Lawrence Berkeley National Laboratory
Recent Work

Title
PEP INJECTION LINE DIPOLES 25B5249 (B-3 TYPE) RESULTS OF 1978 MAGNETIC MEASUREMENTS LBL ELECTRONICS ENGINEERING NOTE NO. MT 301

Permalink
https://escholarship.org/uc/item/6k51x0qd

Authors
Nelson, D.H.
Dorst, J.H.
Peterson, J.M.

Publication Date
1981-11-20

eScholarship.org
Powered by the California Digital Library
University of California

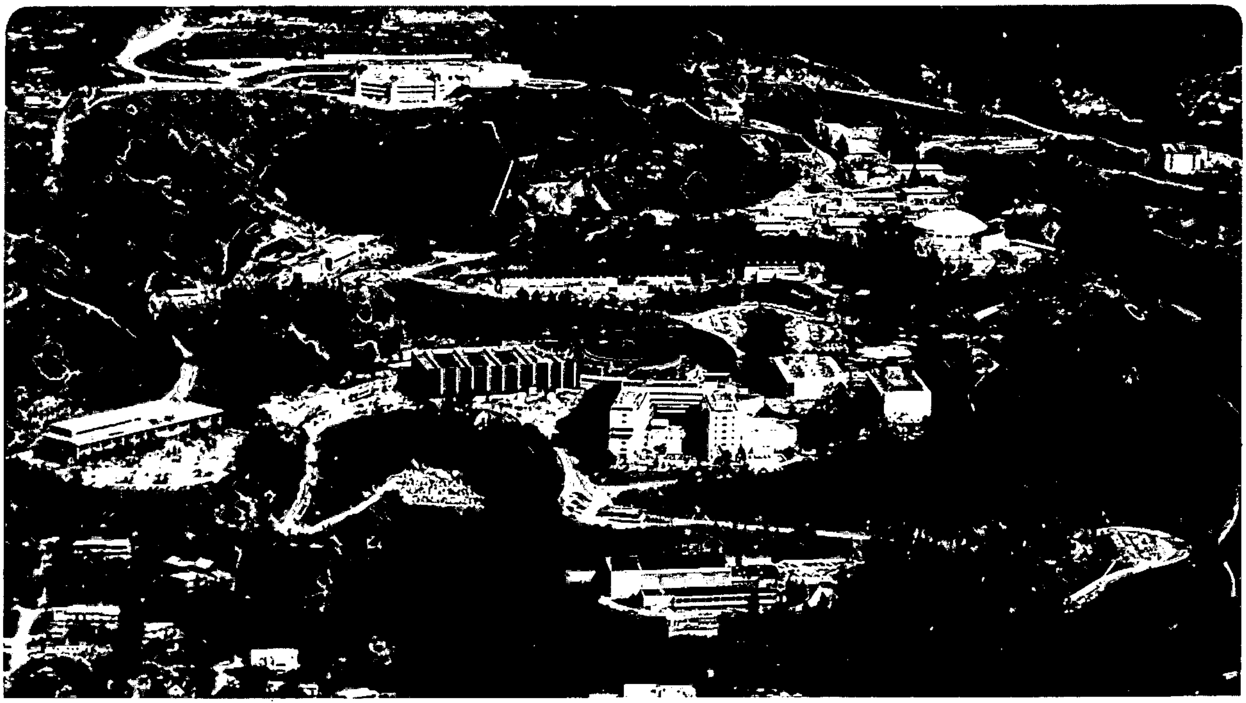
LBID-512
c.1

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

Engineering & Technical Services Division

RECEIVED
LAWRENCE
BERKELEY LABORATORY
MAY 24 1982
LIBRARY AND
DOCUMENTS SECTION

For Reference
Not to be taken from this room



LBID-512
c.1

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

LBID-515

LAWRENCE BERKELEY LABORATORY - UNIVERSITY OF CALIFORNIA. **ENGINEERING NOTE**		CODE MME Book No. 579[18]	SERIAL MT301	PAGE i OF 50
AUTHOR D.H. Nelson, J.H. Dorst & J.M. Peterson	DEPARTMENT Electronics Engineering	LOCATION B25A-124	DATE November 20, 1981	

PEP INJECTION LINE DIPOLES 25B5249 (B-3 TYPE)

RESULTS OF 1978 MAGNETIC MEASUREMENTS

LBL ELECTRONICS ENGINEERING NOTE NO. MT301

D.H. Nelson, J.H. Dorst & J.M. Peterson

LBID-515

LAWRENCE BERKELEY LABORATORY - UNIVERSITY OF CALIFORNIA **ENGINEERING NOTE**	CODE MME Book No. 579^{18}	SERIAL MT301	PAGE 1 OF 50
AUTHOR Nelson, Dorst, Peterson	DEPARTMENT Electronics Engineering	LOCATION B25A-124	DATE November 20, 1981

Page

I. Table of Contents 1

II. Introduction 2

  A. Glossary 3
  B. Magnet Assignments 4

III. Schedule of Measurements 5

IV. Measurement Procedures 7

  A. General Description 7
  B. Data Acquisition Cycle Description 8
  C. Magnetic Measurement Description 11

V. Test Results 14

  A. Reference Magnet (S/N 456201) 15

    1. Tabulations (4 Cycles) . . . . 15 (16 - 19)
    2. Graphical Representations 15

      a. Point Magnetization Plots B vs. E_x . . . . (20, 21)
      b. Integral Magnetization Plots $\int Bds$ vs. E_x . . . . (22, 23)
      c. Effective Length Plots, $L_{eff} = \int Bds/B$ vs. E_x 24 (25)

  B. Subject Magnets (S/N 456202 - 456214) Relative Results 24

    1. Tabulations . . . . (Appendix)
    2. Graphical Representations, $\Delta\int Bds$ vs. E_x . . . . (28 - 40)
    (Thirteen graphs, each showing four data acquisition cycles)

  C. Single-turn Flux-loop Data 41

    1. Tabulations 41 (42)

VI. Discussion 44

  A. Magnetic Conditioning 44
  B. Systematic-errors introduced by too few conditioning cycles . . 44
  C. 20/20 Hindsight 46

VII. Acknowledgements 47

VIII. References 47

IX. Distribution 48

X. Index to Figures 49

XI. Index to Tables 50

TABLE I Table of Contents

INTRODUCTION

In 1978 Don Nelson and Ed Cyr of LBL's Magnetic Measurements Engineering Group tested PEP (Positron Electron Project) injection line dipoles. This report describes the tests and presents test results of the fourteen (nominally) identical dipoles commonly referred to as B3 type dipoles (formally designated 25B5249, S/N 456201 - 456214 inclusively - Elma Manufacturing).[1-6*]

In preparing this report, we followed an outline. We have converted the outline to a table of contents and included it as Table I (page 1) of this report. Because of the large number of technical terms with specialized interpretations, we have provided the reader with a glossary in Table II (page 3). Figures and tables are indexed in Tables XI and XII (pages 49 and 50) respectively.

We carried out the measurements outlined in a test plan[7] and a follow-up memorandum.[8] The original specification for the accuracy of $\int B_z ds$ (E_x), i.e., integral over particle path of magnetic induction as a function of transductor potential, E_x, was $\pm 0.005 \int B_z ds$ (absolute) and $\pm 0.001 \int B_z ds$[7] (relative strengths of the 14 magnets). After the first two magnets were tested, by mutual agreement, the absolute specification was tightened to $\pm 0.001 \int B ds$ over the energy range ($4 \text{ GeV} \leq T \leq 20 \text{ GeV}$). We believe that all the $\int B_z ds$ numbers reported herein are accurate to ± 0.008 Tesla meter, i.e, $\pm 0.0013 \int B_z ds$ ($T = 15$ GeV).

The fourteen magnets were tested in the order of their production and their serial numbers reflect that order. For brevity, we often identify a magnet by the last two digits of its serial number.** Based on preliminary information on relative strength, the magnets were assigned to positions in the two injection lines, i.e., North Injection Tunnel (NIT) and South Injection Tunnel (SIT) as shown in Table III (page 4).

---

*References are listed on pages 47 - 48.

**That is, Magnet No. 1 (the reference) was S/N 456201.

$Q(E_x)$	Q is a function of E_x.
B_z or B	The vertical component of magnetic induction (Teslas)
$\int ds$	Approximation to path of particles passing through the energized magnet - a circular arc with radius at curvature 40198 mm and bend angle 0.1313 radians extended by tangental straight line segments at each end (meters)
s = 0	Denotes center of magnet pole area
z = 0	Denotes vertical midplane of magnet aperture
E_x	Transductor potential (Volts)
$E_{x\,max}$	Highest transductor potential in the minor hysteresis loop of interest (Volts)
$E_{x\,min}$	Lowest transductor potential in either minor hysteresis loop (Volts)
(GeV)	(10^9 Electron Volts)
NIT, SIT	North, South Injection Tunnel
nw	Turns-width product of integral coil (meters)
T, T_{max}	Symbols denoting energy and maximum energy respectively (GeV)
ref	Subscript denoting reference magnet S/N 456201
subj	Subscript denoting subject magnet, i.e., the subject of the measurement (S/N 456202, 03, 04 ... 456214)
$\varnothing_{nn}$	Flux in the 1-turn flux loop which generates an emf in the 1-turn flux loop on the periphery of the lower pole tip of magnet S/N 4562nn
Δ	Denotes the difference between a quantity of the subject magnet (n) and the same quantity in the reference magnet (1), $(Q_n - Q_1)$
δ	Difference between two values of the same dependent variable corresponding to two values of the independent variable. In this note, E_x is usually the independent variable and one of its values is usually $E_{x\,max}$ corresponding to either the 20 GeV or 15 GeV value of transductor potential.
LAB	SLAC Light Assembly Building
We	In discussing measurement activities, we $\equiv$ Don Nelson and Ed Cyr. In discussing test results, we $\equiv$ Don Nelson and Joe Dorst, and/or Jack Peterson.

TABLE II Glossary

TABLE III

Positions of the 14 B3-Type Bend Magnets in the PEP Beam-Transport Lines

Magnet Number (n)	Deviation From Reference Magnet* (%)	Lattice Assignment^{+}
1	0.00	41B4
2	-0.49	42B6
3	-0.21	41B6
4	-0.15	41B3
5	-0.21	41B7
6	-0.77	42B3
7	-0.65	42B5
8	-0.16	41B5
9	-0.47	42B9
10	-0.35	41B8
11	-0.37	41B9
12	-0.61	42B8
13	-0.63	42B4
14	-0.44	42B7

$$\text{*Deviation} \equiv 100\, \frac{{}_{n}\!\int B_z ds - {}_{1}\!\int B_z ds}{{}_{1}\!\int B_z ds} \left(\%\text{ of } {}_{1}\!\int B_z ds\right)$$

$^{+}$Line 41 is the south injection tunnel (SIT)
Line 42 is the north injection tunnel (NIT)

SCHEDULE OF MEASUREMENTS

Table IV is a schedule of magnet measurements for B-3 type and other PEP injection-line magnets. Included in Table IV are effort charges against the account provided for measurements of PEP injection-line magnets during 1978.

It may be of interest to those planning similar measurement programs to compare the effort charged with the estimates made in the test plan. Below, we have summarized these efforts for the periods of initial measurements (magnets 1 and 2) and the routine production line measurements (magnets 3 - 14 and 1).

	Test Plan - Minimum Effort (Shifts)*	Effort Charged to Account No. 8484-26 During Period Coinciding With Activities (Shifts)	
		Nelson	Cyr
Set Up/Shakedown Test Equipment	10	24	10
Magnetic Measurements of 14 B-3 Type Magnets	38	50	25

Note that the effort charged by Ed Cyr accurately portrays the number of shifts required to acquire these data. Nelson's time included planning, software - coding, data analysis, data processing, and preliminary report writing.

---

*The number of men in a shift was not defined in the test plan, but Nelson intended and used two-man shifts for all measurements.

Activity	Period	S/N	Coil Matching Condition (See Note)	Map No. 20 GeV	Map No. 15 GeV	Effort Charged to Account No. 8484-26 (Man Hours) Don	Ed
Test Plan Revised	2/03/78					30	10
Measurement System Shakedown/ Preliminary Measurements	3/10/78 - 5/1/78	1 & 2				~164	72
					Total	194 (24 shifts)	82 (10 shifts)
						(Preliminary Measurements)	
Measurements of Magnet No. 2	5/02/78 - 5/3/78	2	1	17	19*		
Status Report Meeting No. 1	5/04/78						
Measurements of Magnet No. 3	5/09/78	3	1	22	23	105	71
Measurements of Magnet No. 4	5/19/78	4	1	26	27		
Measurements of Magnet No. 5	5/23/78	5	1	33	34		
Status Report Meeting No. 2	6/01/78						
Measurements of Magnet No. 6	6/06/78	6	2	41	42	16	8
Test B1 & B2 Magnets	6/12/78 - 7/28/78					164**	29**
Measurements of Magnet No. 7	8/08/78	7	2	73	74		
Measurements of Magnet No. 8	8/09/78 - 9/1/78	8	2/3	83	77	118	62
Measurements of Magnet No. 9	9/01/78	9	3	84	85		
Calibration of L-45 in Main Ring Magnet	9/05/78					28**	22**
Measurements of 18 (BV 1 & BV 2 Type) Magnets	9/ /78 - 10/29/78						
Measurements of Magnet No. 10	10/30/78 - 10/31/78	10	4	92	93	54	35
Measurements of Magnet No. 11	10/31/78	11	4	94	95		
Measurements of Magnet No. 12	11/22/78	12	4	97	98	24	13
Measurements of Magnet No. 13	12/19/78	13	1	102	103		
Measurements of Magnet No. 14	12/19/78	14	4	104	105		
Ref. Magnet Magnetization @ 15 GeV 16 Point-Data	12/27/78	1	4				
Coil Calibration Point-Data for Num. Integration	12/27/78	1	4			76	10
Coil Calibration Point-Data for Num. Integration Supplement	12/28/78	1	4				
Ref Magnet Magnetization @ 20 GeV 16 Point-Data	12/28/78	1	4				
					Total	393 (50 shifts)	199 (25 shifts)
						(B-3 Type Production Measurements)	

NOTE: Coil matching conditions are shown in Table V

---

*Magnetic conditioning before testing different for magnet 2 (compared to others, i.e., 3 - 14)

**Effort for testing other injector line magnets. Not included in totals in Table I.

TABLE IV Schedule of Measurement for PEP Injection Line Magnets, B-3 Type

MEASUREMENT PROCEDURES

General Description

When each B-3 type magnet was fabricated, Elma Manufacturing would ship the magnet to the SLAC Light Assembly Building (LAB) for tests. Bob Byers, SLAC, accepted the magnet and either 1) stored it in the LAB until the previously delivered magnet had been released and stored, or 2) placed the magnet on the LAB test stand directly over the reference magnet (S/N 456201). Zohrab Vassilian and/or others in the SLAC Magnetic Measurements Group connected 2 water lines, 2 power lines and a ground lead to the magnet.

When the magnet was ready for testing, Don Nelson and Ed Cyr would do the following:

1. make preliminary tests, e.g., polarity, test equipment connections, etc.,
2. condition magnets for 20 GeV minor hysteresis loop data, $T_{max} = 20$ GeV
3. measure: $$\left.\begin{array}{l} B_{ref}(E_x\{T_{max}\}),\ B_{subj}(E_x\{T_{max}\}) \\ \int Bds_{subj}(E_x\{T_{max}\})\ \&\ \int Bds_{ref}(E_x\{T_{max}\}) \\ \Delta B(E_x\{T_{max}\}),\ \Delta\int Bds(E_x\{T_{max}\}) \end{array}\right\}\ \text{"In/Out" Measurements}$$
   (See Table II for definition of terms)
4. collect power and cooling data[9]
5. make graphical magnetization runs
6. measure: δB_{ref}, $\delta\int Bds_{ref}$, $\delta\phi_{ref}$, δB_{subj}, $\delta\int Bds_{subj}$, $\delta\phi_{subj}$, $\delta\Delta B$, $\delta\Delta\int Bds$, $\delta\Delta\phi$ at regular current increments (a) on descending portion of 20 GeV minor hysteresis loop and (b) on ascending portion of 20 GeV minor hysteresis loop.

7 - 11. Steps 7 through 11 correspond to steps 2 through 6 respectively except $T_{max} = 15$ GeV (15 GeV minor hysteresis loop).

12. tag magnet, mark polarity, etc.
13. process data on magnetic tape at LBL
14. notify Bob Byers to have magnet disconnected, "blown down", and removed from test stand for storage.

Data Acquisition Cycle Description

In preliminary tests, following a procedure suggested by G. Fischer[10], we determined magnet currents corresponding to beam energies of both 15 GeV (∿804 A) and 20 GeV (∿1466 A). We also chose as a minimum current ∿46 A which corresponded to 100 counts on our current setting DAC (digital to analog converter) controller.

These current values became the minimum and maximum current values for our two data acquisition cycles and defined the end points of the two minor hysteresis loops which we refer to as 15 and 20 GeV minor hysteresis loops.

After conditioning the magnet(s) under test by cycling three times between the minimum and appropriate maximum current, we cycled the current between limits while recording data on the descending portion of three current cycles and on the ascending portion of three additional cycles. Figure 1 shows transductor potential as a function of elapsed time for the 20 GeV minor hysteresis loop. Figure 2 shows the same quantities for the 15 GeV minor hysteresis loop.

As shown in Figures 1 and 2, for collecting both the ascending data (shown as a solid line) and the descending data (dashed line), we started and ended each data acquisition cycle at the appropriate maximum current (points labeled 1 and 1') respectively. The (lack of) closure of the field quantities associated with current points 1 and 1' was used to adjust the magnetic field data, assuming that the drift-rate of each of the three integrators was constant during a measurement cycle.

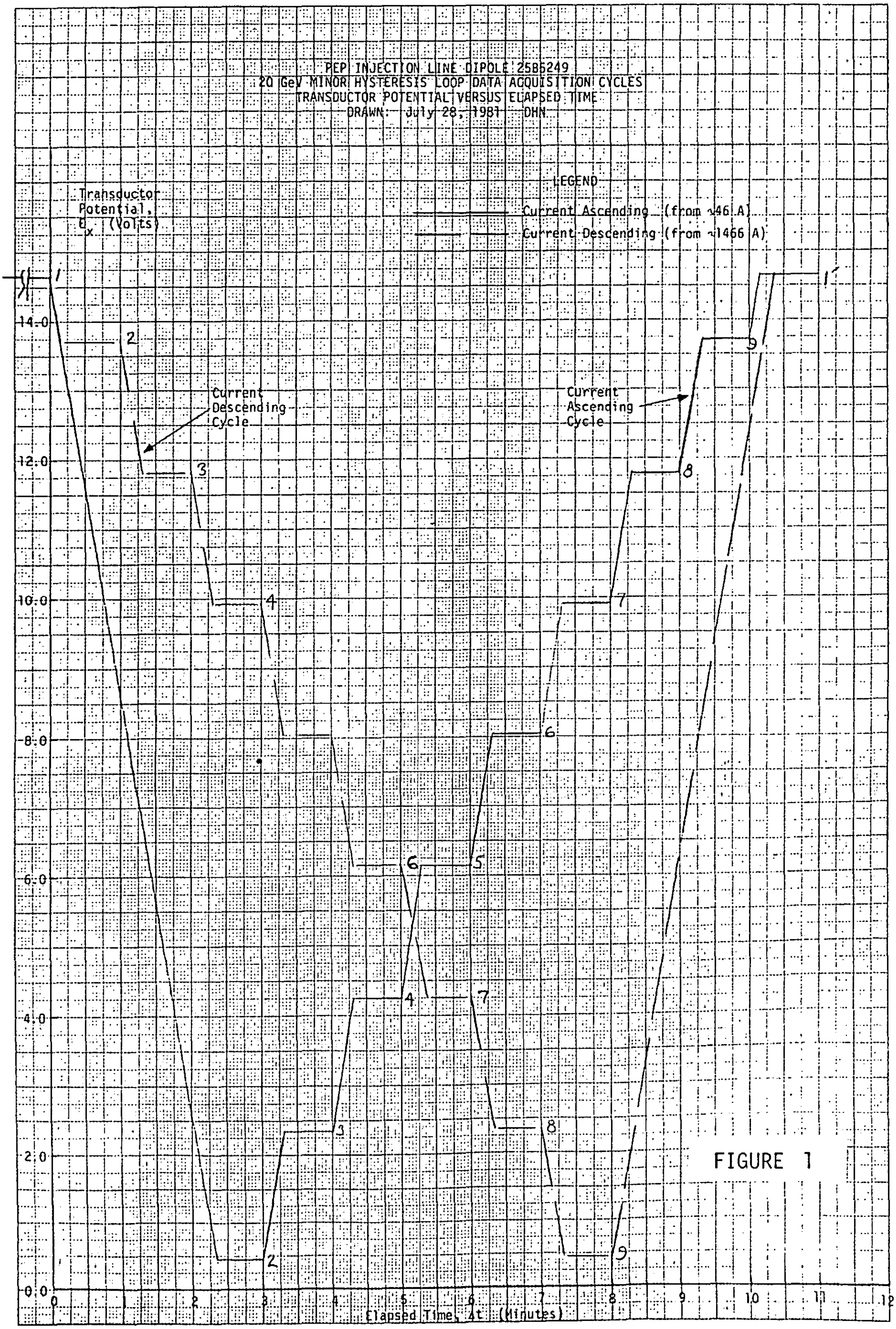
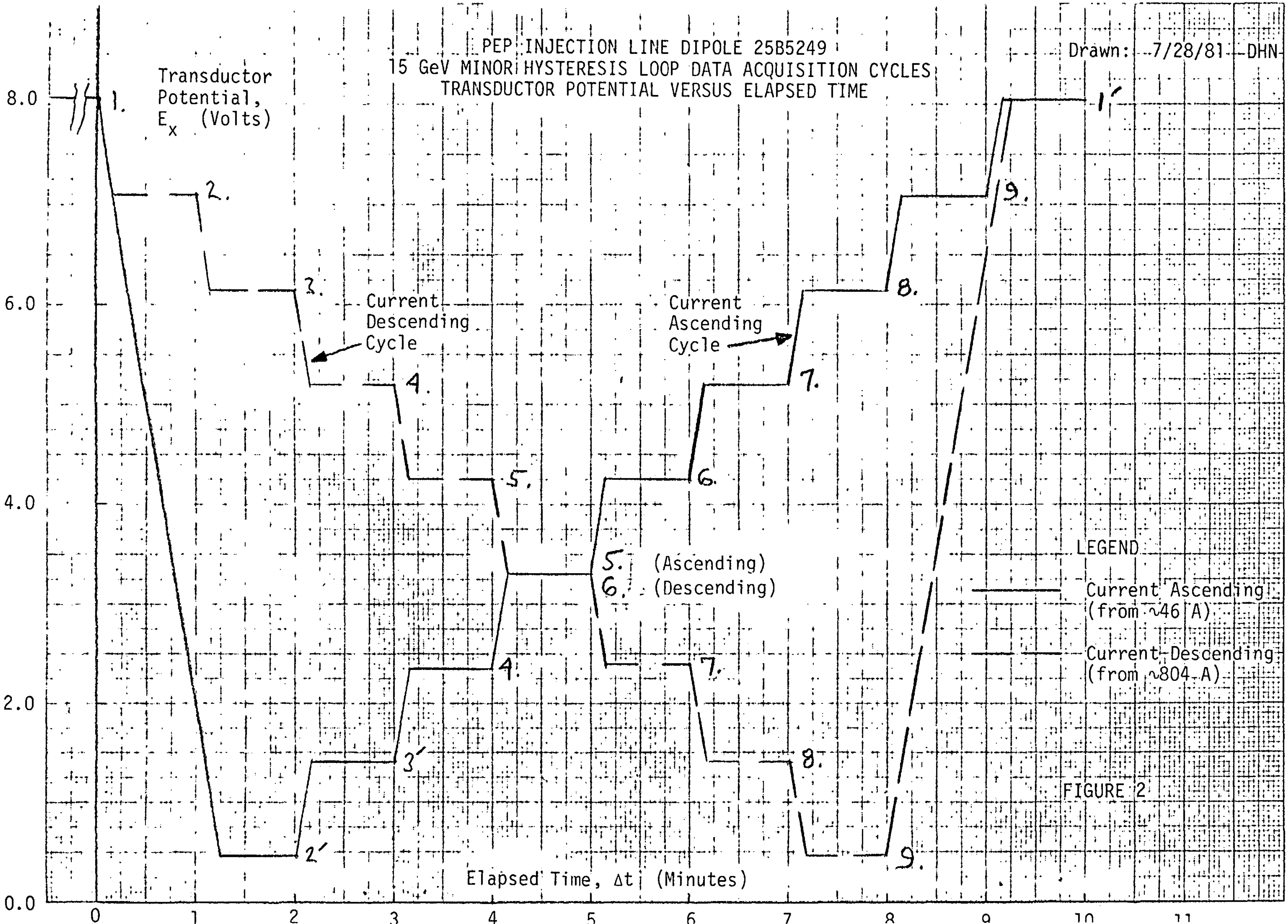

PEP INJECTION LINE DIPOLE 25B6249
20 GeV MINOR HYSTERESIS LOOP DATA ACQUISITION CYCLES
TRANSDUCTOR POTENTIAL VERSUS ELAPSED TIME
DRAWN: July 28, 1981 DHN
LEGEND
Current Ascending (from ~46 A)
Current Descending (from ~1466 A)
Transductor Potential, E_x (Volts)
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
Elapsed Time, Δt (Minutes)
0
1
2
3
4
5
6
7
8
9
10
11
12
Current Descending Cycle
Current Ascending Cycle
1
2
3
4
6
2
3
4
5
6
7
8
9
1
7
8
9

FIGURE 1

SQUARE 10 X 10 TO THE CENTIMETER AS 6014



PEP INJECTION LINE DIPOLE 25B5249
15 GeV MINOR HYSTERESIS LOOP DATA ACQUISITION CYCLES
TRANSDUCTOR POTENTIAL VERSUS ELAPSED TIME

Drawn: 7/28/81 DHN

FIGURE 2

Our hardware limited our current control rate to 10 A/second. We determined that up to that rate there were no significant variation with rate so all currents changes were ramped at the rate of 10 A/second.

Magnetic Measurement Description

The data represented in this report were collected with the LBL computer mapper.[11] Both the data acquisition program and the data processing program were extensively modified for this project. Figure 3 and Table V show the test equipment used for these tests.

For measuring the first four magnets, we collected data under three conditions; namely, virgin 15 GeV data, 20 GeV data, brown-out mode (i.e., post 20 GeV) 15 GeV data. Comparison of the virgin 15 GeV data and the brown-out mode 15 GeV data led to the decision to measure the remaining magnets only under the latter two conditions as outlined below:

I. 20 GeV data acquisition procedure $E_{x\,max} = E_x$ (T = 20 GeV)
  A. Condition Magnet for $E_{x\,max}$ (Three Cycles)
  B. Acquire In/Out Data @ $E_{x\,max}$
    1. Collect Reference Magnet Data
    2. Collect Subject Magnet Data
    3. Collect Reference - Subject Magnet Data
  C. Manually Record Power and Cooling Data[9]
  D. Generate Graphical Data (Two Cycles Minimum)
    1. Plot $\delta\int_n B_z ds$
    2. Plot $\delta\Delta\int_n B_z ds$
  E. Acquire Magnetization Data (Six Cycles Minimum)
    1. $\delta\int_1 B_z ds$, δB_{z1}, $\delta\phi_1$
    2. $\delta\int_n B_z ds$, δB_{zn}, $\delta\phi_n$
    3. $\delta\Delta\int_{(1-n)} B_z ds$, $\delta\Delta B_{z(1-n)}$, $\delta\Delta\phi_{(1-n)}$

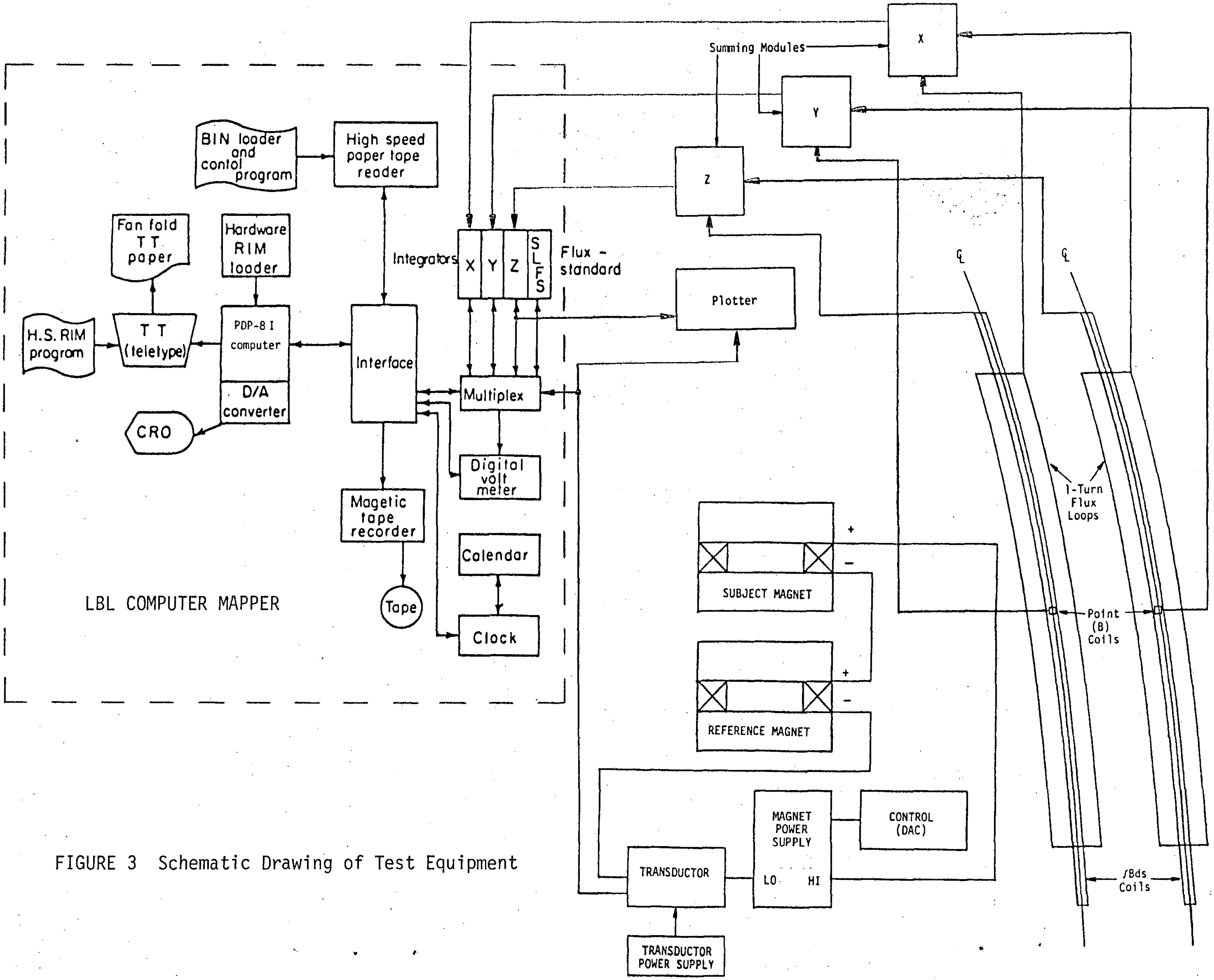


FIGURE 3 Schematic Drawing of Test Equipment

TABLE V Test Equipment

Device	Identification	Notes
Flux Standard	SLFS 39.5	Ø = 0.5061 (Wb)
Integral Coil (Ref Magnet)	L-45 Assy. Drwg. No. AD204-223-13	nw = 0.05179 (m)*
Integral Coil (Subj Magnet)	L-46 Assy. Drwg. No. AD204-223-13	(See footnote)
Integrator	"Z"	R = 46.4 kΩ, C = 2.0 μF, Atten = 296
Point Coil (Ref Magnet)	B-140	nA = 5265 (cm^2) (signal, divided to match B-149, {0.9989})
Point Coil (Subj Magnet)	B-149	nA = 5259 (cm^2)
Integrator	"Y"	R = 46.4 kΩ, C = 2.0 μF, Atten = 350
1-Turn Flux Loop	Installed in each magnet	(On periphery of lower pole)
Integrator	"X"	R = 46.4 kΩ, C = 1.0 μF, Atten = 412
Transductor/Trans P. S.	SA-901-119-11	S/N 6
Computer Mapper	LBL Report - LBL-1311	Modified Extensively
Data Acquisition Program	LBL MSS Set Mapper II, subset M604152	Modified Extensively (Update)
Data Processing Program	BCOMA	OLD PL = MSS/COMA76U 34565 (Last Update - January 23, 1980)

---

*Coil L-45 was divided in an attempt to match the sensitivity of coil-46. While measuring subject magnet S/N 456208, coil L-46 opened and was rewound. After measuring subject magnet S/N 456209, coil L-46 opened again and was discarded. For magnets S/N 456210 - 456214, coil L-45 (and B-140) was used to measure both reference and subject magnets. The divider used on coil L-45, the relative turn-width product of L-45 divided and L-46, and the (apparent) turn-width product of L-46 are given below for four conditions:

Coil Matching Condition	Divider On Reference Coil (L-45)	$\frac{nw_{L-45}(Div)}{nw_{L-46}}$	nw_{L-46}(Apparent) (turn m)
1	0.9899 (Initial Matching)	0.9992	0.05131
2	0.9905 (Improved Matching)	0.9996	0.05132
3	0.9963 (Rewound Coil L-46)	0.9999	0.05160
4	1.0000 (Undivided)	N.A.	Permanently Open

II. 15 GeV data acquisition procedure $E_{x\,max} = E_x$ (T = 15 GeV)

A - E Repeat of I A - E (page 11)

In addition to the measurements outlined on page 11, we collected two additional sets of data for the reference magnet as follows:

1. We measured B_z (s) for numerical integration over s and calibration of the integral coil;
2. We measured $\delta\int B_z ds$ at different (intermediate) values of E_x (except at the end points which define the minor hysteresis loop).

The first set was used to calibrate the integral coil, L-45. We did not calibrate this integral coil in a main ring dipole because of scheduling difficulties. The second set known as "high density or 16 point" excitation data was collected on December 29, 1978. Because power in the LAB had been inadvertently interrupted over the Christmas holiday, this "high density" data set was of inferior quality to the previously measured data.

TEST RESULTS

Preliminary results were officially transmitted to SLAC in January, 1979.[12] MT 274 listed $\int B_z ds$ vs E_x for the reference magnet and $\Delta\int B_z ds$ vs E_x for the thirteen subject magnets. The difference data were refined in February, 1980.[13]

We believe the 12 and 13 set average reference magnet data represented in this report are superior to the 16 point data delivered in January, 1979 as explained in a separate memorandum.[14]

The four transductors used for operational measurement of current of the 14 B-3 type magnets were calibrated against the transductor used during the magnetic measurement program.[15] The output potential of the four operation transductors is 0.9990 ±0.0002 of the corresponding potential of the transductor we used for any current in the range $200 \leq I \leq 800$ A. The operation transductors are reported to have sensitivities of 99.95 A per volt.[16]

Reference Magnet

For the reference magnet (S/N 456201), we have tabulated $\int Bds$, $\int Bds/E_x$, B, B/E_x and $\int Bds/B$ for 9 values of E_x for the 4 magnetic conditions described below.

Table	Page	Magnetic Condition
VI	16	20 GeV Minor Hysteresis Loop, Current Ascending
VII	17	20 GeV Minor Hysteresis Loop, Current Descending
VIII	18	15 GeV Minor Hysteresis Loop, Current Ascending
IX	19	15 GeV Minor Hysteresis Loop, Current Descending

Graphical Representations

Point Magnetization Plots

Figure 4 (page 20) shows magnetic induction and normalized magnetic induction as functions of current-monitoring-transductor potential. We show curves representing the 20 GeV minor hysteresis loop, and we plotted data from the 15 GeV minor hysteresis loop for comparison.

Figure 5 (page 21) shows the same quantities up to an energy level of 15 GeV and at an expanded scale. We show curves representing both the 15 GeV minor hysteresis loop (shown as a solid line) and data from the 20 GeV minor hysteresis loop up to ∿15 GeV (shown as a dashed line).

Integral Magnetization Plots

Figure 6 (page 22) shows integral of magnetic induction and normalized integrals as functions of current-monitoring-transductor potential. The curves represent the 20 GeV minor hysteresis loop and we plotted data from the 15 GeV minor hysteresis loop for comparison.

Figure 7 (page 23) shows the same qualities up to an energy level of 15 GeV and at an expanded scale. The 15 GeV curves are shown as solid lines while the 20 GeV curves are dashed.

(text continues on page 24)

Transducor Potential, E_x (Volts)	Integral of Magnetic Induction, $\int Bds$ (Tm)	Normalized Integral, $\frac{\int Bds}{E_x}$ (Tm/V)	Magnetic Induction, B (Teslas)	Normalized Induction, $\frac{B}{E_x}$ (T/V)	Effective Length, $\frac{\int Bds}{B}$ (Meters)
14.661	8.802	0.6004	1.6793	0.1145	5.241
13.716	8.589	0.6261	1.6387	0.1195	5.241
11.827	8.093	0.6842	1.5435	0.1305	5.243
9.934	7.458	0.7505	1.4214	0.1431	5.247
8.041	6.483	0.8060	1.2335	0.1534	5.256
6.146	5.063	0.8238	0.9620	0.1565	5.263
4.247	3.526	0.8302	0.6698	0.1577	5.264
2.350	1.960	0.8340	0.3726	0.1586	5.260
0.458	0.407	0.889	0.0777	0.1697	5.240

TABLE VI REFERENCE MAGNET (S/N 456201)
20 GeV Minor Hysteresis Loop Data
(Twelve Set Average)
Current Ascending (from ∿46 A)

Transducor Potential, E_x (Volts)	Integral of Magnetic Induction, $\int Bds$ (Tm)	Normalized Integral, $\frac{\int Bds}{E_x}$ (Tm/V)	Magnetic Induction, B (Teslas)	Normalized Induction, $\frac{B}{E_x}$ (T/V)	Effective Length, $\frac{\int Bds}{B}$ (Meters)
14.661	8.802	0.6004	1.6793	0.1145	5.241
13.716	8.594	0.6265	1.6398	0.1195	5.241
11.827	8.111	0.6857	1.5472	0.1308	5.242
9.934	7.501	0.7549	1.4300	0.1440	5.245
8.041	6.564	0.8163	1.2489	0.1553	5.256
6.146	5.116	0.8314	0.9708	0.1580	5.264
4.247	3.557	0.8375	0.6755	0.1591	5.266
2.350	1.984	0.8443	0.3770	0.1604	5.263
0.458	0.406	0.886	0.0776	0.1694	5.230

TABLE VII REFERENCE MAGNET (S/N 456201)
20 GeV Minor Hysteresis Loop Data
(Twelve Set Average)
Current Descending (from ∿1466 A)

Transducor Potential, E_x (Volts)	Integral of Magnetic Induction, $\int Bds$ (Tm)	Normalized Integral, $\frac{\int Bds}{E_x}$ (Tm/V)	Magnetic Induction, B (Teslas)	Normalized Induction, $\frac{B}{E_x}$ (T/V)	Effective Length, $\frac{\int Bds}{B}$ (Meters)
8.040	6.477	0.8056	1.2310	0.1531	5.262
7.090	5.799	0.8179	1.1007	0.1552	5.268
6.146	5.062	0.8236	0.9603	0.1562	5.271
5.198	4.301	0.8274	0.8155	0.1569	5.274
4.247	3.526	0.8302	0.6685	0.1574	5.274
3.298	2.745	0.8323	0.5203	0.1578	5.276
2.350	1.960	0.8340	0.3713	0.1580	5.279
1.404	1.177	0.8383	0.2229	0.1586	5.280
0.458	0.403	0.8800	0.0767	0.1671	5.250

TABLE VIII REFERENCE MAGNET (S/N 456201)
15 GeV Minor Hysteresis Loop Data
(Thirteen Set Average)
Current Ascending (from ∿46 A)

Transductor Potential, E_x (Volts)	Integral of Magnetic Induction, $\int B ds$ (Tm)	Normalized Integral, $\frac{\int B ds}{E_x}$ (Tm/V)	Magnetic Induction, B (Teslas)	Normalized Induction, $\frac{B}{E_x}$ (T/V)	Effective Length, $\frac{\int B ds}{B}$ (Meters)
8.040	6.477	0.8056	1.2310	0.1531	5.262
7.090	5.849	0.8250	1.1100	0.1565	5.269
6.146	5.107	0.8309	0.9684	0.1576	5.274
5.198	4.338	0.8346	0.8224	0.1582	5.275
4.247	3.558	0.8378	0.6743	0.1588	5.277
3.298	2.773	0.8408	0.5255	0.1593	5.277
2.350	1.986	0.8451	0.3762	0.1601	5.279
1.404	1.198	0.8533	0.2267	0.1614	5.285
0.458	0.408	0.891	0.0769	0.1675	5.310

TABLE IX REFERENCE MAGNET (S/N 456201)
15 GeV Minor Hysteresis Loop Data
(Thirteen Set Average)
Current Descending (from ∿804 A)

LBID-515

LAWRENCE BERKELEY LABORATORY - UNIVERSITY OF CALIFORNIA ENGINEERING NOTE	CODE MME Book No. 579	SERIAL MT301	PAGE 20 OF 50
AUTHOR Nelson, Dorst, Peterson DEPARTMENT Electronics Engineering	LOCATION B25A-124	DATE November 20, 1981	

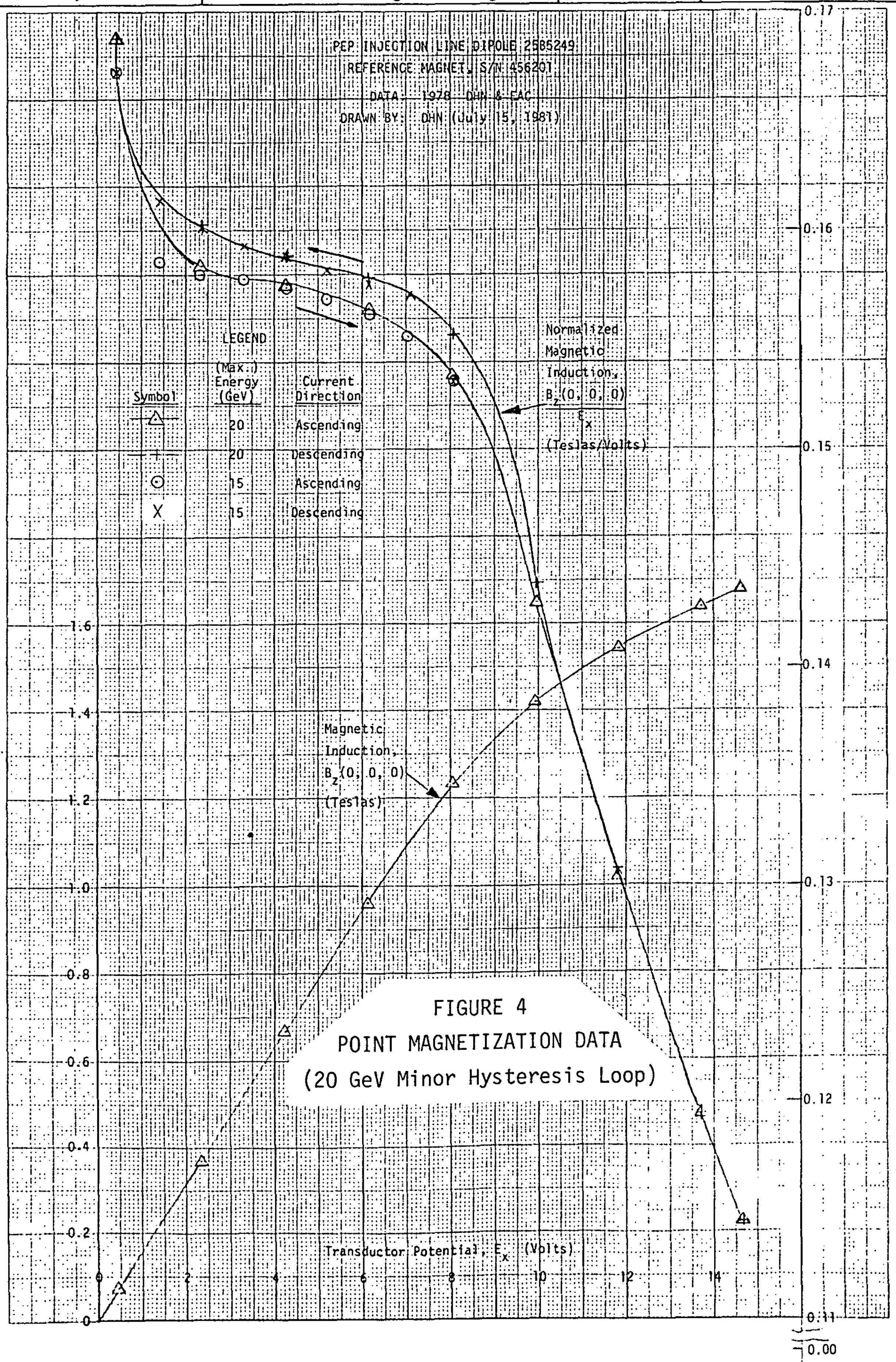


FIGURE 4
POINT MAGNETIZATION DATA
(20 GeV Minor Hysteresis Loop)

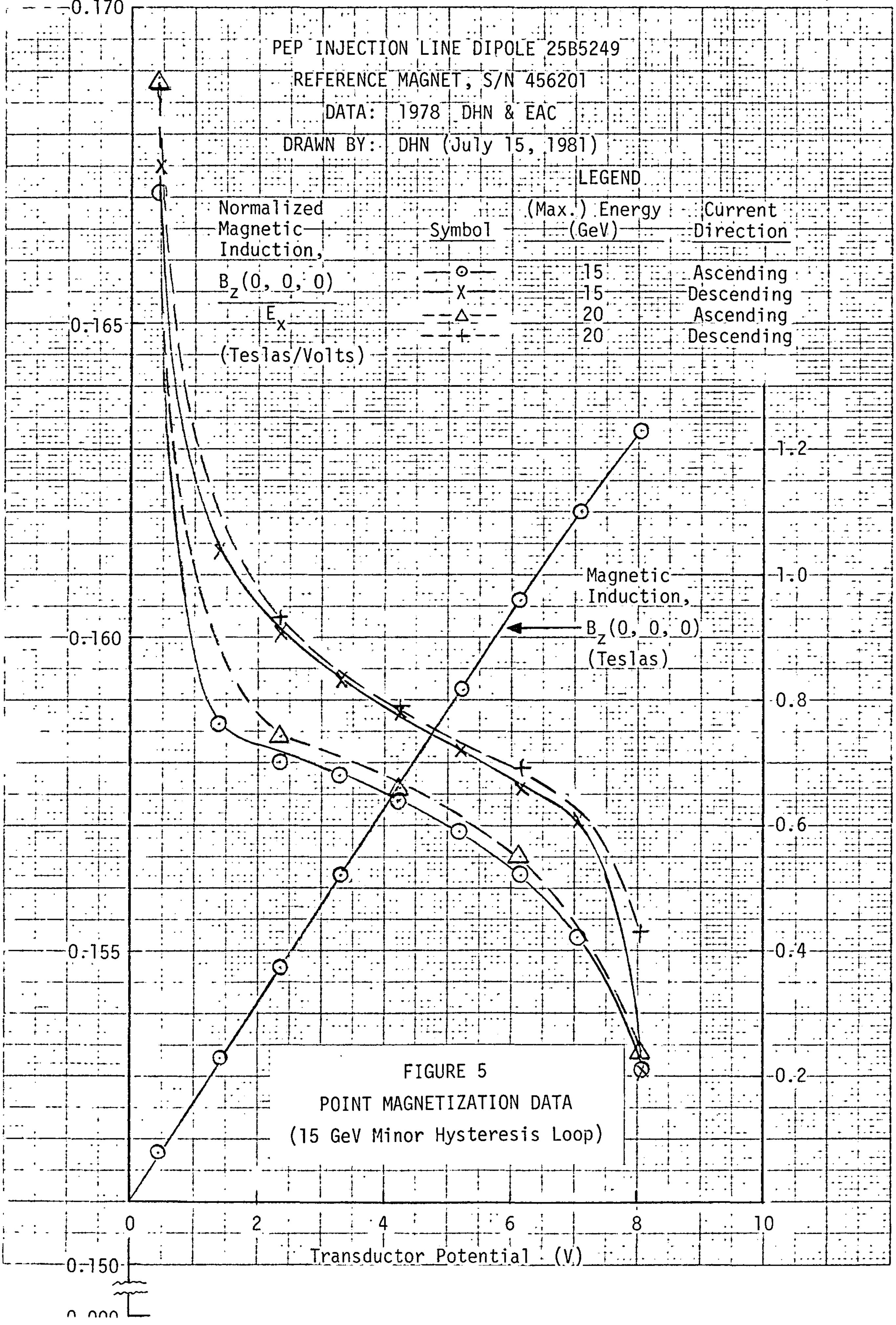


FIGURE 5

POINT MAGNETIZATION DATA

(15 GeV Minor Hysteresis Loop)

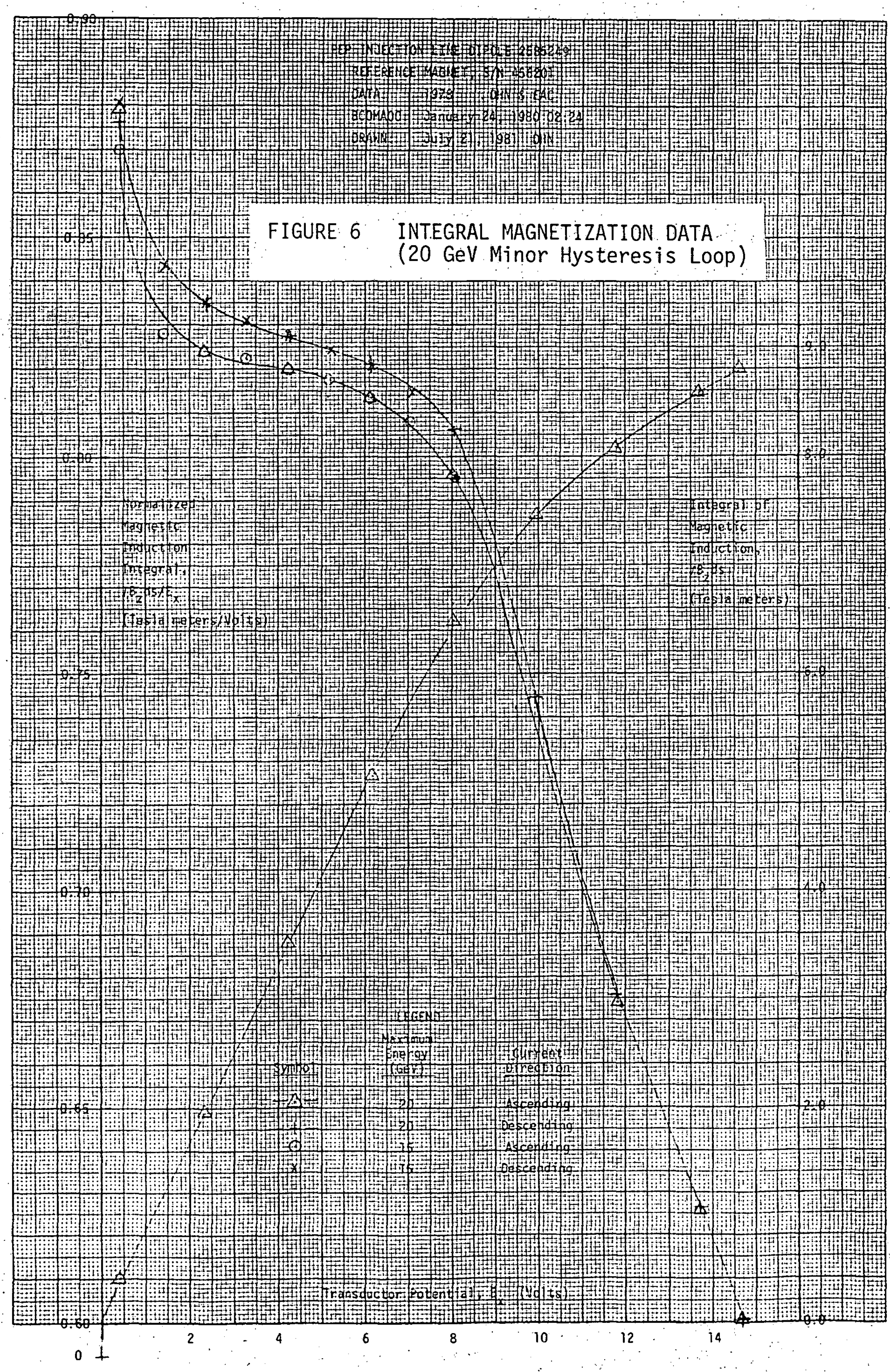


FIGURE 6 INTEGRAL MAGNETIZATION DATA
(20 GeV Minor Hysteresis Loop)

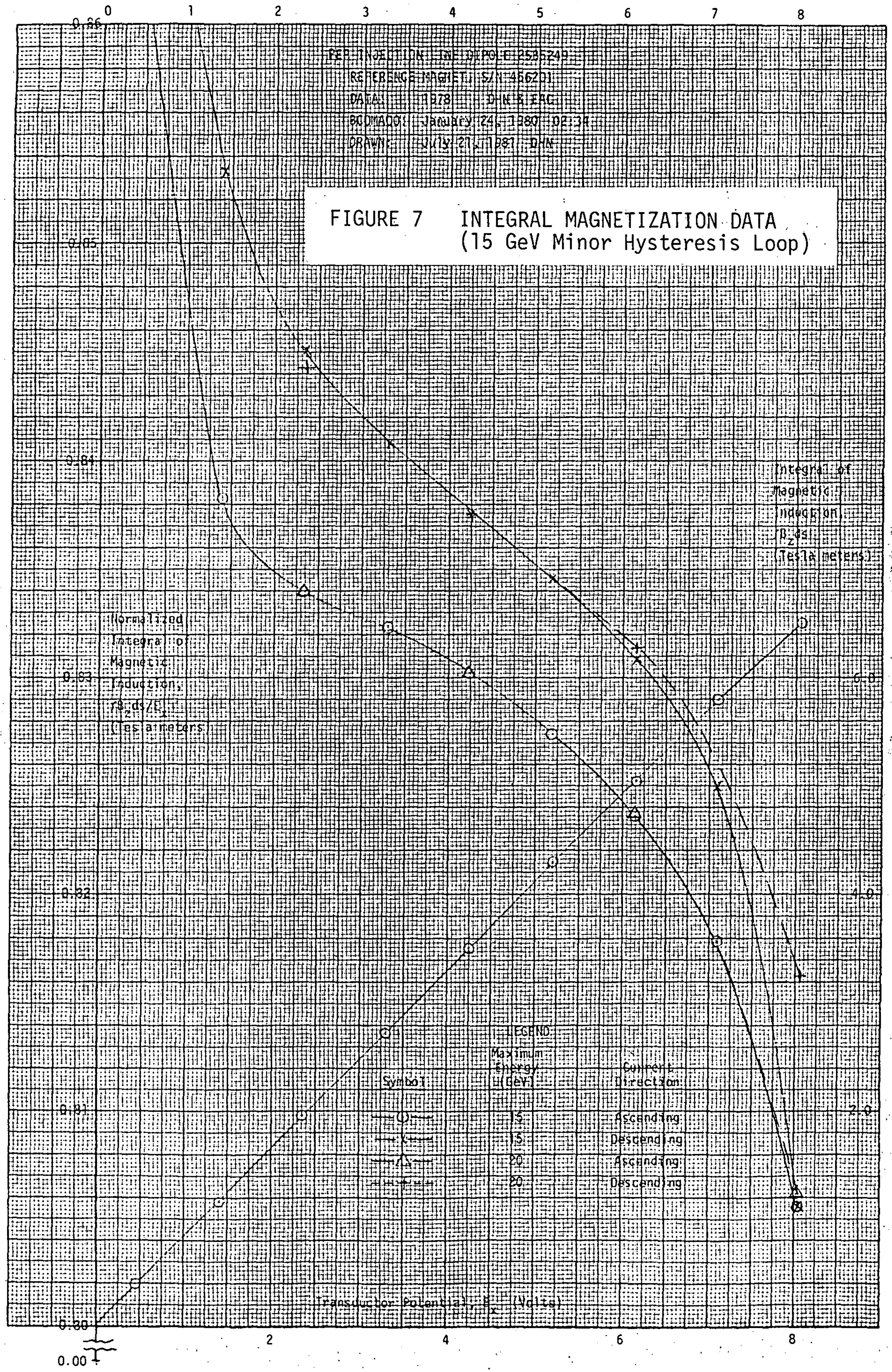


FIGURE 7 INTEGRAL MAGNETIZATION DATA
(15 GeV Minor Hysteresis Loop)

Effective Length Plots

Figure 8 (page 25) shows effective length as a function of transductor potential (15 GeV - solid line, 20 GeV - dashed line)

Relative Strengths of Magnets

The relative strengths (integral of magnetic induction over particle trajectory) of magnets S/N 456202 to S/N 456214 (relative to magnet S/N 456201) are tabulated and plotted as functions of transductor potential (E_x).

The tabulated relative strength data have been relegated to Appendix A for three reasons:

1. They are not of general interest.
2. To avoid tedious proof reading of typed tables of data, the tables in Appendix A are not typed.
3. We will send Jack Truher a copy of Appendix A and anyone else who wishes may request a copy.

Figures 9 through 21 each display four data sets (five for magnets S/N $\geq$10) as follows:

Data Set	Symbol	Minor Loop Maximum Energy	Ascending/Descending
1	⊙	15 GeV	Ascending
2	×	15 GeV	Descending
3	△	20 GeV	Ascending
4	+	20 GeV	Descending
5	□	15 GeV	Ascending "Smoothed"

(text continues on page 26)

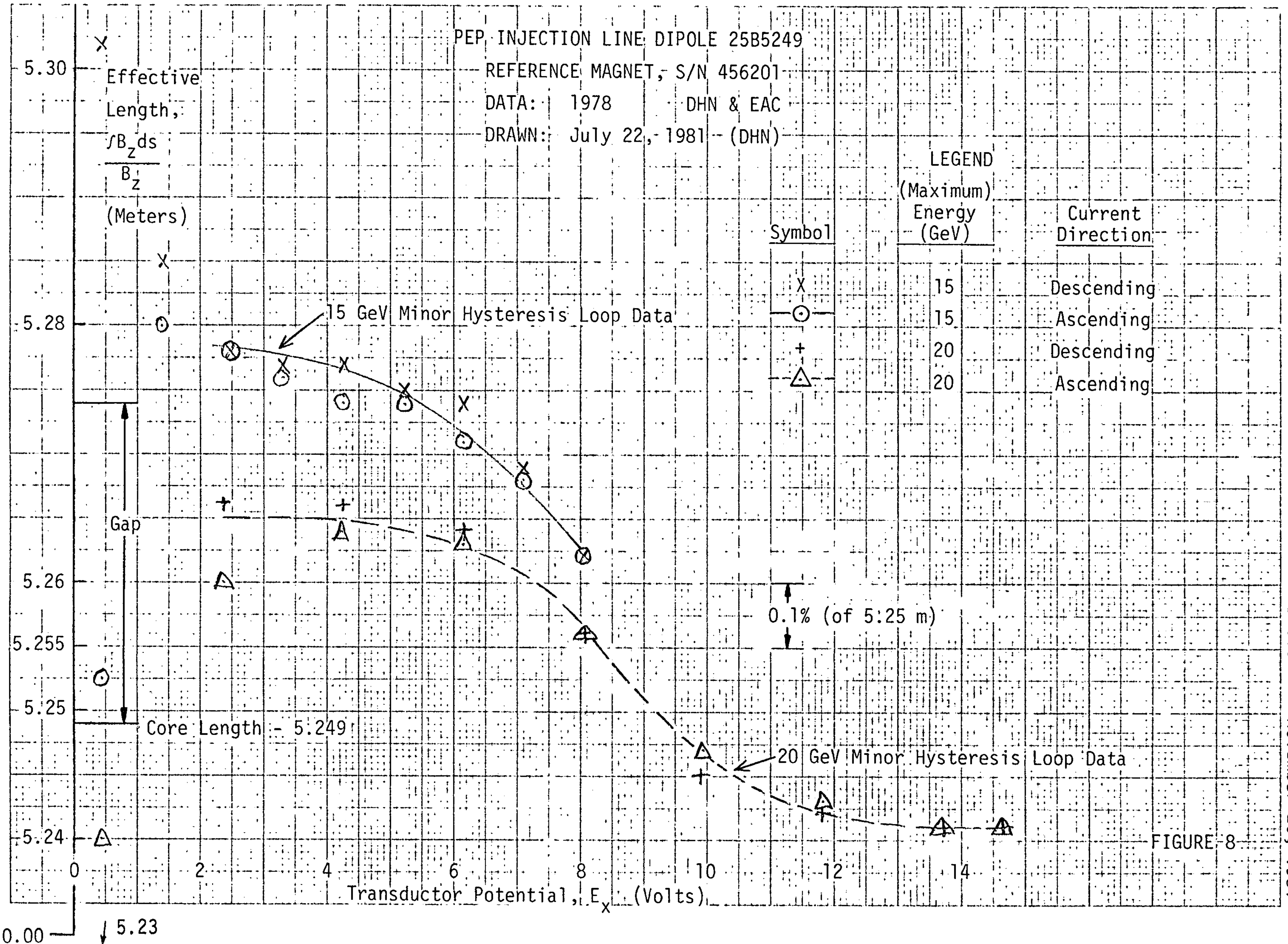

PEP INJECTION LINE DIPOLE 25B5249
REFERENCE MAGNET, S/N 456201
DATA: 1978 DHN & EAC
DRAWN: July 22, 1981 (DHN)
Effective Length, $\frac{\int B_z ds}{B_z}$ (Meters)
5.30
5.28
5.26
5.255
5.25
5.24
0.00
5.23
Gap
Core Length - 5.249
15 GeV Minor Hysteresis Loop Data
20 GeV Minor Hysteresis Loop Data
0.1% (of 5.25 m)
LEGEND
Symbol
(Maximum) Energy (GeV)
Current Direction
X 15 Descending
⊙ 15 Ascending
+ 20 Descending
△ 20 Ascending
0
2
4
6
8
10
12
14
Transductor Potential, E_x (Volts)

FIGURE 8

In addition, the factor presently used to represent the relative strength of each magnet in the energy range $4 \text{ GeV} \le T \le 15 \text{ GeV}$ is displayed as a horizontal line on the graph for that magnet. The following discussion on the subject of relative strengths may be supplemented by examining Figures 9 through 21.

On February 14, 1980, a set of punched cards, listings of the cards and computer generated plots of $\Delta\int Bds$ vs E_x were delivered to Jack Truher, in an attempt to improve on the 15 GeV ascending data that had previously been used for setting magnet currents.

Truher analyzed these data and determined that in the range of energy 4 - 15 GeV that the relative strengths of each of the magnets 2 - 14 could be represented by a single factor. To compute those factors, he used the relative strengths at $\sim$425 A ($\sim$4.25 V transductor voltage, $\sim$8 GeV point from each data set). In his memorandum to MCC operators, dated August 20, 1980, he summarized his adjustments to the "NIT/SIT data tables".

In preparing this report, we found that:

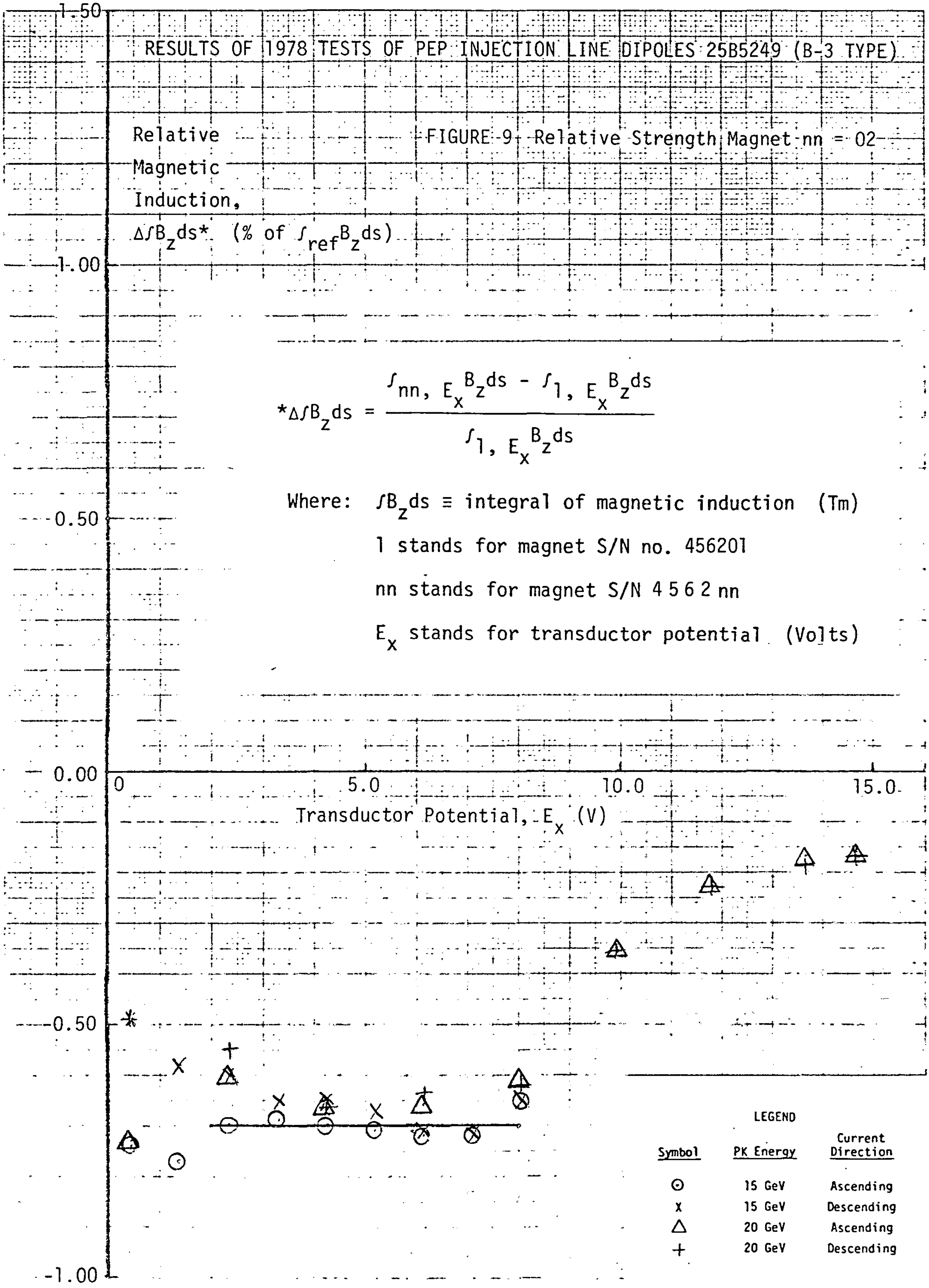
1. Truher's single point representation of strength differences is better than a polynomial fit to un-smoothed data points because of flucuations in the $\sim$46 A ($\sim$0.46 V transductor voltage, $\sim$1 GeV) point;
2. Truher's single point representation is probably accurate to ±0.1% over the energy range of interest, i.e., $4 \text{ GeV} \le T \le 15 \text{ GeV}$;
3. a more accurate representation for each magnet could be arrived at by fitting a first order polynomial to <u>selected</u> data for each magnet (in the energy range $4 \le T \le 15$ GeV);
4. below 15 GeV, the <u>relative</u> strength data from the 20 GeV minor hysteresis loop agrees with data from the 15 GeV minor hysteresis loop;

5. above 15 GeV, the relative-strength magnitudes systematically decrease. We attribute this decrease to the effects of saturation. The reference magnet has the smallest aperture of the 14 magnets. At lower currents where the permeability of the magnet iron is so high that strength is dominated by the gap dimension, the strength differences are relatively constant (as supported by Truher's single point representations of the differences). However, as saturation effects become more dominant, differences in gap become less important, resulting in decreasing magnitudes of relative strengths. If or when these magnets are operated over the 20 GeV minor hysteresis loop, this effect should be accounted for.

6. some of the relative strength data sent to Truher on February 14, 1980 is different from the data represented in this report.
    a. The data for magnets 2 - 9 is identical.
    b. For magnets 13 and 14, the data used by Truher agrees to ±0.01%.
    c. For magnets 10, 11 and 12 (and probably 13 and 14), we evidently smoothed the data before delivering it, resulting in differences as large as 0.05% for the data used by Truher as follows:

S/N	Difference in Relative Strength Data
10	0.03%
11	0.05%
12	0.03%

(text continues on page 41)



RESULTS OF 1978 TESTS OF PEP INJECTION LINE DIPOLES 25B5249 (B-3 TYPE)

FIGURE 9 Relative Strength Magnet nn = 02

$$*\Delta\int B_z ds = \frac{\int_{nn,\ E_x} B_z ds - \int_{1,\ E_x} B_z ds}{\int_{1,\ E_x} B_z ds}$$

Where: $\int B_z ds$ ≡ integral of magnetic induction (Tm)

1 stands for magnet S/N no. 456201

nn stands for magnet S/N 4562nn

E_x stands for transductor potential (Volts)

RESULTS OF 1978 TESTS OF PEP INJECTION LINE DIPOLES 25B5249 (B-3 TYPE)

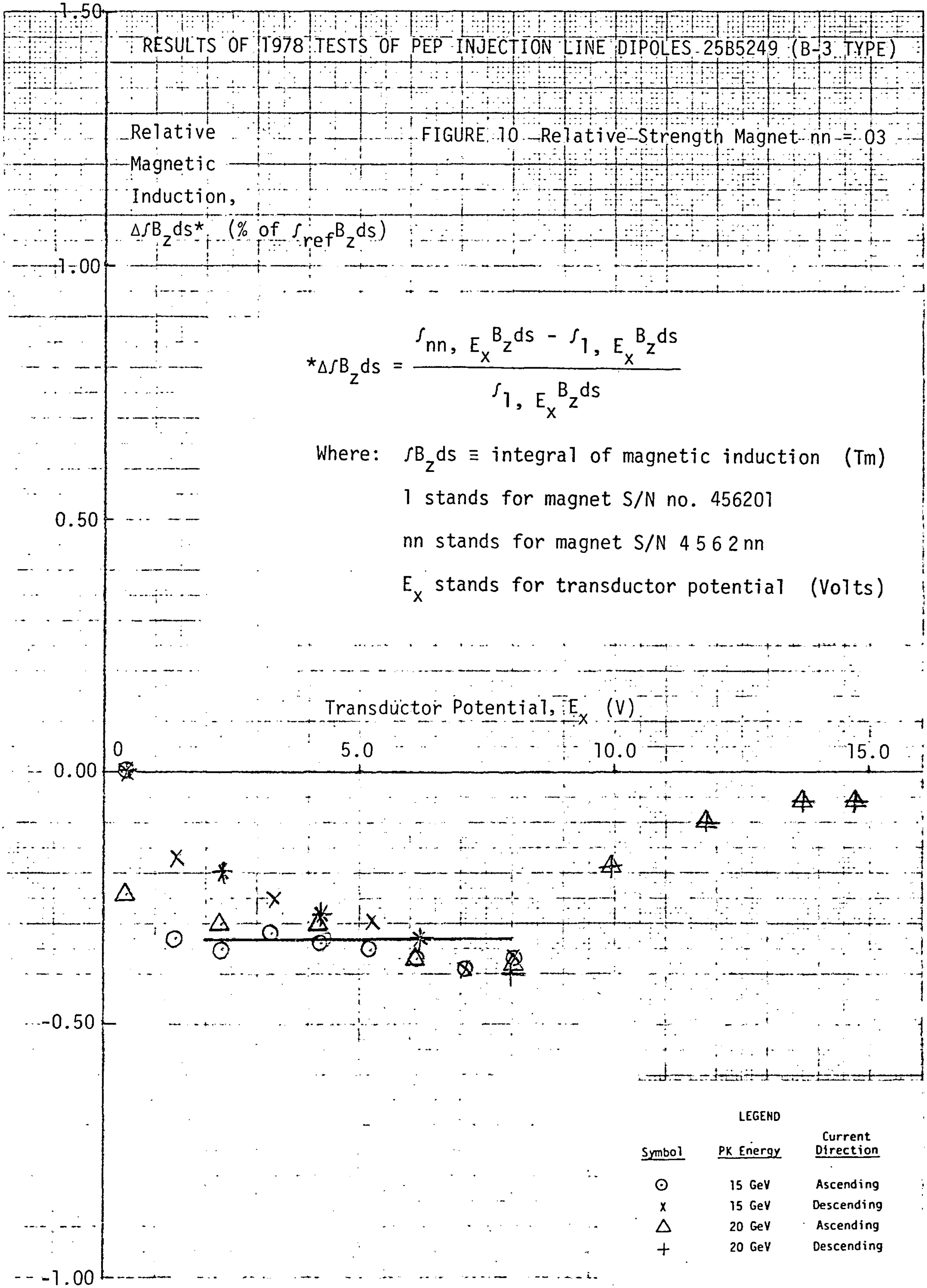


FIGURE 10 Relative Strength Magnet nn = 03

$$*\Delta\int B_z ds = \frac{\int_{nn,\, E_x} B_z ds - \int_{1,\, E_x} B_z ds}{\int_{1,\, E_x} B_z ds}$$

Where: $\int B_z ds \equiv$ integral of magnetic induction (Tm)

1 stands for magnet S/N no. 456201

nn stands for magnet S/N 4562nn

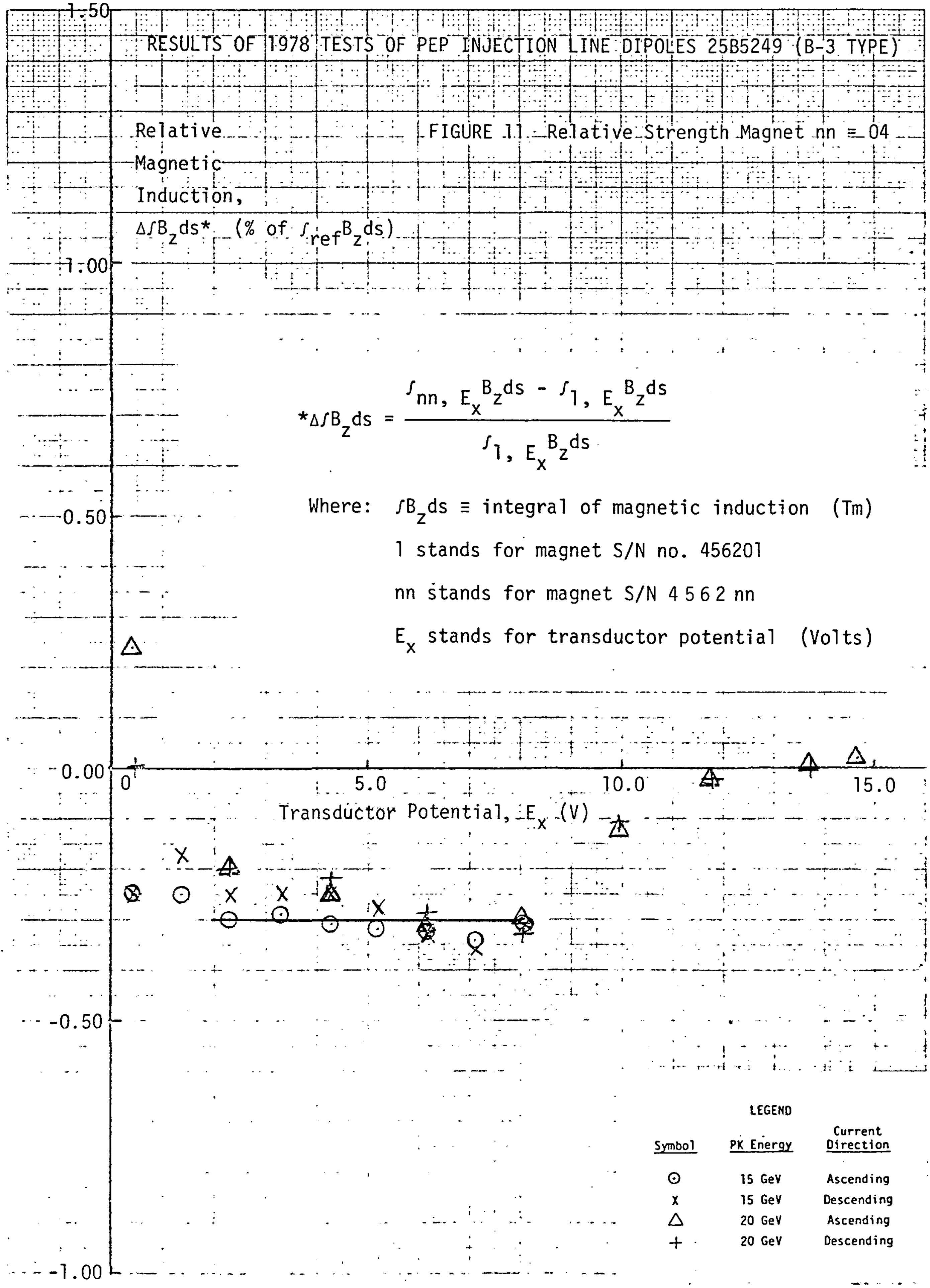
E_x stands for transductor potential (Volts)

LEGEND

Symbol	PK Energy	Current Direction
⊙	15 GeV	Ascending
x	15 GeV	Descending
△	20 GeV	Ascending
+	20 GeV	Descending

RESULTS OF 1978 TESTS OF PEP INJECTION LINE DIPOLES 25B5249 (B-3 TYPE)

FIGURE 11 - Relative Strength Magnet nn = 04



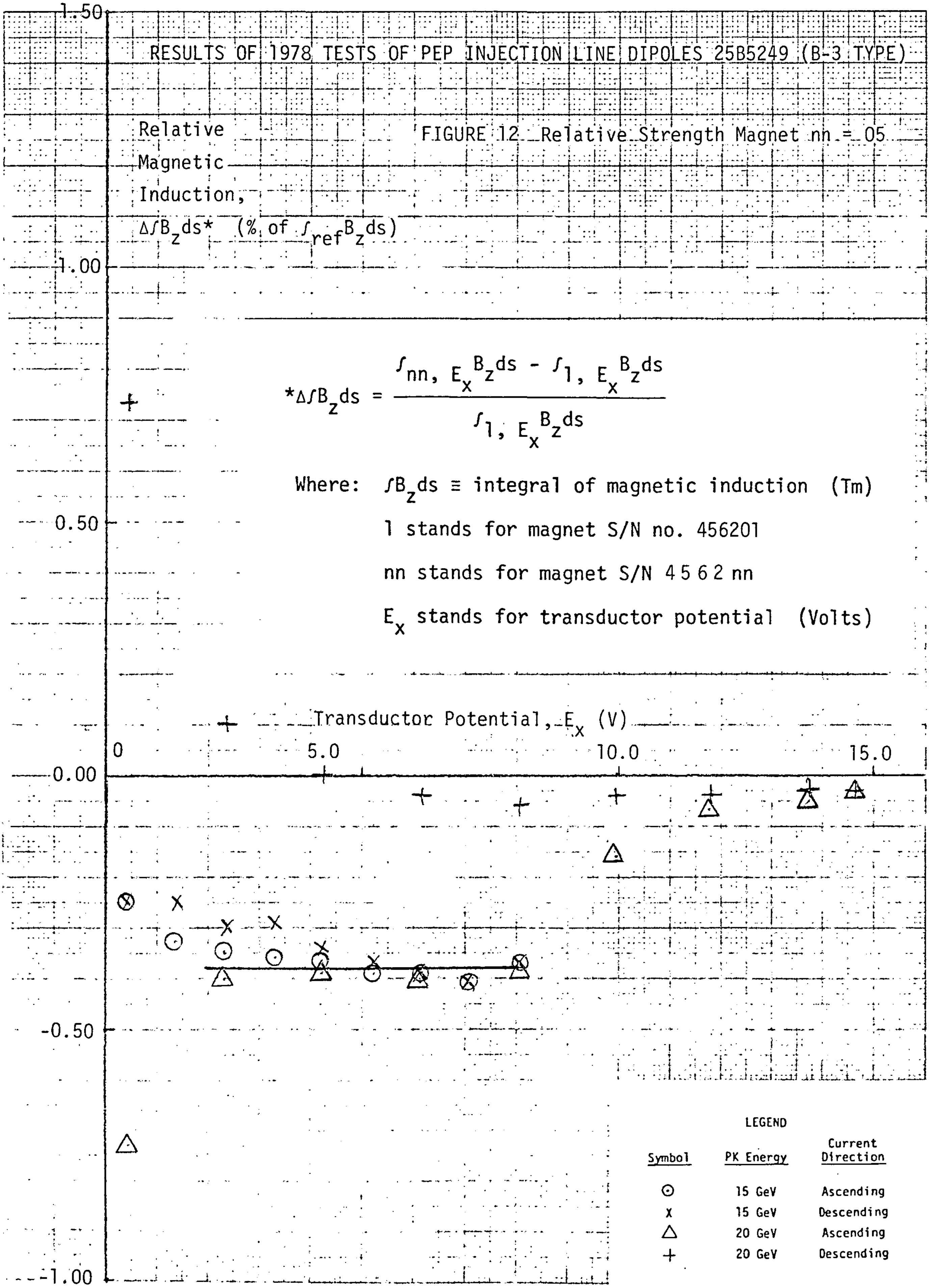
$$*\Delta\int B_z ds = \frac{\int_{nn,\,E_x} B_z ds - \int_{1,\,E_x} B_z ds}{\int_{1,\,E_x} B_z ds}$$

Where: $\int B_z ds \equiv$ integral of magnetic induction (Tm)

1 stands for magnet S/N no. 456201

nn stands for magnet S/N 4 5 6 2 nn

E_x stands for transductor potential (Volts)



RESULTS OF 1978 TESTS OF PEP INJECTION LINE DIPOLES 25B5249 (B-3 TYPE)

FIGURE 12 Relative Strength Magnet nn = 05

$$*\Delta\int B_z ds = \frac{\int_{nn,\,E_x} B_z ds - \int_{1,\,E_x} B_z ds}{\int_{1,\,E_x} B_z ds}$$

Where: $\int B_z ds \equiv$ integral of magnetic induction (Tm)

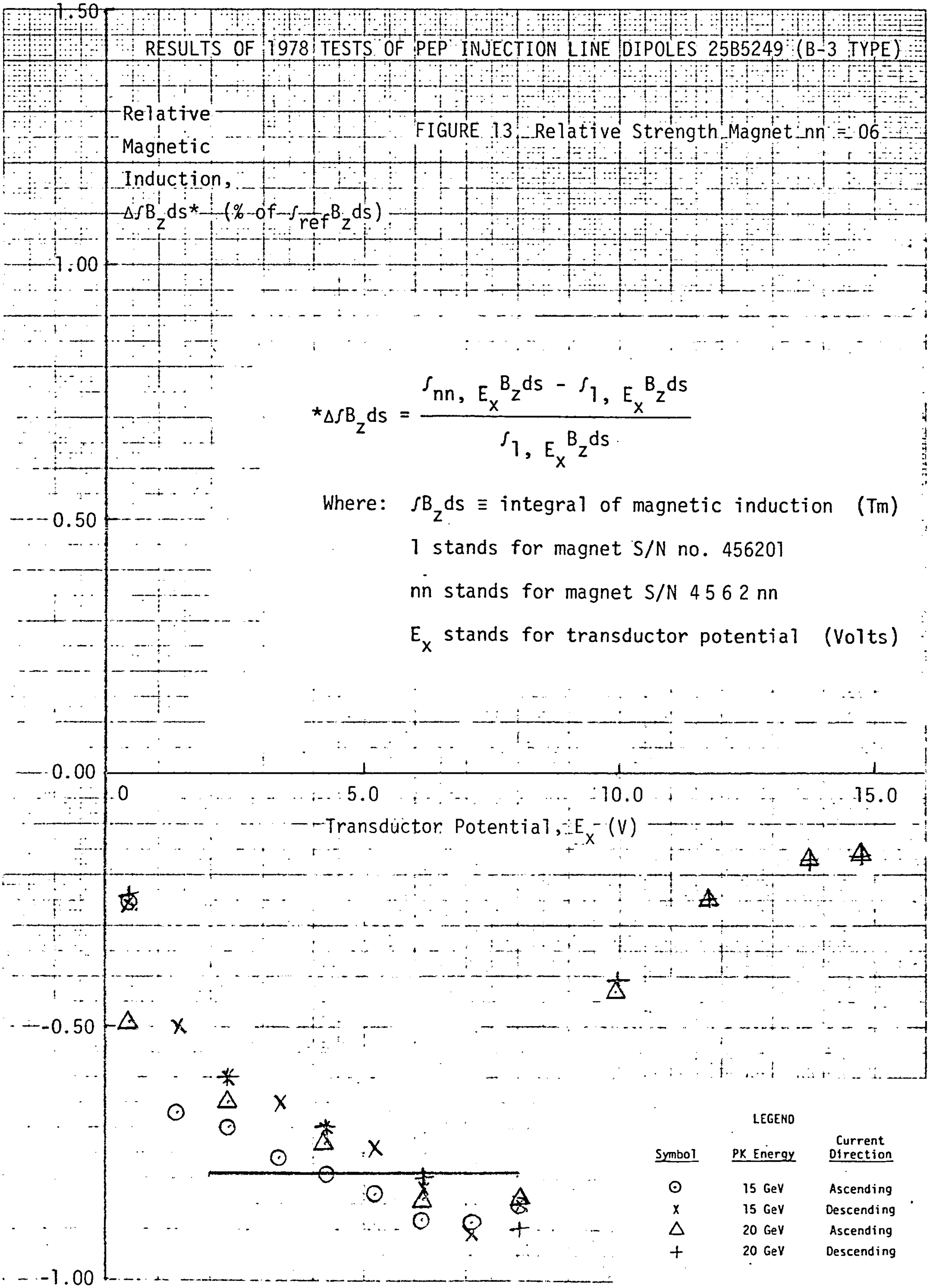
1 stands for magnet S/N no. 456201

nn stands for magnet S/N 4 5 6 2 nn

E_x stands for transductor potential (Volts)

RESULTS OF 1978 TESTS OF PEP INJECTION LINE DIPOLES 25B5249 (B-3 TYPE)

FIGURE 13 Relative Strength Magnet nn = 06



$$*\Delta\int B_z ds = \frac{\int_{nn,\ E_x} B_z ds - \int_{1,\ E_x} B_z ds}{\int_{1,\ E_x} B_z ds}$$

Where: $\int B_z ds$ ≡ integral of magnetic induction (Tm)

1 stands for magnet S/N no. 456201

nn stands for magnet S/N 4 5 6 2 nn

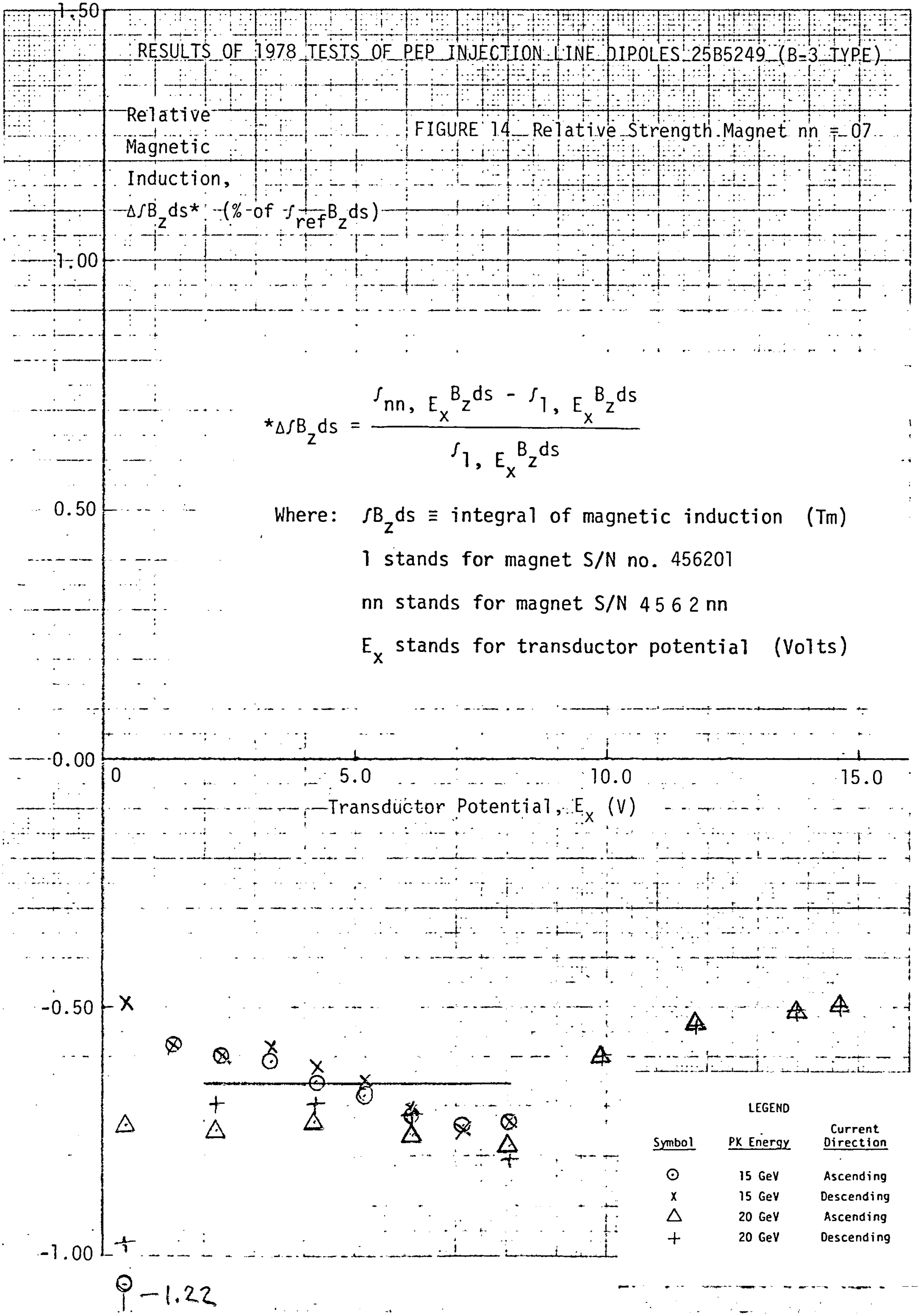
E_x stands for transductor potential (Volts)

LEGEND

Symbol	PK Energy	Current Direction
⊙	15 GeV	Ascending
x	15 GeV	Descending
△	20 GeV	Ascending
+	20 GeV	Descending

RESULTS OF 1978 TESTS OF PEP INJECTION LINE DIPOLES 25B5249 (B-3 TYPE)

FIGURE 14 Relative Strength Magnet nn = 07



$$*\Delta\int B_z ds = \frac{\int_{nn,\ E_x} B_z ds - \int_{1,\ E_x} B_z ds}{\int_{1,\ E_x} B_z ds}$$

Where: $\int B_z ds$ ≡ integral of magnetic induction (Tm)

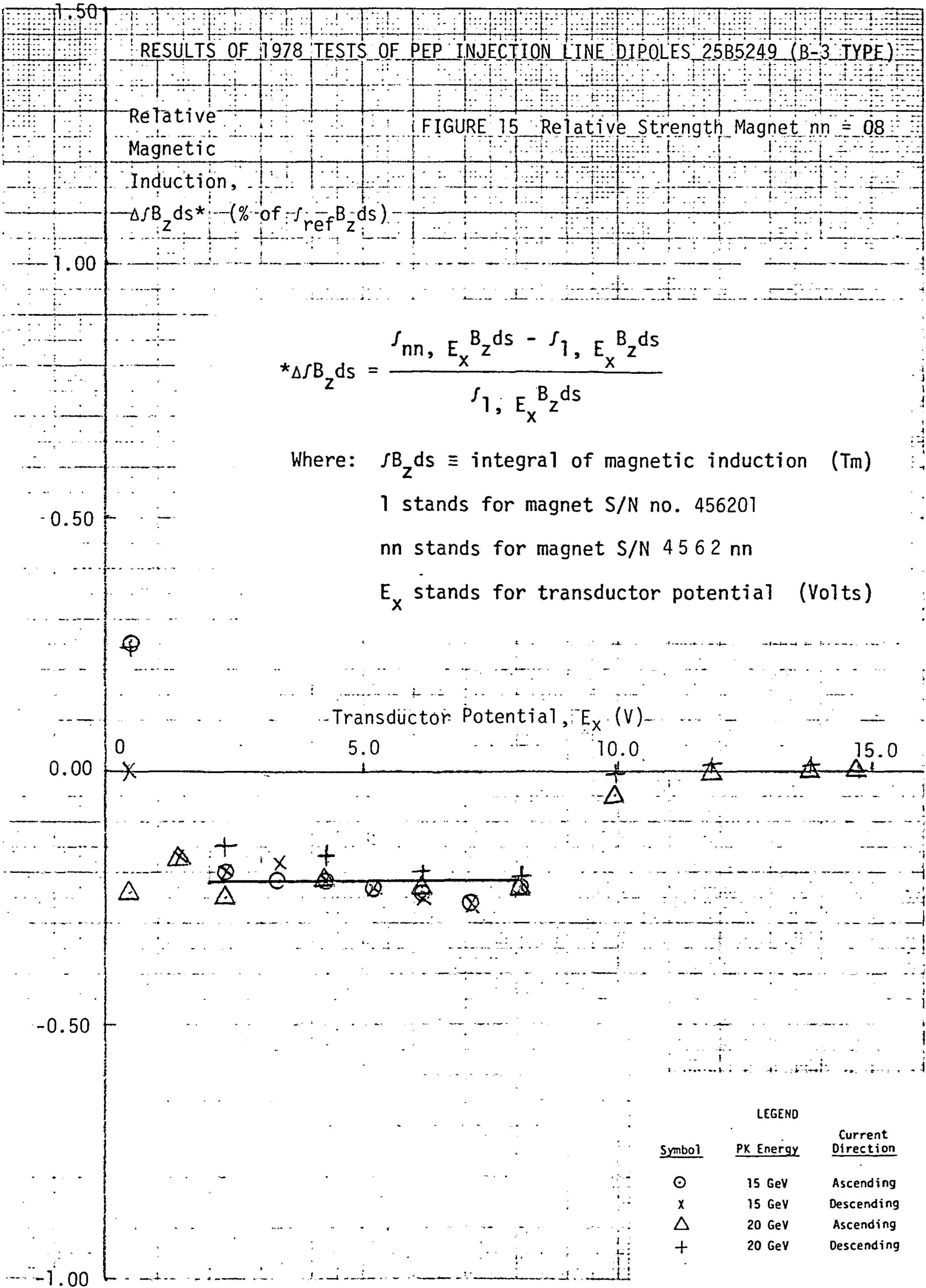
1 stands for magnet S/N no. 456201

nn stands for magnet S/N 4562nn

E_x stands for transductor potential (Volts)

LEGEND

Symbol	PK Energy	Current Direction
⊙	15 GeV	Ascending
x	15 GeV	Descending
△	20 GeV	Ascending
+	20 GeV	Descending



RESULTS OF 1978 TESTS OF PEP INJECTION LINE DIPOLES 25B5249 (B-3 TYPE)

FIGURE 15 Relative Strength Magnet nn = 08

$$*\Delta\int B_z ds = \frac{\int_{nn,\, E_x} B_z ds - \int_{1,\, E_x} B_z ds}{\int_{1,\, E_x} B_z ds}$$

Where: $\int B_z ds$ ≡ integral of magnetic induction (Tm)

1 stands for magnet S/N no. 456201

nn stands for magnet S/N 4 5 6 2 nn

E_x stands for transductor potential (Volts)

LEGEND

Symbol	PK Energy	Current Direction
⊙	15 GeV	Ascending
X	15 GeV	Descending
△	20 GeV	Ascending
+	20 GeV	Descending

RESULTS OF 1978 TESTS OF PEP INJECTION LINE DIPOLES 25B5249 (B-3 TYPE)

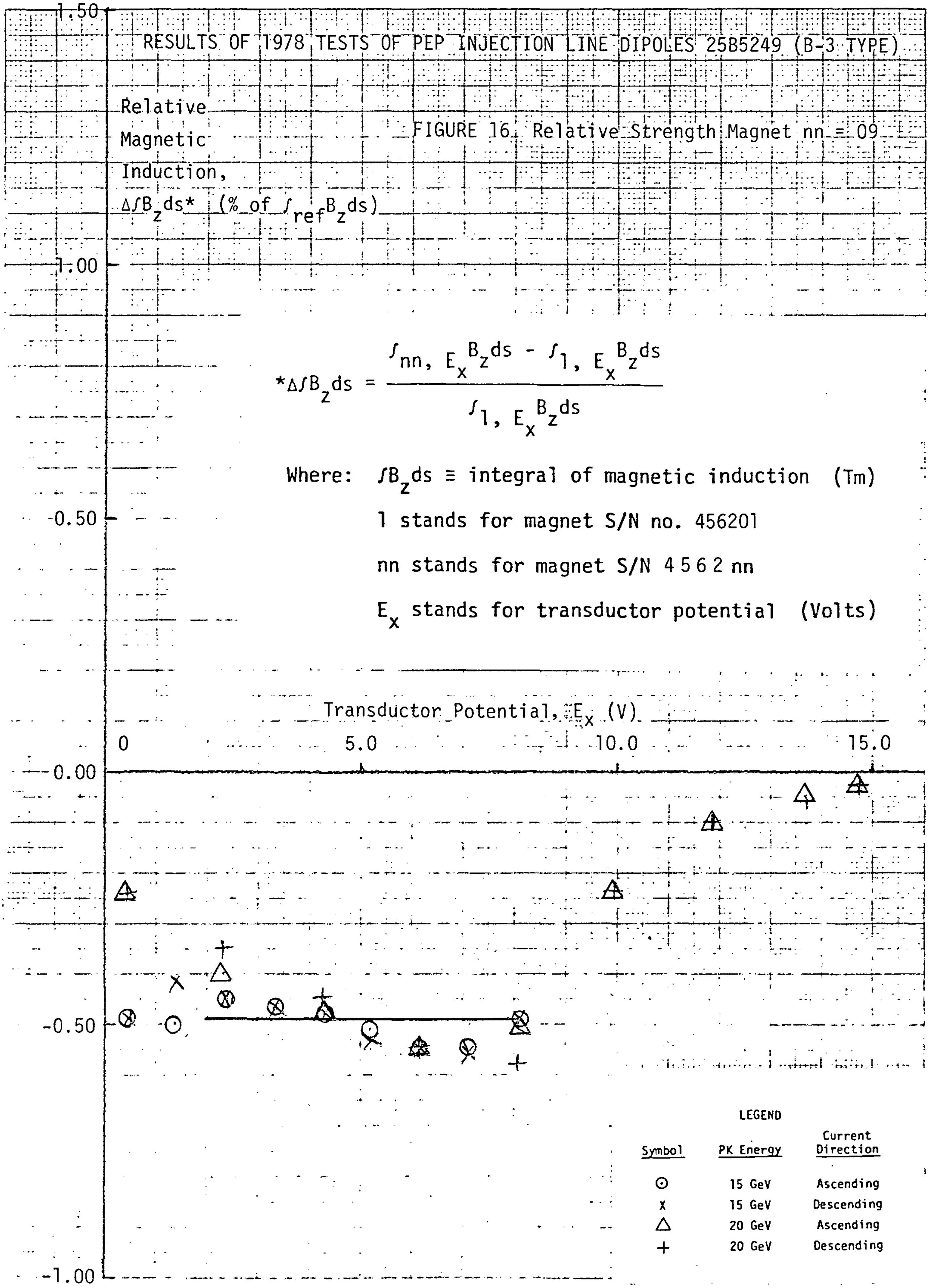


FIGURE 16 Relative Strength Magnet nn = 09

$$^*\Delta\int B_z ds = \frac{\int_{nn,\,E_x} B_z ds - \int_{1,\,E_x} B_z ds}{\int_{1,\,E_x} B_z ds}$$

Where: $\int B_z ds$ ≡ integral of magnetic induction (Tm)

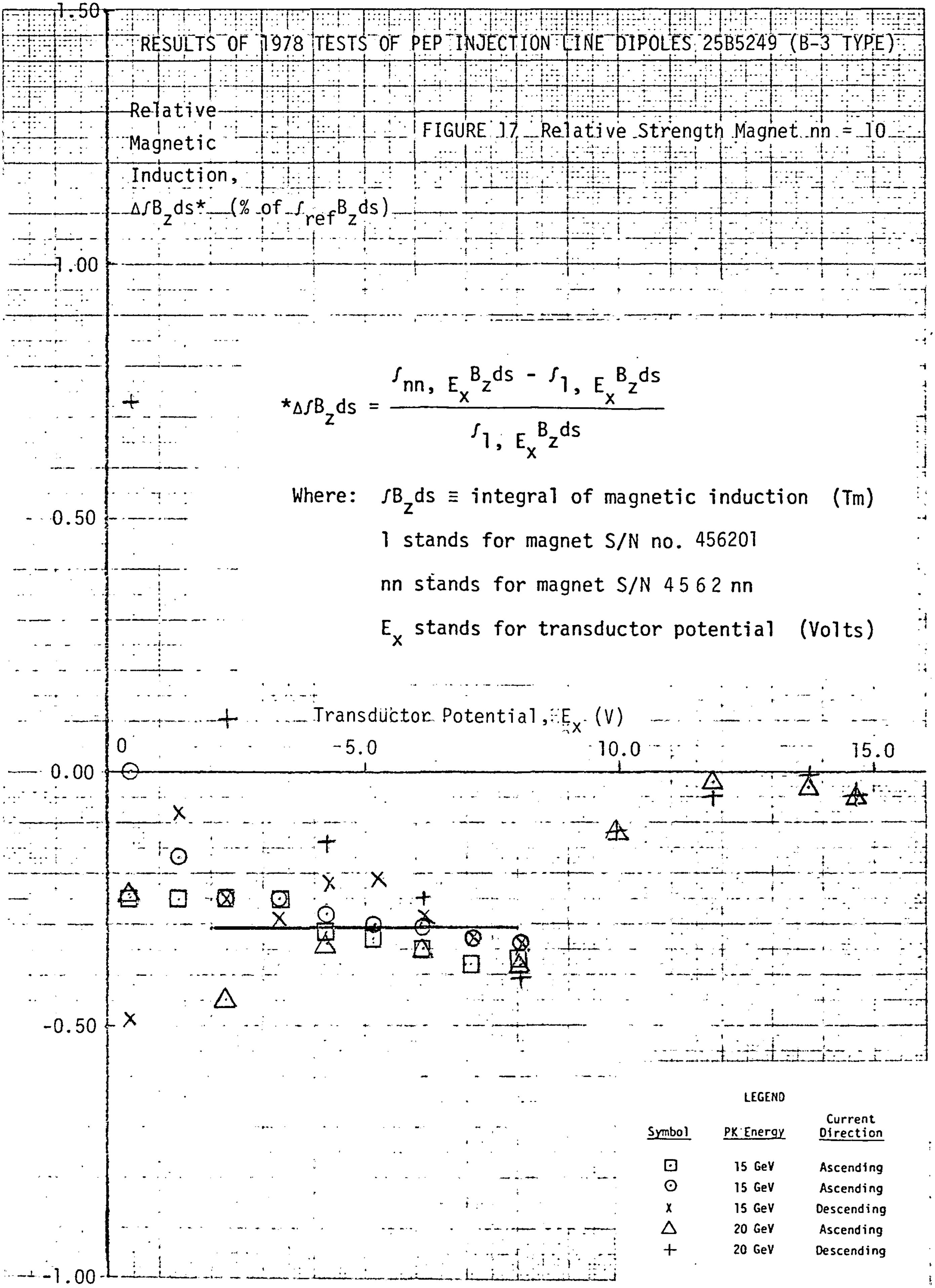
1 stands for magnet S/N no. 456201

nn stands for magnet S/N 4562 nn

E_x stands for transductor potential (Volts)

LEGEND

Symbol	PK Energy	Current Direction
⊙	15 GeV	Ascending
X	15 GeV	Descending
△	20 GeV	Ascending
+	20 GeV	Descending



RESULTS OF 1978 TESTS OF PEP INJECTION LINE DIPOLES 25B5249 (B-3 TYPE)

FIGURE 17 Relative Strength Magnet nn = 10

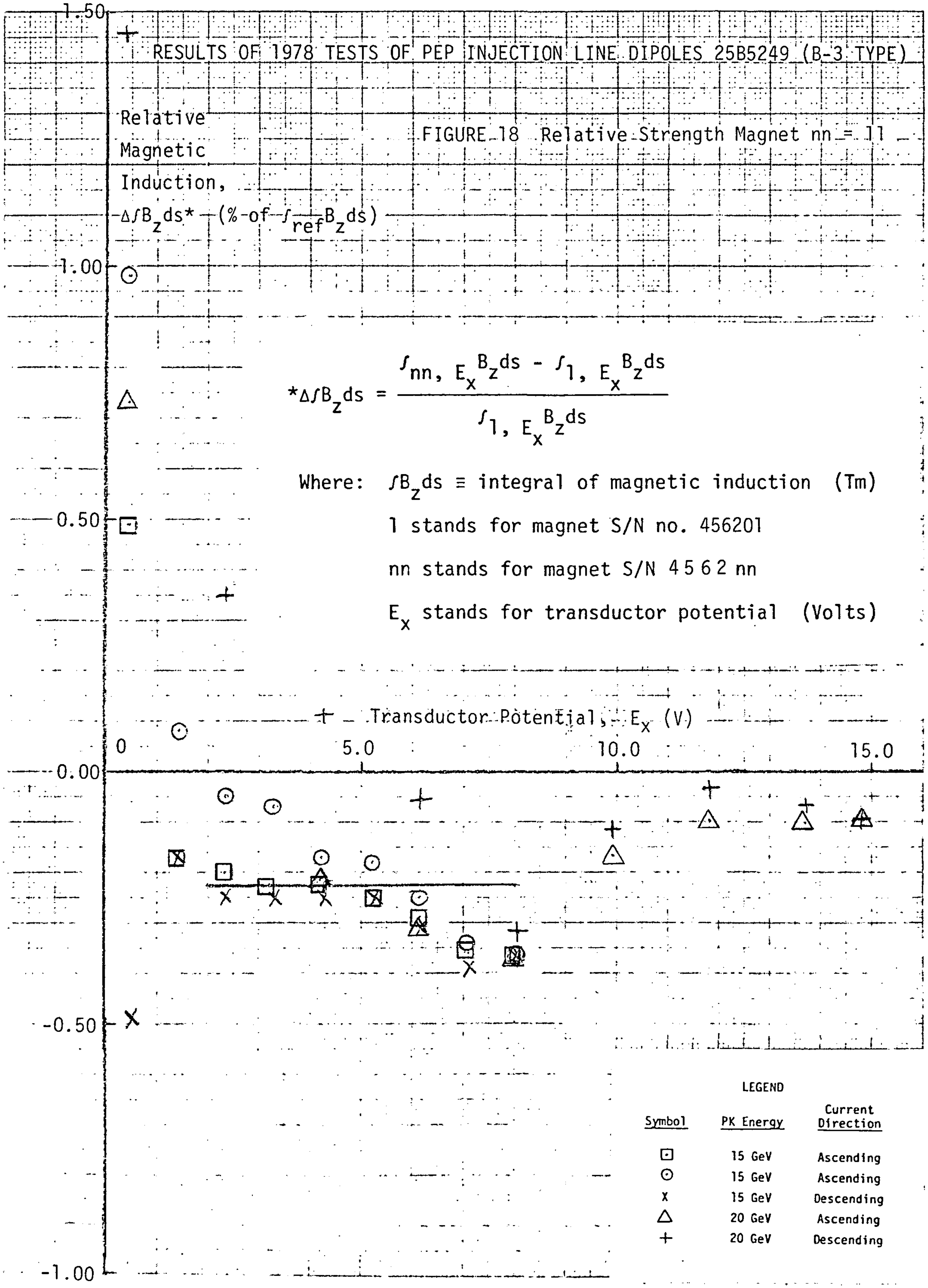
$$*\Delta\int B_z ds = \frac{\int_{nn,\,E_x} B_z ds - \int_{1,\,E_x} B_z ds}{\int_{1,\,E_x} B_z ds}$$

Where: $\int B_z ds \equiv$ integral of magnetic induction (Tm)

1 stands for magnet S/N no. 456201

nn stands for magnet S/N 4 5 6 2 nn

E_x stands for transductor potential (Volts)



RESULTS OF 1978 TESTS OF PEP INJECTION LINE DIPOLES 25B5249 (B-3 TYPE)

FIGURE 18 Relative Strength Magnet nn = 11

$$*\Delta\int B_z ds = \frac{\int_{nn,\ E_x} B_z ds - \int_{1,\ E_x} B_z ds}{\int_{1,\ E_x} B_z ds}$$

Where: $\int B_z ds \equiv$ integral of magnetic induction (Tm)

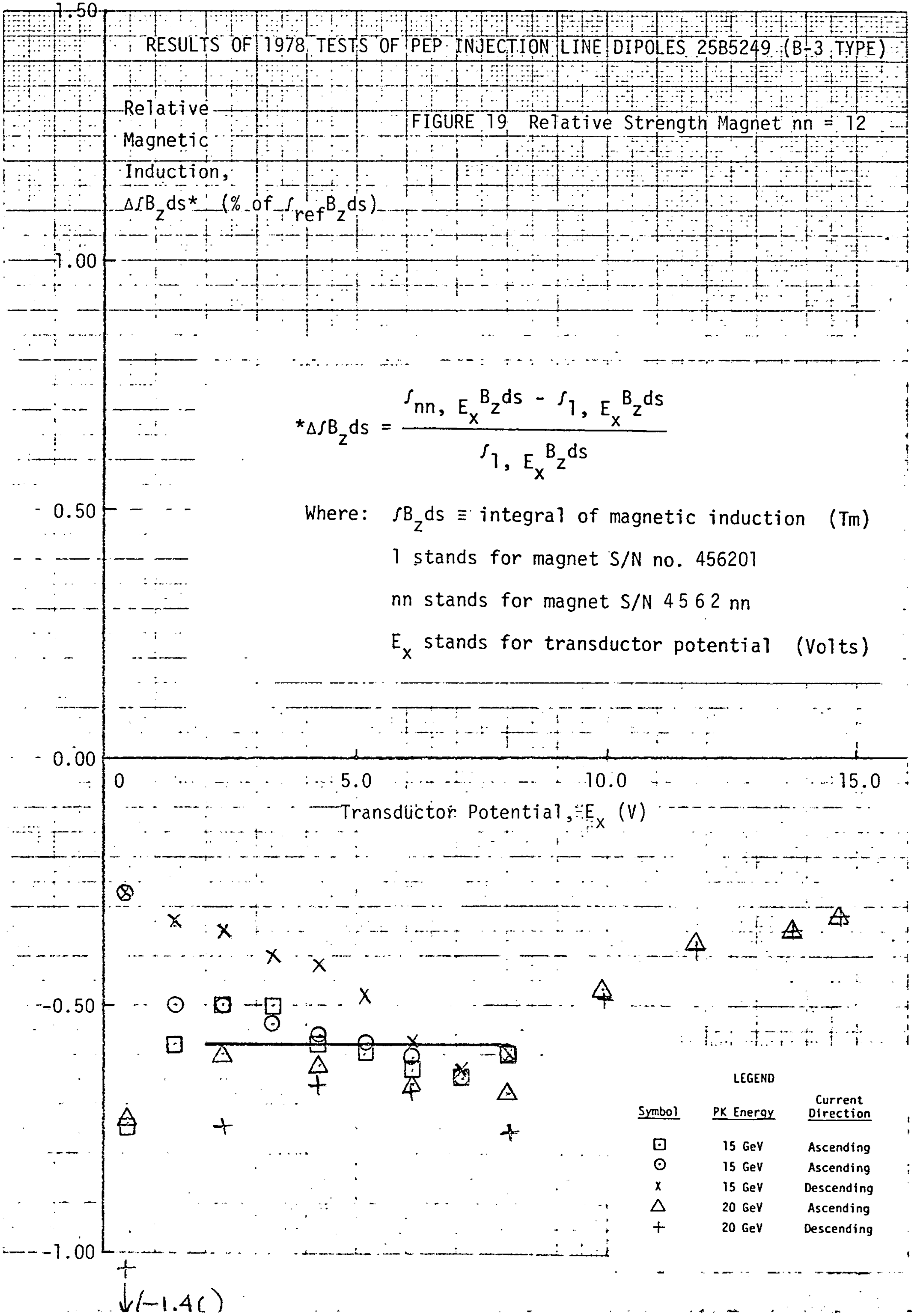
1 stands for magnet S/N no. 456201

nn stands for magnet S/N 4 5 6 2 nn

E_x stands for transductor potential (Volts)

LEGEND

Symbol	PK Energy	Current Direction
⊡	15 GeV	Ascending
⊙	15 GeV	Ascending
x	15 GeV	Descending
△	20 GeV	Ascending
+	20 GeV	Descending



RESULTS OF 1978 TESTS OF PEP INJECTION LINE DIPOLES 25B5249 (B-3 TYPE)

FIGURE 19 Relative Strength Magnet nn = 12

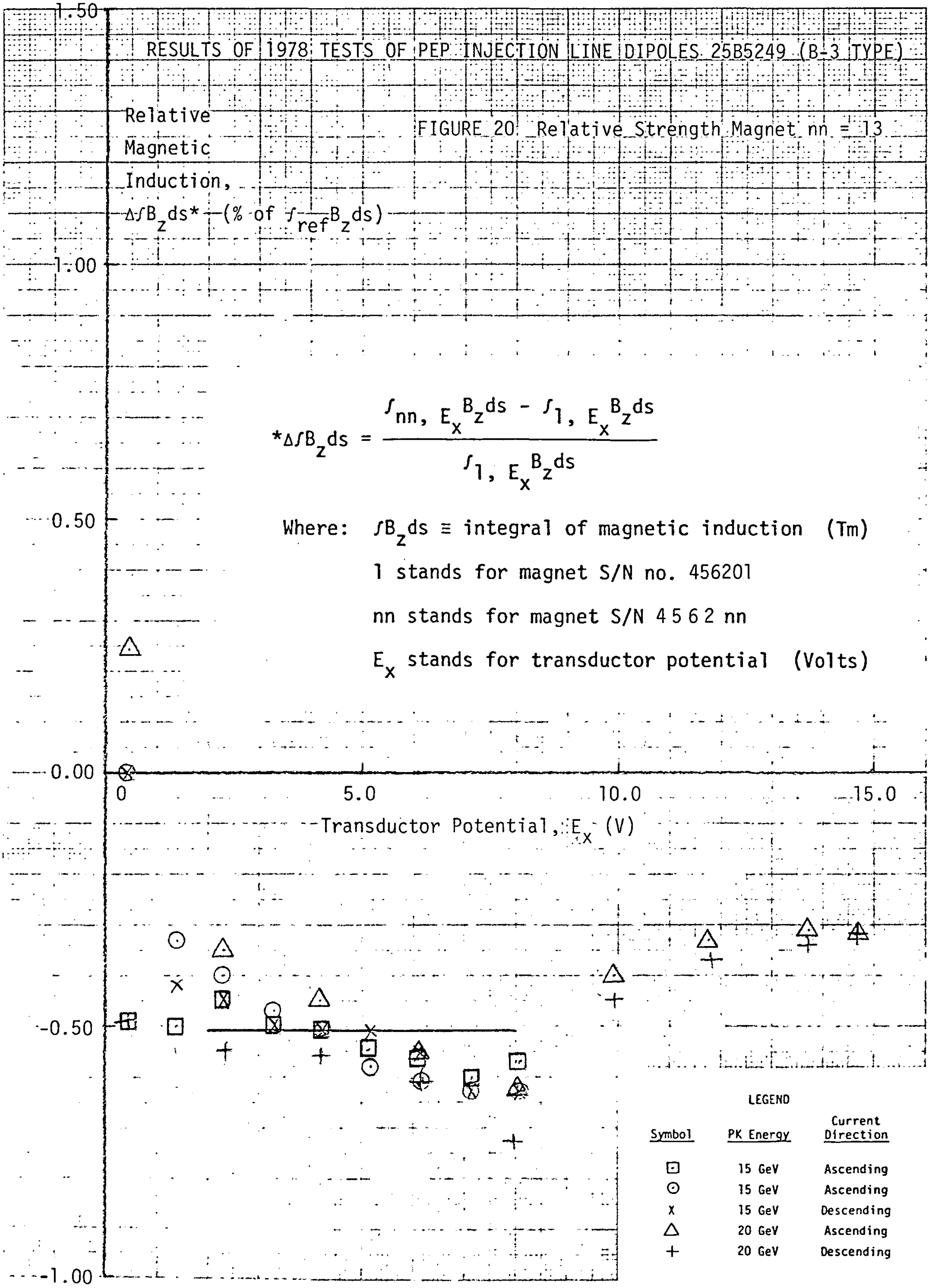
$$*\Delta\int B_z ds = \frac{\int_{nn,\ E_x} B_z ds - \int_{1,\ E_x} B_z ds}{\int_{1,\ E_x} B_z ds}$$

Where: $\int B_z ds$ ≡ integral of magnetic induction (Tm)

1 stands for magnet S/N no. 456201

nn stands for magnet S/N 4 5 6 2 nn

E_x stands for transductor potential (Volts)



RESULTS OF 1978 TESTS OF PEP INJECTION LINE DIPOLES 25B5249 (B-3 TYPE)

FIGURE 20 Relative Strength Magnet nn = 13

$$*\Delta\int B_z ds = \frac{\int_{nn,\,E_x} B_z ds - \int_{1,\,E_x} B_z ds}{\int_{1,\,E_x} B_z ds}$$

Where: $\int B_z ds$ ≡ integral of magnetic induction (Tm)

1 stands for magnet S/N no. 456201

nn stands for magnet S/N 4 5 6 2 nn

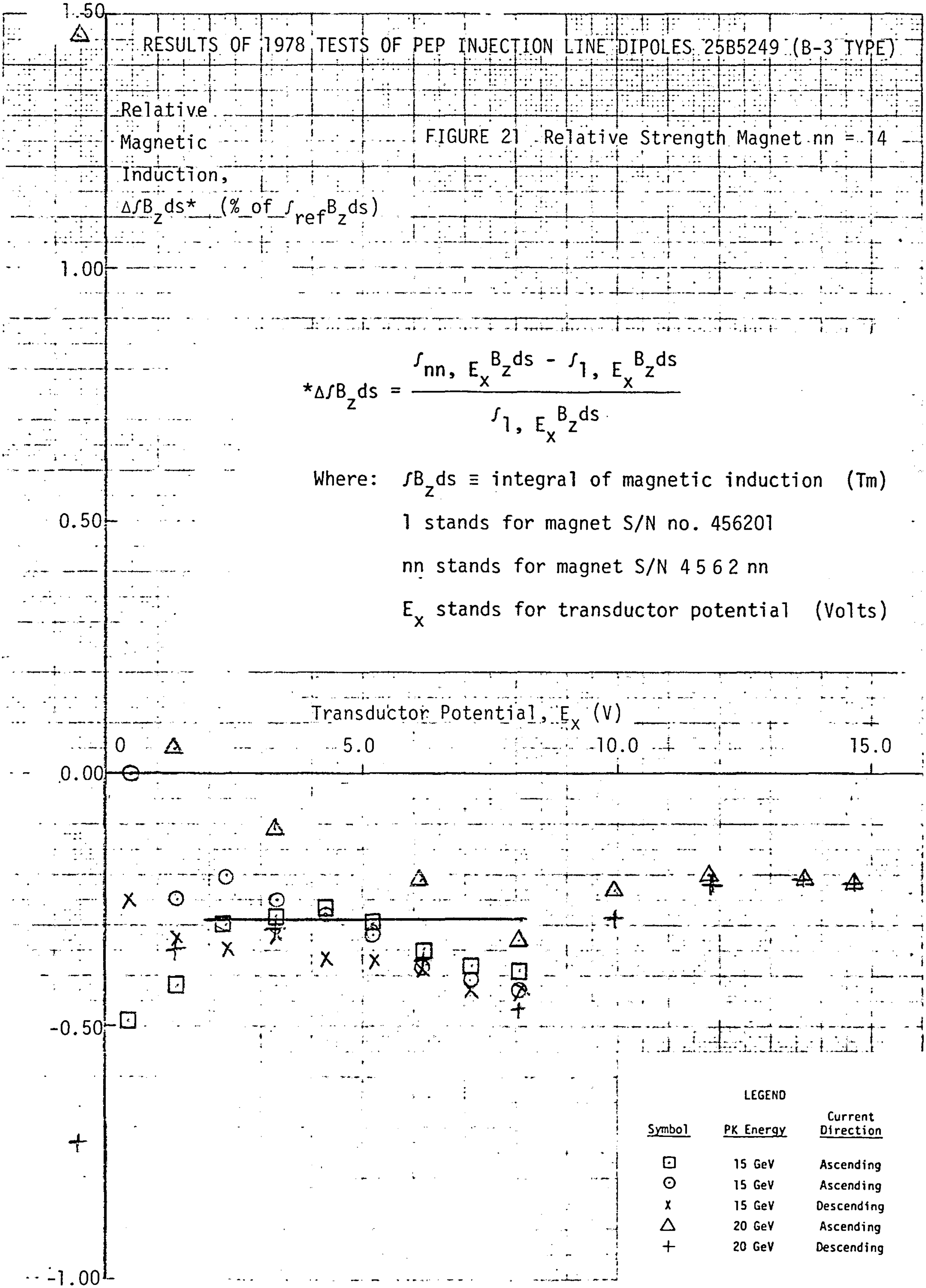
E_x stands for transductor potential (Volts)

LEGEND

Symbol	PK Energy	Current Direction
⊡	15 GeV	Ascending
⊙	15 GeV	Ascending
x	15 GeV	Descending
△	20 GeV	Ascending
+	20 GeV	Descending

RESULTS OF 1978 TESTS OF PEP INJECTION LINE DIPOLES 25B5249 (B-3 TYPE)

FIGURE 21 Relative Strength Magnet nn = 14



$$*\Delta\int B_z ds = \frac{\int_{nn,\,E_x} B_z ds - \int_{1,\,E_x} B_z ds}{\int_{1,\,E_x} B_z ds}$$

Where: $\int B_z ds \equiv$ integral of magnetic induction (Tm)

1 stands for magnet S/N no. 456201

nn stands for magnet S/N 4 5 6 2 nn

E_x stands for transductor potential (Volts)

LEGEND

Symbol	PK Energy	Current Direction
⊡	15 GeV	Ascending
⊙	15 GeV	Ascending
X	15 GeV	Descending
△	20 GeV	Ascending
+	20 GeV	Descending

Relative Strengths of Magnets (continued from page 27)

d. One reason we smoothed data for magnets S/N ≥ 10 is that one of our integral coils failed and was not repaired for measuring the last five magnets. The difference data for the last five magnets were constructed from measurements of the reference magnet and separate measurements of each subject magnet. Inspection of the data sets for the last five magnets revealed significantly more scatter in the relative strength data than in magnets 2 - 9, especially at low currents where small errors in magnitude correspond to relatively high relative errors ($0.001 * \int Bds\{E_x = E_{min}\} \approx 0.0004$ Tesla meters).

Single Turn Flux Loop Data

Single turn flux loops were installed on the periphery of the lower pole as an aid in identifying possible magnet faults (e.g., a shorted turn) without removing the magnet from the beam-line. Table X lists data collected while cycling the magnets in two minor hysteresis loops.

For the 15 GeV loop, we show the changes in flux linkage between the tips of that hysteresis loop during both ascending and descending data acquisition cycles. As expected, the differences between these two cycles are negligible.

For the 20 GeV loop, we show the change in flux linkage in traversing the 20 GeV hysteresis loop, but between currents that correspond to the tips of the 15 GeV loop. Although the currents are (nearly) identical, the flux linkage is different due to hysteresis. The change in flux-linkage for the ascending 20 GeV loop data is consistently about 0.1% greater than the corresponding change in flux linkage between the end points of the 15 GeV loop. The corresponding flux linkage changes on the descending traversal of the 20 GeV loop are consistently 1.2 - 1.3% greater than the change in flux linkage between the end points of the 15 GeV loop (and 1.1 - 1.2% greater than the ascending 20 GeV data).

Magnet S/N 4562nn, nn	15 GeV Loop		20 GeV Loop	
	Ascending	Descending	Ascending	Descending
1	0.09159	0.09160	0.0917	0.0929
2	0.0908	0.0908	0.0909	0.0921
3	0.0912	0.0912	0.0913	0.0925
4	0.0916	0.0916	0.0917	0.0929
5	0.0914	0.0914	0.0915	0.0926
6	0.0912	0.0912	0.0913	0.0924
7	0.0915	0.0915	0.0915	0.0927
8	0.0917	0.0917	0.0918	0.0930
9	0.0915	0.0917	0.0916	0.0927
10	*	*	0.0918	0.0930
11	*	*	*	*
12	*	*	0.0909	0.0921
13	0.0909	0.0909	0.0909	0.0921
14	0.0913	0.0912	0.0913	0.0925

---

*1-turn flux loop not properly connected to integrator input. Possible to measure in place; D. Nelson estimates 1 day, including travel to make the necessary measurements to complete the table (power supply limitation probably limits us to making 15 GeV measurements only).

Data Tabulated: $\frac{\Delta\phi}{\Delta E_x} \equiv \frac{\phi_{E_x\,(15\text{ GeV})} - \phi_{E_x\,(\text{min})}}{E_x\,(15\text{ GeV}) - E_x\,(\text{min})} \quad \left[\frac{\text{Wb}}{\text{Volt}}\right]$

TABLE X 1-Turn Flux Loop Data

All of these observations are consistent (qualitatively at least) with our understanding of the effects of different histories on the resultant.

Starting with magnet no. 10, our measurement procedure changed and we inadvertently omitted some 1-turn flux loop measurements. We could make measurements to complete Table X. If requested, Don Nelson estimates that he and Ed Cyr could make all the required measurements in one day, assuming they have access to the magnets and power supplies. If these additional measurements are requested, we recommend repeating measurements of magnet no. 1 for reference. If time allowed, magnets 4, 5, 7, 8 and 9 should be retested also, since the changes in flux linkage for those magnets are suspiciously similar to the changes in the reference magnet, and it is possible that we may have forgotten to make the proper connection at the time of measurement.

Analysis of the 15 GeV loop data led Nelson to the following conclusions:

1. Reproducibility of setting current with the DAC and of monitoring the associated current was $\sim\pm 0.25$ A over the course of these tests, introducing an uncertainty of $\sim\pm 0.03\%$ in the 1-turn flux loop data.
2. a. The standard deviation of $\Delta Ø/\Delta E_X$ for thirteen measurements of the reference magnet's 1-turn flux loop is $\sim 0.034\%$ of the average value reported in Table X. (The total spread in the change in flux linkage between the 15 GeV end points was 0.08% of the average value during the entire 1978 measurement period.)

   b. From the same data, the standard deviation of $\Delta Ø$ separately is 0.02% of the average of $\Delta Ø$, suggesting that the current setting hardware (DAC and power supply transductor provided by SLAC) is more reproducible than the current monitoring hardware (transductor & DVM).

DISCUSSION

Magnetic Conditioning

In April, 1978, we attempted to establish a magnetic conditioning procedure, i.e., a current cycling routine that would insure reproducibility of magnet strength ($\int Bds$) as a function of transductor potential. The questions posed were (1) Is it practical to relate magnet strength to transductor potential by repeated cycling between current limits that define a minor hysteresis loop? (2) If so, how many cycles are required to establish reproducibility within ±0.1% in the energy ranges 4 GeV $\leq$ T $\leq$ 15 GeV and 4 GeV $\leq$ T $\leq$ 20 GeV?

We first established that effective length ($\int B_Z ds/B_Z$) was relatively insensitive to conditioning procedures and hysteresis (see Figure 8 for corroboration). We then measured magnetic induction with a NMR at transductor potentials corresponding to eight energy levels in the range 4 GeV $\leq$ T $\leq$ 20 GeV. Approximately 120 measurements were made on the ascending portion of two minor hysteresis loops after having preset the magnet current to one of three levels (∿-800 A, +800 A and +1466 A).

From these measurements, we concluded that after three cycles between the extreme currents of either minor hysteresis loop, magnetic quantities can be reproduced at all currents (to less than 0.1% of the 15 GeV values).

Systematic Error Source (Due To Few Conditioning Cycles)

Although that conclusion is correct and can be applied to magnet strengths on either the ascending or descending portions of the two minor hysteresis loops, the improper application of this information may have introduced a systematic error of a few tenths of one percent at the lowest magnet strengths of interest.

A mechanism for a systematic error in the magnetization data follows.

1. The establishment of an exactly reproducible minor hysteresis loop requires an infinite number of cycles.
2. Based on the data we examined, magnetic induction in three cycles approaches asymptotically the "final" values and is within 0.1% of these "final" values.
3. We first measured magnet quantities at the upper energy during one current cycle (say cycle #4). Several cycles later, we measured the differences in magnetic quantities (strengths) between the upper energy and selected current levels on the descending portion of the next three cycles, e.g., 7, 8, and 9. Next, we measured the differences in magnetic quantities at the same selected current levels on the ascending portion of the next three cycles, e.g., 10, 11 and 12.
4. After routine processing, the difference values were added to the upper energy values to produce magnetic quantities for each of the lower energies.
5. We believe that between the 4th and 12th cycles, the magnetic quantities at the 15 GeV level decreased a maximum of about 0.05%. The error introduced in the 4 GeV final value is 0.05% 15/4 $\approx$ 0.2% of the 4 GeV value.
6. In addition, because we were not aware of this systematic error, we were not consistent and did not bother to record the complete history of measurements.
7. The low current of both minor hysteresis loops corresponds to $\sim$1 GeV; so the corresponding error introduced by this mechanism is $\sim$0.9%. Although 1 GeV is out of the operating range, variations in the reported magnetic quantities corresponding to the lowest magnet current have raised questions on the quality of the data.[17]

20/20 Hindsight

If we had the opportunity to rewrite the test plan for testing the B-3 type dipoles, knowing what we know now, we would consider the following:

1. It would have been helpful and increased our confidence in the reported accuracy to have had direct measurements of B and $\int Bds$ at the lower point on the two minor hysteresis loops (i.e., in/out data at E_{min} as well as at E_{max}).
2. We took a great risk in waiting until the end of the measurement program to determine the sensitivity of the integral coil, L-45. An absolute calibration should have been done early in the program and repeated periodically.
3. It may have been false economy to have used the computer mapper as a data logger for this project. Although there was pressure during the planning stages to minimize investments in hardware and software, it probably would have been cost effective to have immediate data processing capabilities in the field.
4. The conditioning of magnets to produce a standard minor loop following a higher excitation is slowed by a low current-setting rate, e.g., 10 A/sec. Differences per cycle were small and nearly undetectable, but cumulative changes after many cycles were apparently the cause of most of the uncertainty in final values of $\int Bds$. This problem was only identified during post measurement data analysis.
5. The effective length plot (Figure 8 on page 25) is a sensitive indicator of internal consistency in our measurements of B and $\int Bds$. Examination of either the 15 GeV or 20 GeV data above 4 GeV suggests reproducibility better than 0.1% in both B and $\int Bds$. It is not clear why the two curves differ by as much as 0.25% at the low end.

ACKNOWLEDGEMENTS

We wish to acknowledge the valuable consultations of Charles Dols and Bob Main throughout this project. Charles retired in October, 1981, but we plan to continue to rely on his expert advice. We thank Michael I. Green for his critique of this note.

REFERENCES

1. R. Reimers, A. Lake, "PEP Transport Bend Magnet 25B5249, Description of", LBL Engineering Note M5017, Dec. 8, 1976.
2. A. Lake, R. Avery, "Coils for PEP Injection Bend Magnet 25B5249", LBL Specification M486, Dec. 30, 1976.
3. R. Reimers, "Aluminum Conductors for PEP Magnet 25B5249", LBL Specification M487, Jan. 13, 1977.
4. A. Lake, R. Avery, "Assembly of PEP Injection Bend Magnet 25B5249", LBL Specification M488, Sect. 5.4, March 1, 1977.
5. A. Lake, R. Avery, "Cores for PEP Injection Bend Magnet 25B5249", LBL Specification M489.
6. D. Morris, "25B5249 Magnet Assembly", LBL Mech. Engr. Drwg. No. 17M3726, Dec. 17, 1976.
7. D. Nelson, "PEP Transport Bend Magnets, 25B5249; Magnetic Measurements Test Plan", LBL Magnetic Measurements Engineering Note MT 264 A, Revised Feb. 3, 1978.
8. D. Nelson, Memorandum - Revision of Test Plan for Magnetic Measurements of PEP Transport Bend Magnets Designated 25B5249, Feb. 3, 1978.
9. D. Nelson, "PEP Transport Bend Magnet 25B5249", LBL Magnetic Measurements Engineering Data Book No. 579D, LAB Log Book, 1978.
10. G. Fischer, R. Helm, M. Lee, PEP Technical Memo PTM-138 - Proposal for Bend Magnet Excitation Measurement, Feb. 14, 1978.
11. C.G. Dols, "A Computer-Controlled, 3-D, Magnetic Field Mapping System", Proceedings of the Fourth International Conference on Magnet Technology, BNL, Upton, N.Y. LBL Report - LBL-1311, September, 1972.
12. D.H. Nelson, "PEP Transport Bend Magnets 25B5249 Preliminary Test Results", LBL Electronics Engineering Note MT 274, Jan. 29, 1981.

13. D.H. Nelson, Memorandum to Jack Truher with attachments - corrections and adjustments (to difference data), February 14, 1980.

14. D.H. Nelson, Memorandum to Jack Truher, "An Improved Data Set for Reference Magnet", August 20, 1981.

15. J. Truher, Memorandum to J.M. Peterson, Subject: NIT/SIT INUSE REF 1000 Amp Transductors; Tracking Comparison, November 2, 1979.

16. J. Truher, Memorandum to Wes Ascher, et al., Subject: NIT/SIT Bend Ampere Readouts, March 26, 1981.

17. J. Truher, Private Communications, 1979, 1980.

18. D.H. Nelson, LBL Magnetic Measurements Engineering Data Books 579 A, B, C, D, E, L1, L2, L3 PEP Transport and Magnet 25B5249 - Various Subtitles. (Also 579 F, G&H).

Distribution

R.T. Avery
R. Bell (SLAC)
K. Brown (SLAC)
J. Cobb (SLAC)
C.G. Dols
T. Elioff
M.I. Green
K. Halbach
E.C. Hartwig/L.J. Wagner/W.H. Deuser
R.M. Main
J. Rees (SLAC)
R.M. Reimers
J. Truher (SLAC)
Electronics Engineering Master File
Magnetic Measurements Engineering (4)
Authors

This work was supported by the U.S. Dept. of Energy under Contract DE-AC03-76SF00098.

Figure Number	Page	Title
1	9	Transductor Potential Versus Elapsed Time (20 GeV Data Acquisition Cycles)
2	10	Transductor Potential Versus Elapsed Time (15 GeV Data Acquisition Cycles)
3	12	Schematic Drawing of Test Equipment
4	20	Reference Magnet Point Magnetization Plot 20 GeV
5	21	Reference Magnet Point Magnetization Plot 15 GeV
6	22	Reference Magnet Integral Magnetization Plot 20 GeV
7	23	Reference Magnet Integral Magnetization Plot 15 GeV
8	25	Reference Magnet Effective Length 20 GeV and 15 GeV
9 – 21	28 - 40	Subject Magnet Relative Strength Plots

TABLE XI Index to Figures

Table Number	Page	
I	1	Table of Contents
II	3	Glossary
III	4	Magnet Beam Line Assignments
IV	6	Schedule of Measurements
V	13	Test Equipment
VI - IX	16 - 19	Reference Magnet Parameters - Four Magnetic Conditions
X	42	1-Turn Flux-Loop Flux Linkage Data
Appendix A	A1 - A13	Relative Strength ($\Delta\int Bds$ versus E_x) for the Thirteen "Subject" Magnets (S/N 456202 - 456214)
XI	48	Index to Figures
XII	49	Index to Tables

TABLE XII Index to Tables

LBID-515

LAWRENCE BERKELEY LABORATORY - UNIVERSITY OF CALIFORNIA **ENGINEERING NOTE**	Appendix A	FILE NO. MT 301	PAGE A1 of A15
SUBJECT PEP Injection Line Dipoles (B-3 Type) Relative Strength ($\Delta\int B_z ds$) Tabulations		NAME Donald H. Nelson DATE November 20, 1981	

The tables in Appendix A of MT 301 were prepared in July, 1981. The data were extracted from summary listings of the data processing program BCOMA00 which were produced on January 24, 1980, MME Book No. 579-L.

The $\Delta\int Bds$ data from the listings have been rounded to 10^{-3} Tesla meters, 0.05% of the lowest value of $\int B_z ds$ of interest. The values of E_x are approximate as $\Delta\int Bds$ is not strongly dependent on E_x. Similarly, the 13 set averages of the 15 GeV ascending or the 20 GeV ascending data sets were used for computing the % variation with respect to the reference magnet (S/N 456201) for both the ascending and descending relative data. Those 13 set averages are saved in MME Book No. 579-G.

Because most of the signs of $\Delta\int Bds$ were negative, I defined $-\Delta$ (the quantity plotted) and tabulated Δ. The reference magnet is stronger than the other 13 magnets and - signs in the tables are due to imperfections in the data.

The next 13 pages (1 per magnet) represent 4 data sets for each magnet. The columns are upper energy (minor hysteresis loop designation); E_x, (nominal) transductor potential, {volts}; and two columns each for ascending and descending values of $\Delta\int Bds$. The first column is in Tesla-meters. The second column is in % of $\int Bds$ of the reference magnet (S/N 456201). The 15 and 20 GeV data sets are interspersed.

The final page of Appendix A is an alternate representation of the ascending 15 GeV data set for magnets S/N 456210 — S/N 456214. It is included because 1) it differs slightly from the corresponding data described above, and 2) it corresponds to the data delivered to Jack Truher on February 14, 1980. The differences (∿0.05%) are due to some smoothing operation performed on the earlier delivered data.

MAGNET NO. 2

DATE 01-July

$-\Delta = 1 - N = \mathrm{Ref} - N$

		Current Descending		Current Ascending	
UPPER ENERGY [GeV]	E_x [V]	$\Delta\int B\,ds$ [Tm]	$\frac{100\,\Delta\int B\,ds}{\int B\,ds_{\mathrm{ref}}}$ [%]	$\Delta\int B\,ds$ [Tm]	$\frac{100\,\Delta\int B\,ds}{\int B\,ds_{\mathrm{ref}}}$ [%]
20	14.67	.015	.17	.015	.17
"	13.72	.016	.19	.015	.17
"	11.83	.019	.23	.019	.23
"	9.94	.027	.36	.027	.36
15	8.04	.042	.65	.042	.65
20	8.04	.041	.62	.040	.61
15	7.09	.042	.72	.042	.72
15	6.15	.036	.71	.037	.72
20	6.15	.033	.64	.034	.66
15	5.20	.029	.67	.031	.71
15	4.25	.023	.65	.025	.70
20	4.25	.022	.62	.022	.62
15	3.30	.018	.65	.019	.69
15	2.35	.012	.60	.014	.70
20	2.35	.011	.55	.012	.60
15	1.41	.007	.58	.008	.67
15	0.46	.002	.49	.003	.74
20	0.46	.002	.49	.003	.73

MAGNET NO. 3

$-\Delta = 1 - N = Ref - N$

UPPER ENERGY [GeV]	E_x [V]	Current Descending $\Delta\int B\,ds$ [Tm]	Current Descending $\frac{100\,\Delta\int B\,ds}{\int B\,ds_{ref}}$ [%]	Current Ascending $\Delta\int B\,ds$ [Tm]	Current Ascending $\frac{100\,\Delta\int B\,ds}{\int B\,ds_{ref}}$ [%]
20	14.67	.005	.06	.005	.06
"	13.72	.006	.07	.006	.07
"	11.83	.008	.10	.008	.10
"	9.94	.014	.19	.014	.19
15	8.04	.024	.37	.024	.37
20	8.04	.026	.40	.025	.38
15	7.09	.023	.39	.023	.39
15	6.15	.017	.33	.019	.37
20	6.15	.017	.33	.019	.37
15	5.20	.013	.30	.015	.35
15	4.25	.010	.28	.012	.34
20	4.25	.010	.28	.011	.31
15	3.30	.007	.25	.009	.32
15	2.35	.004	.20	.007	.35
20	2.35	.004	.20	.006	.30
15	1.41	.002	.17	.004	.33
15	0.46	.000	0	.000	0
20	0.46	.000	0	.001	.24

MAGNET NO. 4

$-\Delta = 1 - N = \text{Ref} - N$

UPPER ENERGY [GeV]	E_x [V]	Current Descending $\Delta \int B\,ds$ [Tm]	Current Descending $\frac{100\,\Delta \int B\,ds}{\int B\,ds_{ref}}$ [%]	Current Ascending $\Delta \int B\,ds$ [Tm]	Current Ascending $\frac{100\,\Delta \int B\,ds}{\int B\,ds_{ref}}$ [%]
20	14.67	-.002	-.02	-.002	-.02
"	13.72	.000	.00	-.001	-.01
"	11.83	.002	.02	.002	.02
"	9.94	.008	.11	.009	.12
15	8.04	.020	.31	.020	.31
20	8.04	.022	.33	.020	.30
15	7.09	.021	.31	.020	.34
15	6.15	.017	.33	.017	.33
20	6.15	.015	.29	.016	.31
15	5.20	.012	.28	.014	.32
15	4.25	.009	.25	.011	.31
20	4.25	.008	.22	.009	.25
15	3.30	.007	.25	.008	.29
15	2.35	.005	.25	.006	.30
20	2.35	.004	.20	.004	.20
15	1.41	.002	.17	.003	.25
15	0.46	.001	.25	.001	.25
20	0.46	.000	.00	-.001	-.24

MAGNET NO. 5

$-\Delta = 1 - N = \text{Ref} - N$

UPPER ENERGY [GeV]	E_x [V]	Current Descending $\Delta\int B\,ds$ [Tm]	Current Descending $\frac{100\,\Delta\int B\,ds}{\int B\,ds_{ref}}$ [%]	Current Ascending $\Delta\int B\,ds$ [Tm]	Current Ascending $\frac{100\,\Delta\int B\,ds}{\int B\,ds_{ref}}$ [%]
20	14.67	.003	.07	.003	.07
"	13.72	.003	.03	.004	.05
"	11.83	.003	.04	.006	.07
"	9.94	.003	.04	.012	.16
15	8.04	.024	.37	.024	.37
20	8.04	.004	.06	.025	.38
15	7.09	.024	.41	.024	.41
15	6.15	.020	.39	.020	.39
20	6.15	.002	.04	.021	.41
15	5.20	.016	.37	.017	.39
15	4.25	.012	.34	.013	.37
20	4.25	.000	.00	.014	.39
15	3.30	.008	.29	.010	.36
15	2.35	.006	.30	.007	.35
20	2.35	-.002	-.10	.008	.40
15	1.41	.003	.25	.004	.33
15	0.46	.001	.25	.001	.25
20	0.46	-.003	-.73	.003	.73

-Δ= 1-N =Ref-N

UPPER ENERGY [GeV]	E_x [V]	Current Descending $\Delta\int B ds$ [T m]	Current Descending $\frac{100\Delta\int B ds}{\int B ds_{ref}}$ [%]	Current Ascending $\Delta\int B ds$ [T m]	Current Ascending $\frac{100\Delta\int B ds}{\int B ds_{ref}}$ [%]
20	14.67	.014	.16	.014	.16
"	13.72	.015	.17	.015	.17
"	11.83	.020	.25	.020	.25
"	9.99	.031	.41	.032	.43
15	8.09	.055	.85	.055	.85
20	8.09	.059	.90	.055	.84
15	7.09	.053	.91	.052	.89
15	6.15	.042	.82	.045	.88
20	6.15	.041	.80	.043	.84
15	5.20	.032	.79	.036	.83
15	4.25	.025	.70	.028	.79
20	4.25	.025	.70	.026	.73
15	3.30	.018	.65	.021	.76
15	2.35	.012	.60	.014	.70
20	2.35	.012	.60	.013	.65
15	1.41	.006	.50	.008	.67
15	0.46	.001	.25	.001	.25
20	0.46	.001	.29	.002	.49

. MAGNET NO. 7 DATE 8/dx/

$\Delta = 1 - N = \text{Ref} - N$

UPPER ENERGY [GeV]	E_x [V]	Current Descending $\Delta\int B ds$ [Tm]	 $\frac{100\Delta\int B ds}{\int B ds_{ref}}$ [%]	Current Ascending $\Delta\int B ds$ [Tm]	 $\frac{100\Delta\int B ds}{\int B ds_{ref}}$ [%]
20	14.67	.044	.50	.044	.50
"	13.72	.044	.51	.044	.51
"	11.83	.044	.54	.043	.53
"	9.94	.045	.60	.045	.60
15	8.04	.047	.73	.047	.73
20	8.04	.053	.81	.051	.78
15	7.09	.044	.75	.043	.74
15	6.15	.036	.71	.037	.72
20	6.15	.037	.72	.039	.76
15	5.20	.028	.65	.029	.67
15	4.25	.022	.62	.023	.65
20	4.25	.025	.70	.026	.73
15	3.30	.016	.58	.017	.61
15	2.35	.012	.60	.012	.60
20	2.35	.014	.70	.015	.75
15	1.41	.007	.58	.007	.58
15	0.46	.002	.49	.003	.74
20	0.46	.004	.98	.005	1.22

MAGNET NO. 8

DATE [illegible]

$-\Delta = 1 - N = \text{Ref} - N$

		Current Descending		Current Ascending	
UPPER ENERGY [GeV]	E_x [V]	$\Delta \int B\,ds$ [Tm]	$\frac{100\,\Delta \int B\,ds}{\int B\,ds_{\text{ref}}}$ [%]	$\Delta \int B\,ds$ [Tm]	$\frac{100\,\Delta \int B\,ds}{\int B\,ds_{\text{ref}}}$ [%]
20	14.67	.000	.00	.000	.00
"	13.72	−.001	−.01	.000	.00
"	11.83	−.001	−.01	.000	.00
"	9.94	.001	.01	.004	.05
15	8.04	.015	.23	.015	.23
20	8.04	.014	.21	.015	.23
15	7.09	.015	.26	.015	.26
15	6.15	.013	.25	.012	.24
20	6.15	.010	.20	.012	.23
15	5.20	.010	.23	.010	.23
15	4.25	.008	.22	.008	.22
20	4.25	.006	.17	.008	.22
15	3.30	.005	.18	.006	.22
15	2.35	.004	.20	.004	.20
20	2.35	.003	.15	.005	.25
15	1.41	.002	.17	.002	.17
15	0.46	.000	0.00	−.001	−.25
20	0.46	−.001	−.24	.001	.24

MAGNET NO. 9

$-\Delta = 1 - N = \text{Ref} - N$

		Current Descending		Current Ascending	
UPPER ENERGY [GeV]	E_x [V]	$\Delta\int B\,ds$ [Tm]	$\frac{100\,\Delta\int B\,ds}{\int B\,ds_{ref}}$ [%]	$\Delta\int B\,ds$ [Tm]	$\frac{100\,\Delta\int B\,ds}{\int B\,ds_{ref}}$ [%]
20	14.67	.003	.03	.003	.03
"	13.72	.005	.06	.004	.05
"	11.83	.009	.11	.008	.10
"	9.94	.018	.24	.018	.24
15	8.04	.032	.49	.032	.49
20	8.04	.038	.58	.033	.50
15	7.09	.033	.56	.032	.55
15	6.15	.028	.55	.028	.55
20	6.15	.028	.55	.028	.55
15	5.20	.023	.53	.022	.51
15	4.25	.017	.48	.017	.48
20	4.25	.016	.45	.017	.48
15	3.30	.013	.47	.013	.47
15	2.35	.009	.45	.009	.45
20	2.35	.007	.35	.008	.40
15	1.41	.005	.42	.006	.50
15	0.46	.002	.49	.002	.49
20	0.46	.001	.24	.001	.24

MAGNET NO. 10

DATE

$-\Delta = 1 - N = \text{Ref} - N$

UPPER ENERGY [GeV]	E_x [V]	Current Descending $\Delta\int B\,ds$ [Tm]	$\frac{100\,\Delta\int B\,ds}{\int B\,ds_{ref}}$ [%]	Current Ascending $\Delta\int B\,ds$ [Tm]	$\frac{100\,\Delta\int B\,ds}{\int B\,ds_{ref}}$ [%]
20	14.67	.004	.05	.004	.05
"	13.72	.001	.01	.003	.03
"	11.83	.004	.05	.002	.02
"	9.94	.009	.12	.009	.12
15	8.04	.023	.35	.023	.35
20	8.04	.027	.41	.025	.38
15	7.09	.019	.32	.019	.32
15	6.15	.015	.29	.016	.31
20	6.15	.013	.25	.018	.35
15	5.20	.009	.21	.013	.30
15	4.25	.008	.22	.010	.28
20	4.25	.005	.14	.012	.34
15	3.30	.008	.29	.007	.25
15	2.35	.005	.25	.005	.25
20	2.35	−.002	−.10	.009	.45
15	1.41	.001	.08	.002	.17
15	0.46	−.002	.49	.000	.00
20	0.46	−.003	−.73	.001	.29

MAGNET NO. 11

DATE 21 July

$-\Delta = 1 - N = \text{Ref} - N$

		Current Descending		Current Ascending	
UPPER ENERGY [GeV]	E_x [V]	$\Delta\int B\,ds$ [Tm]	$\frac{100\,\Delta\int B\,ds}{\int B\,ds_{ref}}$ [%]	$\Delta\int B\,ds$ [Tm]	$\frac{100\,\Delta\int B\,ds}{\int B\,ds_{ref}}$ [%]
20	14.67	.009	.10	.009	.10
"	13.72	.006	.07	.009	.10
"	11.83	.003	.04	.008	.10
"	9.94	.009	.12	.013	.17
15	8.04	.024	.37	.024	.37
20	8.04	.021	.32	.025	.38
15	7.09	.023	.39	.020	.34
15	6.15	.016	.31	.013	.25
20	6.15	.003	.06	.016	.31
15	5.20	.011	.25	.008	.18
15	4.25	.009	.25	.006	.17
20	4.25	−.004	−.11	.008	.22
15	3.30	.007	.25	.002	.07
15	2.35	.005	.25	.001	.05
20	2.35	−.007	−.35	.003	.15
15	1.41	.002	.17	−.001	−.08
15	0.46	.002	.49	−.004	.98
20	0.46	−.006	−1.46	−.003	−.73

MAGNET NO. 12

$-\Delta = 1 - N = \text{Ref} - N$

[illegible] ENERGY [GeV]	E_x	Current Descending $\Delta\int B\,ds$ [Tm]	$100\,\Delta\int B\,ds / \int B\,ds_{\text{ref}}$ [%]	Current Ascending $\Delta\int B\,ds$ [Tm]	$100\,\Delta\int B\,ds / \int B\,ds_{\text{ref}}$ [%]
20	14.67	.028	.32	.028	.32
〃	13.72	.030	.35	.030	.35
〃	11.83	.032	.39	.031	.38
〃	9.94	.037	.49	.035	.47
15	8.04	.039	.60	.039	.60
20	8.04	.050	.76	.045	.68
15	7.09	.037 ~~.035~~	.63	.038	.65
15	6.15	.029	.57	.031	.61
20	6.15	.035	.68	.034	.66
15	5.20	.021	.48	.025	.58
15	4.25	.015	.42	.020	.57
20	4.25	.024	.67	.022	.62
15	3.30	.011	.40	.015	.54
15	2.35	.007	.35	.010	.50
20	2.35	.015	.75	.012	.60
15	1.41	.004	.33	.006	.50
15	0.46	.001	.27	.001	.27
20	0.46	.006	1.41	.003	.73

MAGNET NO. 13 DATE 6 July

$\Delta = I - N = \mathrm{Ref} - N$

		Current Descending		Current Ascending	
UPPER ENERGY [GeV]	E_v [V]	$\Delta\int B\,ds$ [Tm]	$\frac{100\,\Delta\int B\,ds}{\int B\,ds_{ref}}$ [%]	$\Delta\int B\,ds$ [Tm]	$\frac{100\,\Delta\int B\,ds}{\int B\,ds_{ref}}$ [%]
20	14.67	.028	.32	.028	.32
"	13.72	.029	.34	.027	.31
"	11.83	.030	.37	.027	.33
"	9.94	.034	.45	.030	.40
15	8.04	.048	.63	.041	.63
20	8.04	.048	.73	.041	.62
15	7.09	.037	.63	.037	.63
15	6.15	.028	.55	.031	.61
20	6.15	.031	.61	.028	.55
15	5.20	.022	.51	.025	.58
15	4.25	.018	.51	.018	.57
20	4.25	.020	.56	.016	.45
15	3.30	.014	.50	.013	.47
15	2.35	.009	.45	.008	.40
20	2.35	.011	.55	.007	.35
15	1.41	.005	.42	.004	.33
15	0.46	.0.00	00	.000	00
20	0.46	.002	.49	−.001	−.24

DATE

MAGNET NO. 17

$-\Delta = 1 - N = \text{Ref} - N$

		Current Descending		Current Ascending	
UPPER ENERGY [GeV]	E_x [V]	$\Delta\int B\,ds$ [Tm]	$\frac{100\,\Delta\int B\,ds}{\int B\,ds_{ref}}$ [%]	$\Delta\int B\,ds$ [Tm]	$\frac{100\,\Delta\int B\,ds}{\int B\,ds_{ref}}$ [%]
20	14.67	.019	.22	.019	.22
"	13.72	.018	.21	.018	.21
"	11.83	.018	.22	.016	.20
"	9.94	.022	.29	.017	.23
15	8.04	.028	.43	.028	.43
20	8.04	.031	.47	.022	.33
15	7.09	.025	.43	.024	.41 ✓
15	6.15	.020	.39	.020	.39
20	6.15	.019	.37	.011	.21
15	5.20	.016	.37	.014	.32
15	4.25	.013	.37	.010	.28
20	4.25	.011	.31	.004	.11
15	3.30	.009	.32	.007	.25
15	2.35	.007	.35	.004	.20
20	2.35	.007	.35	−.001	−.05
15	1.41	.004	.33	.003	.25
15	0.46	.001	.25	.000	00
20	0.46	.003	.73	−.006	−1.46

Data sent to Truher Feb 14 1980 in format for Appendix A MT 301

Ascending 15 GeV data (evidently smoothed based on descending & 20 GeV data.

~E_x		10 Δ∫Bds [Tm]	[%/1]			11 Δ∫Bds [Tm]	[%/1]	
8.09		.024	.37			.024	.37	
7.09		.022	.38			.021	.36	
6.15		.018	.35			.015	.29	
5.20		.014	.32			.011	.25	
4.25		.011	.31	.28		.008	.22	.17
3.30		.007	.25			.006	.22	
2.35		.005	.25			.004	.20	
1.41		.003	.25			.002	.17	
0.46		.001	.25		−	.002	-.49	

		12				13			14 Δ∫Bds [Tm]	[%/1]	
8.09		.039	.60			.037	.57		.025	.39	
7.09		.038	.65			.035	.60		.022	.38	
6.15		.032	.63			.029	.57		.018	.35	
5.20		.026	.60			.024	.55		.013	.30	
4.25		.021	.59	.56		.018	.51	.51	.010	.28	.2
3.30		.014	.50			.014	.50		.008	.29	
2.35		.010	.50			.009	.45		.006	.30	
1.40		.007	.58			.006	.50		.005	.42	
0.46		.003	.74			.002	.49		.002	.49	

This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.

TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720