Title
SSRL - LBL - SSRL UNDULATOR/RESULTS OF 1980 MAGNETIC MEASUREMENTS

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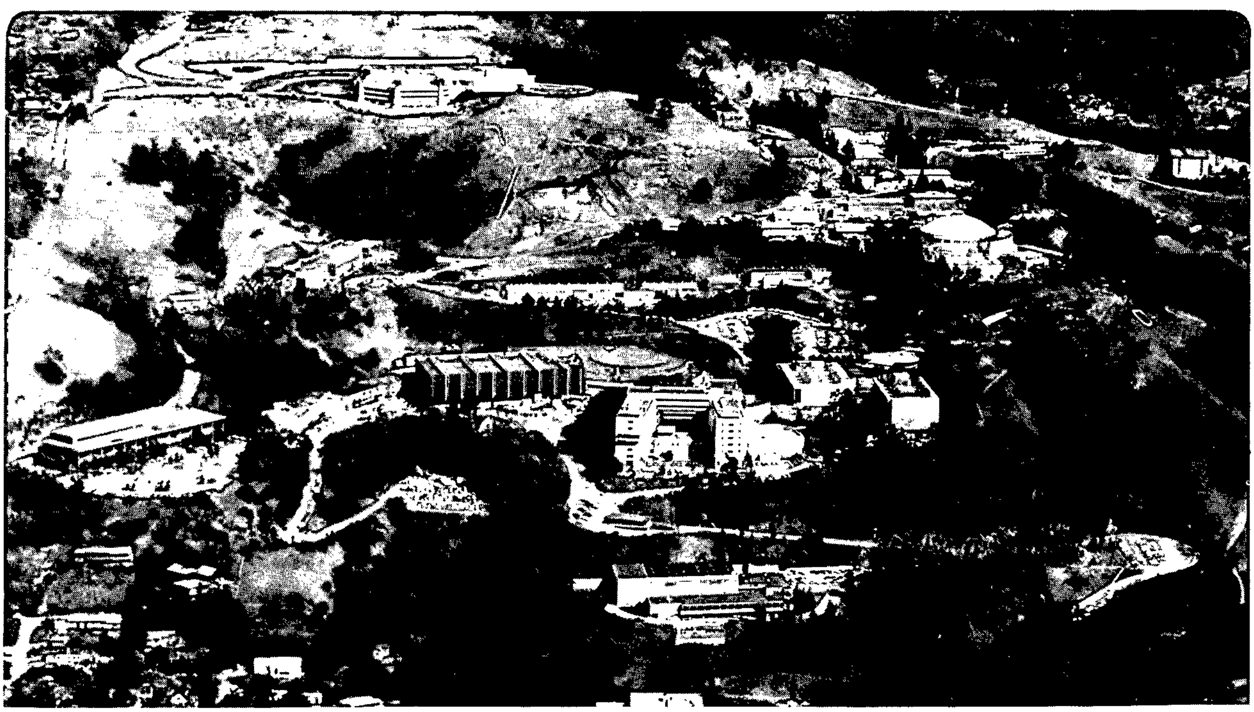
Publication Date
1980-12-01

LBID-324 c.1
UC-28

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

Engineering & Technical Services Division



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STANFORD SYNCHROTRON RESEARCH LABORATORY

LBL - SSRL UNDULATOR

RESULTS OF 1980 MAGNETIC MEASUREMENTS

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LAWRENCE BERKELEY LABORATORY

MAGNETIC MEASUREMENTS ENGINEERING

DECEMBER 15, 1980

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PROGRAM — PROJECT — JOB				
TITLE Stanford Synchrotron Research Laboratory Undulator Results of Magnetic Measurements				

INTRODUCTION

On September 12, 1980, we completed magnetic measurements of the Stanford Synchrotron Research Laboratory (SSRL) Undulator. We followed the test plan described in a previous engineering note[1] with minor variations.* The purposes of this report are:

1. to identify data,
2. to present some preliminary test results.

SUMMARY OF SIGNIFICANT RESULTS

1. Mean Amplitude Of Peaks And Valleys For Four Gaps:
   a. Table X, page 35, summarizes calculated values of mean and standard deviation of the mean from peak/valley measurements of magnetic induction for 2.7, 3.5, 4.5 and 6.0 cm gaps.
   b. Figure 16, page 36, displays both mean values of magnetic induction and measured gap as functions of gap counter display.
2. Rotatable End Magnet Counter Displays:
   a. Initial Settings

      +x End Counter Display 9309

      -x End Counter Display 2718

*Figures 1 and 2 (reproductions of Figures 1 and 2 of Reference 1) represent the undulator and the coordinate system for the measurements.

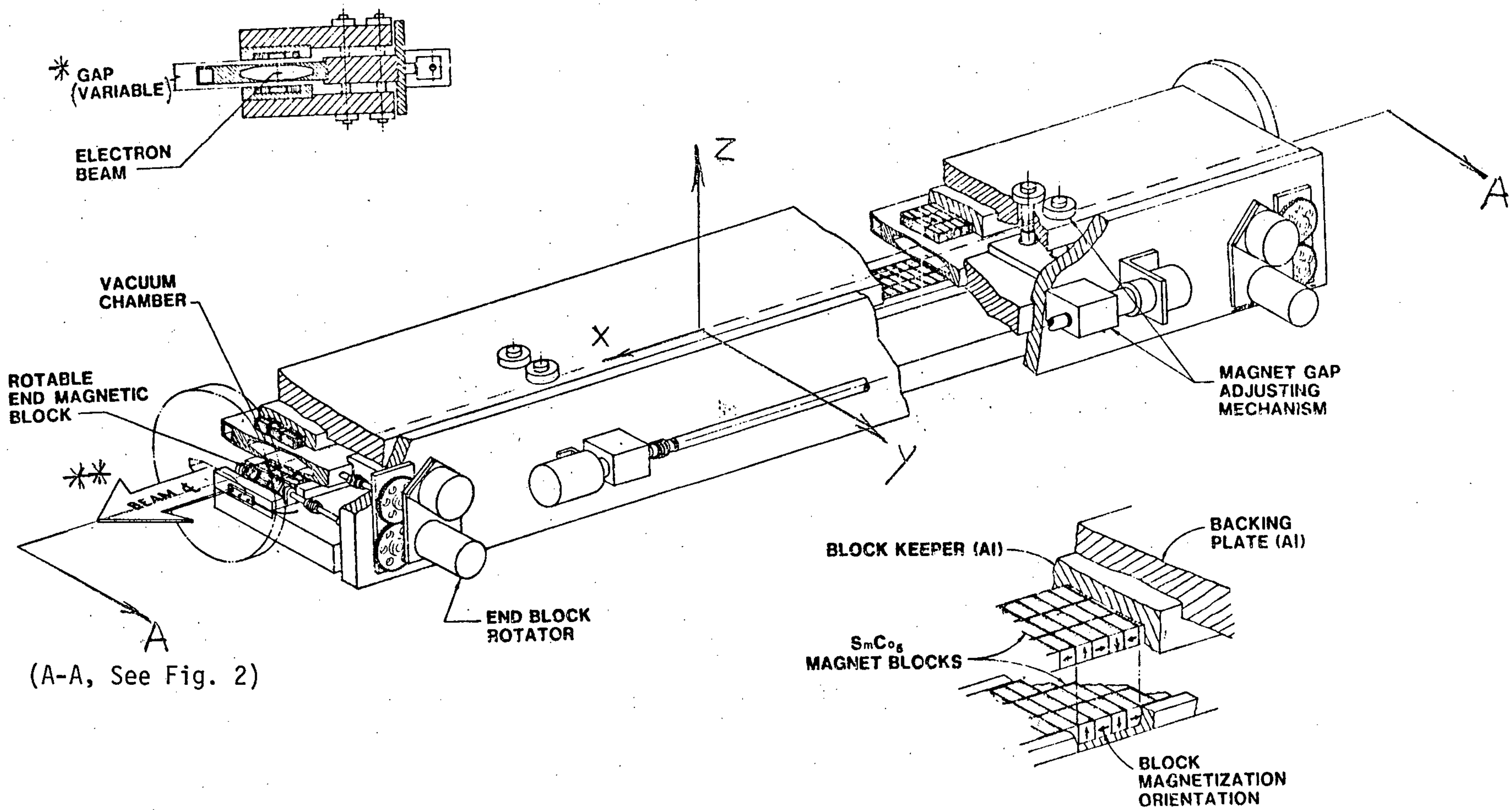


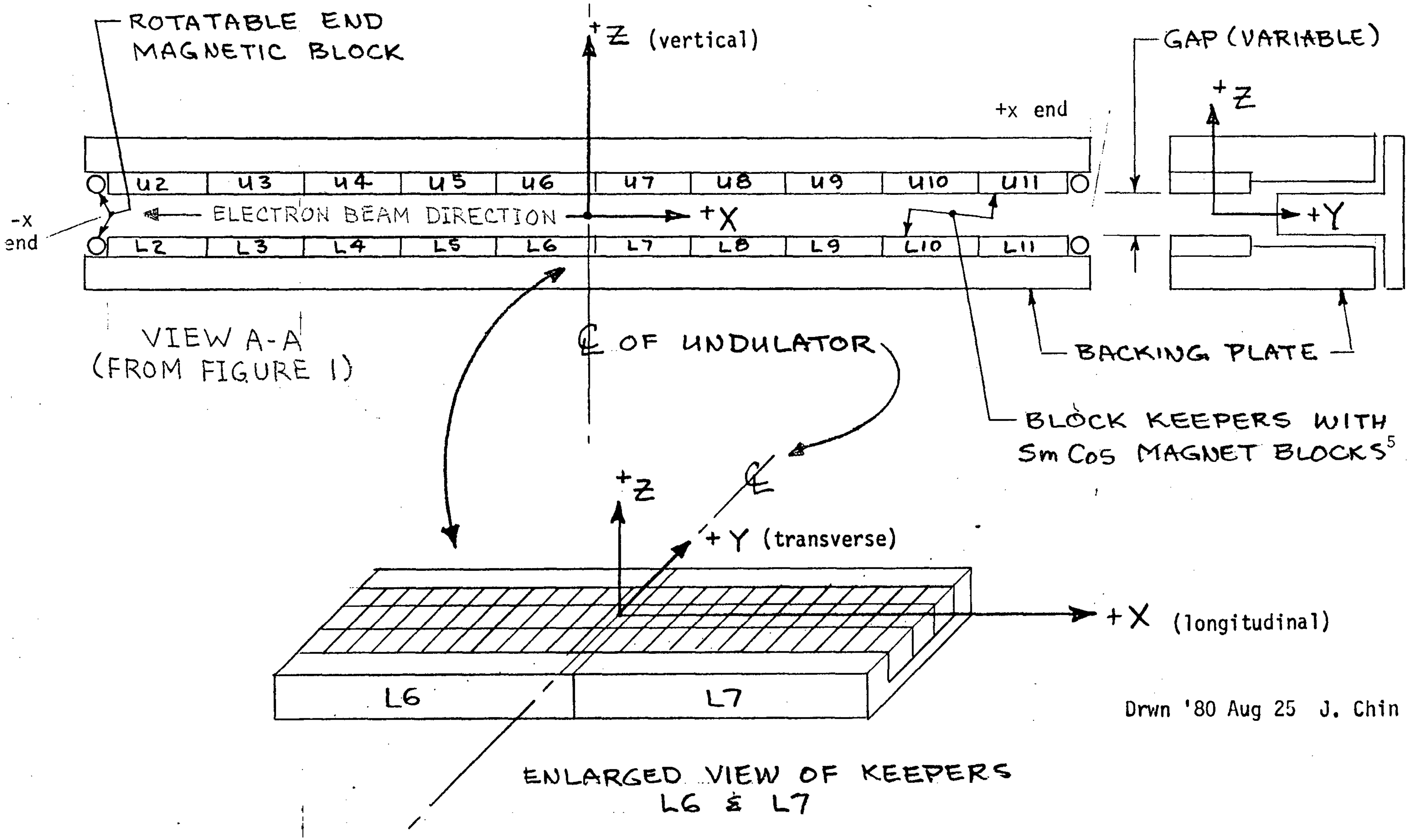
FIGURE 1 LBL - SSRL UNDULATOR

Drwn '80 April Tom Chan

*Gap Dimensions Selected for Measurement: 2.7, 3.5, 4.5 & 6.0 (cm)

Corresponding Gap Counter Display } { 13900 10807 06867 00844 } { Counts

**Beam Arrow Shows Direction Of Positron Beam Through Undulator
Electron Direction Will Be The -x Direction



UNDULATOR FIG 2

2. Rotatable End Magnet Counter Displays (continued)

   b. Net integrals with above settings are summarized in Table IVC, page 28.

   c. To reduce resultant beam deflection, (1) start with above counter displays and (2) try decreasing entrance counter and increasing exit counter by equal amounts.

DATA IDENTIFICATION

Data Book No. 626[2]

Table I is the index to LBL Magnetic Measurements Engineering Data Book No. 626.[2] All data has been collected in this book.

Data On Magnetic Tape Cartridge (3 M DC300A Magnetic Tape Cartridges)

Digital data (Test Plan, Sections VII and VIII) were recorded on cartridges. We have the following cartridges in Building 25A:

MME GPIB #1 Original

MME GPIB #1 Duplicate (with editing)

MME Undulator Data Processing

Table II is an index to the duplciate cartridge. Table III is an index to the data processing cartridge.

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		Performed By (Initials)
	Job Sheet/Index	
	Test Plan, MT 291 (With Modifications)	DHN
I.	Calibration of 3 cm & 6 cm Coils	DHN/EAC
II.	Synchronization of Rotatable Magnets	DHN/EAC
III.	Tuning Range of Rotatable Magnets	
	A. Model of End Effects (MT 289)	DHN
IV.	Transverse (y) Profiles	DHN/EAC
V & VI.	$_0\int^\infty B_z dx \to 0$ and $_{-\infty}\int^0 B_z dx \to 0$ and $_{-\infty}\int^\infty B_z dx \to 0$	DHN/EAC/KS
	Program for Digital Measurements (VII & VIII)	MIG
VII.	Longitudinal (x) End Profiles $\{B_z(x, 0, 0)\}$ Ends	

	Tester(s)	Gap	Location/Density	Data Pairs	Tape File	Date
A.	DHN/EAC	2.7 cm	z = 0.071 in (0.5 cm Data)	62	11	9/8
B.	DHN/EAC	2.7 cm	+x End CTR = 9419	54	12	9/8
C.	DHN/EAC	2.7 cm	+x End CTR = 9309	52	13	9/8
D.	DHN/EAC	2.7 cm	-x End CTR = 2718	31	14	9/8
E.	DHN/EAC	2.7	-x End CTR = 2633	32	15	9/8
F.	DHN/EAC	2.7 cm	-x End (CTR = 2663 & 2718)	(not saved)		9/8
G.	DHN/EAC	2.7 cm	+x End (CTR = 9309 & 9419)	(not saved)		9/8
H.	DHN/EAC	6.0 cm	Both Ends (some data not saved)	65	16	9/9
I.	DHN/EAC	4.5 cm	Both Ends	127	17	9/9
J.	DHN/EAC	3.5 cm	Both Ends	133	18	9/9

VIII. Longitudinal, $B_z(x, 0, 0)$ vs x, Interior Profiles

	Tester(s)	Gap	Data Type	Data Pairs	File	Date
A.	EAC/JWC	2.7 cm	Manual Data Peaks/Valleys	58	19	8/29
B.	DHN/EAC	2.7 cm	0.5 cm Increments	353	5	9/4
C.	DHN/EAC	2.7 cm	Peaks/Valleys, Zeros	116	6	9/4
D.	DHN/EAC	3.5 cm	0.5 cm Increments	355	7	9/5
E.	DHN/EAC	3.5 cm	Peaks/Valleys, Zeros	117	8	9/5
F.	MIG/EHH	4.5 cm	All Data	409	9	9/5
G.	MIG/YZ	6.0 cm	All Data	410	10	9/6
H.	EHH/JWC	2.7 cm	Manual Data, Peaks/Valleys	28	20	9/11

IX.	Longitudinal Periodicity Not Done	
X.	Vertical Symmetry $\{B_z(+z) - B_z(-z)\}$ vs x	EHH
	Memorandums/Reports	DHN, et. al.
	Drawings	EHH/JWC

TABLE I INDEX TO MAGNETIC MEASUREMENTS ENGINEERING DATA BOOK NO. 626

Notes: CTR: Counter Reading

JWC = John W. Chin; DHN = Donald H. Nelson

EAC = Ed A. Cyr; K S = Kathy Schiff

MIG = Michael I. Green; Y Z = Yadu Zambre

EHH = Egon H. Hoyer

FILE	CONTENTS	MAGNETIC MEASE. ENG.--GPIB #1 DUPL
1	DIRECTORY PROGRAM,(8192),80-09-22 LINE 150	
2	TWO PARAMETER GPIB INPUT PROGRAM(9216)80/09/05	
3	SLAC UNDULATOR,PROGRAM TEST,I=400,8/21-16:12,(9216)	
4	SLAC UNDULATOR,2.7CM GAP,I=177,9/4-13:13,(9216)	
5	SLAC UNDULATOR,2.7CM GAP,I=353,9/4-13:13,(9216)	
6	SLAC UNDULATOR,2.7CM GAP,I=116,9/4-15:37,(9216)	
7	SLAC UNDULATOR,3.5CM GAP,I=355,9/5-09:36,(9216)	
8	SLAC UNDULATOR,3.5CM GAP,I=117,9/5-10:57,(9216)	
9	SLAC UNDULATOR,4.5CM GAP,I=409,9/5-17:14,(9216)	
10	SLAC UNDULATOR,6.0CM GAP,I=410,9/6-08:47,(9216)	
11	SLAC UNDULATOR,2.7CM GAP,I=62,9/8-11:08,(9216)	
12	SLAC UNDULATOR,2.7CM GAP,I=54,9/8-12:38,(9216)	
13	SLAC UNDULATOR,2.7CM GAP,I=52,9/8-13:13,(9216)	
14	SLAC UNDULATOR,2.7CM GAP,I=31,9/8-13:47,(9216)	
15	SLAC UNDULATOR,2.7CM GAP,I=32,9/8-14:09,(9216)	
16	SLAC UNDULATOR,6.0CM GAP,I=70,9/9-08:11,(9216)	
17	SLAC UNDULATOR,4.5CM GAP,I=127,9/9-10:05,(9216)	
18	SLAC UNDULATOR,3.5CM GAP,I=133,9/9-11:04,(9216)	
19	SLAC UNDULATOR,2.7CM GAP,I=58,8/28 MANUAL(2048)	
20	SLAC UNDULATOR,2.7CM GAP,I=28,9/11 MANUAL(2048)	

TABLE II INDEX TO DATA ON MME GPIB #1 DUPLICATE CASSETTE

FILE	CONTENTS	MAGNETIC MEASE. ENG.--GPIB #1 DUPL	
1	DIRECTORY PROGRAM,(8192),80-09-22 LINE 150		
2	TWO PARAMETER GPIB INPUT PROGRAM(9216)80/09/26		
3	SLAC UNDULATOR,2.7CM.GAP,I=638 ,9/26	(14000)	
4	SLAC UNDULATOR,3.5CM GAP,I=605,9/26	(14000)	
5	SLAC UNDULATOR,4.5CM GAP,I=536 9/26	,(14000)	
6	SLAC UNDULATOR,6.0CM GAP,I=480,9/26	,(14000)	
7	BAD FILE	(14000)	
8	SLAC UNDULATOR,2.7 cm GAP,I=55,9/4/''80	(2048)	(See Table VI)
9	SLAC UNDULATOR,3.5 cm GAP,I=55,9/5/''80	(2048)	(See Table VII)
10	SLAC UNDULATOR,4.5 cm GAP,I=55,9/5/''80	(2048)	(See Table VIII)
11	SLAC UNDULATOR,6.0 cm GAP,I=55,9/6/''80	(2048)	(See Table IX)

TABLE III INDEX TO DATA ON DATA PROCESSING TAPE

PRELIMINARY TEST RESULTS*

Referring to the tests itemized in the test plan,[1] we summarize the following preliminary results.

I. Calibration Of Coils (See Reference 1, Page 41)

II. Synchronization Of Rotatable Magnets

Following the procedure described in the test plan, we synchronized the upper and the lower rotatable magnets at each end of the undulator. To prevent slipping between the magnet assemblies and the shafts which rotate the magnet assemblies, John Chin had set-screws installed as a temporary measure. Index lines on the rotatable assembly line up with stationary fiducial lines on the "END MAGNET HOLDER SUPPORT MOUNT"[3] when the counters read the following:

Exit 02466

Entrance 9235, 8737, 9735 (indicates 500 counts = 360°)

Note: There are two index lines on each rotatable assembly (approximately 180° apart). The above counter values correspond to the index lines that line up with the fiducials when the set screws which secure the index sleeves are accessible.

---

*Roman numerals used in this section correspond both to those used in Table I and those used in Reference 1 (The Test Plan).

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III. Tuning Range (And Sensitivity) Of Rotatable Magnets

A. Plots of change in $\int B_z dx$ with rotation of rotatable magnet assemblies at each end:

Figures 3 - 5 represent $\Delta\int B_z dx$ vs counter output, where $\Delta\int B_z dx$ is the change in $\int B_z dx$ and the counter output is proportional to orientation of the rotatable magnet assembly at each end of the undulator.

B. Effects on the amplitude of magnetic induction (B_z) at selected x-positions near the +x end of the undulator due to changes in orientation of the rotatable magnet assembly at the +x end of the undulator:

Figure 6 is a plot of the maximum changes in magnetic induction $\Delta B_z(x, 0, 0)$ vs x resulting from rotation of the +x end rotatable magnet assembly. The x-positions were selected by searching for local maxima and minina when the entrance counter displayed 9165 (arbitrary orientation). With the probe for measuring magnetic-induction held stationary, we rotated the +x end rotatable magnet assembly, recording maximum and minimum values where the maxima and minima values of magnetic-induction were observed.

C. Differences in each end region for two orientations of each end assembly that produce a "net" zero $\int B_z dx$:

The purpose of the rotatable magnet assembly at each end of the undulator is to reduce $_o\int^{\infty} B_z dx$ (+x end) and $_{-\infty}\int^{o} B_z dx$ (-x end) to to zero. The contribution to the integrals of the end assemblies is roughly sinusoidal with cancellation near a valley (maximum negative contribution). There are two unique orientations for each rotatable assembly that null the half-magnet integral.

Figures 7 - 10 show end profiles for each end with the two "null" orientations.

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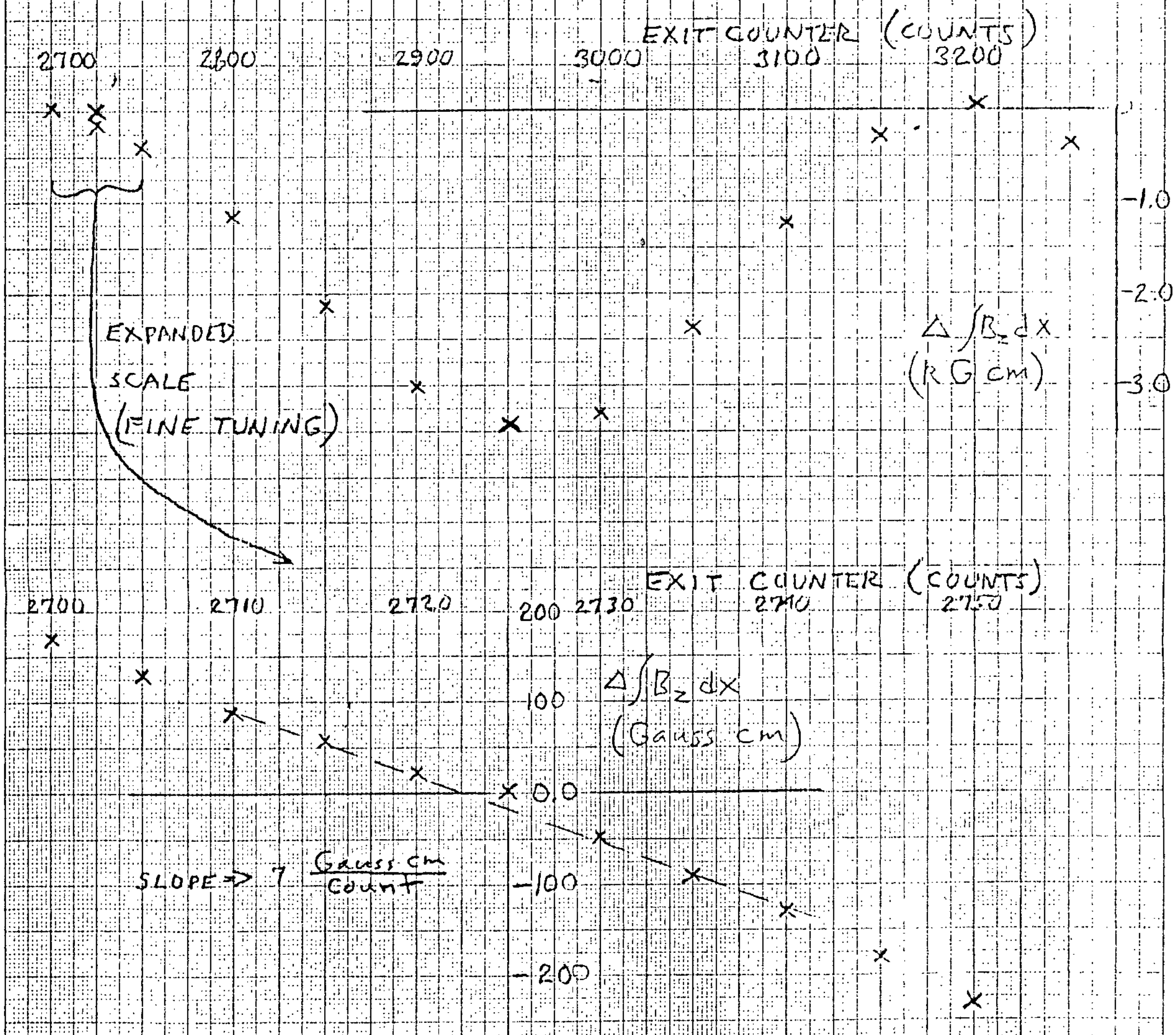
Fig 3 STANFORD SYNCHROTRON RESEARCH LAB UNDULATOR CHANGE IN MAGNETIC-INDUCTION INTEGRAL WITH ORIENTATION OF ROTATABLE MAGNET AT −X END



DATA: 80 Sept 12 DHN/EAC
DRAWN: 80 Sept 18 DHN
GAP = ~2.7 cm
$\frac{\Delta \int B\,dl}{\Delta E_{int}}$ = 9.93 Gauss cm/in

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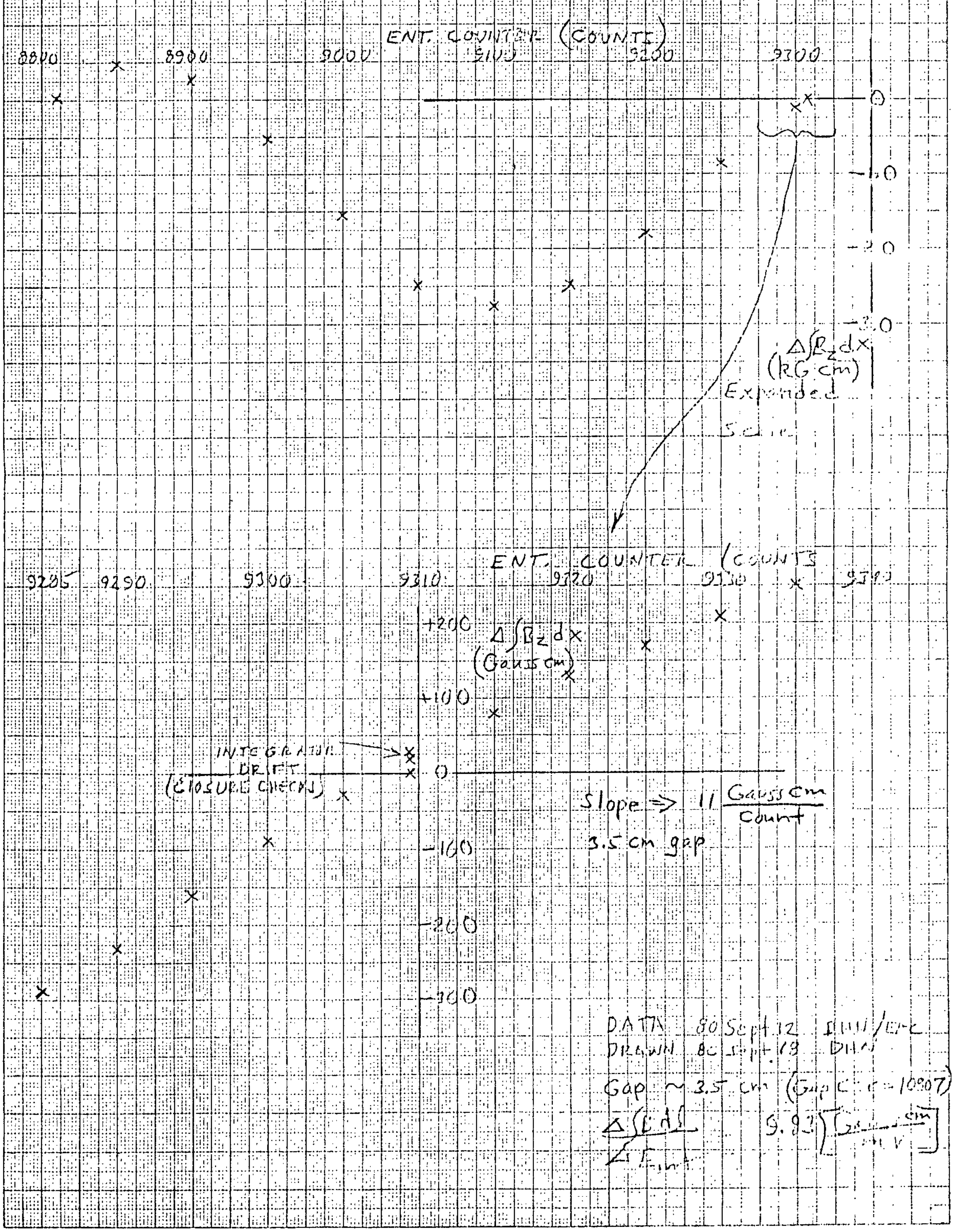
FIG 4 STANFORD SYNCHROTRON RESEARCH LAB UNDULATOR
CHANGE IN MAGNETIC INDUCTION INTEGRAL WITH
ORIENTATION OF ROTATABLE MAGNET AT +E END



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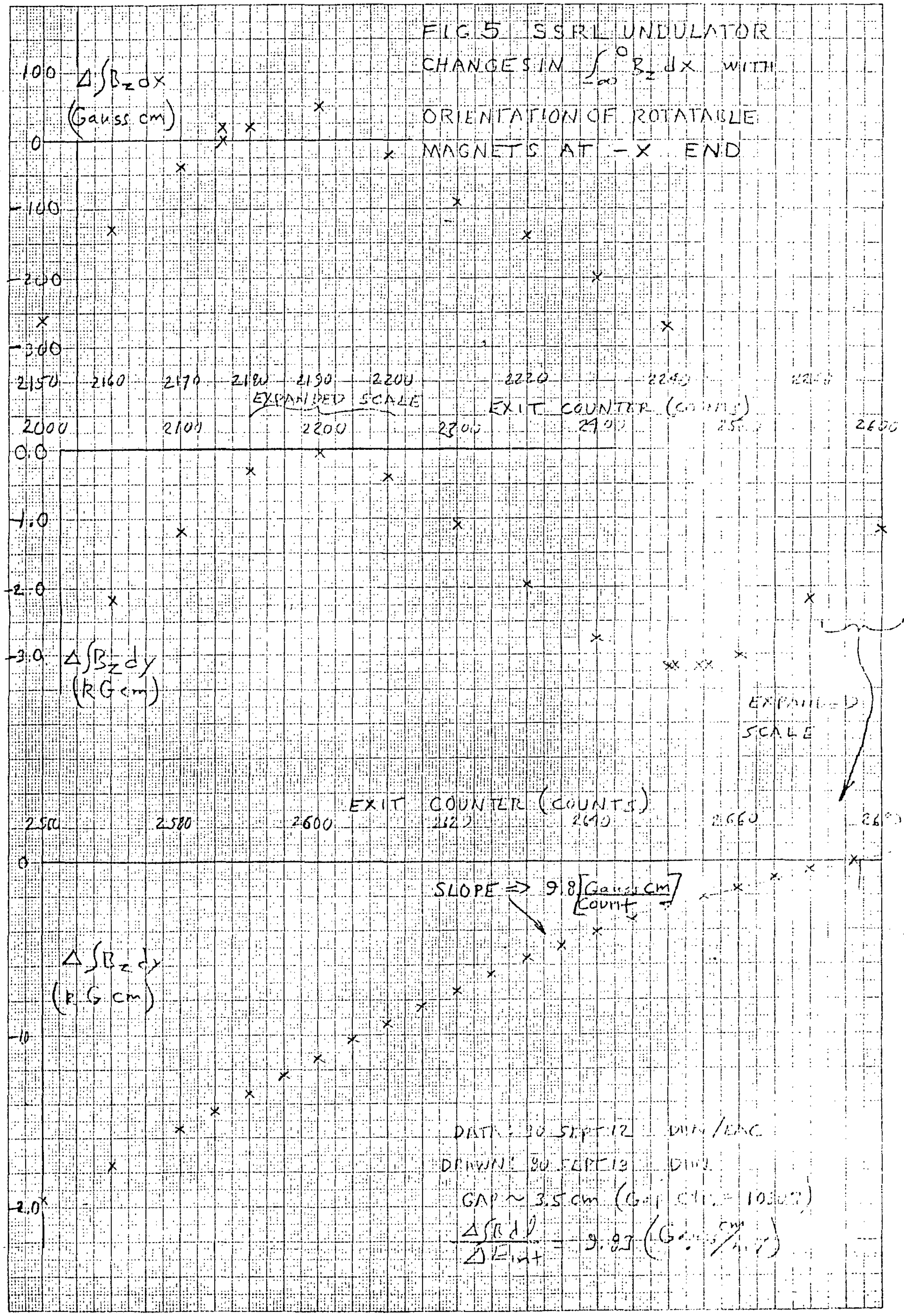


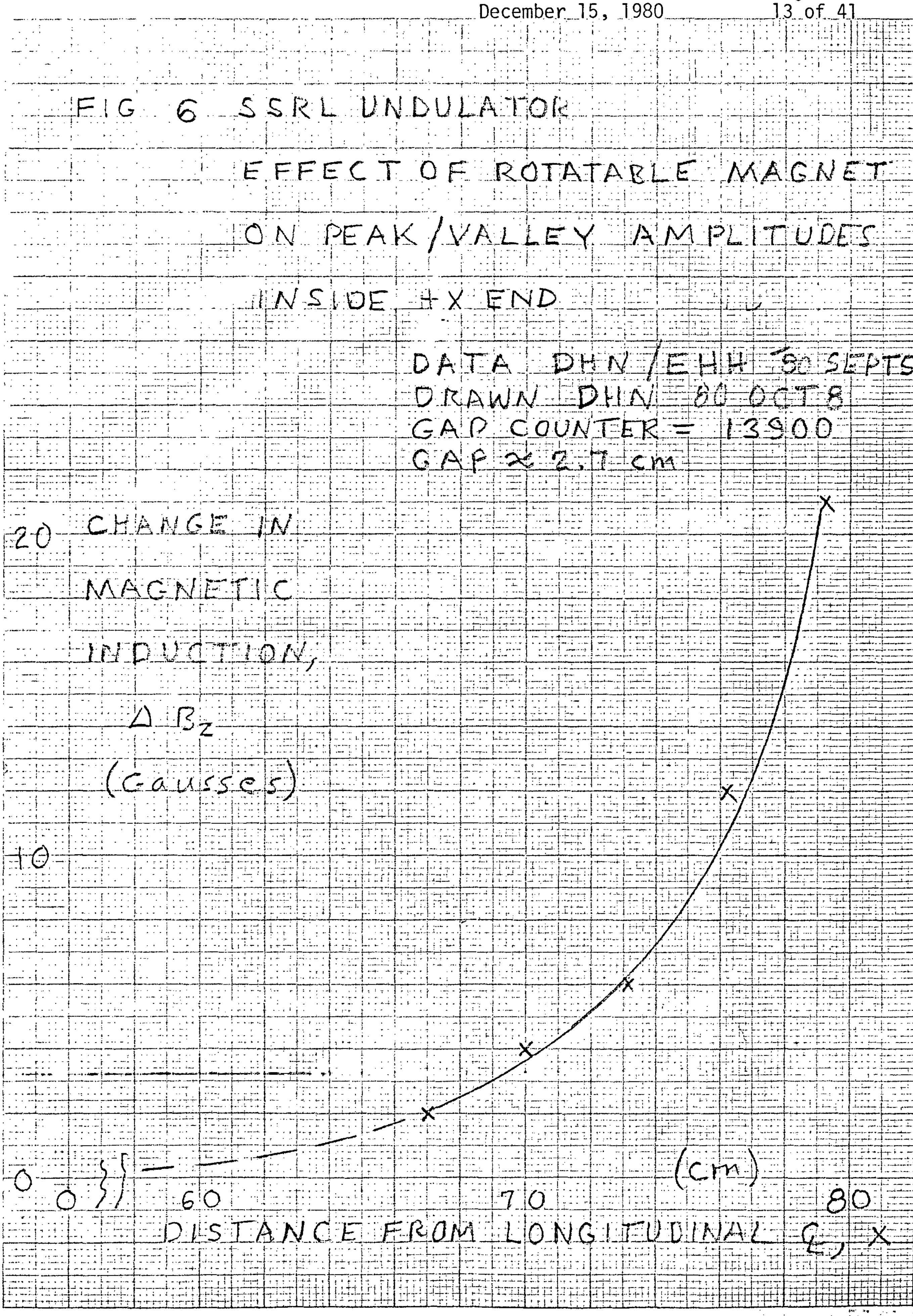
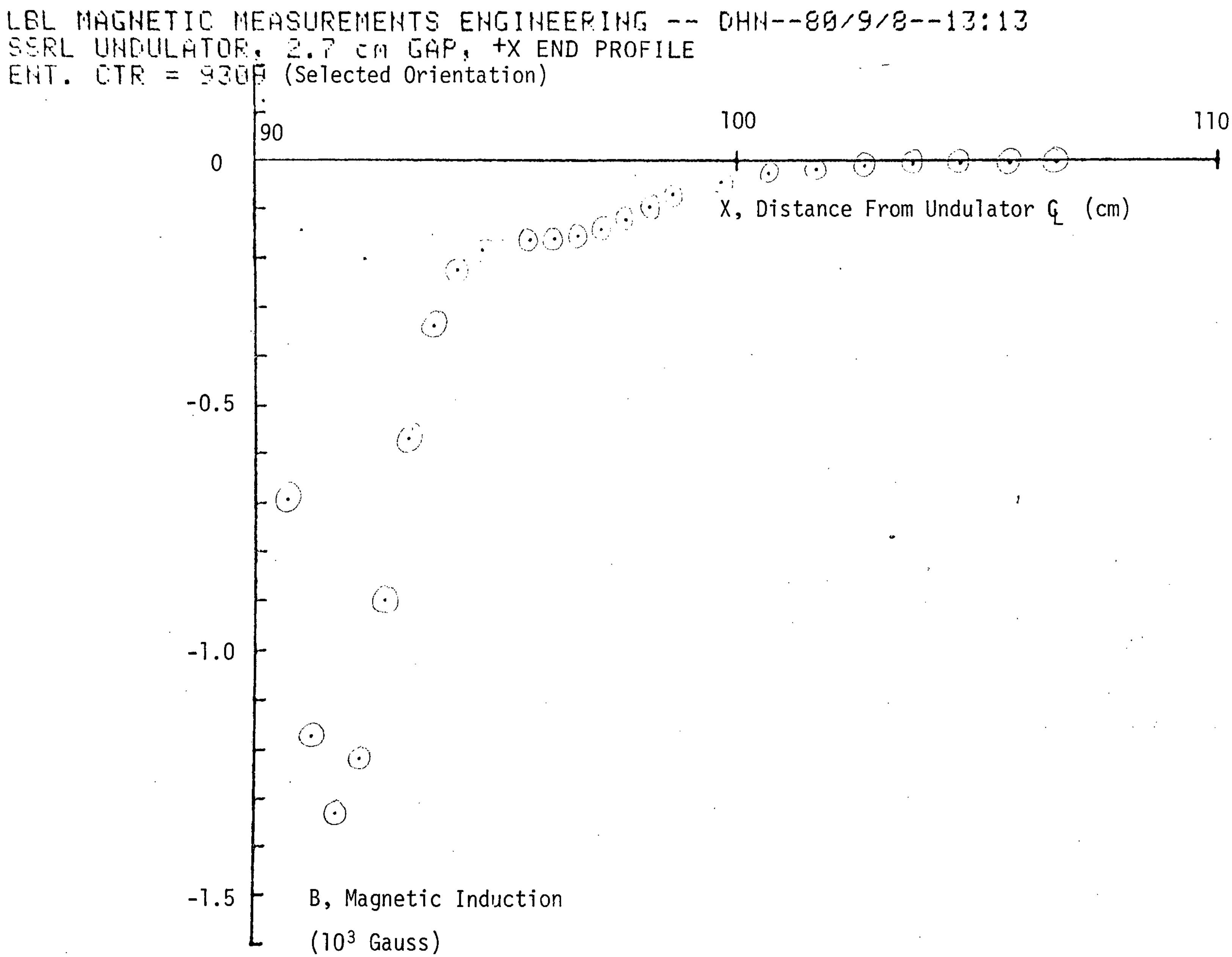


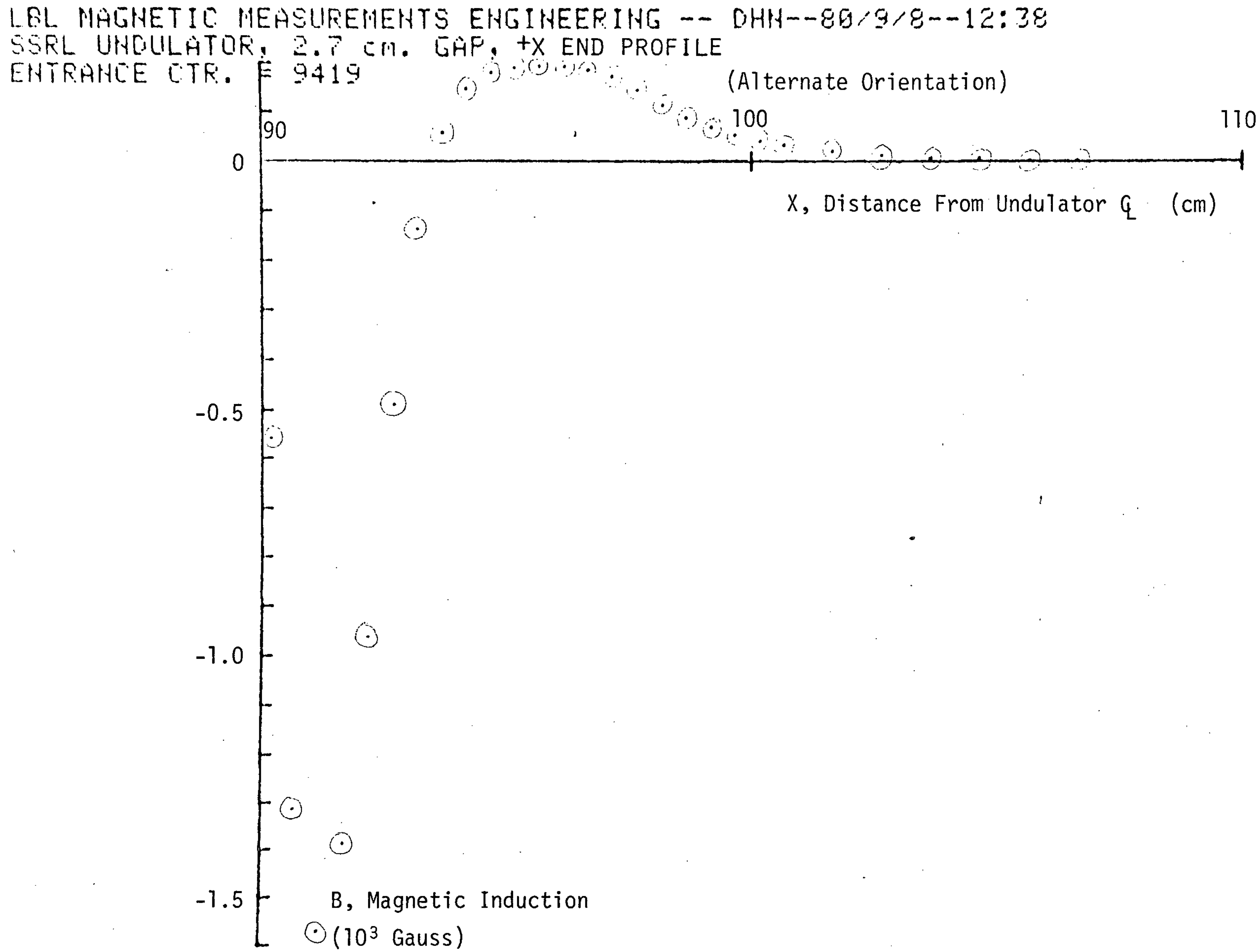
FIG 6 SSRL UNDULATOR
EFFECT OF ROTATABLE MAGNET
ON PEAK/VALLEY AMPLITUDES
INSIDE +X END
DATA DHN/EHH 80 SEPT5
DRAWN DHN 80 OCT8
GAP COUNTER = 13900
GAP ≈ 2.7 cm
CHANGE IN MAGNETIC INDUCTION, ΔB_z (Gausses)
20
10
0
0
60
70
80
(cm)
DISTANCE FROM LONGITUDINAL ℄, X

FIGURE 7



LBL MAGNETIC MEASUREMENTS ENGINEERING -- DHN--80/9/8--13:13
SSRL UNDULATOR, 2.7 cm GAP, +X END PROFILE
ENT. CTR = 930Ø (Selected Orientation)
90
100
110
0
-0.5
-1.0
-1.5
X, Distance From Undulator ℄ (cm)
B, Magnetic Induction
(10^3 Gauss)

FIGURE 8



LBL MAGNETIC MEASUREMENTS ENGINEERING -- DHN--80/9/8--12:38
SSRL UNDULATOR, 2.7 cm. GAP, +X END PROFILE
ENTRANCE CTR. = 9419
(Alternate Orientation)
90
100
110
0
-0.5
-1.0
-1.5
X, Distance From Undulator ℄ (cm)
B, Magnetic Induction
(10³ Gauss)

FIGURE 9

LBL MAGNETIC MEASUREMENTS ENGINEERING -- DHN--80/9/8--13:47
SSRL UNDULATOR, 2.7 cm GAP, -X END PROFILE
EXIT CTR = 271B (Selected Orientation)

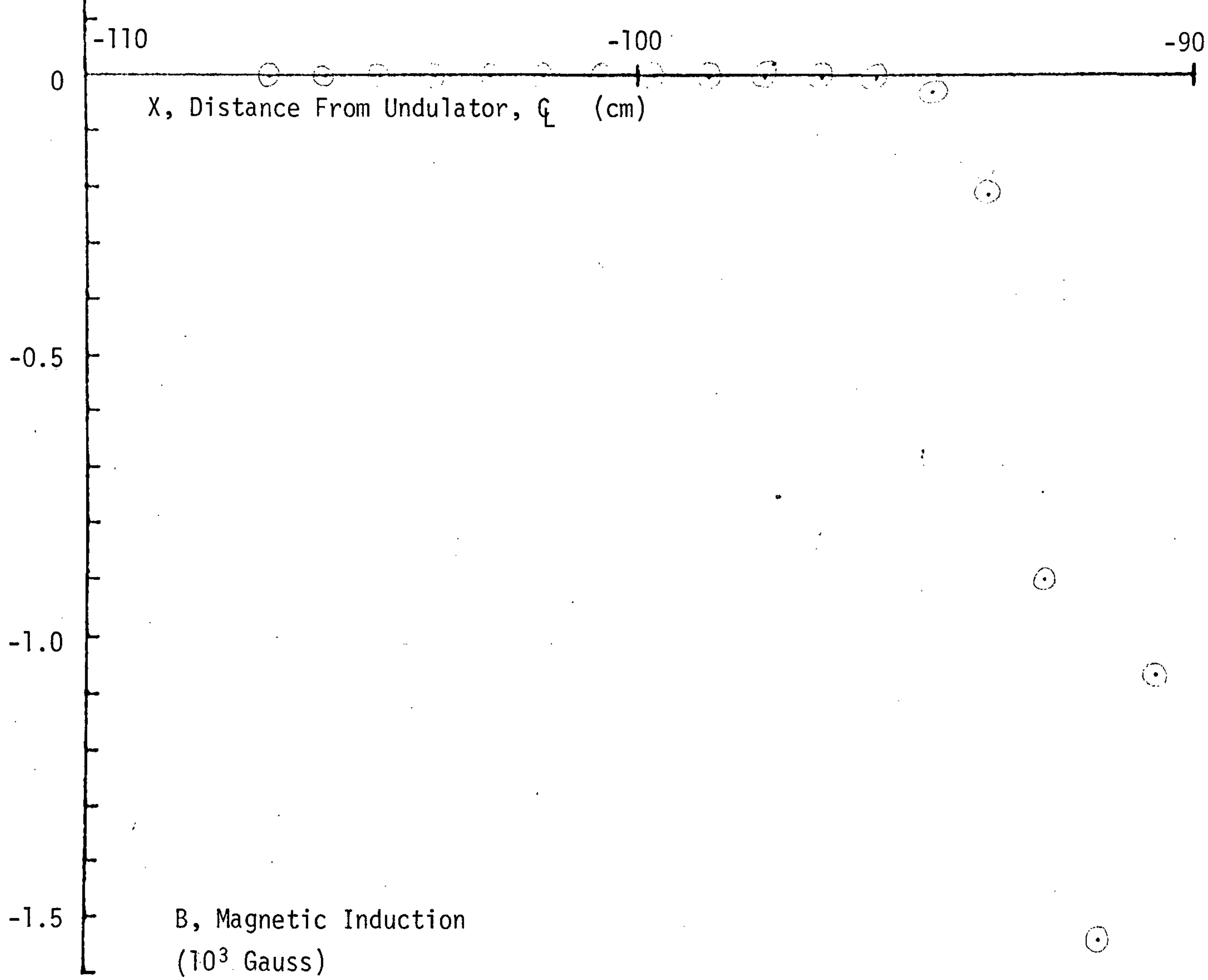
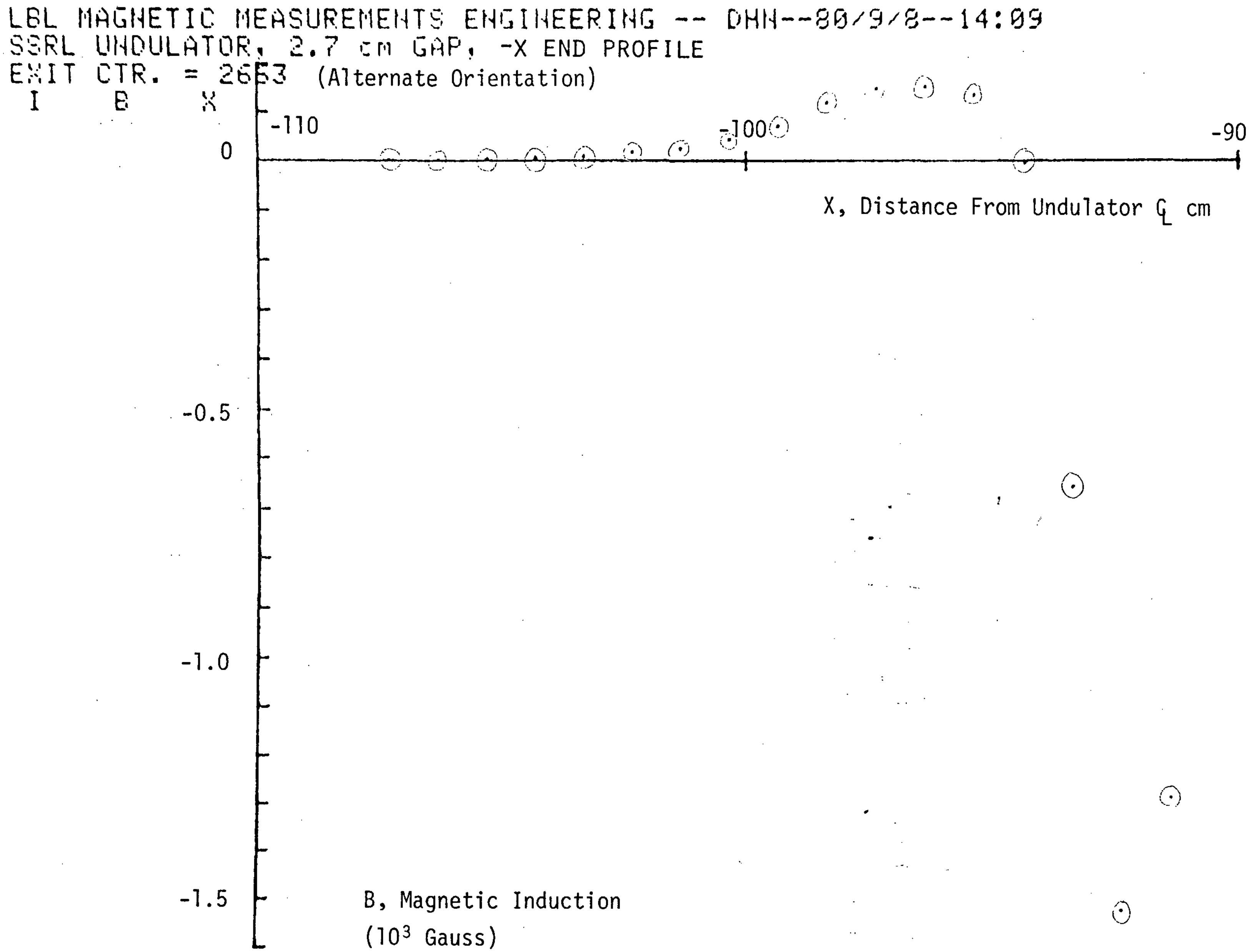


FIGURE 10


LBL MAGNETIC MEASUREMENTS ENGINEERING -- DHN--80/9/8--14:09
SSRL UNDULATOR, 2.7 cm GAP, -X END PROFILE
EXIT CTR. = 2653 (Alternate Orientation)
I B X
-110
-100
-90
0
-0.5
-1.0
-1.5
X, Distance From Undulator ℄ cm
B, Magnetic Induction
(10³ Gauss)

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III. Tuning Range (And Sensitivity) Of Rotatable Magnets

C. Differences in each end region for two orientations for each end assembly that produce a "net" zero $\int B_z dx$ (continued):

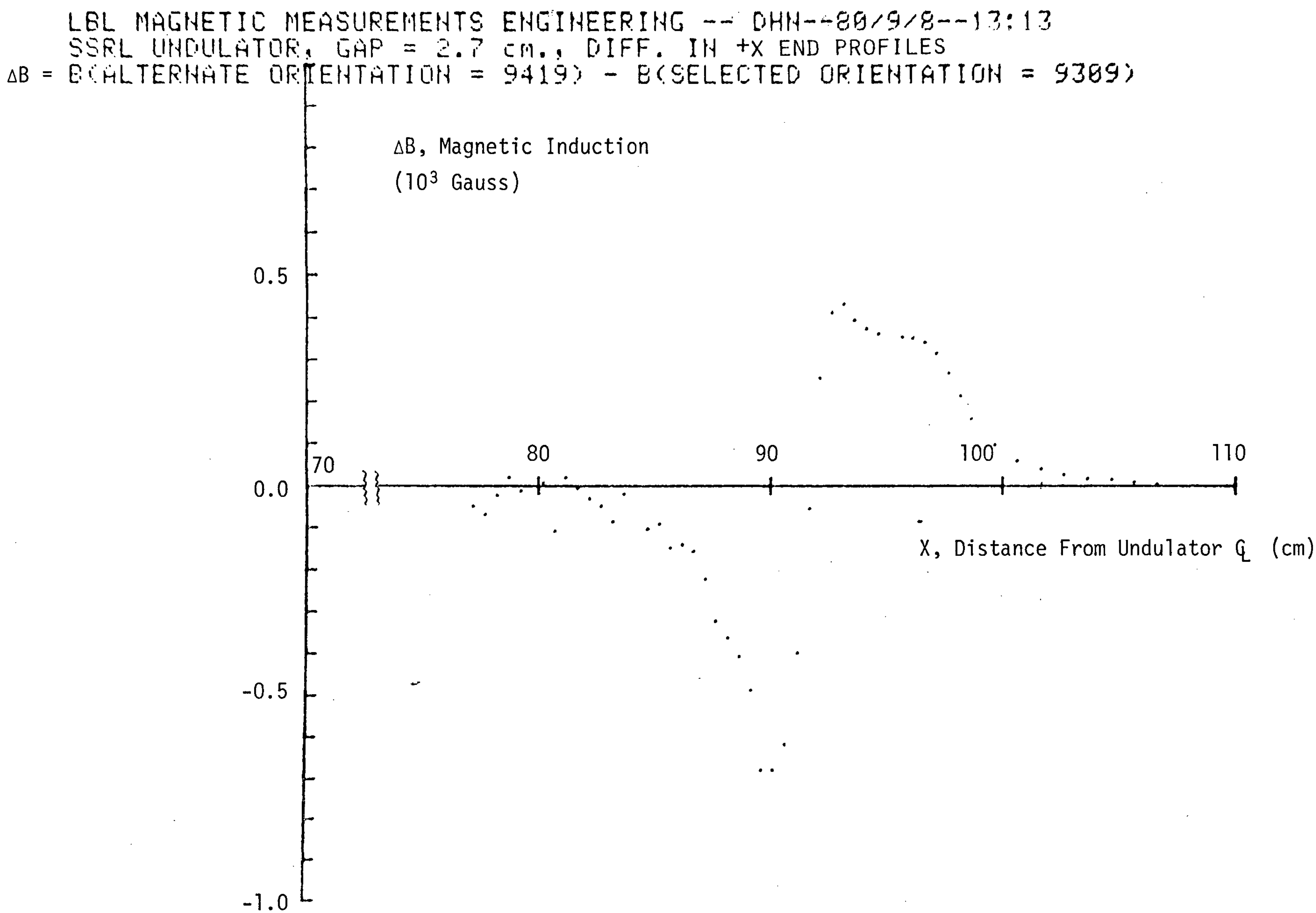
Egon Hoyer observed that at each end that one "null" orientation reduced the magnitude of internal peaks and valleys more than the other. Since large peaks/valleys are favorable in an indulator, the orientation with the minimum internal reduction of peak/valleys was selected (by Herman Winick) for undulator operation.

Figures 11 and 12 represent point by point differences between alternate and selected orientations of the rotatable magnet assemblies at the +x and -x ends respectively. All the digital end-region data (Section VII) were collected with the orientations selected for the 2.7 cm gap.

1. Subsequent measurements of half-magnet integrals indicate that minor adjustments may be required for other gaps.

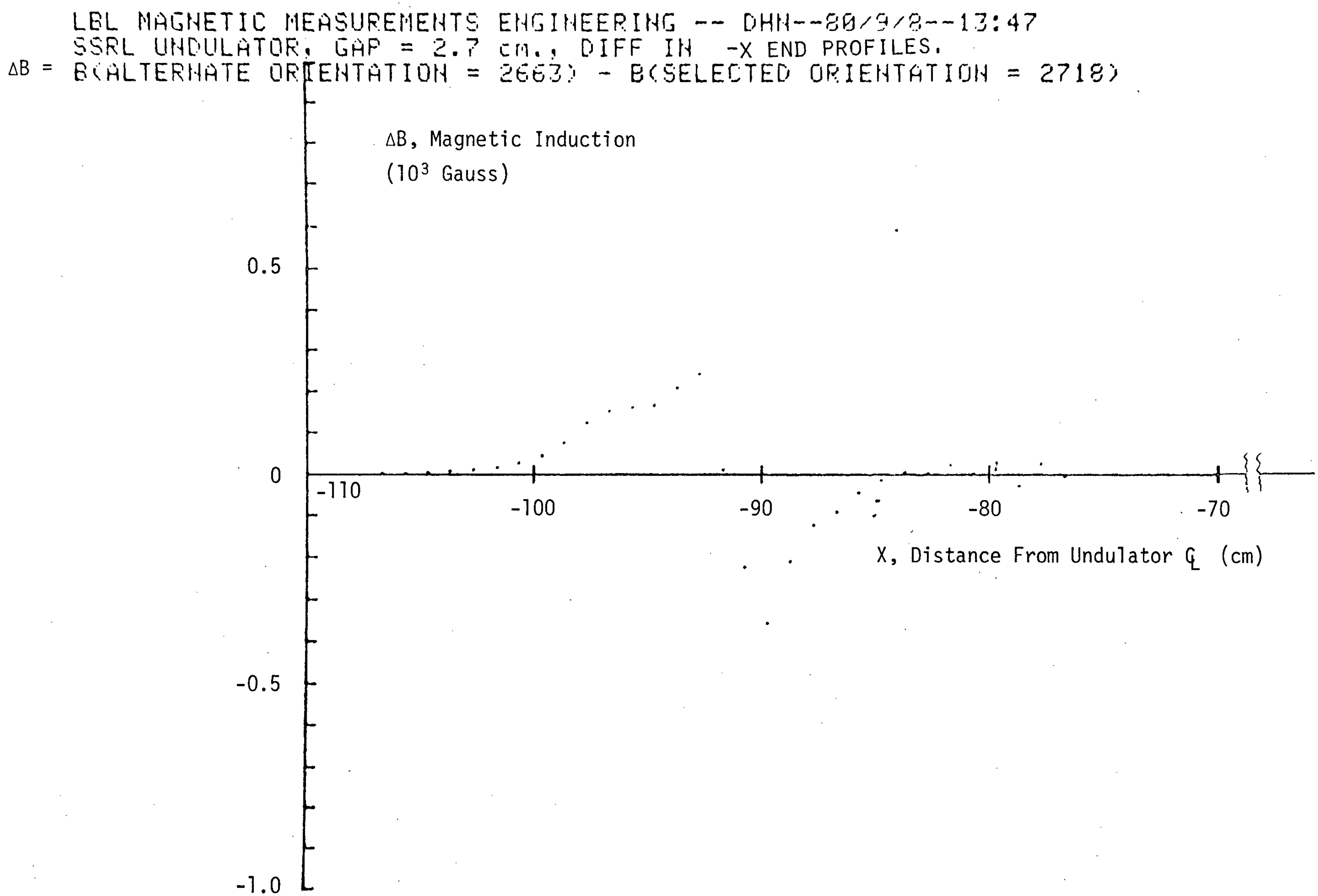
2. Internal measurements (Section VIII) were completed prior to selecting the orientations of the rotatable magnet assemblies. When we made internal measurements, the orientation of the +x end rotatable magnet assembly was close to the selected orientation; however, the -x end rotatable magnet assembly was close to the alternate orientation.

FIGURE 11



LBL MAGNETIC MEASUREMENTS ENGINEERING -- DHN--80/9/8--13:13
SSRL UNDULATOR, GAP = 2.7 cm., DIFF. IN +X END PROFILES
ΔB = B(ALTERNATE ORIENTATION = 9419) - B(SELECTED ORIENTATION = 9309)
ΔB, Magnetic Induction
(10³ Gauss)
0.5
0.0
-0.5
-1.0
70
80
90
100
110
X, Distance From Undulator ℄ (cm)

FIGURE 12



LBL MAGNETIC MEASUREMENTS ENGINEERING -- DHN--80/9/8--13:47
SSRL UNDULATOR, GAP = 2.7 cm., DIFF IN -X END PROFILES.
ΔB = B(ALTERNATE ORIENTATION = 2663) - B(SELECTED ORIENTATION = 2718)
ΔB, Magnetic Induction
(10³ Gauss)
0.5
0
-0.5
-1.0
-110
-100
-90
-80
-70
X, Distance From Undulator ℄ (cm)

IV. Transverse Profiles

Transverse profiles, $B_z(x, y, 0)$ vs y, were made as described in the test plan.[1] Figures 13 - 14 are reduced copies of the data as recorded. In addition, a single x-profile at $y = z = 0$ was made from data on a 0.1 cm grid $-51.3 \leq x \leq -42.2$cm. Figure 15 is a reduced copy of a plot of that data.

V. (Determine correct) Orientation of rotatable magnet assemblies for reducing $\int_0^\infty B_z dx$ (+x end) and $\int_{-\infty}^0 B_z dx$ (-x end) to zero; and

VI. (Check by measuring) $\int_{-\infty}^\infty B_z dx$:

Test V was conducted basically as described in Reference 1 except: 1) the same coil (L-2) was used for measuring each half-magnet integral; 2) because of uncertainty ($\pm$0.01 in.) in the "effective-end" of coil L-2, we made separate measurements with L-2 shifted 1/4 period (0.6 in. in the +x direction), so the "effective-end" was near a zero crossing of $B_z(x, 0, 0)$ vs x. This minimized the error introduced due to an uncertainty in the effective edge location; 3) Test VI was done with a 10' long integral coil, L-30; 4) we shifted L-30 1/2 period in order to investigate error due to systematic variations in effective width; 5) coil L-30 is higher than 2.7 cm so the minimum gap measured by coil L-30 was 2.77 cm; 6) most measurements were made by flipping the integral coil rather than moving from a mu-metal shield to the position inside the magnet.

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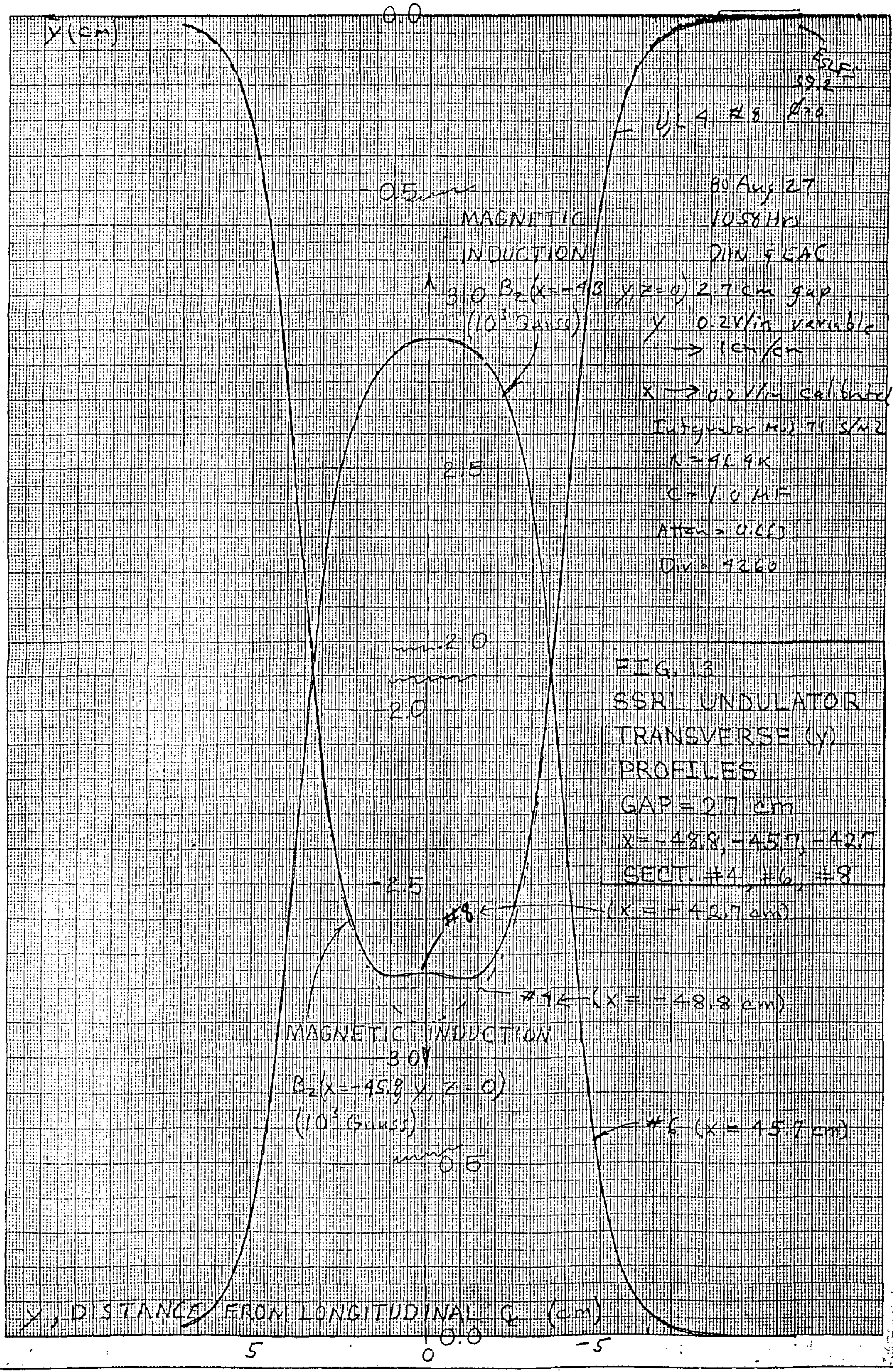

FIG. 13
SSRL UNDULATOR
TRANSVERSE (y)
PROFILES
GAP = 2.7 cm
x = -48.8, -45.7, -42.7
SECT. #4, #6, #8

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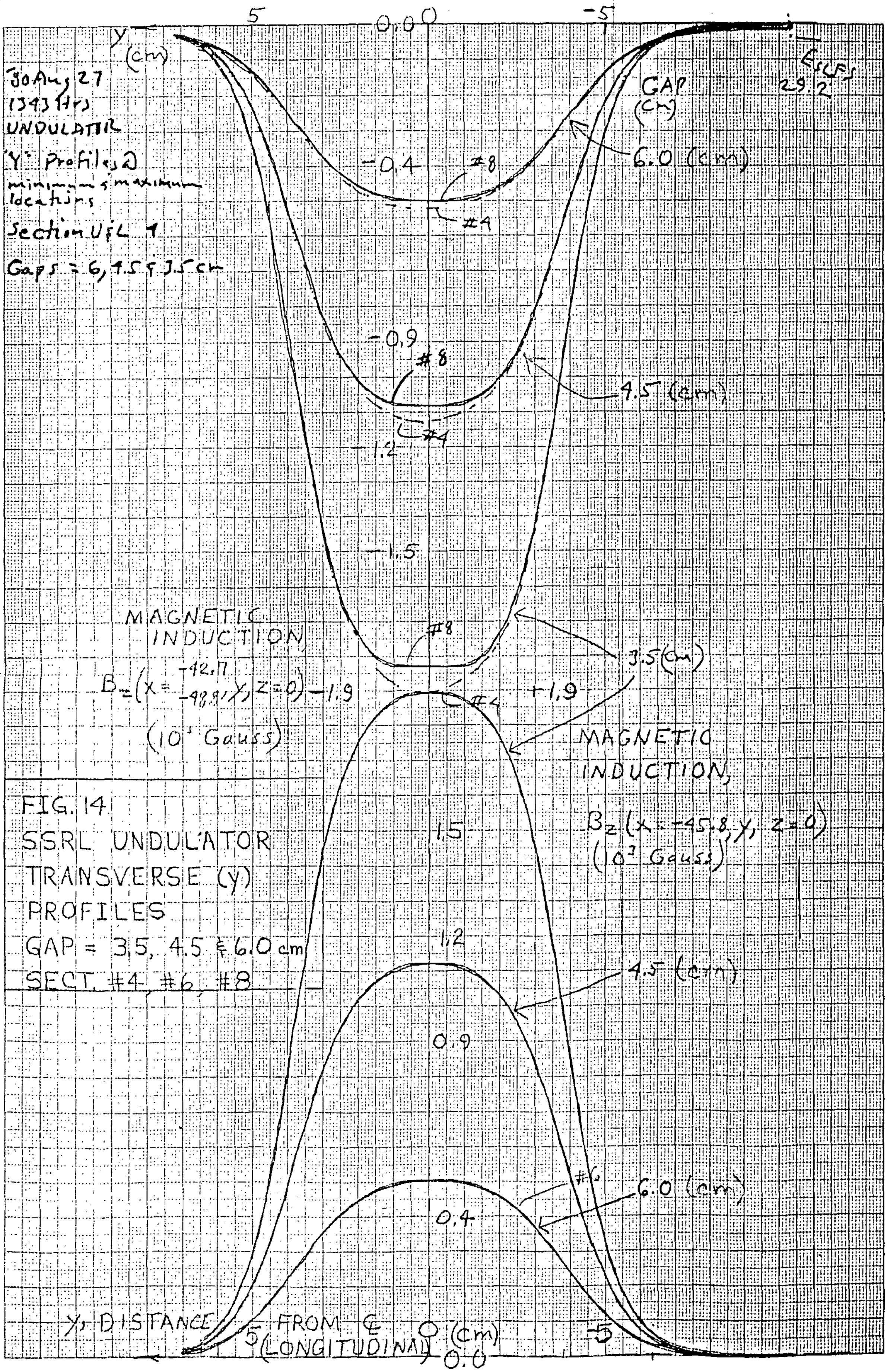

FIG. 14
SSRL UNDULATOR
TRANSVERSE (y)
PROFILES
GAP = 3.5, 4.5 & 6.0 cm
SECT. #4, #6, #8

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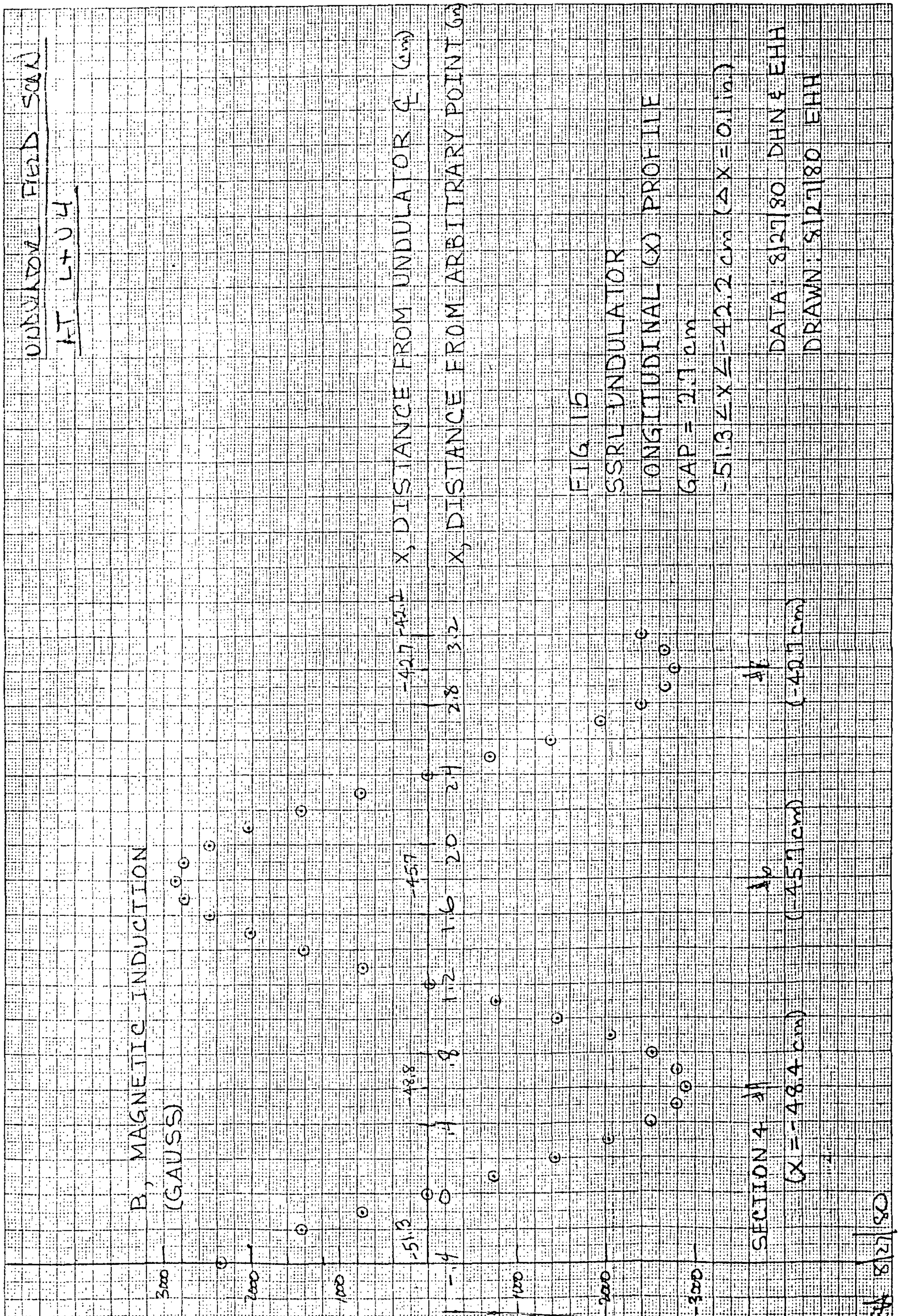

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VI. (Check by Measuring) $_{-\infty}\int^{\infty} B_z dx$ (continued):

Results of Tests V And VI

A. Table IVA lists the counter values that minimized $_{-E}\int^{\infty} B_z(x, 0, 0)dx$ and $_{-\infty}\int^{E} B_z(x, 0, 0)\, dx$. These counter displays were used for internal measurements with four gaps (Section VIII). Table IVB lists counter displays corresponding to measurements of the two end regions Section VII). Table IVC lists counter values, full magnet integral and half-magnet integrals at the end of the tests.

B. Possible reasons for differences in counter displays shown in Tables IVA and IVC: 1) errors in coil position; 2) real differences due to removal and replacement of magnet sections; 3) real differences due to magnet history; 4) errors due to measurement system.

VII. Longitudinal End Profiles

A. We used the Magnetic Measurements Engineering Data Logger to collect longitudinal, end profile data.

B. We measured over the x ranges $-107 \leq x \leq -77$ (-x end) and $77 \leq x \leq 107$ (+x end). (The effect of the rotatable magnet extends about 4 periods from each end, i.e., to $|x| = 67$ cm {see Figure 4}.)

C. For each gap, we measured end profiles on 0.5 cm grid.

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Nominal Gap (cm)	Measured Gap (cm) Ent	x = 0	Exit	Gap Counter	-x Counter	$_{-\infty}\int^{E} Bd\ell$ (G cm)	+x Counter	$_{-E}\int^{\infty} Bd\ell$ (G cm)
2.7	2.743	2.715	2.769	13900	2660	+2.5	9311	-9.9
3.5	3.541	3.543	3.518	10807	2665	-7.4	9317	-8.6
4.5	4.531	4.519	4.534	06867	2672	0.0	9318	1.2
6.0	6.022	6.020	6.030	00844	2677	-3.7	9317	+8.7

TABLE IVA ROTATABLE MAGNET ASSEMBLY ORIENTATIONS USED FOR (INTERNAL) UNDULATION MEASUREMENTS SECTION VIII AND OTHER DATA

NOTES TO TABLE IVA:

For 6.0 cm gap,

a. $_{-\infty}\int^{E} Bd\ell + {}_{-E}\int^{\infty} Bd\ell = (-3.7 + 8.7) = +5.0$ Gcm

b. $_{-\infty}\int^{+1.524} Bd\ell + {}_{1.524}\int^{\infty} Bd\ell = (+547 - 527) = +20$ Gcm

c. Computation of Location of Effective Edge "E" of Coil L-2 From Assumed Location

$$_{-\infty}\int^{\infty} B_z dx = {}_{-\infty}\int^{+E} B_z dx + {}_{-E}\int^{+\infty} B_z dx - 2E * B(x = 0)$$

$$= {}_{-\infty}\int^{(+1.524 + E)} B_z dx + {}_{1.524 - E}\int^{+\infty} B_z dx - 2E * B(x = 1.524)$$

Assumptions:

E is the error in the position of the effective edge (assumed positive for purposes of calculations).

$B(x \sim 1.524) \equiv 0$ (1/4 period)

$B(x = 0) = -508$ Gauss Digital Data Section VIII - G

$$E = \frac{{}_{-\infty}\int^{1.524} B_z dx + {}_{1.524}\int^{\infty} B_z dx - \left[{}_{-\infty}\int^{E} B_z dx + {}_{E}\int^{\infty} B_z dx\right]}{-2B(x = 0)}$$

$$= \frac{(+20 - 5)}{-2(-508)} = 0.015 \text{ (cm)} \quad (0.006 \text{ (in.)})$$

This includes E_1 = error in fabrication of coil, E_2 = error in locating coil with respect to fiducial (may vary from measurement to measurement) and E_3 = error in defining fiducial identifying x = 0.

d. Measurement with 10' long coil $|{}_{-\infty}\int^{\infty} B_z dx| = 15$ Gauss cm (sign undetermined).

e. Comparing b to d, we have either a 5 Gcm or a 35 (Gcm) difference in the two measurements depending on the sign of the measurement made in (d).

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Nominal Gap (cm)	Gap Counter (Counts)	+x Counter (Counts)	-x Counter (Counts)	Data File Number
2.7	13899	9419	2633	12 , 15
2.7	13899	9309	2718	13 , 14
3.5	10807	9309	2718	18
4.5	06867	9309	2718	17
6.0	00844	9309	2718	16

Note: Files 12 and 15 contain digital data for alternate orientations that produce nulls for the half-magnet integrals

TABLE IVB ROTATABLE MAGNET ASSEMBLY ORIENTATIONS USED FOR END PROFILE MEASUREMENTS (SECTION VII)

AUTHOR: Donald H. Nelson, Michael I. Green | DEPARTMENT: Electronics Engineering | LOCATION: LBL

Nominal Gap (cm)	Gap Counter (Counts)	+x Counter (Counts)	$L^+ = \int_{-E}^{\infty} B_z dx$ (Gcm)	Data* 9/12 Page	-x Counter (Counts)	$L^- = \int_{-\infty}^{E} B_z dx$ (Gcm)	Data* 9/12 Page	$L = L^+ + L^-$ (G cm)	$\lvert \int_{-\infty}^{\infty} B_z dx \rvert$[1,2] (G cm)	Data* 9/12 Page
2.7	13900	9309	-79	7/7	2718	-53	6/7	-132	-	-
2.7	-	9303	+5	7/7	2725	+9	6/7	+14	-	-
2.77	13671	9309	-48	6/7	2718	-79	6/7	-127	120	1/7
3.5	10807	9309	+3	6/7	2718	+116	2/7	+119[3]	161[4]	1/7
3.5	10807	9309	-	-	2718	-	-	-	181[4]	1/7
4.5	06867	9309	-	-	2718	-	-	-	188	1/7
6.0	00844	9309	-	-	2718	-	-	-	143	1/7
3.5	10807	-	-	-	2676	-23	2/7	-	-	-

*9/12 ≡ September 12 Date of Data (7 pages filed in Reference 2, Section V/VI)

TABLE IVC SUMMARY OF HALF MAGNET AND FULL MAGNET INTEGRALS[5] FOR SELECTED COUNTER DISPLAYS

NOTES TO TABLE IVC:

1. $\lvert \int_{-\infty}^{\infty} B_z dx \rvert$ with coil L-30 at y = -0.13 cm
2. We do not know the sign of $\int_{-\infty}^{\infty} B_z dx$, but we believe the signs are all the same.
3. We suspect the sign recorded on page 2/7 (+) 119 Gauss cm is incorrect, i.e., it probably should have been recorded as (-).
4. The two magnitudes reported for L-30 in a 3.5 cm gap correspond to two positions of coil L-30 separated by 1/2 period in the x-direction. The assumption is that if there were some systematic, periodic variation in the turns-width-product of coil L-30 (with a period of 1.2 cm), then moving the coil 1.2 cm would reverse the sign of the contribution of that error to the total signal. From the data shown, I would conclude that $\lvert \int_{-\infty}^{\infty} B_z dx \rvert$ = 171 Gauss cm with a coil error of $\pm$10 Gcm depending on position.
5. Using assumptions 2, 3 and 4 above, and the information from Table IVA, Note C, one could check the consistency of the data. Similarly, by numerically integrating the digital data either using the peak/valley data or the 0.5 cm grid data, one could check the consistency of the data.

VIII. Interior, Longitudinal Profiles

These measurements were made as planned but supplemented by two sets of manual data collected at the start and end of the measurement program. The manual data were collected to check the effect of repair and replacement of sections of the undulator (see Table V for details). The manual data sets were later saved on the "duplicate" cassette to facilitate subsequent data processing.

Tables VI through IX contain peak/valley measurements with data pairs for x < (-77) omitted.* Table X lists the mean and the standard deviation for six data sets including the data from Tables VI through IX. Figure 16 plots the mean-values from Table X as a function of gap counter display. Measured gap is also plotted in Figure 16. Figure 17 shows point-by-point differences in recorded field values from the two manually recorded data sets. Figure 18 shows point-by-point differences between corresponding measurements in a manual set (File 19 duplicate tape) and a peak/valley set (File 8 data processing tape).

IX. Longitudinal Periodicity - Not Measured (May be determined from 0.5 cm data collected in Sections VII and VIII).

X. Vertical Symmetry

The variation over each magnet section (2 through 11) of the quantity $\{B_z(x, 0, +0.6) - B_z(x, 0, -0.6)\}$ vs x was measured and recorded in Figure 19 (reduced for report).

*Data pairs for x < (-77) were omitted because the rotatable -x end magnet assembly was oriented at an alternate orientation modifying magnetic induction for x < (-77).

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Date(s)	Activity
8/28	Manual Data Set (MME GPIB #1 Duplicate Cassette, File 19) Peak/Valley
8/29	L-6 Removed For Repair And Replacement
9/3	L-5 Removed For Repair And Replacement
9/4	Determined Orientations Of Rotatable End Assemblies Minimizing $\int_{-E}^{\infty} B_z dx$ and $\int_{-\infty}^{E} B_z dx$
9/4 - 9/6	Longitudinal Interior Profiles
9/8	Selected Favorable Orientation Of Rotatable End Assemblies
9/8 - 9/9	Longitudinal End Profiles
9/10	L-8 and L-9 Removed For Repair And Replacement
9/11	Manual Data Set (MME GPIB Duplicate Cassette, File 20)
9/12	Recheck of $\int_{-\infty}^{\infty} B_z dx$

TABLE V SCHEDULE OF LONGITUDINAL MAGNETIC MEASUREMENTS AND REPAIRS TO MAGNETS

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LBL MAGNETIC MEASUREMENTS ENGINEERING -- DHN--80/9/4--15.37
SSRL UNDULATOR,GAP=2.7,PEAK/VALLEY DATAA(-77(X),(SUBSE! FILE6-DUP)
COUNTERS: GAP = 13900, +X = 9311, -X = 2660 FILE 8 D.P. TAPE.

I	X(I)	B(I)
1	-76.2	2850.9
2	-73.2	-2757.1
3	-70.1	2769.9
4	-67.1	-2825.2
5	-64	2753.8
6	-61	-2741.8
7	-57.9	2811.1
8	-54.9	-2805.4
9	-51.8	2839
10	-48.8	-2885.8
11	-45.8	2855.7
12	-42.8	-2754.9
13	-39.7	2811.4
14	-36.6	-2846.7
15	-33.5	2875.1
16	-30.5	-2772
17	-27.4	2826.6
18	-24.4	-2840.2
19	-21.3	2741.1
20	-18.3	-2744.8
21	-15.2	2782.1
22	-12.2	-2746.9
23	-9.1	2851.7
24	-6.1	-2861.3
25	-3.1	2815.7
26	-0.1	-2792.1
27	0	-2791.9
28	3	2764.3
29	6.05	-2853.3
30	9.1	2757.7
31	12.5	-2859.1
32	15.2	2871.8
33	18.3	-2798.8
34	21.3	2766.3
35	24.4	-2828.2
36	27.4	2900
37	30.4	-2795.5
38	33.45	2831.1
39	36.5	-2805.9
40	39.6	2760.3
41	42.6	-2866.6
42	45.7	2925.1
43	48.7	-2733.2
44	51.7	2725.7
45	54.8	-2838.5
46	57.9	2778.1
47	60.9	-2806.4
48	64	2834.2
49	67	-2853.9
50	70	2827.1
51	73.1	-2832.5
52	76.2	2806.5
53	79.2	-2592.5
54	82.3	2794.7
55	85.3	-2844.2

TABLE VI PEAK VALLEY DATA- 2.7cm GAP

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LBL MAGNETIC MEASUREMENTS ENGINEERING -- DHN--80/9/5--10:57
SSRL UNDULATOR,GAP=3.5,PEAK/VALLEY DATA (X > -77),SUBSET(FILE8DUP)
ZEROS PEAKS AND VALLEYS CONT. FROM10:57 DAT

I	X(I)	B(I)
1	-0.2	-1851.1
2	-3.1	1861.3
3	-6.1	-1884.2
4	-9.2	1881.6
5	-12.2	-1818.5
6	-15.3	1850.3
7	-18.3	-1817.4
8	-221.3	1816.5
9	-24.4	-1881.2
10	-27.4	1859.7
11	-30.5	-1833.4
12	-33.6	1906.5
13	-36.6	-1882.7
14	-39.7	1866.8
15	-42.7	-1829.2
16	-45.7	1892.3
17	-48.8	-1905.7
18	-51.9	1887
19	-54.9	-1867.3
20	-58	1868.4
21	-61.1	-1813.1
22	-64.1	1832.5
23	-67.1	-1883
24	-70.2	1845.7
25	-73.2	-1845.8
26	-76.2	1890.8
27	3	1822.8
28	6.1	-1876.7
29	9.1	1830.5
30	12.2	-1875.6
31	15.2	1906.7
32	18.3	-1850.5
33	21.3	1837
34	24.3	-1867.5
35	27.4	1912.3
36	30.4	-1857.4
37	33.5	1875.6
38	36.6	-1866.7
39	39.6	1837.2
40	42.7	-1899.3
41	45.7	1934
42	48.8	-1813.2
43	51.8	1815
44	54.8	-1898.5
45	57.9	1848.5
46	61	-1873.4
47	64	1886.1
48	67	-1898.3
49	70.1	1883.3
50	73.1	-1891
51	73.1	-1891.8
52	76.2	1866.8
53	79.2	-1729.1
54	82.3	1874.5
55	85.3	-1873.6

TABLE VIIPEAK VALLEY DATA- 3.5 cm GAP

LBL MAGNETIC MEASUREMENTS ENGINEERING -- MIG--80/9/5--17:14
SSRL UNDULATOR, GAP=4.5,PEAK/VALLEY DATA (X> -77),SUBSET(FILE9DUP)
4.5 CM GAP,MAX,MINS,&FIELD PROFILE,G=06867,-X=2672, +X =9318

I	X(I)	B(I)
1	0	-1111.36
2	3.05	1081.54
3	6.1	-1116.62
4	9.15	1095.29
5	12.15	-1108.98
6	15.25	1141.49
7	18.3	-1101.57
8	21.35	1097.34
9	24.4	-1109.3
10	27.45	1135.81
11	30.55	-1105.3
12	33.55	1117.69
13	36.55	-1116.1
14	39.6	1095.99
15	42.7	-1130.48
16	45.7	1150.15
17	48.75	-1077.73
18	51.8	1082.41
19	54.85	-1140.26
20	57.95	1100.69
21	61	-1119.62
22	64	1121.35
23	67.05	-1128.44
24	70.15	1118.23
25	73.15	-1130.13
26	76.2	1111.34
27	79.25	-1026.21
28	82.3	1121.84
29	85.3	-1091.93
30	0	-1110.65
31	-3.05	1111.99
32	-6.1	-1119.93
33	-9.15	1120.9
34	-12.2	-1084.43
35	-15.25	1109.88
36	-18.25	-1082.72
37	-21.3	1085.7
38	-24.35	-1125.45
39	-27.4	1102.25
40	-30.45	-1092.91
41	-33.5	1139.9
42	-36.5	-1119.44
43	-39.65	1117.95
44	-42.7	-1089.48
45	-45.7	1129.05
46	-48.75	-1131.06
47	-51.8	1128.28
48	-54.9	-1112.96
49	-57.9	1114.45
50	-61	-1075.71
51	-64	1092.93
52	-67.05	-1122.07
53	-70.15	1098.35
54	-73.15	-1100.54
55	-76.2	1121.69

TABLE VIII PEAK VALLEY DATA - 4.5 cm gap

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LBL MAGNETIC MEASUREMENTS ENGINEERING -- MIG--80/9/6--08:47
SSRL UNDULATOR, GAP=6.0,PEAK/VALLEY DATA(X > -77),SUBSET(10DUP)
COUNTERS: GAP = 00844, +X = 9317, -X = 2677

I	X(I)	B(I)
1	0	-507.51
2	3.05	497.37
3	6.05	-508
4	9.1	500.15
5	12.15	-498.7
6	15.2	526.54
7	18.3	-498.17
8	21.3	500.37
9	24.35	-503.51
10	27.4	517.04
11	30.5	-501.77
12	33.5	508.88
13	36.6	-510.52
14	39.65	498.2
15	42.65	-513.82
16	45.7	526.05
17	48.75	-486.91
18	51.8	492.3
19	54.85	-528.71
20	57.9	498.11
21	61	-514.27
22	64	509.93
23	67.05	-513.79
24	70.1	508.08
25	73.1	-518.39
26	76.2	510.96
27	79.25	-458.09
28	82.3	522.79
29	85.25	-468.45
30	0	-507.83
31	-3.05	507.42
32	-6.1	-505.9
33	-9.15	510.68
34	-12.15	-490.5
35	-15.2	508.81
36	-18.3	-491.42
37	-21.3	493.24
38	-24.35	-515.96
39	-27.4	496.52
40	-30.45	-495.52
41	-33.5	523.31
42	-36.55	-506.18
43	-39.6	513.2
44	-42.7	-492.16
45	-45.7	516.09
46	-48.75	-512.07
47	-51.8	516.68
48	-54.9	-507.34
49	-57.95	509.77
50	-61	-485.74
51	-64	499.96
52	-67.1	-512.87
53	-70.1	500.79
54	-73.2	-502.52
55	-76.2	511.54

TABLE IX PEAK VALLEY DATA - 6.0 cm gap

LBID-324

AUTHOR Donald H. Nelson, Michael I. Green | DEPARTMENT Electronics Engineering | LOCATION LBL
DATE December 15, 1980

			Positive Peaks				Valleys = Negative Peaks			
					Standard Deviation				Standard Deviation	
Nominal Gap (cm)	Date	Table	No. of Data Pairs	Mean $\overline{B}$ (10^3 G)	σ (10^3 G)	σ %($\overline{B}$)	No. of Data Pairs	Mean $\overline{B}$ (10^3 G)	σ (10^3 G)	σ %($\overline{B}$)
2.7	8/28	-	14	2.821	0.062	2.2	15	-2.806	0.070	2.5
2.7	9/4	VI	27	2.812	0.050	1.8	27	-2.803	0.060	2.2
3.5	9/5	VII	27	1.867	0.030	1.7	27	-1.859	0.040	2.1
4.5	9/5	VIII	27	1.113	0.018	1.6	27	-1.106	0.024	2.1
6.0	9/6	IX	27	0.508	0.011	2.1	27	-0.502	0.025	3.0
2.7	9/11	-	12				12	-2.824	0.046	1.6

TABLE X SUMMARY OF PEAK/VALLEY INFORMATION

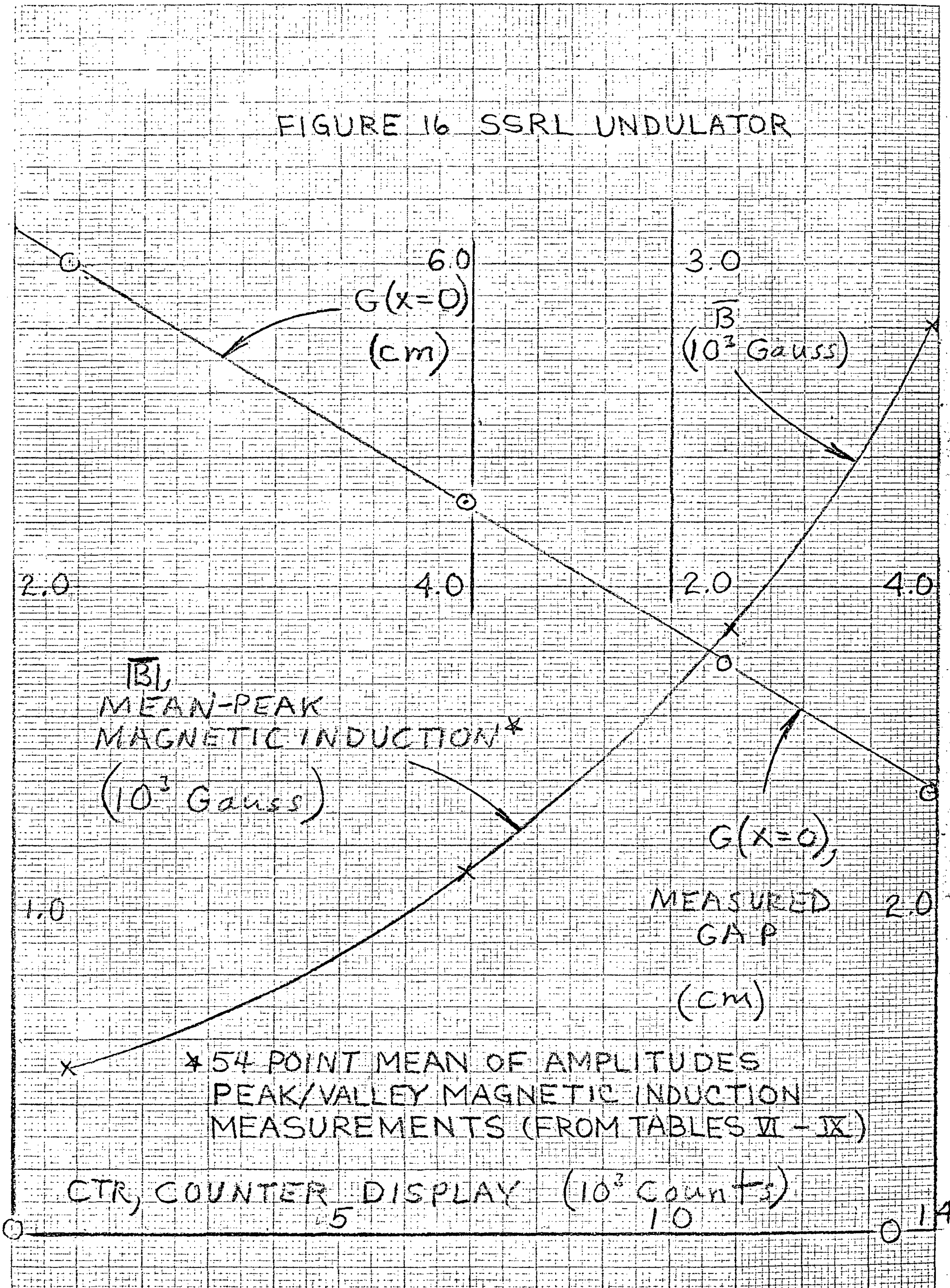


FIGURE 16 SSRL UNDULATOR

FIGURE 17

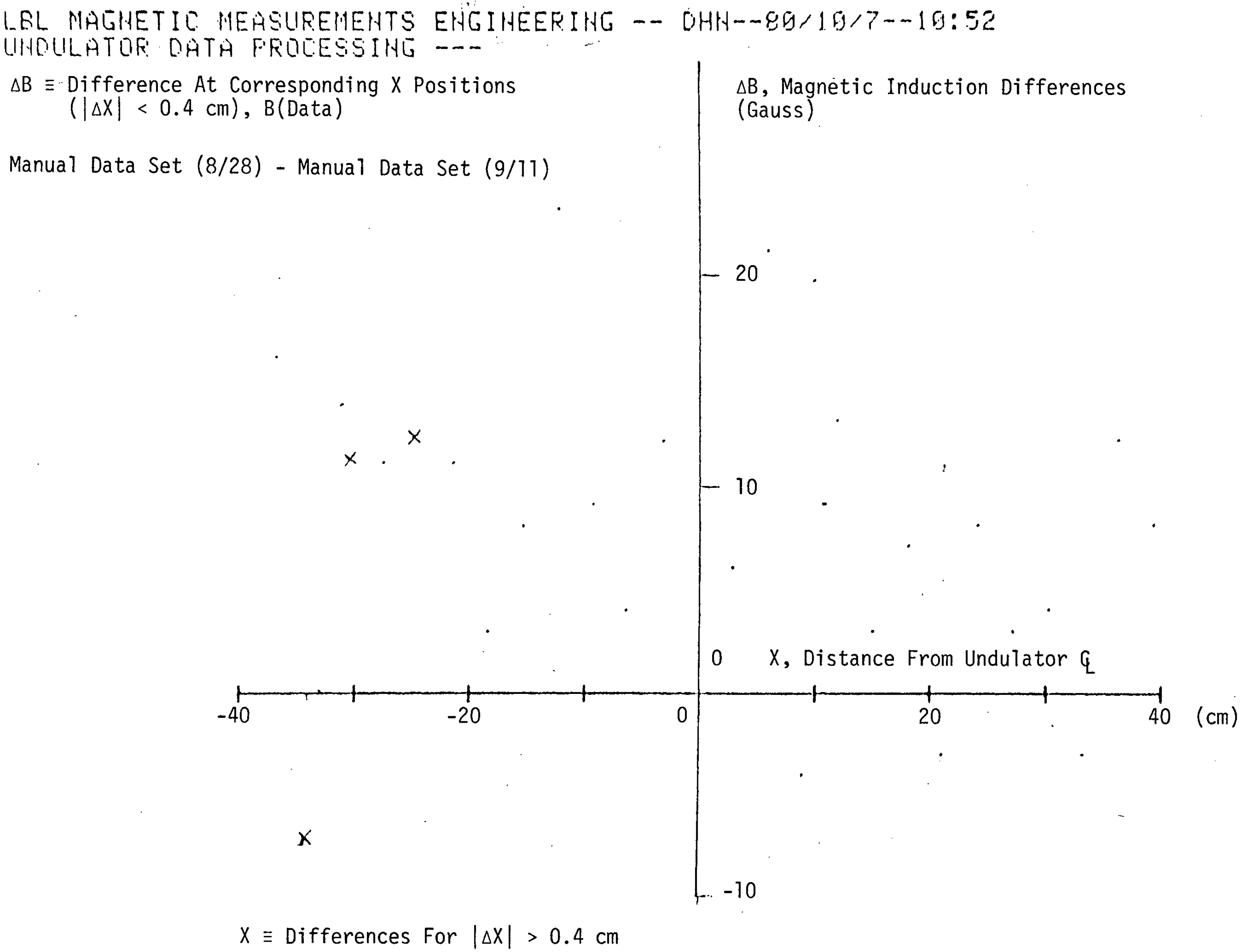
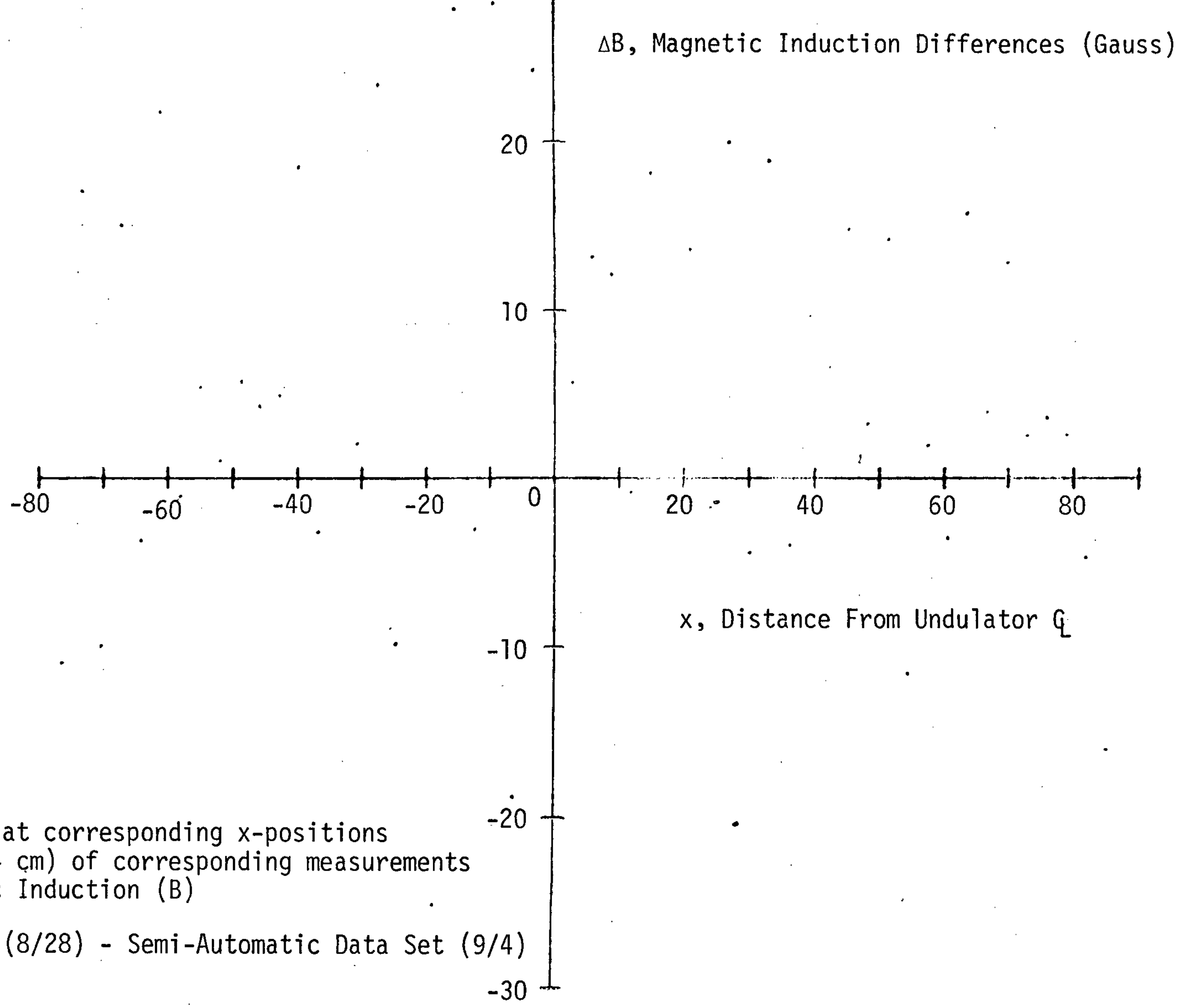

LBL MAGNETIC MEASUREMENTS ENGINEERING -- DHN--80/10/7--10:52
UNDULATOR DATA PROCESSING ---
ΔB ≡ Difference At Corresponding X Positions
(|ΔX| < 0.4 cm), B(Data)
Manual Data Set (8/28) - Manual Data Set (9/11)
ΔB, Magnetic Induction Differences
(Gauss)
20
10
0
-10
X, Distance From Undulator ℄
-40
-20
0
20
40
(cm)
X ≡ Differences For |ΔX| > 0.4 cm

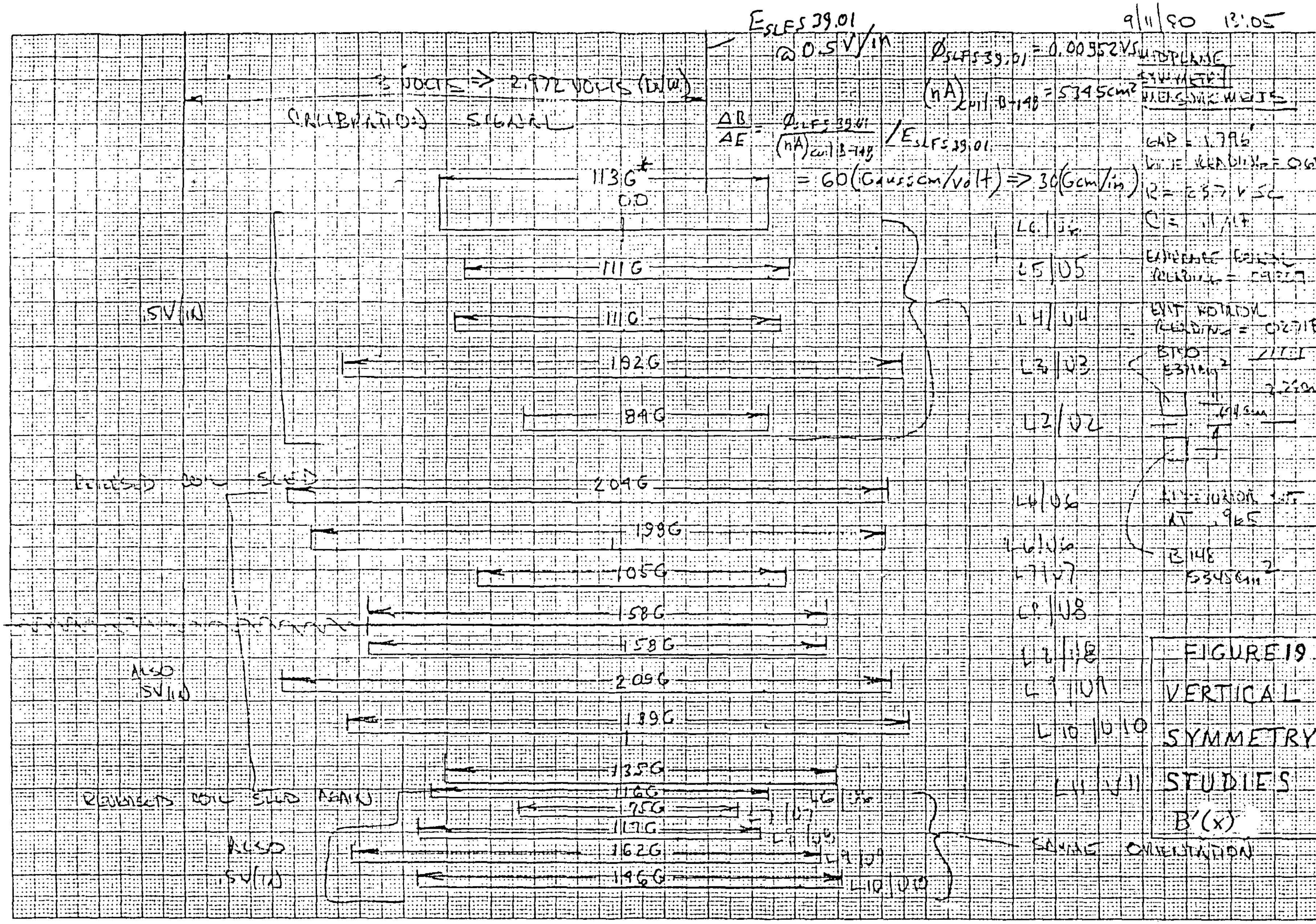
FIGURE 18

LBL MAGNETIC MEASUREMENTS ENGINEERING -- DHH--80/9/4--15.37
SSRL UNDULATOR--DIFFERENCES AT MATCHING(L.T. +/-0.5 cm) X's
2.7cm GAP, FILE 19 DUP TAPE - FILE 8 DATA PROCESSING TAPE
I B X



ΔB ≡ Difference at corresponding x-positions (|Δx| < 0.4 cm) of corresponding measurements of Magnetic Induction (B)

Manual Data Set (8/28) - Semi-Automatic Data Set (9/4)



* Magnitudes Tabulated: $|\{B_z(x_{max}, 0, 0.6) - B_z(x_{max}, 0, -0.6)\} - \{B_z(x_{min}, 0, 0.6) - B_z(x_{min}, 0, -0.6)\}|$

$x_{max} \equiv$ local maximum of $B_z(x, 0, 0.6) - B_z(x, 0, -0.6)$

$x_{min} \equiv$ local minimum of $B_z(x, 0, 0.6) - B_z(x, 0, -0.6)$

AUTHOR	DEPARTMENT	LOCATION	DATE
Donald H. Nelson Michael I. Green	Electronics Engineering	LBL	December 15, 1980

DISCUSSION

Data for Sections VII and VIII (Test Plan) were collected with the Magnetic Measurements Engineering Data Logger. The Data Logger facilitated data acquisition, data storage, data processing, and graphical representation of the data, and it is available for subsequent analysis on request.

Accuracy

Klaus Halbach suggested that data accurate to $\sim\pm 1\%$ would be satisfactory for these tests. He suggested that we measure field integrals with a resolution of 25 Gauss cm. We believe we met these requirements. A discussion of errors will be puslished as an appendix to MT 292 on request.

ACKNOWLEDGEMENTS

We wish to acknowledge all the LBL employees who contributed to the successful completion of the Undulator Measurement Project. Klaus Halbach and Egon Hoyer outlined test requirements. Ed Hartwig allowed us to procure the Data Logger System, and Egon Hoyer supported our request to "christen" the Data Logger on the Undulator Measurement Project. The "half-magnet integral coil" (L-2) was specified by Egon Hoyer in consultation with Ivan Wood, Klaus Halbach and the authors. Computer-aided design of the coil was done by Horace Warnock under Ivan Wood's direction. Walter Quan and Cheryl Williams fabricated the coil. Egon Hoyer, John Chin, Otto Draeger, John Wirth and Ed Cyr supported our requirements for "positioning-hardware." Ed Cyr, John Chin, Egon Hoyer, Ya duZambre and Kathy Schiff assisted the authors with data acquisition. Finally, Carolyn Wong patiently and skillfully prepared this report.

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