-	.2
a_6	.00	-.01	-	.1
a_7	<.02	-.01	-	.2
a_8	<.02	-.01	-	.1
b_1	-1.06	.13	.2	1.6 (0.7)
b_3	-.23	.02	.1	.3
b_5	-.05	-.03	.02	.1
b_7	<.02	-.01	.06	.2

General notes:

① standard 10^{-4} units

② feeddown due to meas. var. $\lesssim 0.02$ units; systematics - unknown (interpolating between pos. & neg. values of allowed multipoles to get unallowed multipole where allowed term = 0.)

③ Tolerances from Chao & Tigner (SSC-N-183) and (for quadrupole) SSC-7
The quadrupole values assume shimming of collared coil in yoke.

TABLE III

PW 4-28-88

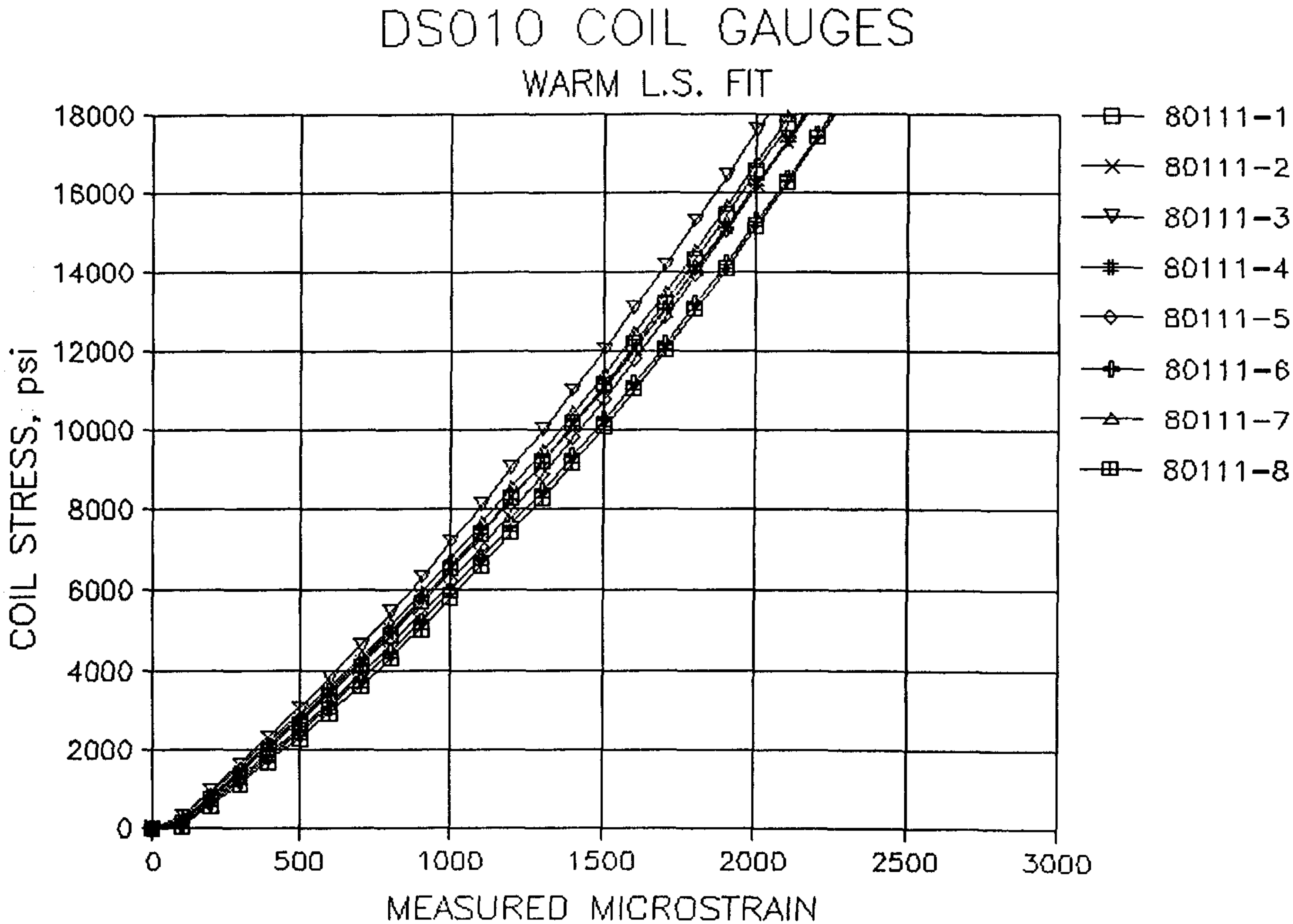

DS010 COIL GAUGES
WARM L.S. FIT
COIL STRESS, psi
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
500
1000
1500
2000
2500
3000
MEASURED MICROSTRAIN
80111-1
80111-2
80111-3
80111-4
80111-5
80111-6
80111-7
80111-8

FIGURE 1

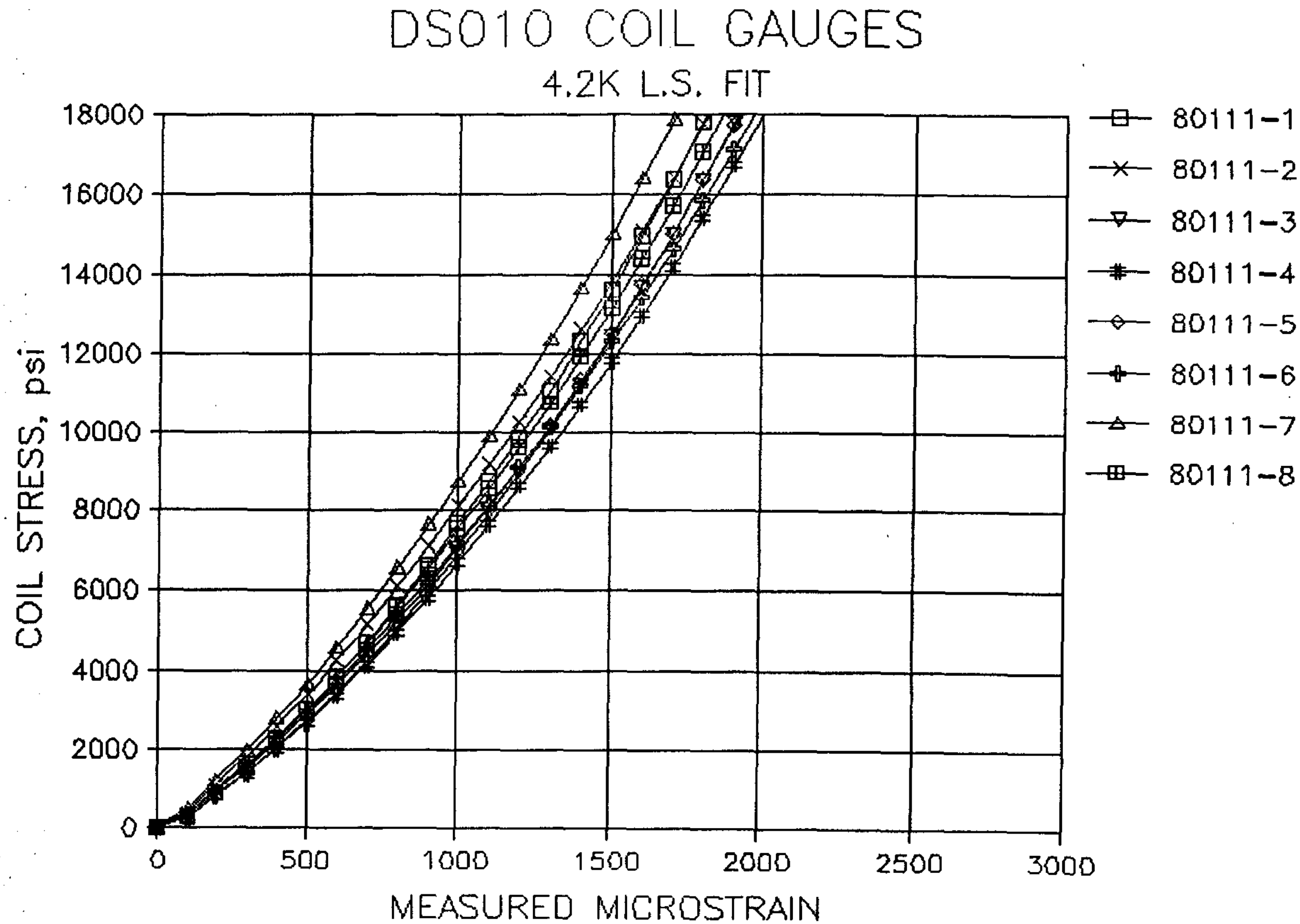

DS010 COIL GAUGES
4.2K L.S. FIT
COIL STRESS, psi
MEASURED MICROSTRAIN
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
500
1000
1500
2000
2500
3000
80111-1
80111-2
80111-3
80111-4
80111-5
80111-6
80111-7
80111-8

FIGURE 2

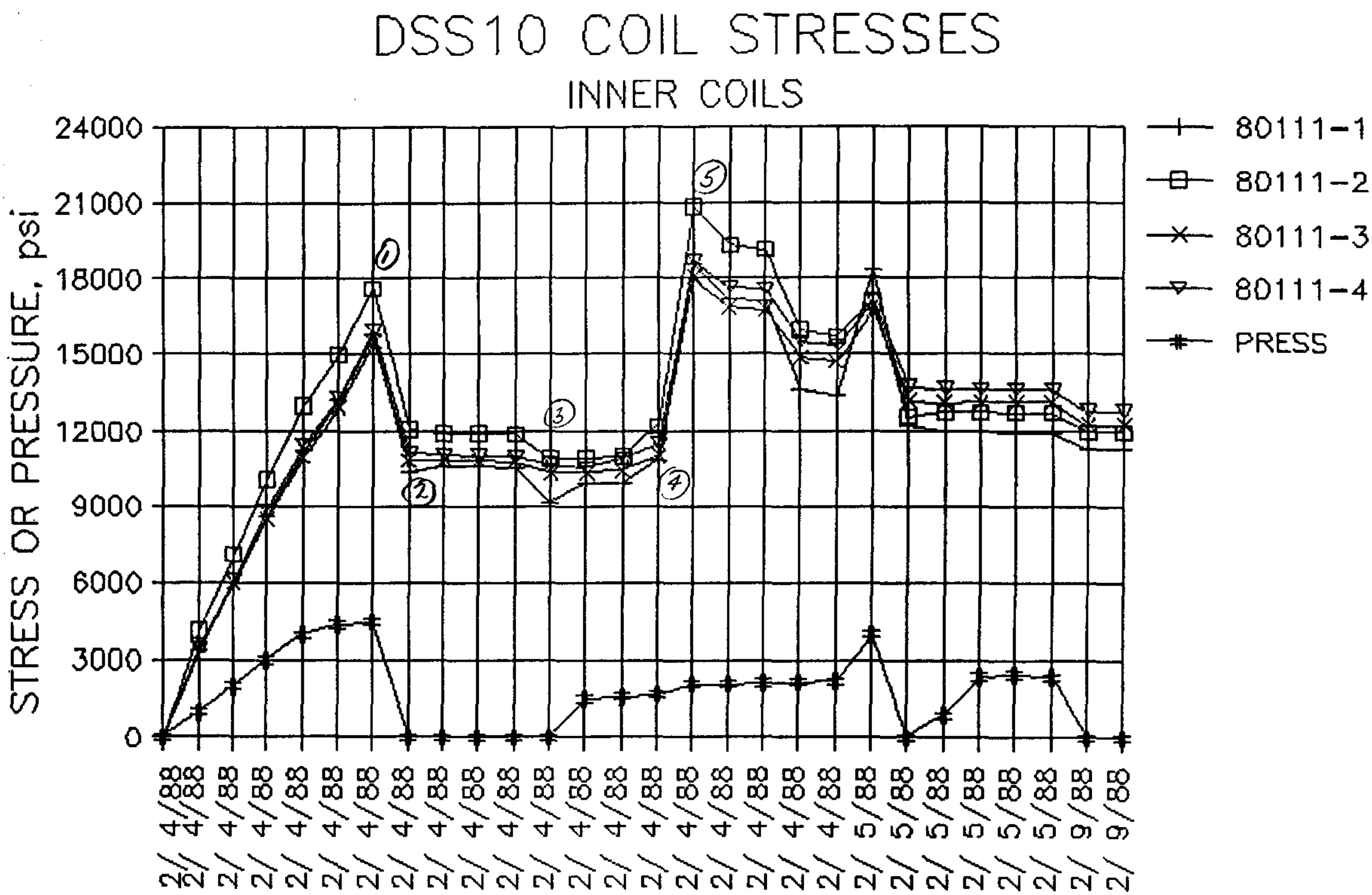

DSS10 COIL STRESSES
INNER COILS
STRESS OR PRESSURE, psi
24000
21000
18000
15000
12000
9000
6000
3000
0
2/ 4/88
2/ 5/88
2/ 9/88
80111-1
80111-2
80111-3
80111-4
PRESS
1
2
3
4
5

FIGURE 3

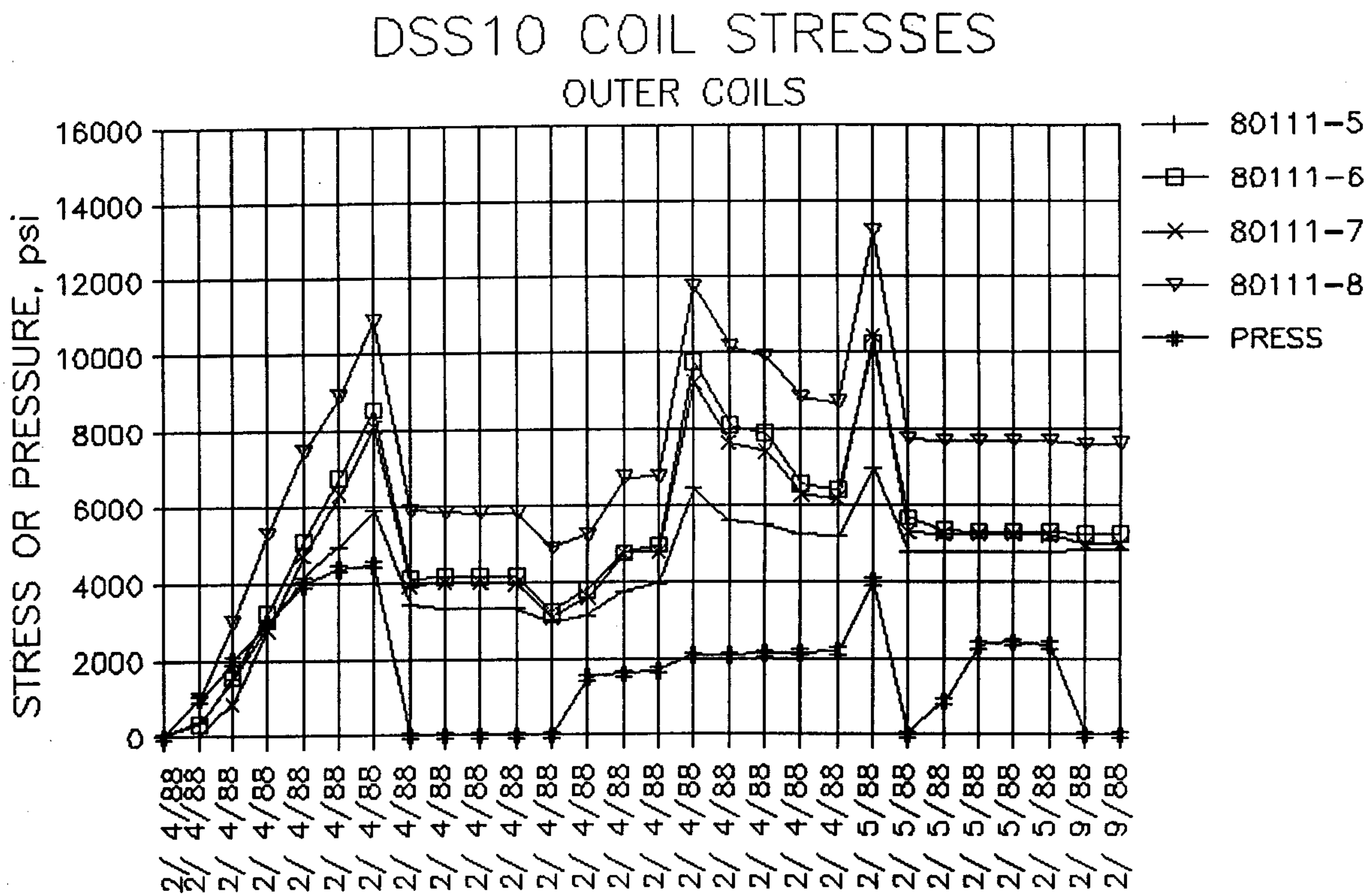

DSS10 COIL STRESSES
OUTER COILS
STRESS OR PRESSURE, psi
16000
14000
12000
10000
8000
6000
4000
2000
0
80111-5
80111-6
80111-7
80111-8
PRESS
2/ 4/88
2/ 5/88
2/ 9/88

FIGURE 4

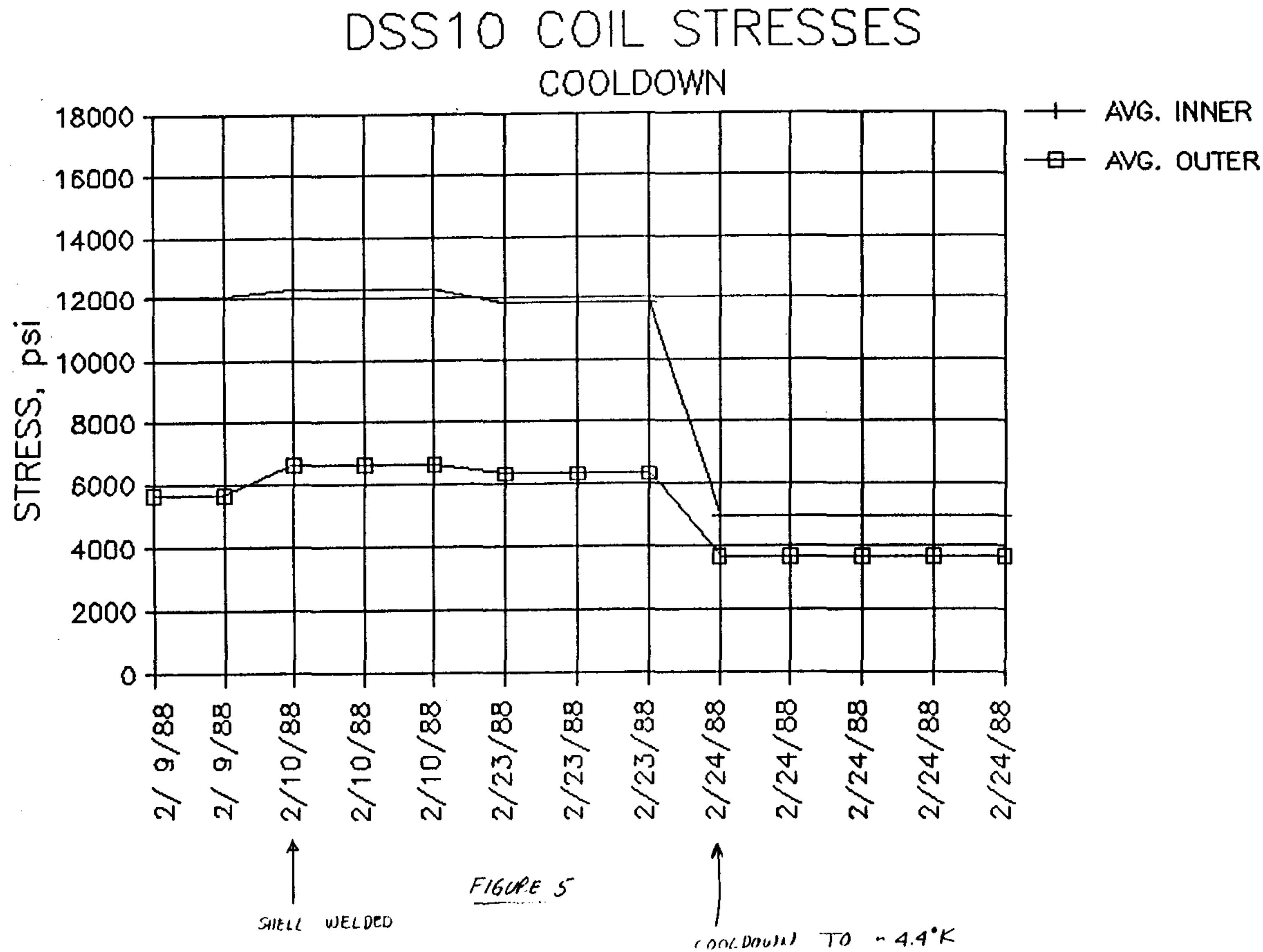

DSS10 COIL STRESSES
COOLDOWN
AVG. INNER
AVG. OUTER
STRESS, psi
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
2/ 9/88
2/ 9/88
2/10/88
2/10/88
2/10/88
2/23/88
2/23/88
2/23/88
2/24/88
2/24/88
2/24/88
2/24/88
2/24/88
SHELL WELDED
COOLDOWN TO ~4.4°K

FIGURE 5

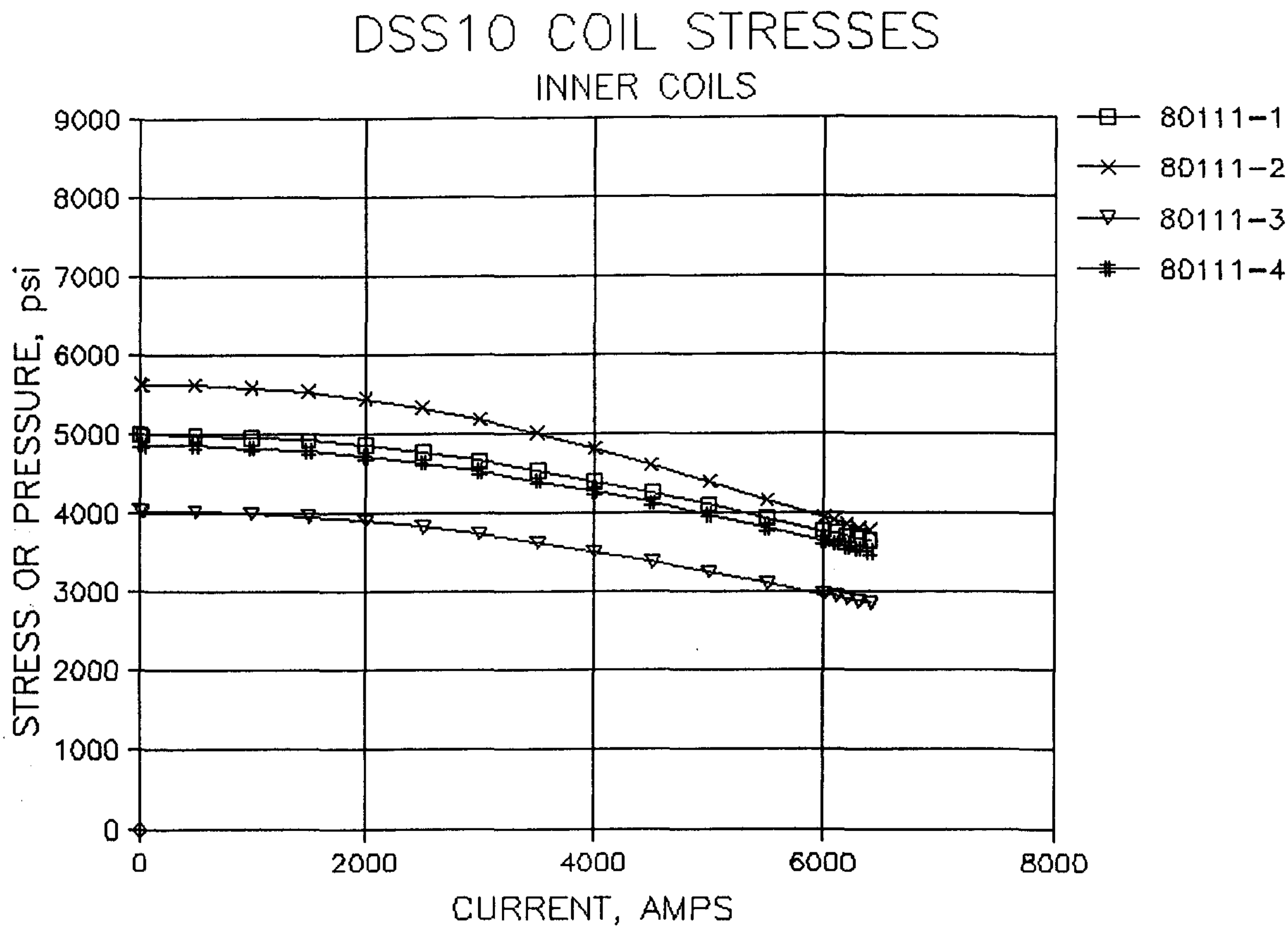

DSS10 COIL STRESSES
INNER COILS
STRESS OR PRESSURE, psi
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
2000
4000
6000
8000
CURRENT, AMPS
80111-1
80111-2
80111-3
80111-4

FIGURE 6

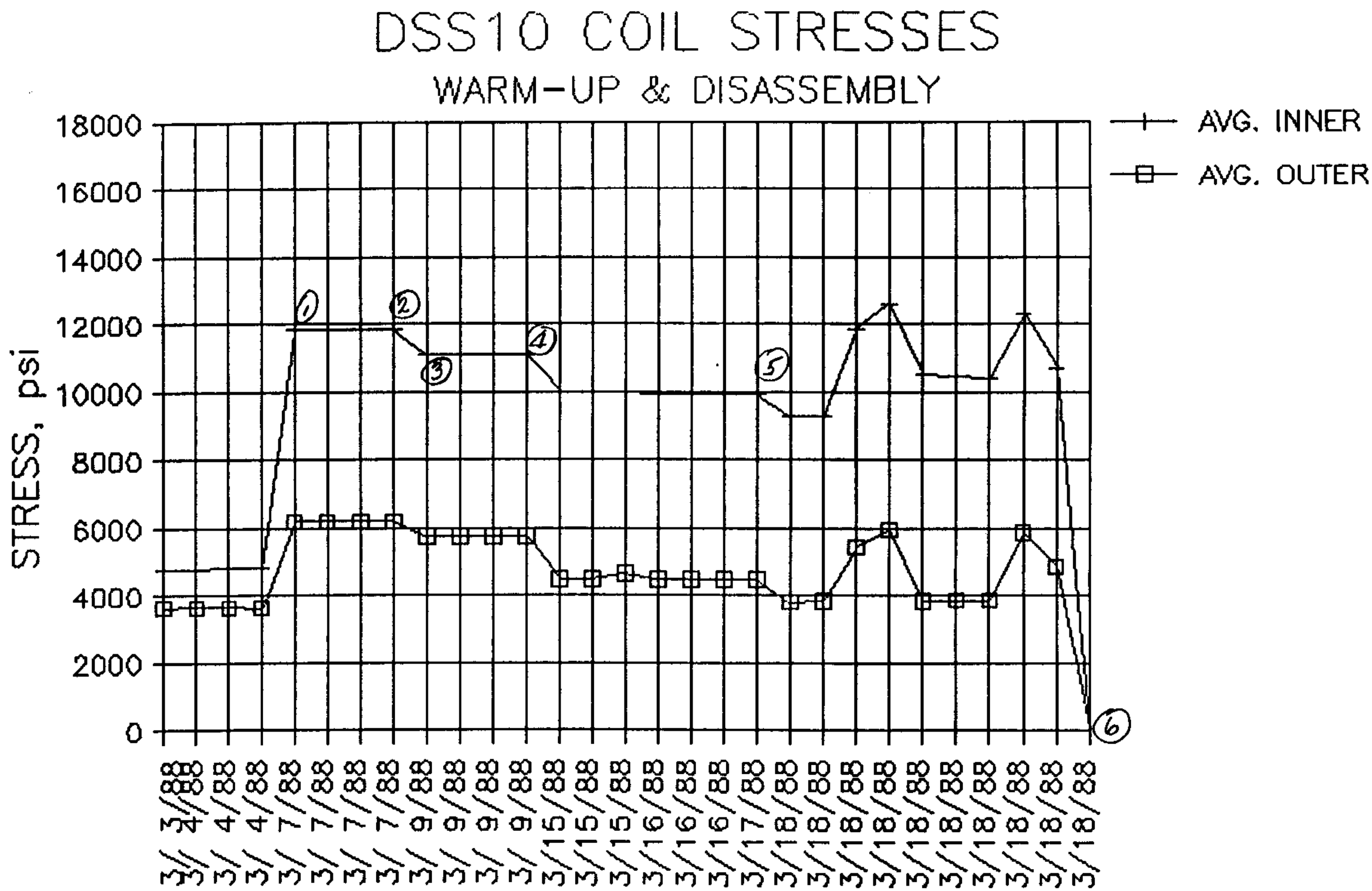

DSS10 COIL STRESSES
WARM-UP & DISASSEMBLY
STRESS, psi
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
AVG. INNER
AVG. OUTER
3/ 3/88
3/ 4/88
3/ 4/88
3/ 4/88
3/ 7/88
3/ 7/88
3/ 7/88
3/ 7/88
3/ 9/88
3/ 9/88
3/ 9/88
3/ 9/88
3/15/88
3/15/88
3/15/88
3/16/88
3/16/88
3/16/88
3/17/88
3/18/88
3/18/88
3/18/88
3/18/88
3/18/88
3/18/88
3/18/88
3/18/88
3/18/88
3/18/88
1
2
3
4
5
6

FIGURE 7

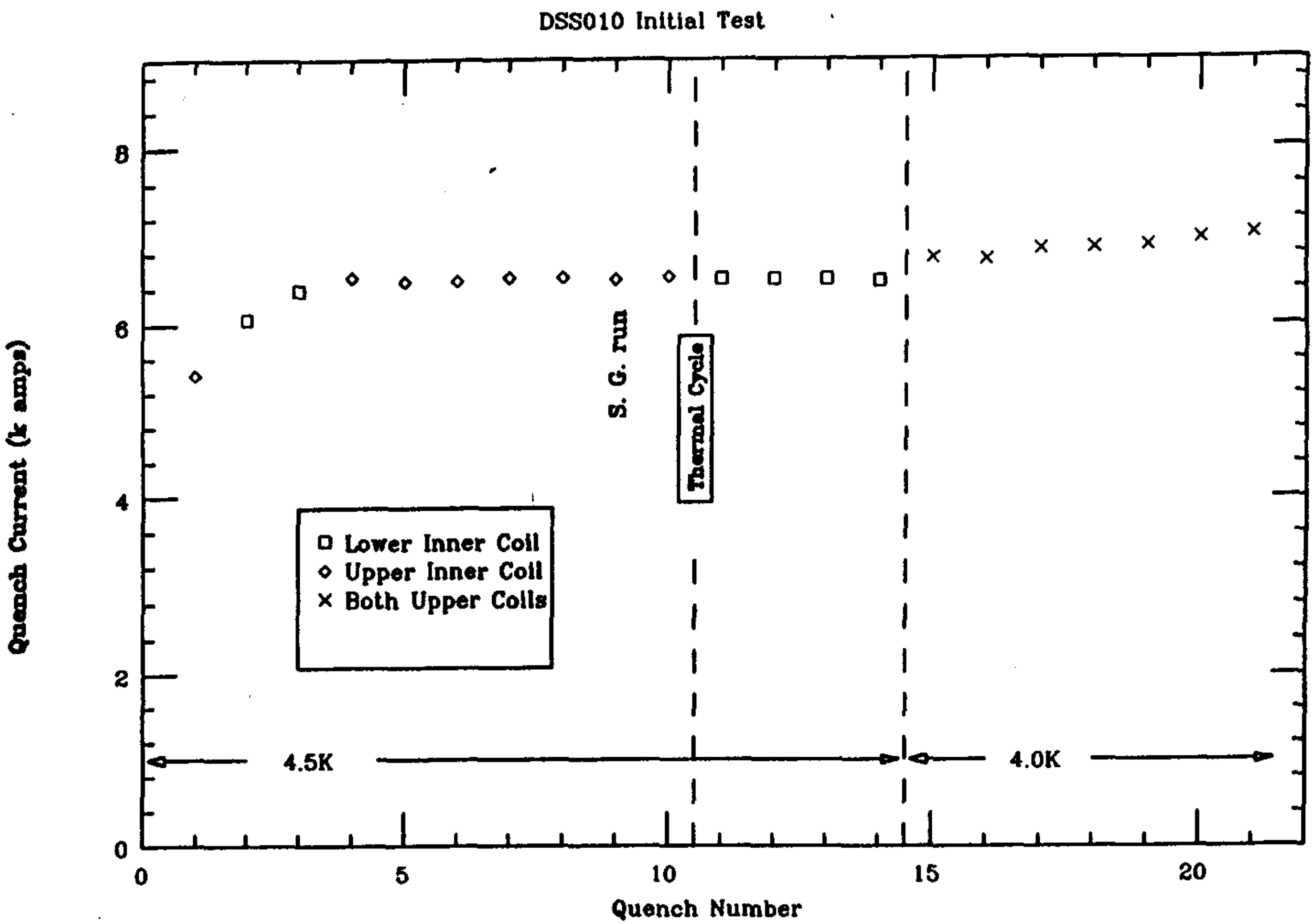
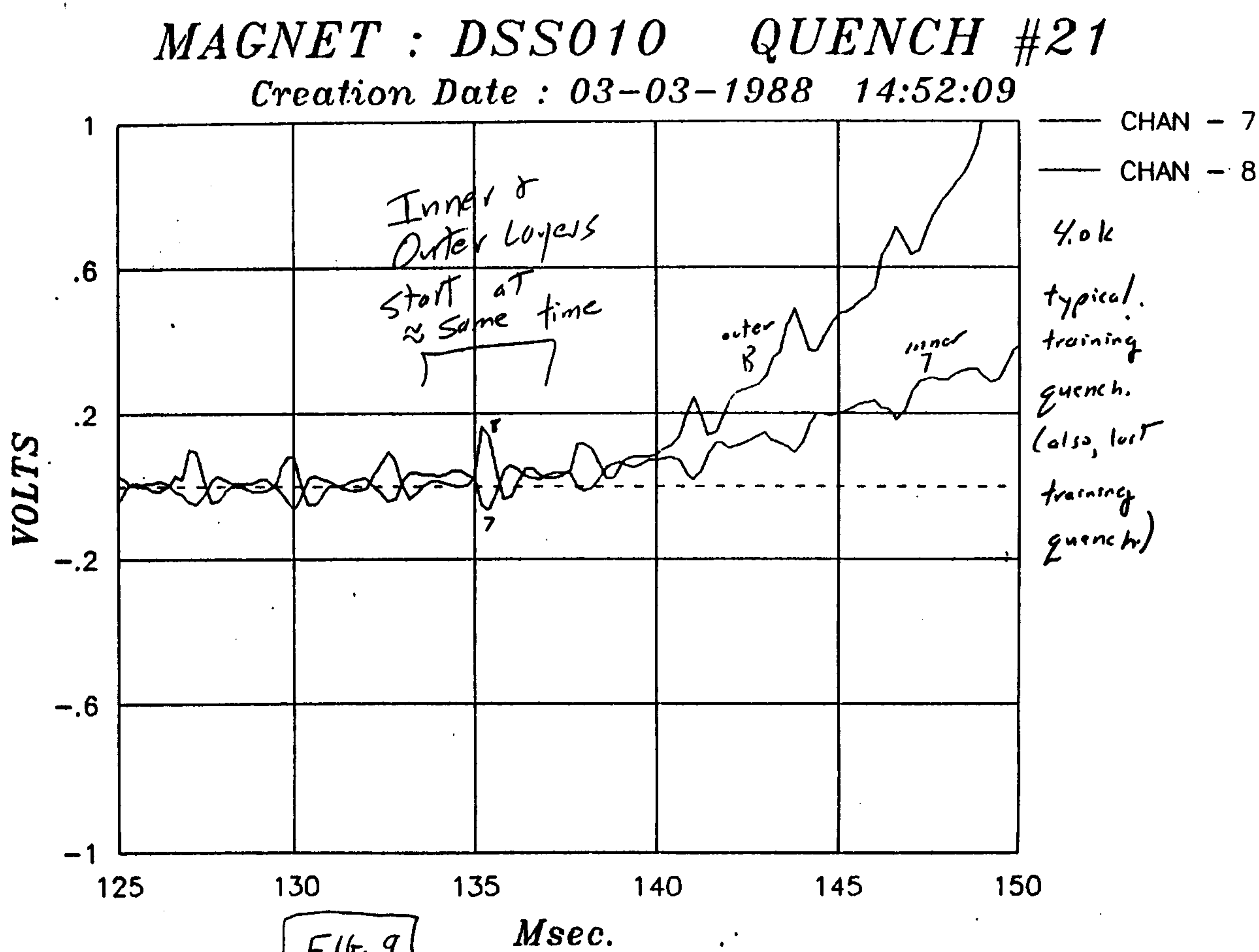

DSS010 Initial Test
8
6
4
2
0
0
5
10
15
20
Quench Number
Quench Current (k amps)
Lower Inner Coil
Upper Inner Coil
Both Upper Coils
S. G. run
Thermal Cycle
4.5K
4.0K

Fig. 8



MAGNET : DSS010 QUENCH #21
Creation Date : 03-03-1988 14:52:09
CHAN - 7
CHAN - 8
1
.6
.2
-.2
-.6
-1
VOLTS
125
130
135
140
145
150
Msec.
Inner & Outer Layers start at ≈ same time
outer 8
inner 7
8
7
4.0k
typical. training quench. (also, last training quench)

FIG. 9

MAGNET : DSS010   QUENCH #13

Creation Date : 03-02-1988 09:41:05

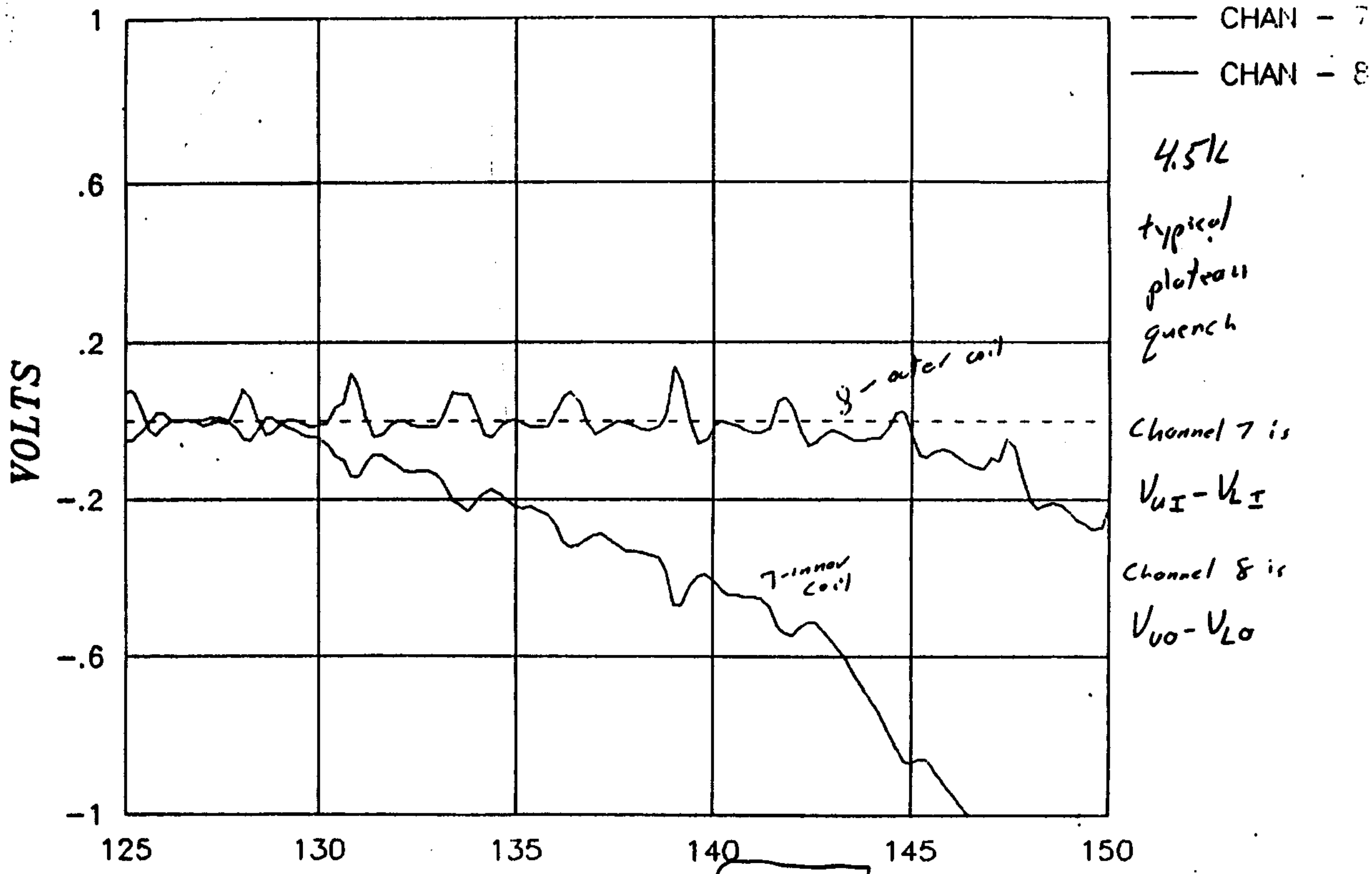


FIG. 10

Inner coil starts ≈15 ms before outer coil.

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