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Comparison of NIKE2D Results with Strain Gauge Pre-Stress Measurements at BNL and LBL

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In the week ending October 17, 1987, strain gauge measurements of pre-stress at 4.35°K were taken as a function of increasing current. At BNL, the measurement was taken during energization of magnet DSS6 with steel collars, and at LBL, the measurement was taken on magnet D15A3 with aluminum collars. LBL and BNL made both inner and outer coil measurements. NIKE2D analysis was performed to compare strain gauge measurements with analytical prediction. It is demonstrated that there is a significant dependence on friction coefficient between various coil components. Both ability to maintain prestress during cool-down and unloading during energization depends on friction. The definitive data on friction between coil components is not available. Plans have been made to measure this property.

In this calculation, friction was varied in an attempt to bracket actual conditions. NIKE2D analysis was performed using strain gauge values as initial stress in elements 129 and 143, top edge of inner coil and outer coil respectively (see Figure 3). Using the NIKE2D model of the cold mass, and applying an initial prestress value of pressure on the coils at 4.35°k, the Lorentz forces were increased with current and the stress in the coil calculated. Calculations were performed with friction equal to zero and 0.3 and for both aluminum and steel collars. The circumferential stress calculated was compared to that measured for the same current.

Figure 1 is a mesh of the entire model delineating the slide lines, collar, coil, wedges, and beam tube. Figure 2 shows the collar, coil and wedges and Fig. 3 is the detailed mesh of the coil elements. It is the circumferential stress in element 129 for inner coil and 143 for the outer coil in Fig. 3 that is compared to strain gauge measurements.

The properties of the coil, the copper wedges, steel or aluminum collar, are given in Table I.

TABLE I

Material Properties (4.35°k)

	E psi	
Copper Wedges	15.6×10^6	.355
Steel	$30\ \times10^6$	.278
Aluminum	1.02×10^7	.33
Coil		
loading		
$p \leq 7000$ psi	1.08×10^6	.3
$p > 7000$ psi	1.77×10^6	.3
unloading		
$2000 \leq p \leq$ psi	2.5×10^6	.3
$0 \leq p < 2000$ psi	$.5\times10^6$	.3

The results given in Figs. 4-7 are in good agreement with the measurements. As the outer coil is in contact with the collar and loaded by inner coil in addition to its own Lorentz forces, one would expect better agreement with higher friction. The inner coil is basically free on the inside surface; it would have a lower friction. The value of zero friction for inner coil and 0.3 for the outer coil results in good agreement between the NIKE2D calculation and measurement. The LBL measurements for the inner coil are somewhat different from top to bottom. NIKE2D results appear to straddle both curves.

In a previous comparison (D00002) with NIKE2D, inner coil, no friction, the results were in good agreement between measurement and calculations. The D00002 comparisons were presented several times orally by V. N. Karpenko, but were never documented outside the presentation. The NIKE2D calculations predicted the current at which the circumferential stress in the inner coil at the pole would go to zero given initial circumferential stress at zero current.

After the Lorentz forces reduce the circumferential prestress to zero, the coil separates from the collar with further increase in Lorentz forces (higher field). The coil elements also rotate as well as translate with higher Lorentz forces after the hoop stress goes to zero. In some cases, depending on the prestress and Lorentz forces, elements can move significant distances and, depending on the distortions, the stresses may increase substantially. In practice, a quench may occur soon after separation. The strain gauges continue to read zero stress while the calculations on the elements adjacent to the collar start to exhibit stress. The reason is that the strain gauges are located in the pole piece and when the coil moves away, it has a free surface and stays zero. If we look at fringes of hoop stress or plot out the hoop stresses of the elements making up the pole piece, we also note zero hoop stress. However, the stress of element 129 and 143 are in the coils and higher Lorentz forces are being applied directly to their nodes.

The strain gauges in the pole piece were calibrated or adjusted to read the stress in the coil at the pole. When the coil is no longer in contact with the pole, the strain gauges will read zero no matter what is going on. The comparison between the gauge readings and NIKE2D must end at this time. However, the calculations are still valid with higher field even though there is no agreement with this measurement.

The results have shown that it is possible to predict the stress in the coil due to assembly, cool-down, and energization. It is believed that NIKE can predict magnet behavior in general as will be further demonstrated by the 30 calculations currently being addressed.

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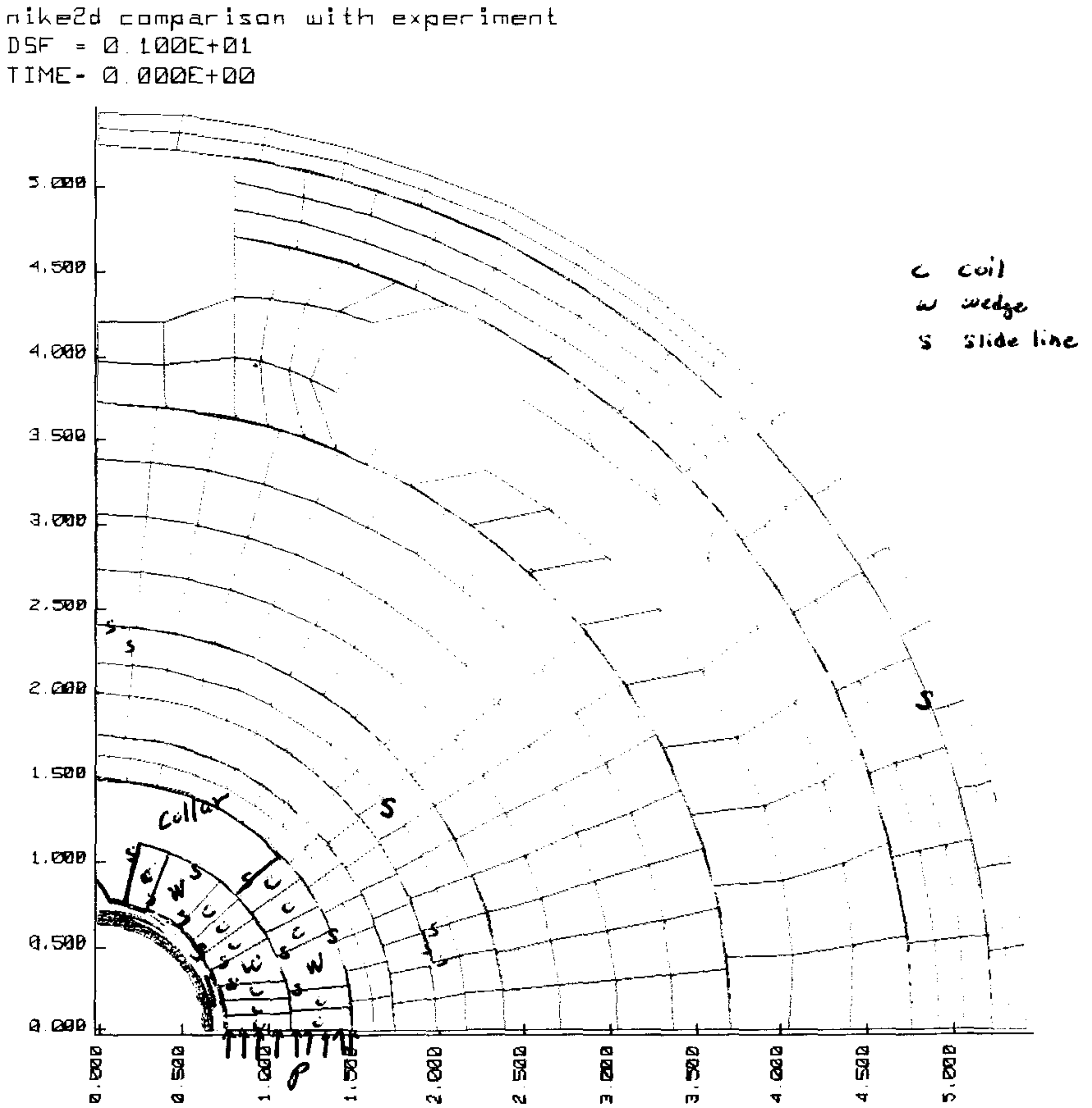


nike2d comparison with experiment
DSF = 0.100E+01
TIME- 0.000E+00
c coil
w wedge
s slide line
collar

Fig. 1

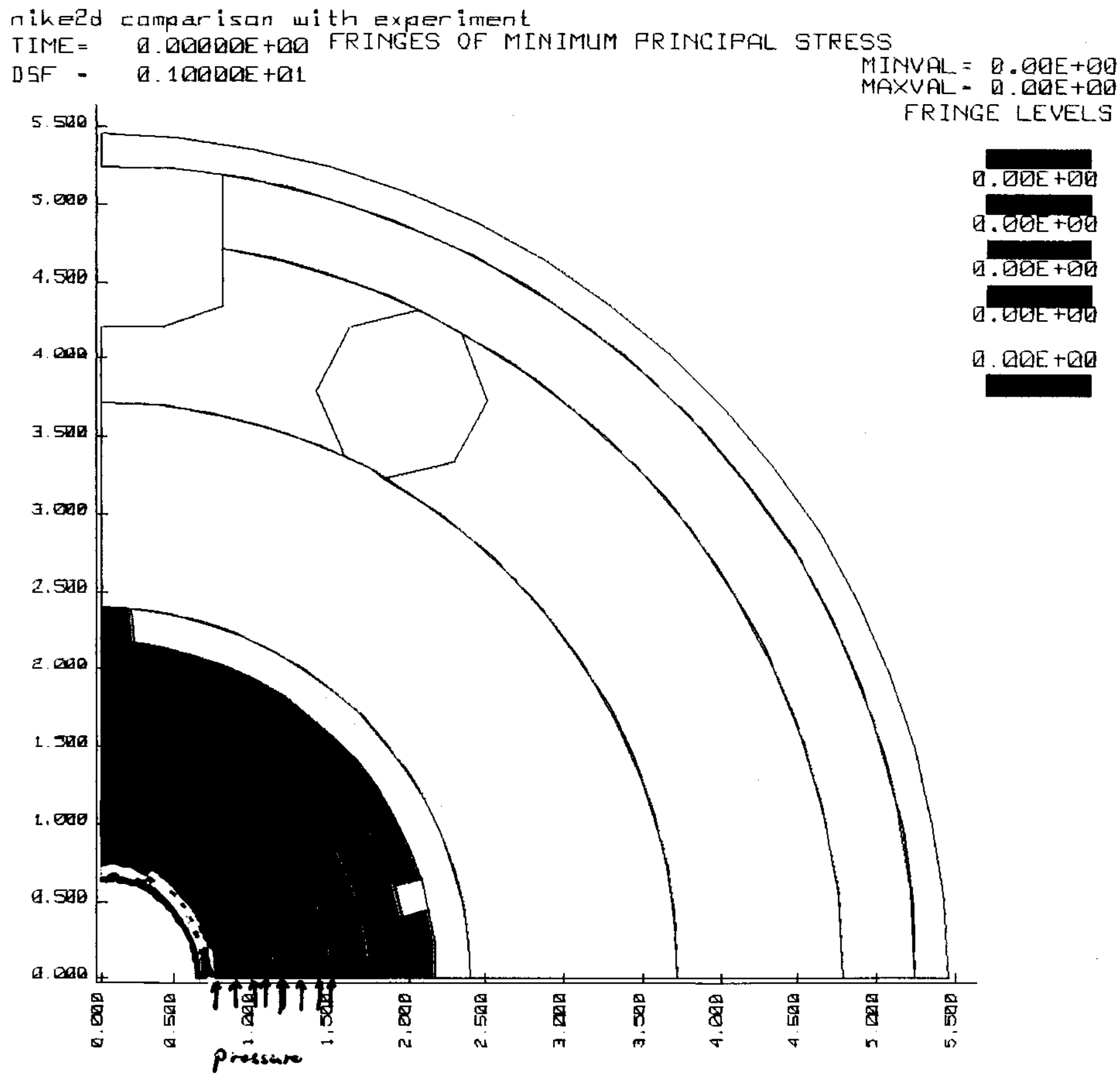
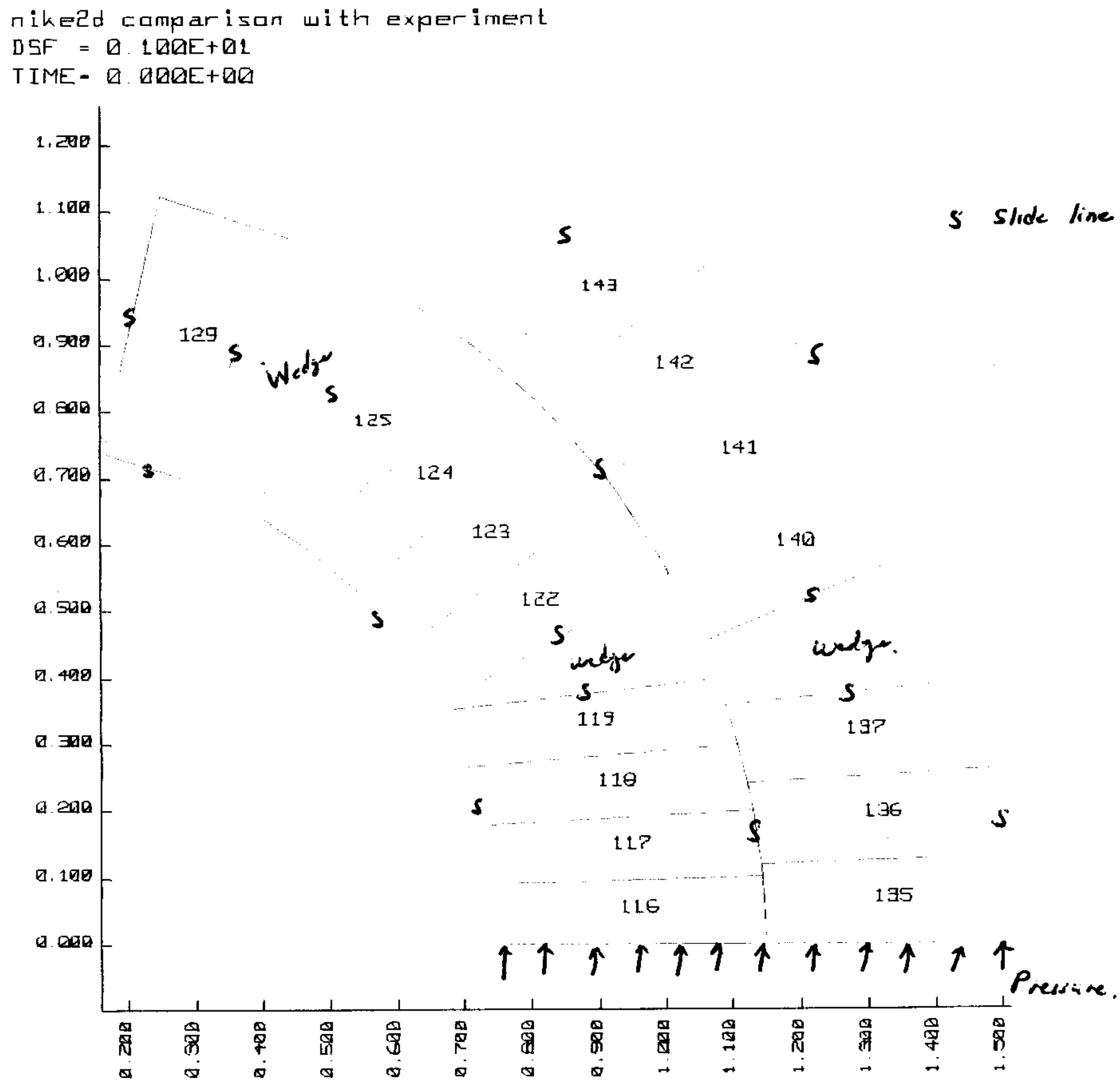

nike2d comparison with experiment
TIME= 0.00000E+00 FRINGES OF MINIMUM PRINCIPAL STRESS
DSF - 0.10000E+01
MINVAL= 0.00E+00
MAXVAL- 0.00E+00
FRINGE LEVELS
0.00E+00
0.00E+00
0.00E+00
0.00E+00
0.00E+00
5.500
5.000
4.500
4.000
3.500
3.000
2.500
2.000
1.500
1.000
0.500
0.000
Pressure

Fig 2



nike2d comparison with experiment
DSF = 0.100E+01
TIME- 0.000E+00
1.200
1.100
1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
0.200
0.300
0.400
0.500
0.600
0.700
0.800
0.900
1.000
1.100
1.200
1.300
1.400
1.500
129
125
124
123
122
119
118
117
116
143
142
141
140
137
136
135
S Slide line
Wedge
wedge
Wedge.
Pressure.

Fig.3

NIKE2D RESULTS ARE IN GOOD AGREEMENT WITH DSSG STRAIN GAGE PRESTRESS MEASUREMENTS

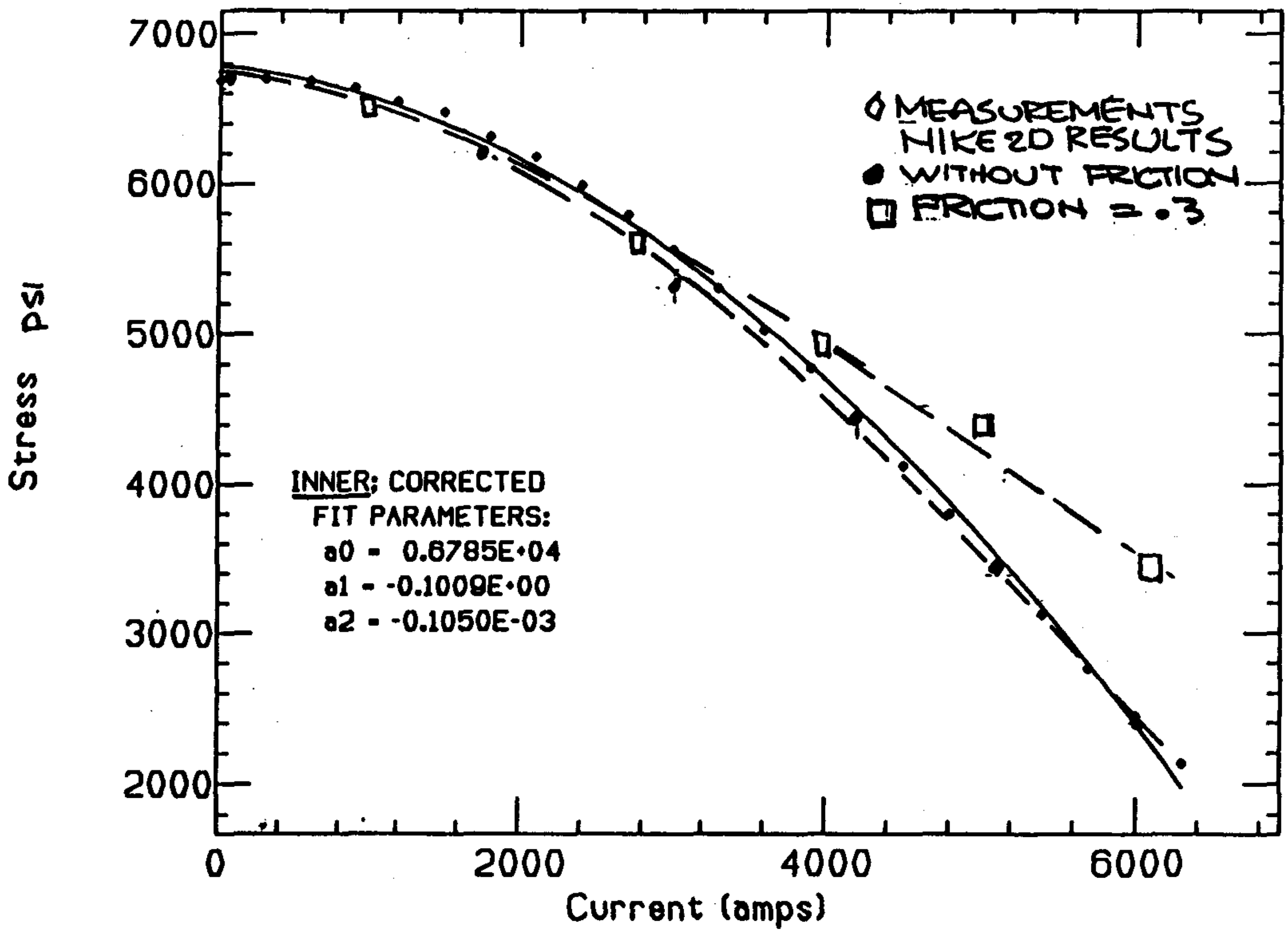


Fig. 4

VK

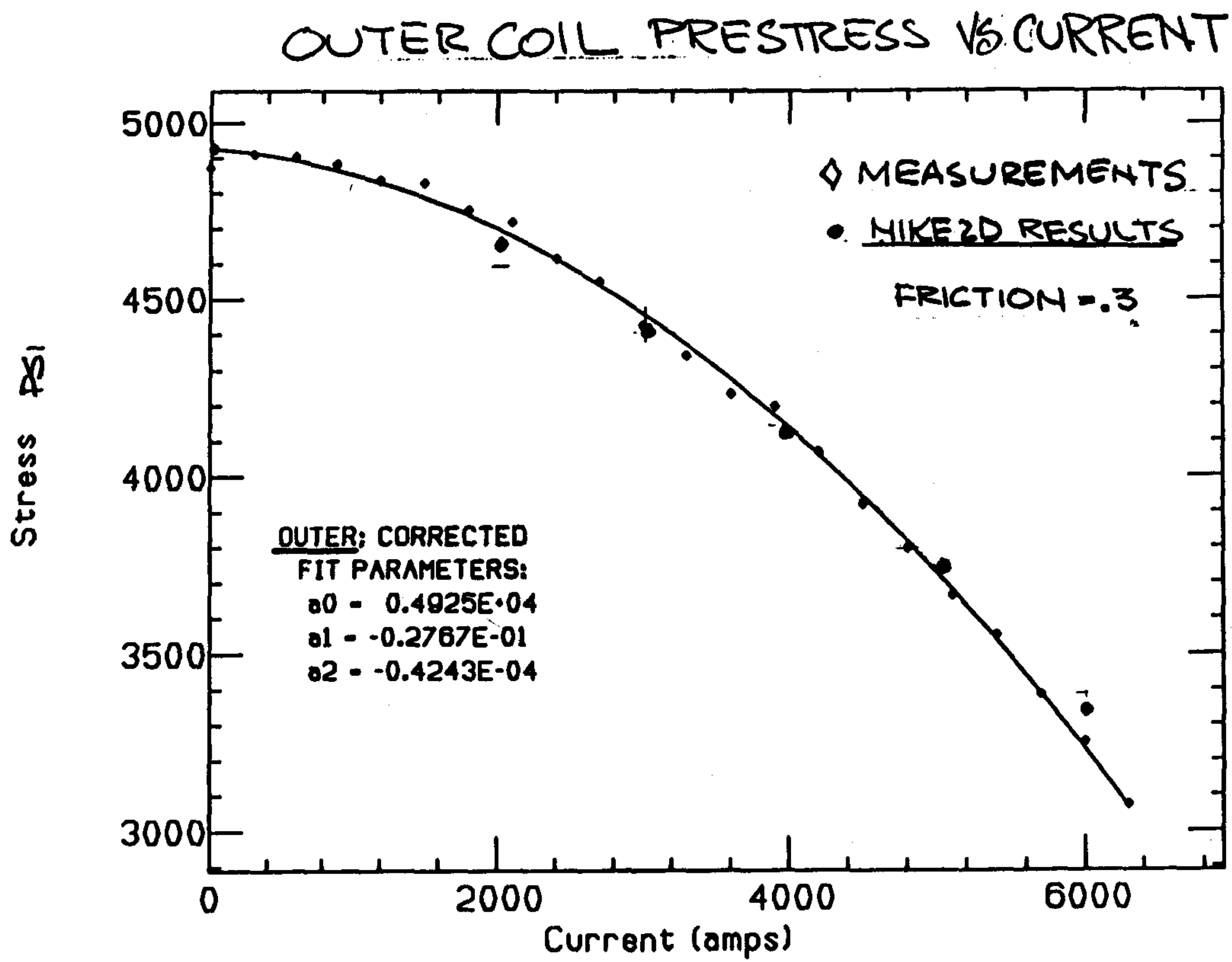

OUTER COIL PRESTRESS VS CURRENT
◊ MEASUREMENTS
● MIKE2D RESULTS
FRICTION = .3
OUTER: CORRECTED
FIT PARAMETERS:
a0 = 0.4925E+04
a1 = -0.2767E-01
a2 = -0.4243E-04
Stress PSI
Current (amps)
5000
4500
4000
3500
3000
0
2000
4000
6000

Fig. 5

VK

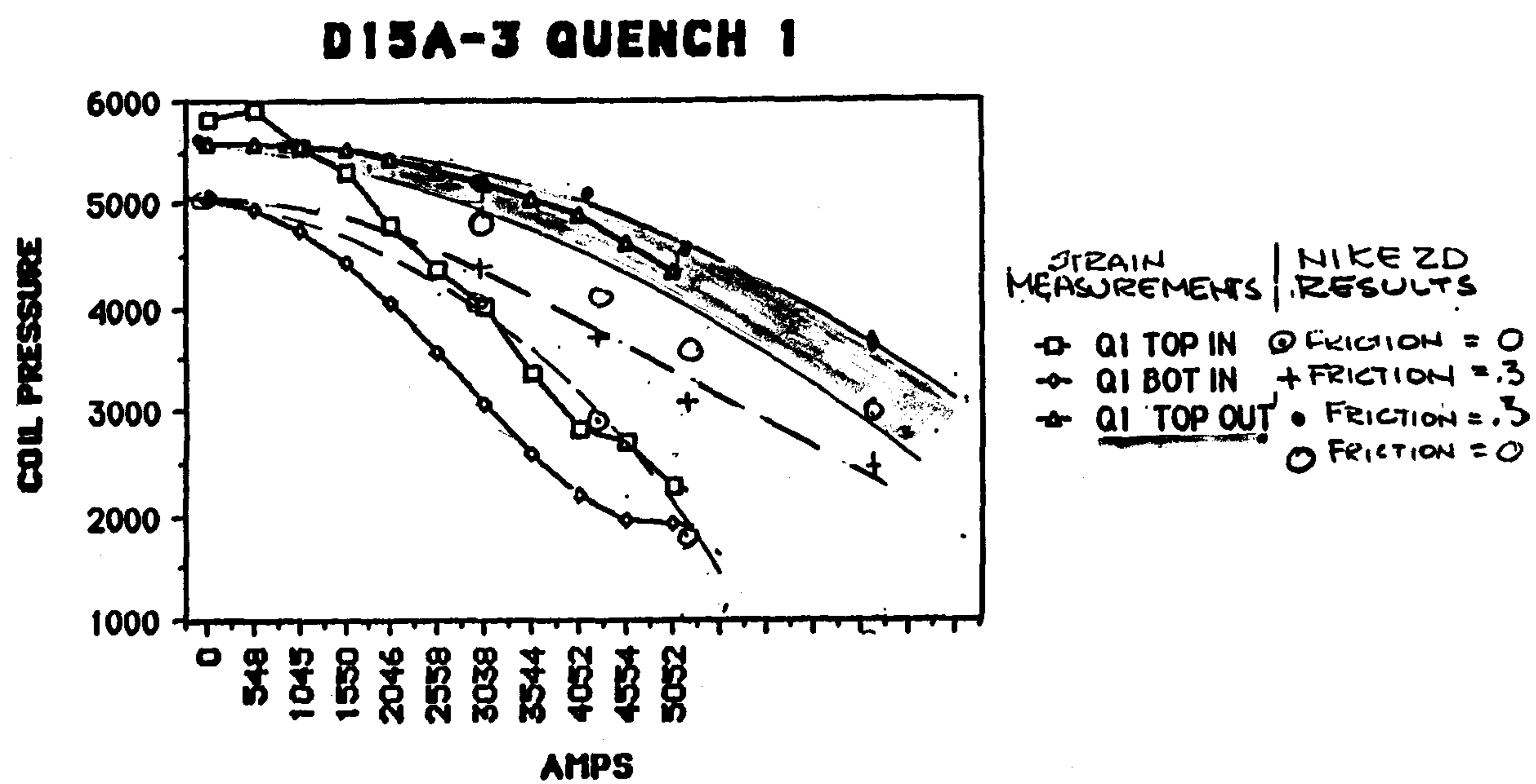

D15A-3 QUENCH 1
6000
5000
4000
3000
2000
1000
COIL PRESSURE
0
548
1045
1550
2046
2558
3038
3544
4052
4554
5052
AMPS
STRAIN MEASUREMENTS
NIKE 2D RESULTS
Q1 TOP IN
Q1 BOT IN
Q1 TOP OUT
FRICTION = 0
FRICTION = .3
FRICTION = .3
FRICTION = 0

Fig. 6

VK

NIKE 2D RESULTS ARE IN FAIR AGREEMENT WITH STRAIN GAGE MEASUREMENTS

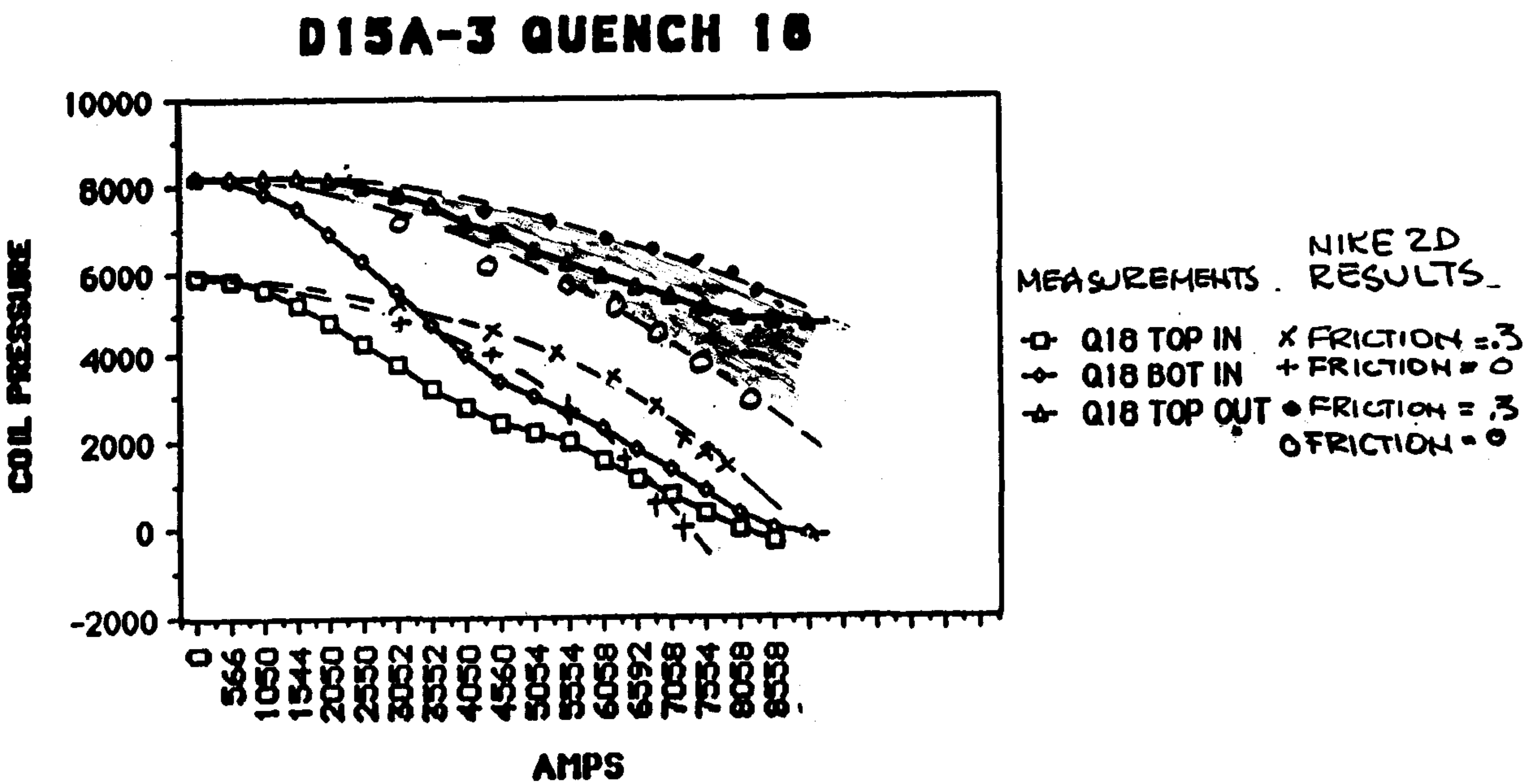


Fig. 7.

VK