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FIELD MEASUREMENTS ON A 6-3-120 DIPOLE MAGNET

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This paper contains information on the 6-3-120 dipole magnet. It includes a description of the measuring method and data on the magnet's point field excitations, $\int Bd\ell$ excitations, field shapes across the gap, fringe field levels, and various electrical and physical characteristics.

The magnet stands employed in the field measurements were two separate 2' x 3' tables with x and y lathes. The stands were anchored to the floor, level and parallel to each other, 15' apart. The magnet alignment accuracy is within ±5 mils.

The power supply utilized for most of the measurements was a Transrex 500-5. The power supply stability over long time intervals is within 1 to 2 ampere range. An external Leeds Northrup current shunt with 0.1% accuracy was employed for measuring the current. The voltmeter used in conjunction with the shunt was a Dana 5900 digital volt meter. The ripple measured at the field coil is approximately 0.2%.

The excitation curves were measured with a small multiturn point coil mounted on a G-10 plate. The field measurements obtained at 9" from the end plate were taken with the power supply operated in the DC current mode up to 2000A and from 2000A back down to 0A. The two field measurements taken at a given current (one taken

while the current was being incremented and the other taken while the current was being decremented) were averaged to reduce any errors introduced by hysteresis effects. Because of cooling limitations in the heat exchanger available at the Fermilab Magnet Facility, the measurements of the excitation curves at 28" from the end plate and the $\int Bd\ell$ curves above 1500A were made only in the mode where the current was incremented. The accuracy of the data for the field data is 0.2%.

The $\int Bd\ell$ data was obtained using a precision flipping type probe with two turns of 0.0035" tungsten wire. The wire turns are separated by special temperature stable glass rods machined to a diameter of 0.5000±0.00005". To measure the $\int Bd\ell$, the wires in the probe were rotated by 180° with the magnet operating at the desired DC current. The accuracy of the data for $\int Bd\ell$ is also 0.2%.

The integrated field shapes across the magnet gap were measured using the precision flipping type probe described above in conjunctic with a bucking coil. The bucking coil was inserted in the magnet gap and its position was adjusted to remove the ripple and current drift problems by bucking the signal of the flipping type probe coils. Because the flipping type probe is constructed with one loop of the coil 0.250" above the midplane and the other loop 0.250" below the midplane, the measured field shapes are average fields at the midplane. In our measurements, data was taken at 700A, 1700A, and 975A in this sequence.

To alleviate any fears that a magnet driven to saturation would alter any subsequent field measurements, a measurement of

the remnant field was made after the magnet had been driven to saturation and was found to be 15.5 gauss. After degaussing the magnet, the final remnant field measured to be 0.5 gauss. The degaussed magnet was then powered to 200A, 700A, and 975A and the field was remeasured. It was found that there was no measurable differences in the field between the measurements taken prior to and subsequent to the degaussing procedure. The accuracy of the field shape measurement is within 0.03%.

The fringe field data was measured using a hand held hall probe positioned with a meter stick. The data was taken with the magnet in the saturation region and also at 1000A.

Equipment Used:

1. Stretch Wire

N	= 2 turns
Wire diameter	= .0035"
R probe wire	= 160Ω
Glass	= .5000±.00005"
RC	= 50.378
R_p + RC	= 50.538
Overall width	= .5035" = 1.27889 cm
Constant	= .050611 V/kG-m

$$V_o = \frac{NA\Delta B}{RC} \times 10^{-1} \text{ kG-m}$$

2. Field Coil

V_k	= .4212 V/kG		
Integrator	= Philbrick 1701		
RC	= 50.378		
Meter	= Dana 5500	Fermilab	17541

3. Current

Leed Northrup shunt
5000A (.1%)

Meter	Dana 5900	Fermilab	12837

4. Power Supply

Transrex 500-5	Fermilab	11566
Ripple error		0.2%
Stability		2.5A above 1000
		1.0A below 1000

5. Gradient Bucking

14" x 2" coil

6. DC Kelvin Bridge Fermilab 10431
   DC resistance = 46.856 mΩ

7. Inductance
   GRC Bridge = 1633A Fermilab 10826
   Oscillator Fermilab 12141

8. Water Flow Measured at Magnet
   Facility pump 40' hose to magnet

Magnet Properties:

B =	15kG measured
$\frac{\Delta B}{B}$ = 0.15% uniformity ±2.5"	measured
I =	975A measured
V at load =	48.4V measured
Power =	47.1 kW measured
DC resistance =	46.856 mΩ measured
L_s at 1 kHz	3.54 mH measured
Q at 1	1.08 measured
V_{ac} at 1 kHz	42V measured
I_{ac} at 1 kHz	1.0A measured
L_s at 50 Hz	13.25 mH measured
Q at 50 Hz	3.90 measured
V_{ac} at 50 Hz	150V measured
I_{ac} at 50 Hz	1.0A measured

Water values measured with 40' of hose

P_{in}	212.5° PSI measured
P_{out}	5.5 PSI measured
T_{in}	96°F measured
T_{out}	116°F measured

Water Cooling Calculated

	Pancake	Saddle
Inlet temperature °F	113	113
Outlet temperature °F	133	155
Average temperature °F	123	134
Total flow gpm	11.82	2.27
Pressure drop	200	200

Coil Data	Pancake	Saddle
Conductor	.625"	.825"
Hole diameter	.250"	
Turns	10	14
Total turns/pole	40	14
Total turns	108	108
Water paths	5	
Average turn length	255"	290"
Total coil length	10'10"	11'3 3/8"

Steel Core	
Length	120"
Width	28 3/4"
Height	25 3/4"
Buss bars top mounted	
Gap height	3.150"
Gap width	6.096
Stainless steel vacuum chamber length	11' 8.25"
Coils and insulation	4,250 lbs
Core	18,000 lbs
Total magnet assembly	22,500 lbs

Calculation Constant	
Transfer constant (T)	15.385 kG/kA

Manufacturer	Elma Engineering
Designers	Fermilab

MAGNET 6-3-120

TABLE I

Field Properties of 377001

I	Fig. 1 B vs I Run I 9" depth kG	Fig. 1 B vs I Run II 28" depth kG	Fig. 2 $\int Bd\ell$ vs I kG-m
0A	.015	.015	.050
100	1.679	1.679	5.236
200	3.366	3.361	10.506
300	5.050	5.042	15.780
400	6.734	6.719	21.034
500	8.407	8.391	26.260
600	10.070	10.052	31.443
700	11.678	11.684	36.507
800	13.087	13.140	41.032
900	14.225	14.330	44.657
1000	15.179	15.334	47.727
1100	16.004	16.215	50.400
1200	16.671	16.957	52.627
1300	17.224	17.544	54.372
1400	17.710	18.045	55.533
1500	18.192	18.523	57.363
1600	18.632	18.963	58.677
1700	19.043	19.381	60.037
1800	19.460	19.787	61.213
1900	19.861	20.130	62.425
2000	20.262	20.526	63.455

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TABLE II

Fringe Field Data/Hand Held Hall Probe

x	Fig. 3 I=1000A	Fig. 3 I=1500A	x	Fig. 3 I=1000A	Fig. 3 I=1500A
+19	15.3×10^3 gauss	18.4×10^3 gauss	-13	56 gauss	20 gauss
14	15.2×10^3	18.3×10^3	-14	35	0
9	15.2×10^3	18.1×10^3	-15	22	-12
8	15.1×10^3	18.1×10^3	-16	13	-20
7	15.1×10^3	18.0×10^3	-17	7	-23
6	15.1×10^3	17.9×10^3	-18	3	-25
5	15.0×10^3	17.8×10^3	-19	0	-26
4	14.9×10^3	17.7×10^3	-20	-1.8	-26
3	15.0×10^3	17.6×10^3	-21	-2.6	-26
2	15.0×10^3	17.6×10^3	-22	-3.5	-24
1	15.2×10^3	17.6×10^3	-23	-4.0	-22
0	12.1×10^3	15.3×10^3 ≈end plates	-24	-4.2	-21
-1	8.2×10^3	9.5×10^3	-25	-4.0	-18
-2	5.7×10^3	6.7×10^3	-26	-4.0	-18
-3	3.8×10^3	4.8×10^3	-27	-3.8	-18
-4	2.5×10^3	3.4×10^3	-28	-3.6	-14
-5	1.7×10^3	2.1×10^3	-29	-3.4	-14
-6	1.2×10^3	1.0×10^3	-30	-3.5	-14
-7	$.9 \times 10^3$	1.1×10^3	-31	-3.3	-12
-8	$.6 \times 10^3$	$.79 \times 10^3$	-32	-3.2	-13
-9	300	300	-33	-3.0	-11
-10	200	220	-43	-2.4	-10
-11	133	100	-48	-1.9	- 8
-12	86	60			

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TABLE III

Field Shape Measurement
Saturated Runs
Accuracy is .03% Absolute

x \ I	Fig. 4 and 6 200A	Fig. 4 700A	Fig. 4 975.5A	Fig. 4 and 7 1700A
2.50"	+.213(%)	+.184(%)	-.128(%)	-1.33(%)
2.25	+.193	+.175	-.064	
2.00	+.138	+.127	-.049	- .72
1.75	+.086	+.082	-.045	
1.50	+.051	+.050	-.039	- .36
1.25	+.022	+.029	-.031	
1.00	+.007	+.015	-.023	- .16
.75	.000	+.008	-.014	
.50	.000	+.004	-.007	- .04
.25	.000	.000	-.003	
-0.00	.000	.000	.000	0
- .25	+.003	.000	-.003	
- .50	+.007	+.003	-.008	- .06
- .75	+.015	+.008	-.012	
-1.00	+.027	+.018	-.019	- .17
-1.25	+.052	+.033	-.030	
-1.50	+.086	+.059	-.036	- .40
-1.75	+.131	+.095	-.038	
-2.00	+.180	+.143	-.043	- .76
-2.25	+.237	+.182	-.070	
-2.50	-	+.177	-.150	-1.42

Looking at the manifold end
+ side is left

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TABLE IV

Field Shape Measurement/After Degaussing Magnet

Accuracy .03% Absolute

x \ I	Figs. 5 and 6 200A	Fig. 5 700A	Fig. 5 975A
2.50"	+.24 (%)	+.175(%)	-.130(%)
2.25	+.176	+.152	-.067
2.00	+.158	+.118	-.053
1.75	+.103	+.073	-.058
1.50	+.065	+.041	-.042
1.25	+.040	+.021	-.033
1.00	+.022	+.010	-.023
.75	+.013	+.004	-.025
.50	+.008	.000	-.007
- .25	+.004	.000	-.002
- .00	.000	.000	.000
- .25	+.003	.000	-.001
- .50	+.005	+.003	-.006
- .75	+.013	+.013	-.013
-1.00	+.026	+.018	-.021
-1.25	+.051	+.034	-.028
-1.50	+.081	+.059	-.033
-1.75	+.125	+.095	-.037
-2.00	+.175	+.143	-.041
-2.25	+.216	+.183	-.063
-2.50	+.210	+.171	-.149

Looking at the manifold end

+ side is left

- side is right

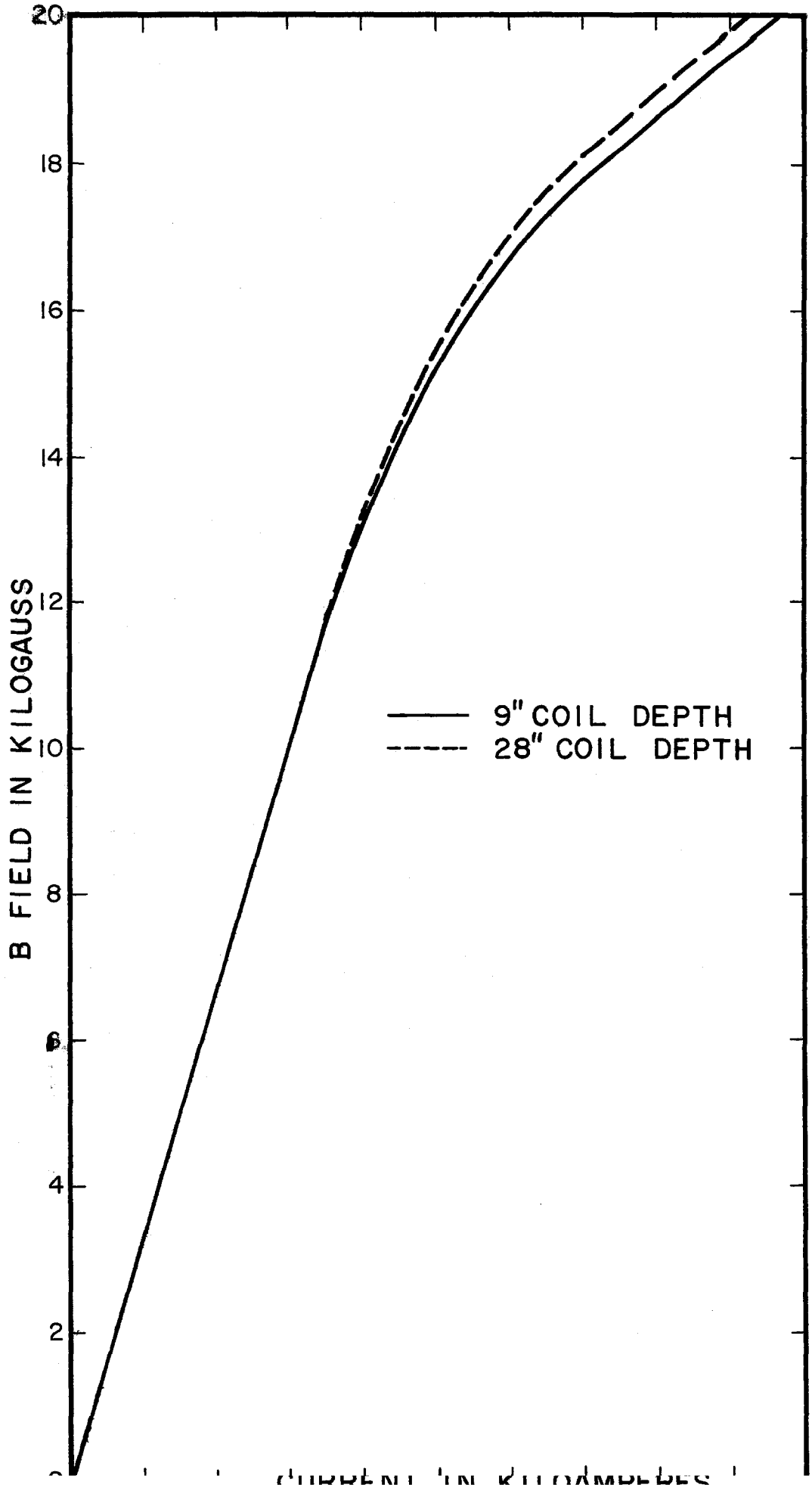

20
18
16
14
12
10
8
6
4
2
B FIELD IN KILOGAUSS
9" COIL DEPTH
28" COIL DEPTH

FIGURE 1

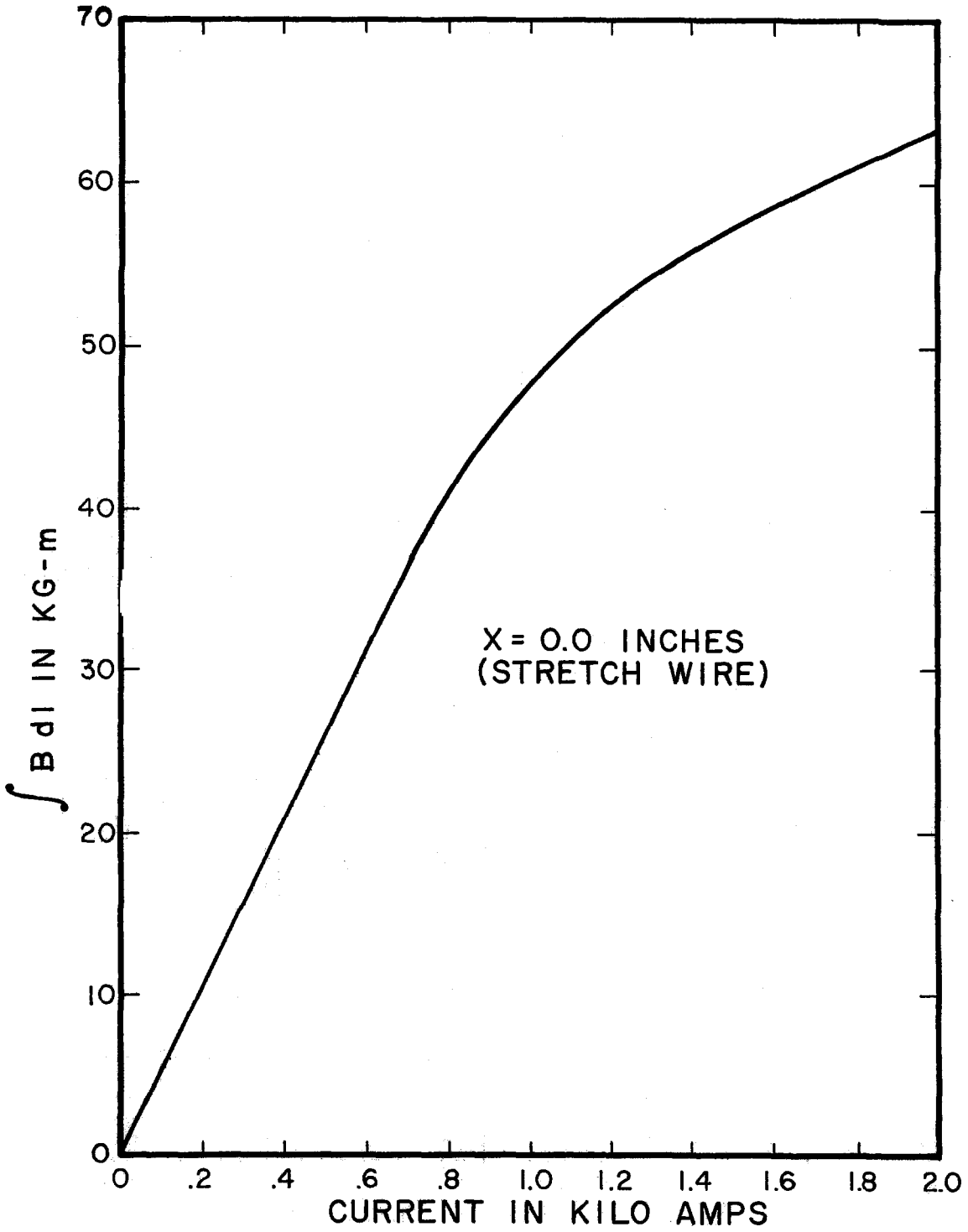

70
60
50
40
30
20
10
0
∫ B dl IN KG-m
X = 0.0 INCHES
(STRETCH WIRE)
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
CURRENT IN KILO AMPS

FIGURE 2

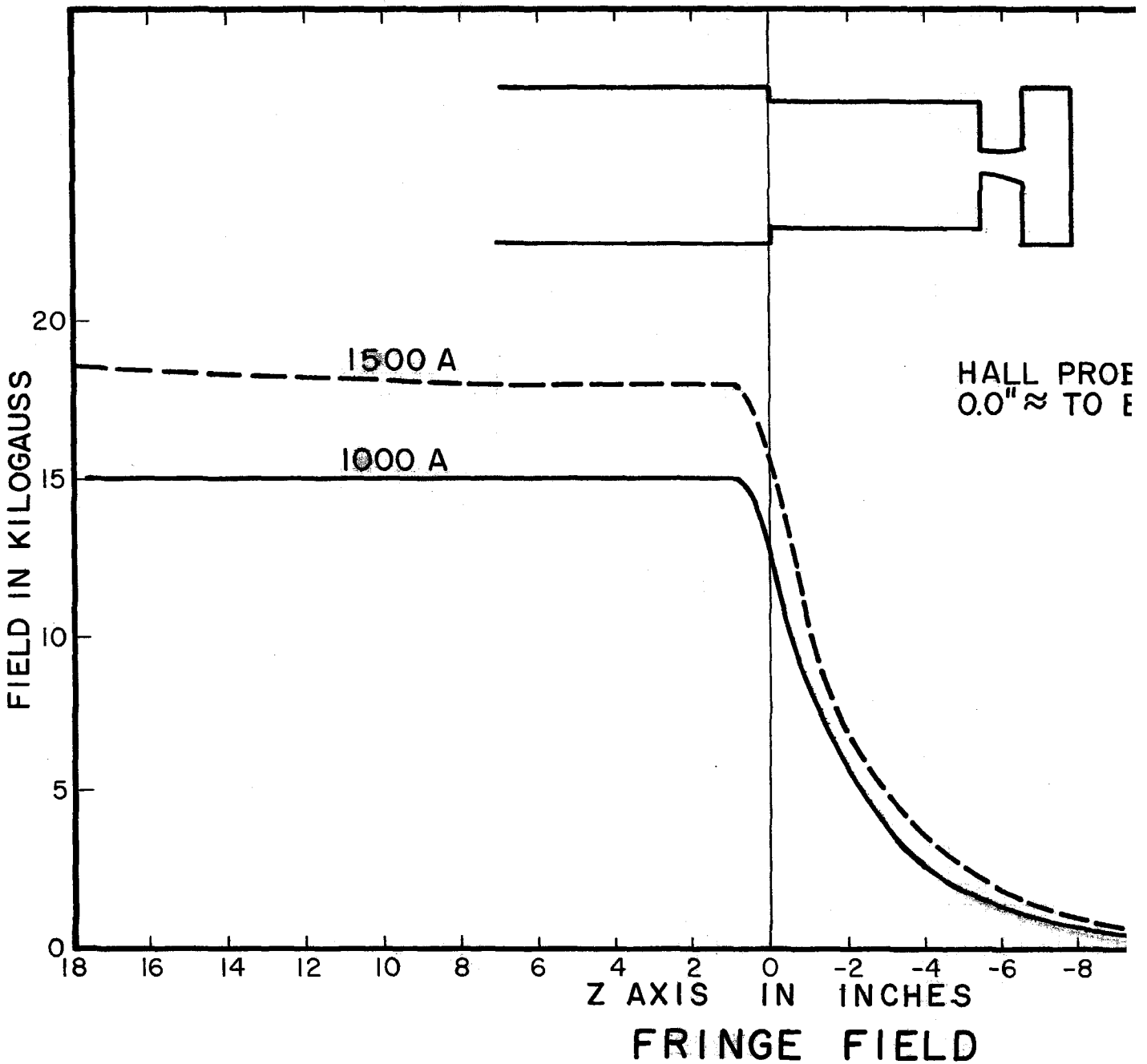
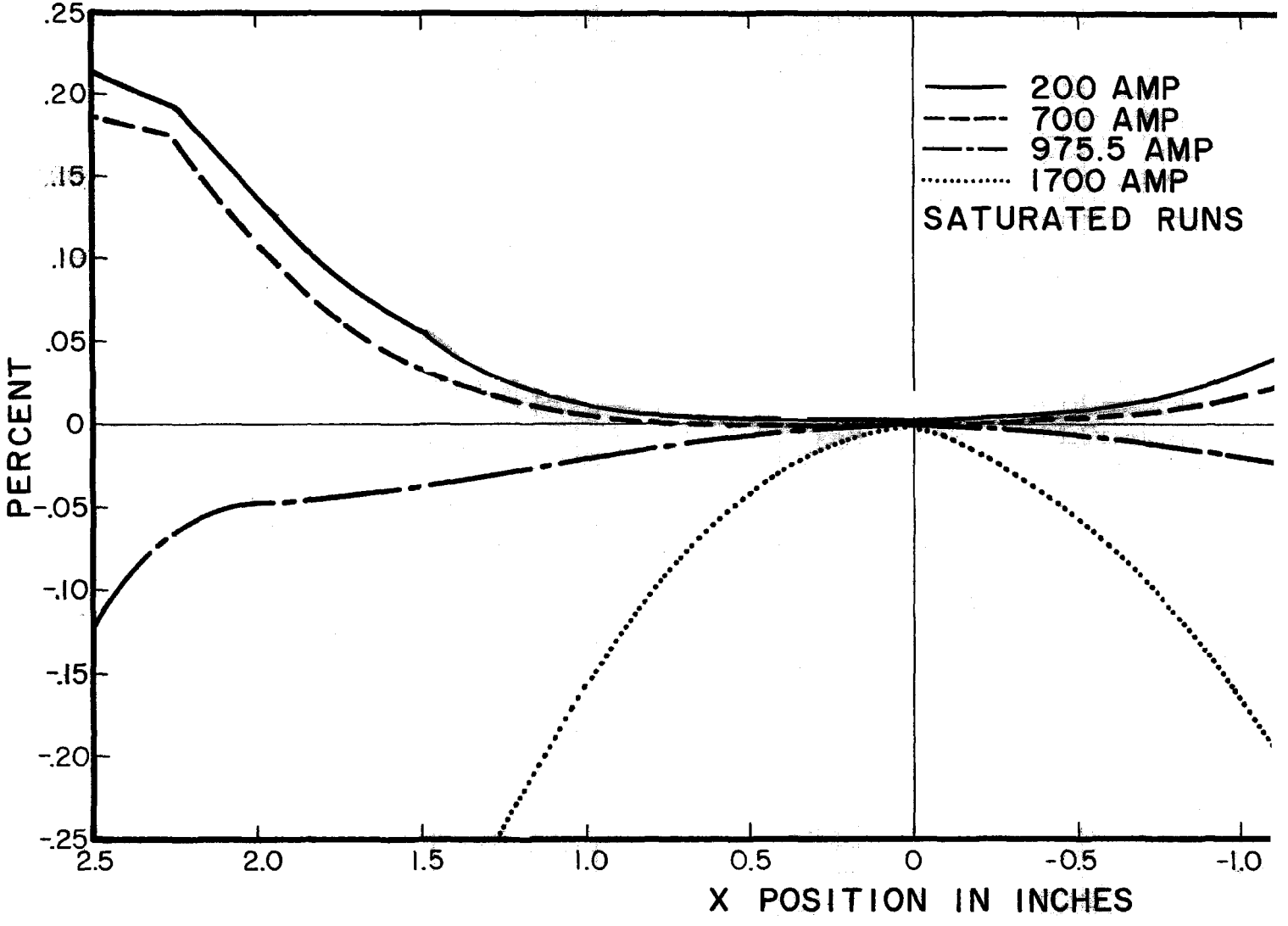

FIELD IN KILOGAUSS
20
15
10
5
0
1500 A
1000 A
HALL PROE
0.0" ≈ TO E
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
Z AXIS IN INCHES
FRINGE FIELD

FIGURE 3



FIELD SHAPE
SATURATED RUNS

FIGURE 4

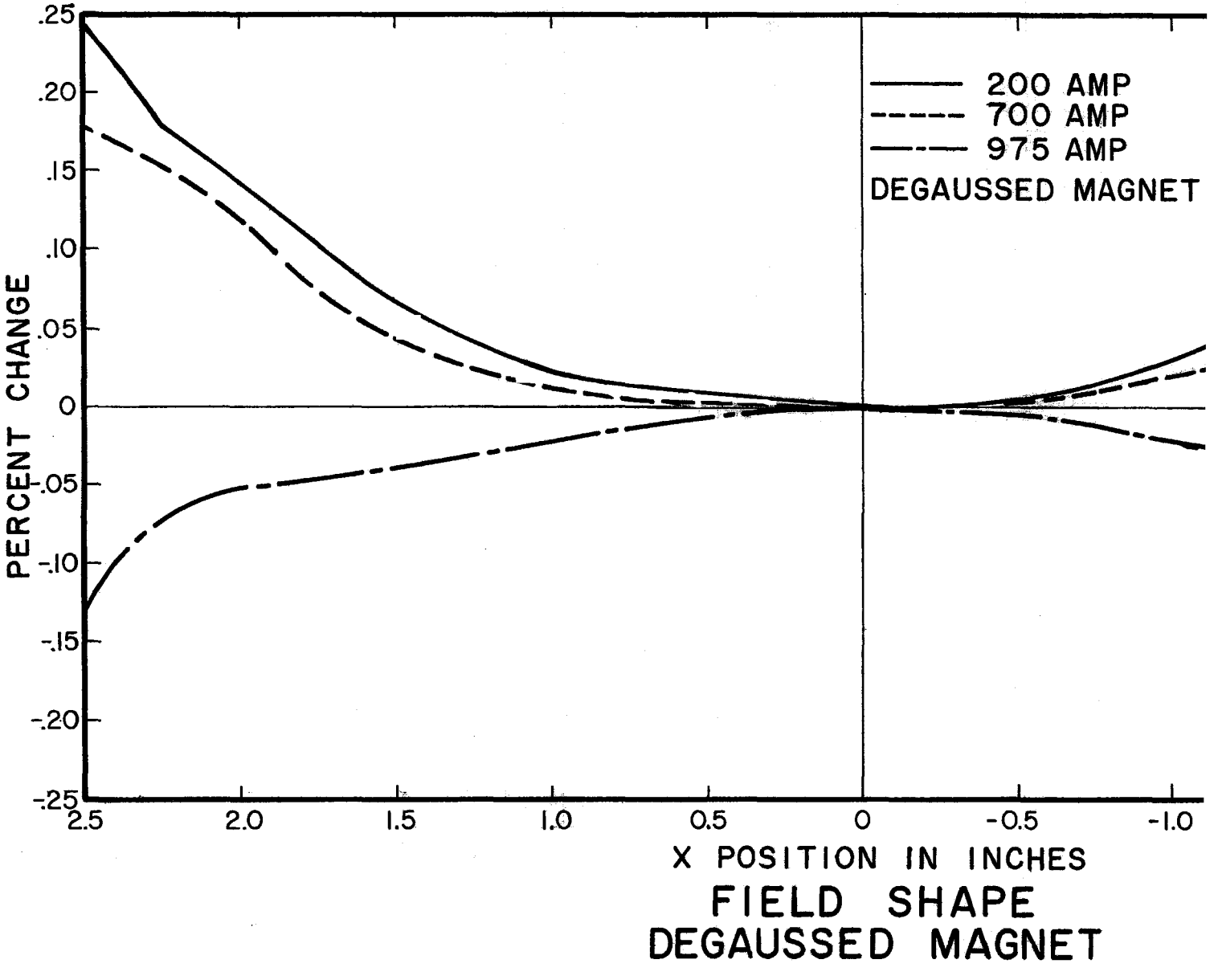

.25
.20
.15
.10
.05
0
-.05
-.10
-.15
-.20
-.25
PERCENT CHANGE
2.5
2.0
1.5
1.0
0.5
0
-0.5
-1.0
X POSITION IN INCHES
200 AMP
700 AMP
975 AMP
DEGAUSSED MAGNET
FIELD SHAPE
DEGAUSSED MAGNET

FIGURE 5

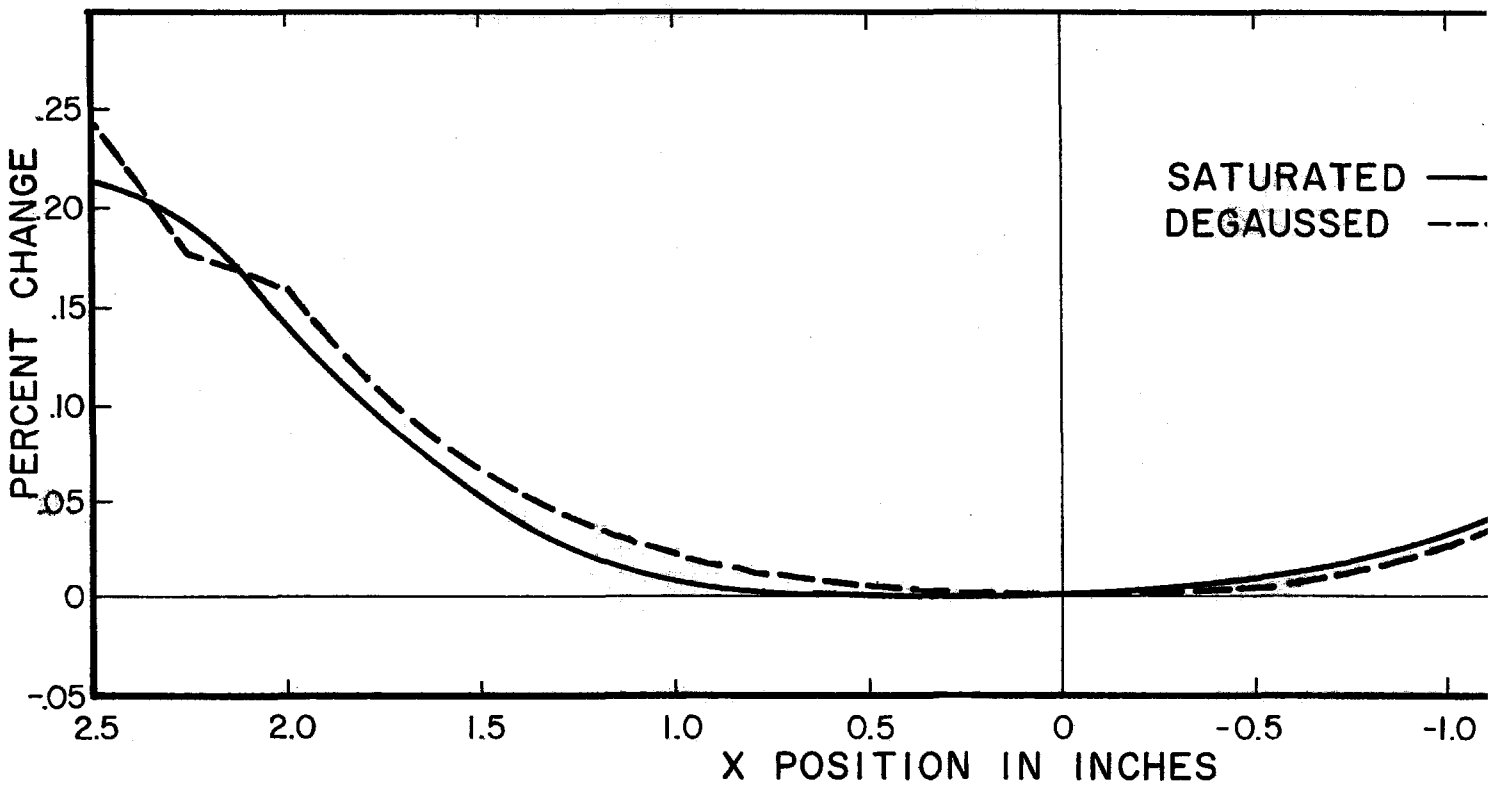

PERCENT CHANGE
.25
.20
.15
.10
.05
0
-.05
2.5
2.0
1.5
1.0
0.5
0
-0.5
-1.0
X POSITION IN INCHES
SATURATED
DEGAUSSED
FIELD SHAPE DATA AT 200 AMP

FIGURE 6

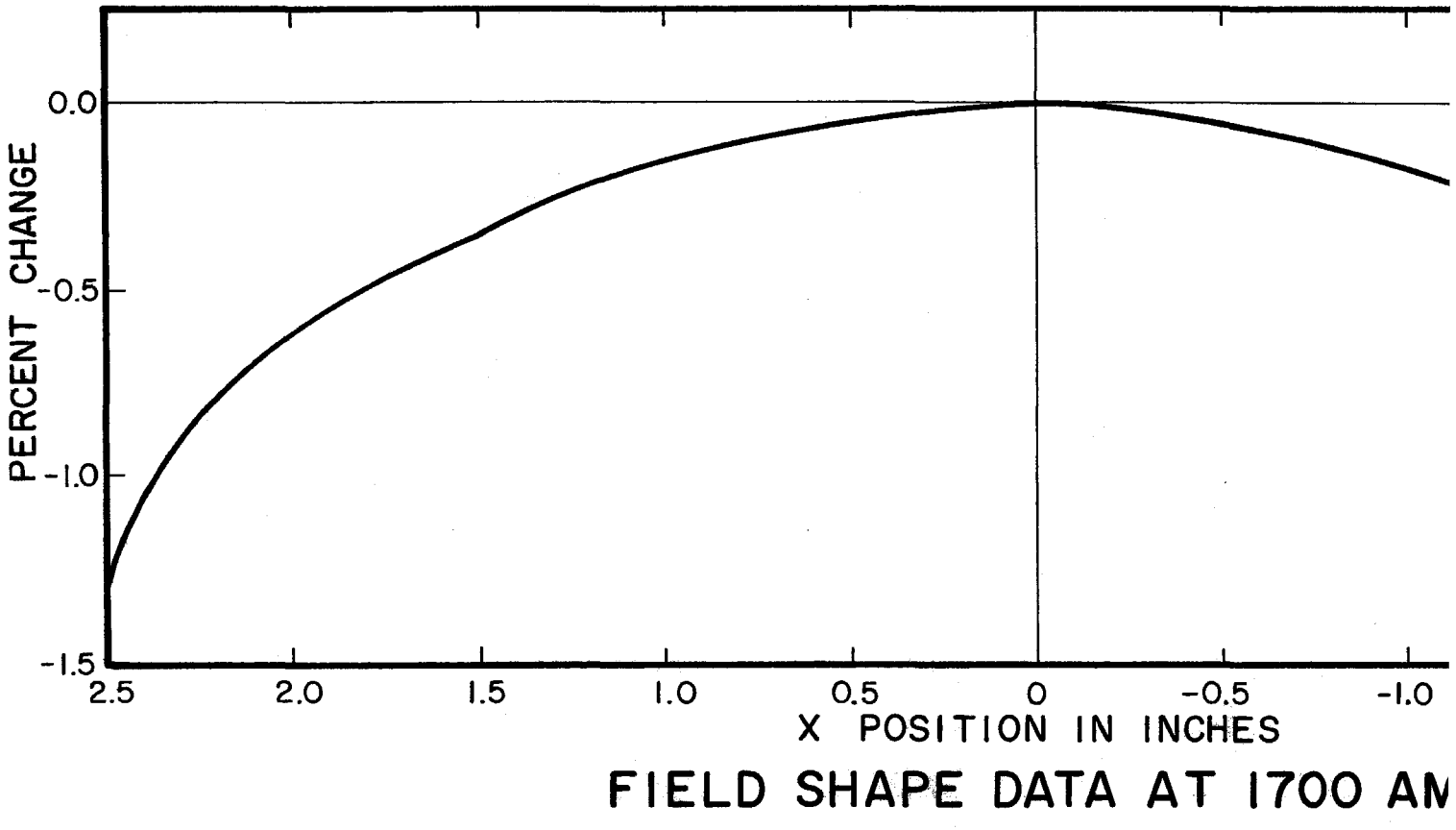

0.0
-0.5
-1.0
-1.5
PERCENT CHANGE
2.5
2.0
1.5
1.0
0.5
0
-0.5
-1.0
X POSITION IN INCHES
FIELD SHAPE DATA AT 1700 AM

FIGURE 7