Title
88-INCH CYCLOTRON MAGNETIC DEFLECTOR TESTS OF THREE STEEL SAMPLES

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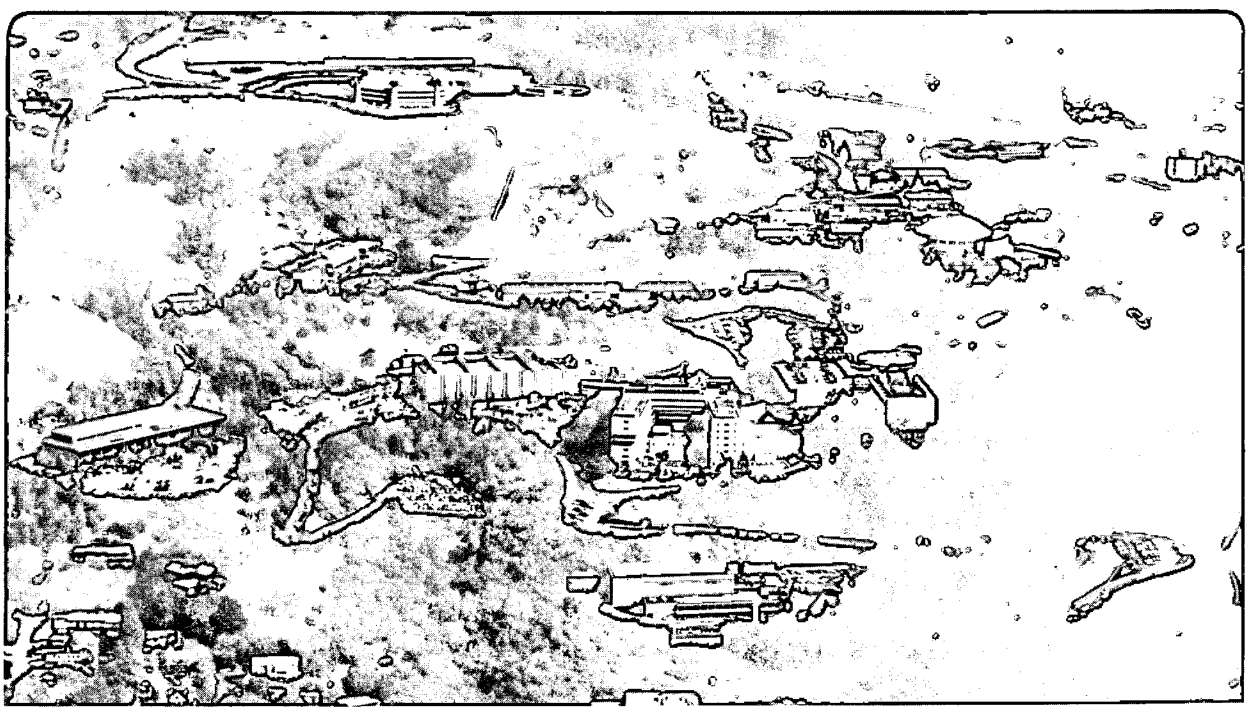
UNIVERSITY OF CALIFORNIA

Engineering & Technical Services Division



DISCLAIMER

SUBJECT 88-Inch Cyclotron Magnetic Deflector Tests of Three Steel Samples

NAME D.H. Nelson & M.I. Green

DATE April 22, 1982

INTRODUCTION

Don Elo, of the 88-Inch Cyclotron Group, requested that Magnetic Measurements Engineering (MME) make comparative permeability measurements of samples of three steels that could be used in the fabrication of the magnetic deflector scheduled for installation in the 88-inch cyclotron extraction region during the 1982 summer shutdown. (Installation and magnetic field measurements are scheduled for the period June 26 - July 26, 1982.) Of interest are the relative permeabilities above 100 Oe and the saturation inductions of the three materials.

We measured the three samples on March 30th and reported small differences in their permeabilities on April 6th (see Discussion on page 17).

The purposes of this note are (1) to present the results of our tests and (2) to demonstrate "new" plotting capabilties of the permeability phase of the MME Data Acquisition System.

DESCRIPTION OF MEASUREMENTS, TEST EQUIPMENT AND SAMPLES

The technique used for these measurements is described in reference 1. Figure 1 (reproduced from reference 1)[1] describes the equipment and Table I lists specific instruments. Appendix A (available on request only) contains source listings of the data processing program PROCC1 and significant subroutines.

Figure 2 shows the sample geometry. The three samples provided by Don Elo are identified in Tables II, III and IV.

For comparison, we show curves of vanadium permendur vacuum annealed at 1120 °C for four hours (Figures 3 - 6) and a sample of LBL stocked 1018 steel (stock no. 9510-10198) vacuum annealed at 840 °C for one hour. (Figure 10)

(text continues on page 8)

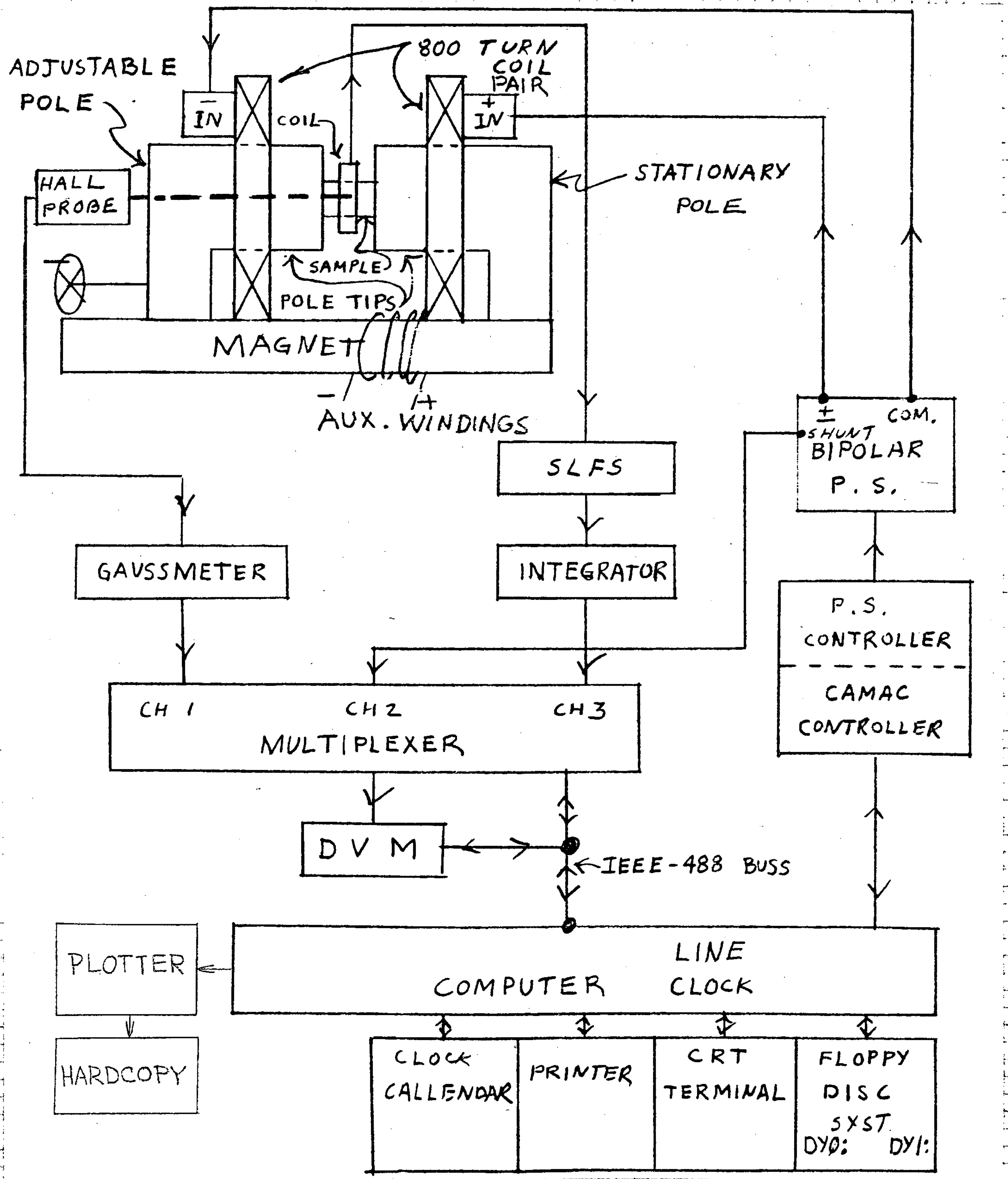


FIGURE 1 Halbach Permeameter MME Data Acquisition System - Phase II

HARDWARE	DESCRIPTION
Samples	Figure 2 gives dimensions. Tables II, III and IV provide manufacturers' specifications.
Coil	B-162, nA = 0.0411 (m^2), n = 100 (T)
Flux Standard	SLFS 40.02, ψ (SLFS) = 0.0210 (Wb)
Integrator	LBL MOD 71 Serial No. 1 R = 19.6 k, C = 0.1 μF ATT = 360, BAL - 497
Hall Probe	F.W. Bell MOD SAE4-0818, SN 155966 CAL = 1.000
Gaussmeter	F.W. Bell Model 620, DOE #501586, Polarity = +
Multiplexer	Hewlett Packard Model 3495A Scanner, DOE #517528
DVM	Hewlett Packard Model 3455A Digital Voltmeter, DOE #517459
Magnet	MME Charging Magnet - 800 turn magnetizing windings
Power Supply	LLNL, LEA 74-4035-01-50 20 VDC at 30 A, Bipolar Regulator LEA 74-4035-41-50
PS Controller	KS 3160 CAMAC, DOE #512977
CAMAC Controller	Std. Eng., CCLSI-II, DOE # 512996
Computer	LSI 11/23
Clock Calendar	TCU-50D, SN 6446
Printer	LA 120, DOE # 519478
CRT Terminal	Zenith H19, DOE # 518712
Floppy Disc Sys.	DSD 440, DOE # 519465
Plotter	Tektronix 4051
Hardcopy	Tektronix 4631

SOFTWARE

PERM7
PROCC1
MPX1
CMCPS1
DEMAG1

F I R M W A R E

Floppy Disc* Designation	Contents
MME 39	LSI 11/23, RT-11 OP. SYSTEM (DY0:)
DATA1	DATA ACQUISITION/SAVE (DY1:)
MME 55	DATA PROCESSING with copy of data files (DY1:)

*Directories of these and related floppy discs are listed in Appendix B which is available on request.

TABLE I - Test Equipment

UNLESS OTHERWISE NOTED

.X± — .XX± — .XXX± —

Angles ± Finish 63 √

Threads are class 2.
Chamfer ends of all screw threads 30.
Cut 1.5 pitch thr'd relief with round nose tool on machine cut threads.
Break edges .016 max. on machined work.
Remove burrs weld spatter & loose scale.
References: ANSI Y 14.5 & B46.1.

REV.	DWN	CHK	DATE	CHANGES

SHOP ORDERS

ACCT. NO | SER. NO.

DATE ISS'D. | DATE REQ'D. | NO. REQ'D.

DEL. TO

SURFACE TREATM'NT CRC 336 RUST PREV

IDENTIF. METHOD

D'WN BY ELO | DATE 3/82

CH'K BY

PATENT CLR | DWG TYPE D | SHOWN ON | DWG. NO | REV. 1

MICROFILMED | DES. ACCT. NO 7449-01 | CATEGORY 880112 | SCALE (Do not scale prints) TWICE

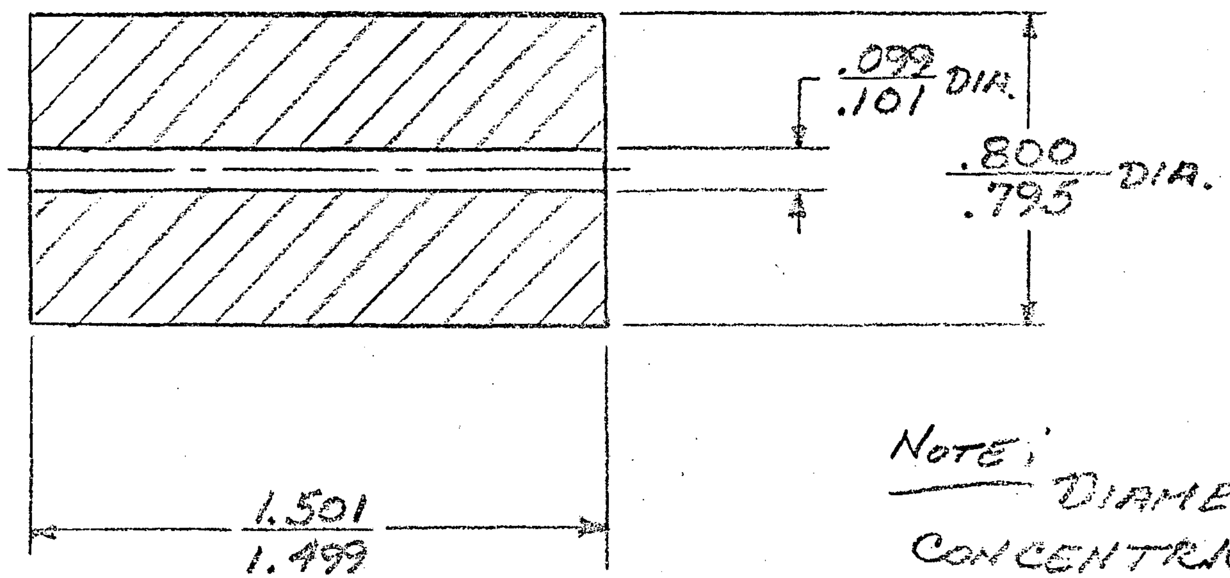
LAWRENCE BERKELEY LABORATORY U.C. BERKELEY

88" CYCLOTRON

DEFLECTOR, II - MAGNETIC CHANNEL

MAGNET MAT'L TEST SAMPLE

MATERIAL	PART No	No REQ'D
Low Carbon Steel AISI 1004	-1	
✓ ✓ ✓ AISI 1018	-2	
✓ ✓ ✓ E-Z Cut 20	-3	



NOTE: DIAMETERS CONCENTRIC .001" T.I.R.

FIGURE 2

SUBJECT: 88-Inch Cyclotron Magnetic Deflector Tests of Three Steel Samples

NAME: D.H. Nelson & M.I. Green

DATE: April 22, 1982

COMBINED AISI & SAE STANDARD STEEL LISTS

BASIC OPEN HEARTH AND ACID BESSEMER STEELS

Chemical Composition Limits, Per Cent

A.I.S.I. Number	Carbon	Manganese	Phosphorus	Sulphur	S.A.E. Number
→ C 1005	0.06 Max.	0.35 Max.	0.040 Max.	0.050 Max.	......
C 1006	0.08 Max.	0.25/0.40	0.040 Max.	0.050 Max.	1006
C 1008	0.10 Max.	0.25/0.50	0.040 Max.	0.050 Max.	1008
C 1010	0.08/0.13	0.30/0.60	0.040 Max.	0.050 Max.	1010
C 1011	0.08/0.13	0.60/0.90	0.040 Max.	0.050 Max.	......
C 1012	0.10/0.15	0.30/0.60	0.040 Max.	0.050 Max.	......
C 1013	0.11/0.16	0.50/0.80	0.040 Max.	0.050 Max.	......
C 1015	0.13/0.18	0.30/0.60	0.040 Max.	0.050 Max.	1015
C 1016	0.13/0.18	0.60/0.90	0.040 Max.	0.050 Max.	1016
C 1017	0.15/0.20	0.30/0.60	0.040 Max.	0.050 Max.	1017
C 1018	0.15/0.20	0.60/0.90	0.040 Max.	0.050 Max.	1018
C 1019	0.15/0.20	0.70/1.00	0.040 Max.	0.050 Max.	1019
C 1020	0.18/0.23	0.30/0.60	0.040 Max.	0.050 Max.	1020
C 1021	0.18/0.23	0.60/0.90	0.040 Max.	0.050 Max.	1021
C 1022	0.18/0.23	0.70/1.00	0.040 Max.	0.050 Max.	1022
C 1023	0.20/0.25	0.30/0.60	0.040 Max.	0.050 Max.	......
C 1024	0.19/0.25	1.35/1.65	0.040 Max.	0.050 Max.	1024
C 1025	0.22/0.28	0.30/0.60	0.040 Max.	0.050 Max.	1025
C 1026	0.22/0.28	0.60/0.90	0.040 Max.	0.050 Max.	1026
C 1027	0.22/0.29	1.20/1.50	0.040 Max.	0.050 Max.	1027
C 1029	0.25/0.31	0.60/0.90	0.040 Max.	0.050 Max.	......
C 1030	0.28/0.34	0.60/0.90	0.040 Max.	0.050 Max.	1030
C 1031	0.28/0.34	0.30/0.60	0.040 Max.	0.050 Max.	......
C 1032	0.30/0.36	0.60/0.90	0.040 Max.	0.050 Max.	......
C 1033	0.30/0.36	0.70/1.00	0.040 Max.	0.050 Max.	1033
C 1034	0.32/0.38	0.50/0.80	0.040 Max.	0.050 Max.	......
C 1035	0.32/0.38	0.60/0.90	0.040 Max.	0.050 Max.	1035
C 1036	0.30/0.37	1.20/1.50	0.040 Max.	0.050 Max.	1036
C 1037	0.32/0.38	0.70/1.00	0.040 Max.	0.050 Max.	......
C 1038	0.35/0.42	0.60/0.90	0.040 Max.	0.050 Max.	1038
C 1039	0.37/0.44	0.70/1.00	0.040 Max.	0.050 Max.	1039
C 1040	0.37/0.44	0.60/0.90	0.040 Max.	0.050 Max.	1040
C 1041	0.36/0.44	1.35/1.65	0.040 Max.	0.050 Max.	1041
C 1042	0.40/0.47	0.60/0.90	0.040 Max.	0.050 Max.	1042
C 1043	0.40/0.47	0.70/1.00	0.040 Max.	0.050 Max.	1043
C 1045	0.43/0.50	0.60/0.90	0.040 Max.	0.050 Max.	1045
C 1046	0.43/0.50	0.70/1.00	0.040 Max.	0.050 Max.	1046
C 1049	0.46/0.53	0.60/0.90	0.040 Max.	0.050 Max.	1049
C 1050	0.48/0.55	0.60/0.90	0.040 Max.	0.050 Max.	1050
C 1051	0.45/0.56	0.85/1.15	0.040 Max.	0.050 Max.	......
C 1052	0.47/0.55	1.20/1.50	0.040 Max.	0.050 Max.	1052
C 1053	0.48/0.55	0.70/1.00	0.040 Max.	0.050 Max.	......
C 1054	0.50/0.60	0.50/0.80	0.040 Max.	0.050 Max.	......
C 1055	0.50/0.60	0.60/0.90	0.040 Max.	0.050 Max.	1055
C 1057	0.50/0.61	0.85/1.15	0.040 Max.	0.050 Max.	......
C 1059	0.55/0.65	0.50/0.80	0.040 Max.	0.050 Max.	......
C 1060	0.55/0.65	0.60/0.90	0.040 Max.	0.050 Max.	1060
C 1061	0.54/0.65	0.75/1.05	0.040 Max.	0.050 Max.	......
C 1062	0.54/0.65	0.85/1.15	0.040 Max.	0.050 Max.	1062
C 1064	0.60/0.70	0.50/0.80	0.040 Max.	0.050 Max.	1064
C 1065	0.60/0.70	0.60/0.90	0.040 Max.	0.050 Max.	1065
C 1066	0.60/0.71	0.85/1.15	0.040 Max.	0.050 Max.	1066
C 1069	0.65/0.75	0.40/0.70	0.040 Max.	0.050 Max.	......
C 1070	0.65/0.75	0.60/0.90	0.040 Max.	0.050 Max.	1070
C 1071	0.65/0.76	0.75/1.05	0.040 Max.	0.050 Max.	......

Don —
The AISI 1004 sample supplied by Jim Haughian was analyzed for carbon content only;
Carbon = .043%,
other content should be similar to AISI 1005
E/o

Section K
Page 9

TABLE II

Ryerson Certificate of C. F. Carbon Bar Analysis

DESCRIPTION 1 CD 1018 1" Rd 0'6" DATE 3/11/82

SHAPE AND SIZE OUR ORDER # 13-754952

YOUR ORDER # verbal - John

University of California
Lawrence Berkeley Lab

COLD-FINISHED CARBON BARS — CHEMICAL ANALYSIS LIMITS

Commodity Description	Carbon	Manganese	Phosphorus	Sulphur	Silicon	Lead
1018	.15/.20	.60/.90	.040 Max	.050 Max	(1)	
10L18	.15/.20	.60/.90	.040 Max	.050 Max		.15/.35
1025	.22/.28	.30/.60	.040 Max	.050 Max	(1)	
1045	.43/.50	.60/.90	.040 Max	.050 Max	.15/.30	
1117	.14/.20	1.00/1.30	.040 Max	.08/.13	.10 Max	
11L17	.14/.20	1.00/1.30	.040 Max	.08/.13	.10 Max	.15/.35
1141	.37/.45	1.35/1.65	.040 Max	.08/.13	.10 Max	
1144	.40/.48	1.35/1.65	.040 Max	.24/.33	.10 Max	
11L41	.37/.45	1.35/1.65	.040 Max	.08/.13	.10 Max	.15/.35
11L44	.40/.48	1.35/1.65	.040 Max	.24/.33	.10 Max	.15/.35
1215 (2)	.09 Max	.75/1.05	.04/.09	.26/.35		
LEDLOY AX (3)	.09 Max	.85/1.15	.04/.09	.26/.35		.15/.35
12L14 (LEDLOY 300)	.15 Max	.85/1.15	.04/.09	.26/.35		.15/.35

(1) - Rounds, Squares and Hexagons 2-15/16 and over and Standard Bar Sizes 29.34 lbs./ft. and over have Silicon Content .15/.30.

(2) - May be Nitrogen Treated.

(3) - Tellurium Added.

This report indicates the Chemical Analysis to which the items listed were manufactured and tested. Based on Test Reports and/or Certificates furnished to us by the producer, we certify them to be within the limits shown.

BY C. Engler
Authorized Agent

Service Centers at: Boston • Buffalo • Charlotte • Chicago
Cincinnati • Cleveland • Dallas • Denver • Detroit • Houston
Indianapolis • Kansas City • Los Angeles • Milwaukee • Minneapolis
New York • Philadelphia • Pittsburgh • St. Louis • Seattle
San Francisco • Spokane • Wallingford

RYERSON
JOSEPH T. RYERSON & SON, INC.

TABLE III

Form 720.150-2 May 75

E-Z-CUT® 20

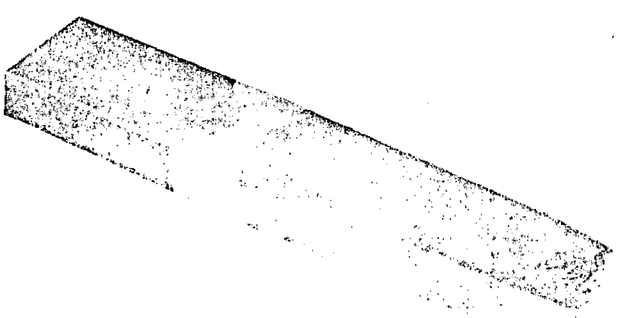
Chemical Composition

	C	Mn	P	S	Si
Percent	.20 max.	1.00/1.35	.05/.10	.20/.35	.15/.30

Mechanical Properties*

Thickness	Tensile Strength P.S.I.	Yield Point P.S.I.	% Elongation in 2"	Surface BHN
½"	71,200	44,700	26.0	156
1"	68,300	42,200	31.3	149
2"	67,500	40,800	31.5	149
3"	66,900	38,300	27.7	143
4"	62,100	35,100	25.8	137
6"	61,000	29,000	26.5	131
8"	57,700	27,500	25.2	126

*Data for E-Z-Cut 20 and 45 is based on single longitudinal tests conforming to ASTM A-20. Standard tensile specimens taken midway between surface and center of plates over ½"—tests under ½" made on full plate thickness using 8 inch gage lengths.



Heat Treating . . . E-Z-Cut 20 offers excellent response to standard case hardening procedures, producing high surface hardness and a tough core. The following Rc surface hardness values were obtained on test pieces, carburized 1/16" at 1700°F, reheated, quenched at 1575°F, tempered 325°F.

Thickness	Oil Quenched	Water Quenched
⅜	60-62	Not tested
½	59-61	59-60
⅝	59-61	60-61
¾	58-60	60-63
1	58-60	59-62
1½	57-60	59-61
2	57-59	59-61

Welding E-Z-Cut 20—pre-heat not required. Use AWS series E70 (E7016 or E7018) low hydrogen electrodes. No post-heating or peening necessary. In weld section at left, results of tensile test show how weld area resisted fracture.

TABLE IV

RESULTS

Figure 3 represents ten complete data sets on four different materials as follows:

Curve Identification	Remarks
Vanadium Permendur (Vd. Perm.)	Annealed at 1120 °C 4 Hours
1004	See Table II (As Machined)
1018	See Table III (As Machined)
E-Z-CUT 20 (EZ20)	See Table IV (As Machined)

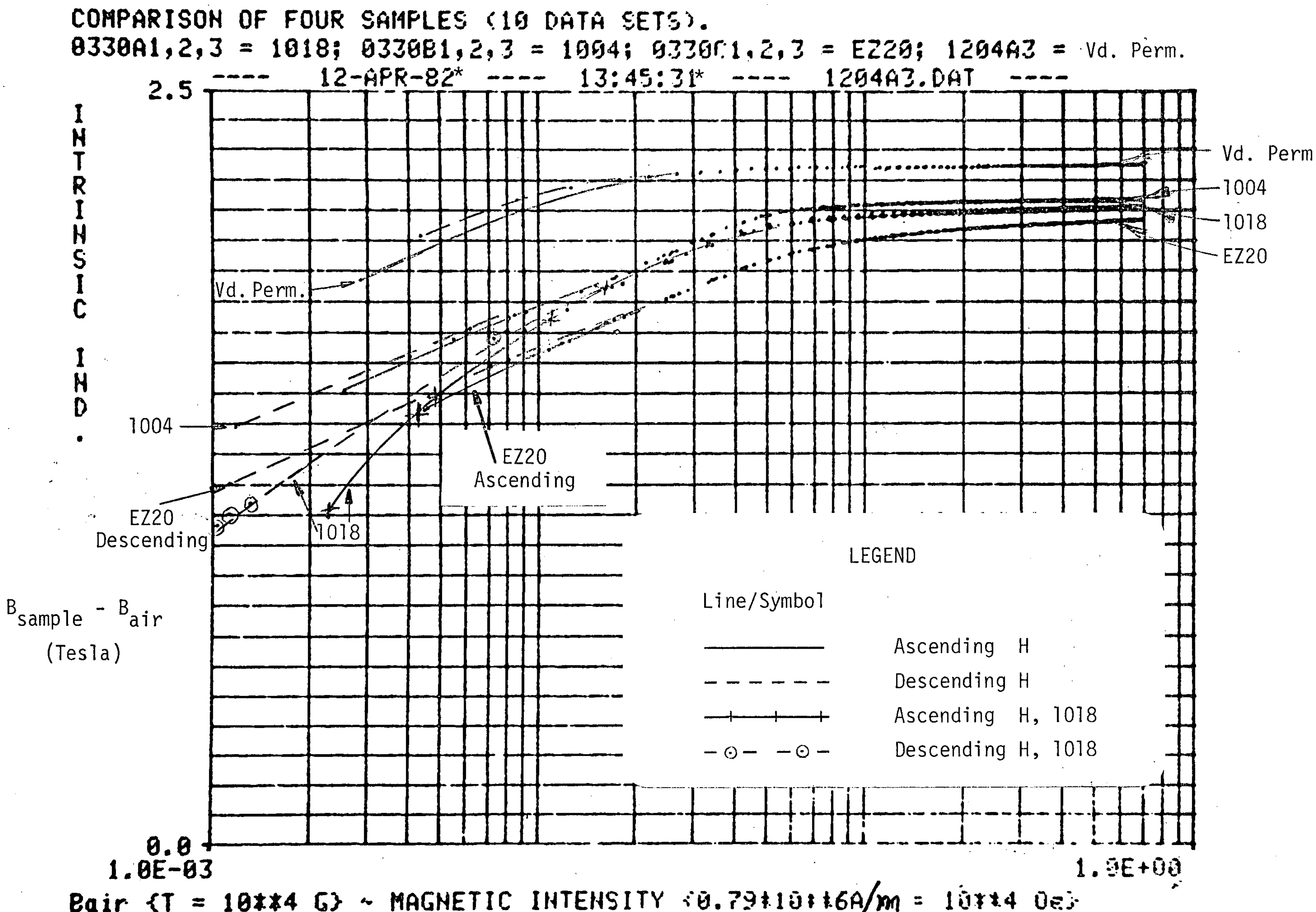
Figures 4 - 6 represent (immediately after demagnetizing) one data set for each material using expanded scales to magnify differences between materials. Figure 4 represents the relative permeability ($B_{sample}/\mu_o H_{air}$) for magnetizing intensities above 1000 Oe (0.79×10^5 A/m). Figure 5 represents magnetic induction (B_{sample}) and Figure 6 represents intrinsic induction ($B_{sample} - \mu_o H$). For Figures 5 and 6, we plotted data for magnetizing intensities above 100 Oe (0.79×10^4 A/m).

From Figures 3 - 6, we observed that the most significant differences between these materials is in their saturation induction. Differences in relative permeability are small compared with variations in the relative permeability of a sample as a function of magnetizing intensity.

Figures 7, 8 and 9 each show data for a single sample to display reproducibility above 100 Oe.

Figure 10 compares two samples of 1018 steel. The one that has not been annealed exhibits slightly higher saturation induction than the annealed sample from LBL stock, suggesting that variations between lots of 1018 steel may be significant.

(text continues on page 17)



*Date/Time of Processing

FIGURE 3

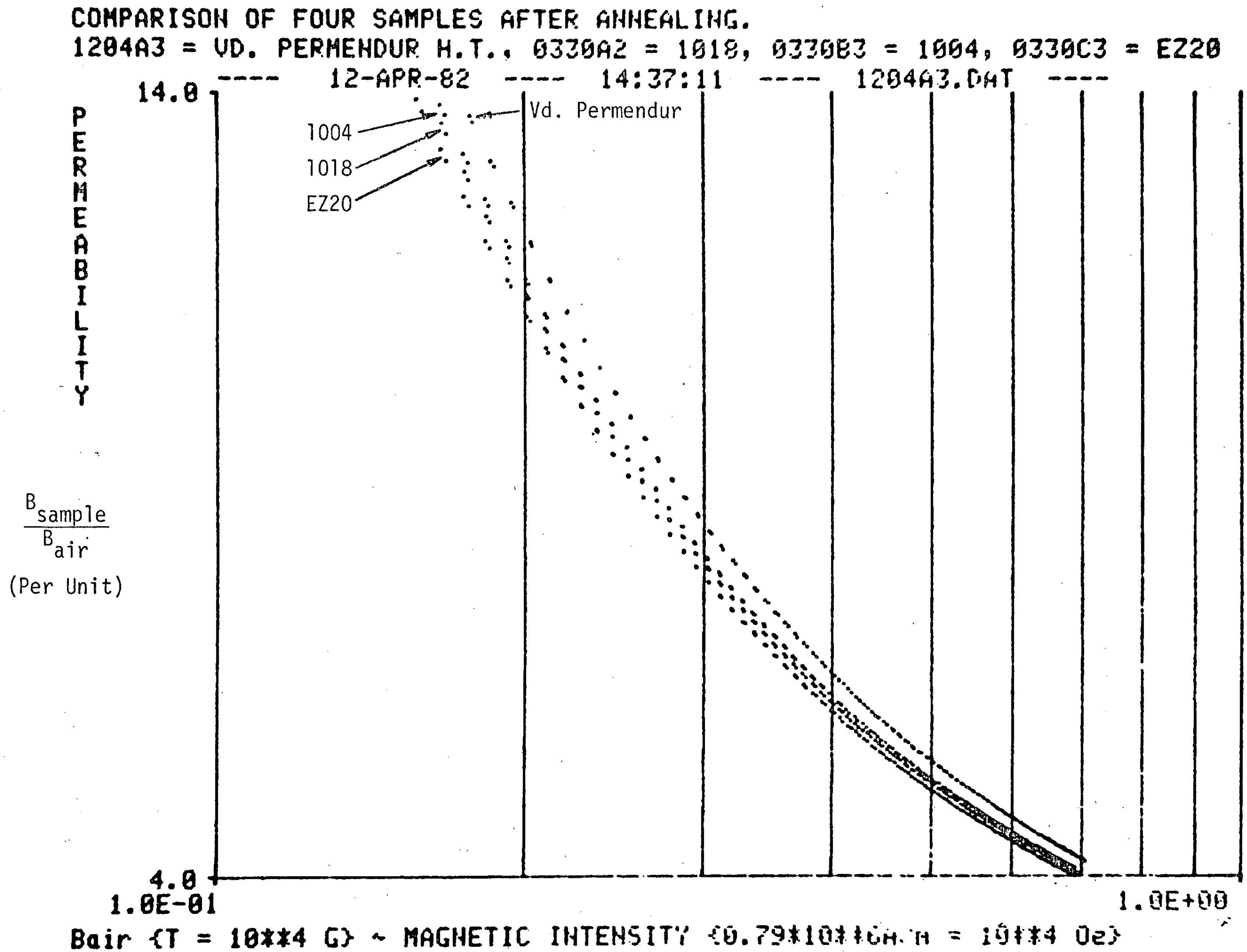

COMPARISON OF FOUR SAMPLES AFTER ANNEALING.
1204A3 = VD. PERMENDUR H.T., 0330A2 = 1018, 0330B3 = 1004, 0330C3 = EZ20
---- 12-APR-82 ---- 14:37:11 ---- 1204A3.DAT ----
14.0
Vd. Permendur
1004
1018
EZ20
PERMEABILITY
B_{sample} / B_{air}
(Per Unit)
4.0
1.0E-01
1.0E+00
Bair {T = 10**4 G} ~ MAGNETIC INTENSITY {0.79*10**6A/m = 10**4 Oe}

FIGURE 4

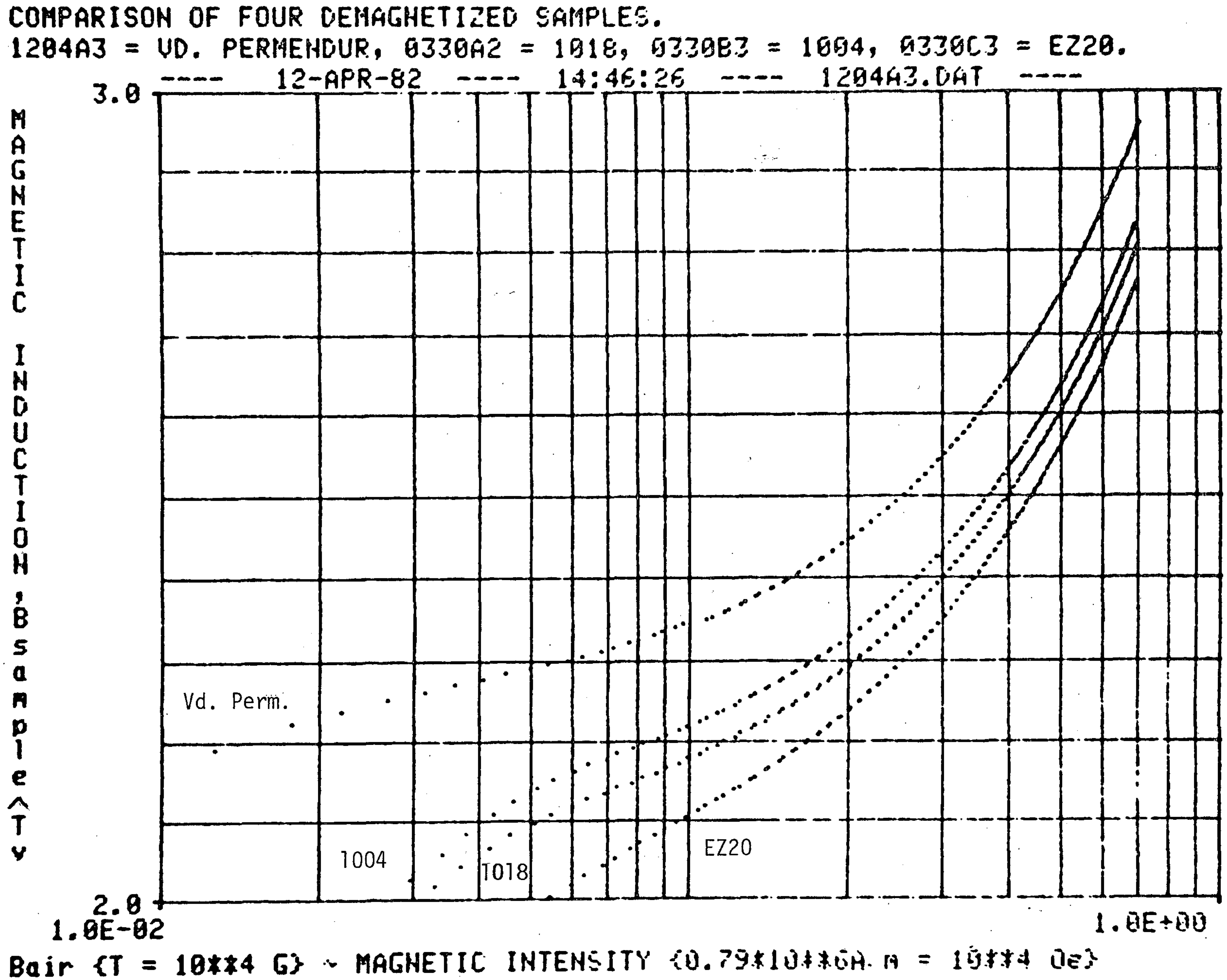

COMPARISON OF FOUR DEMAGNETIZED SAMPLES.
1204A3 = VD. PERMENDUR, 0330A2 = 1018, 0330B3 = 1004, 0330C3 = EZ20.
---- 12-APR-82 ---- 14:46:26 ---- 1204A3.DAT ----
3.0
MAGNETIC INDUCTION ,Bsample^T
2.0
1.0E-02
1.0E+00
Vd. Perm.
1004
1018
EZ20
Bair {T = 10**4 G} ~ MAGNETIC INTENSITY {0.79*10**6A m = 10**4 Oe}

FIGURE 5

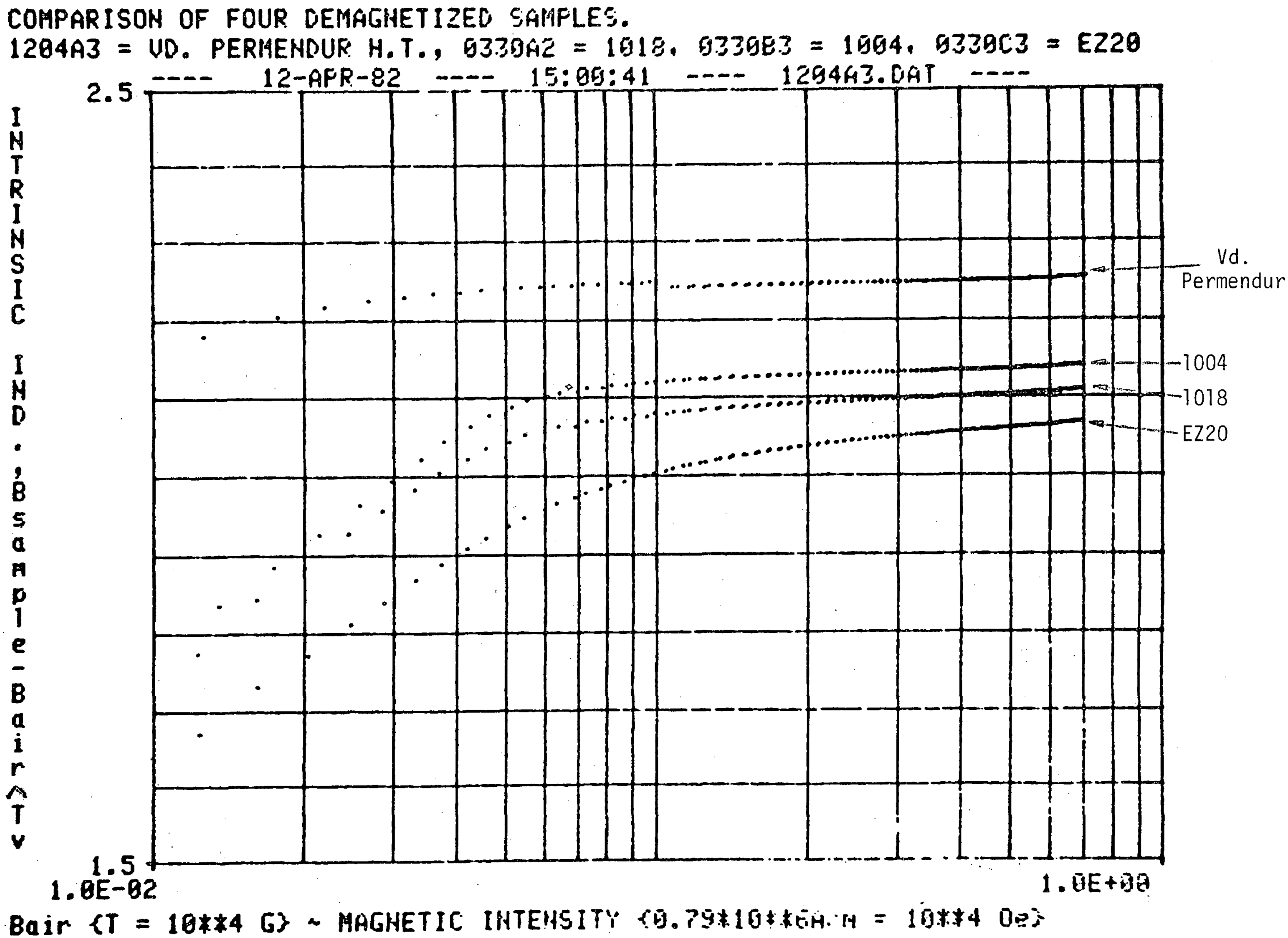

COMPARISON OF FOUR DEMAGNETIZED SAMPLES.
1204A3 = VD. PERMENDUR H.T., 0330A2 = 1018, 0330B3 = 1004, 0330C3 = EZ20
---- 12-APR-82 ---- 15:00:41 ---- 1204A3.DAT ----
2.5
1.5
1.0E-02
1.0E+00
INTRINSIC IND.,Bsample-Bair<T>
Bair {T = 10**4 G} ~ MAGNETIC INTENSITY {0.79*10**6A/m = 10**4 Oe}
Vd. Permendur
1004
1018
EZ20

FIGURE 6

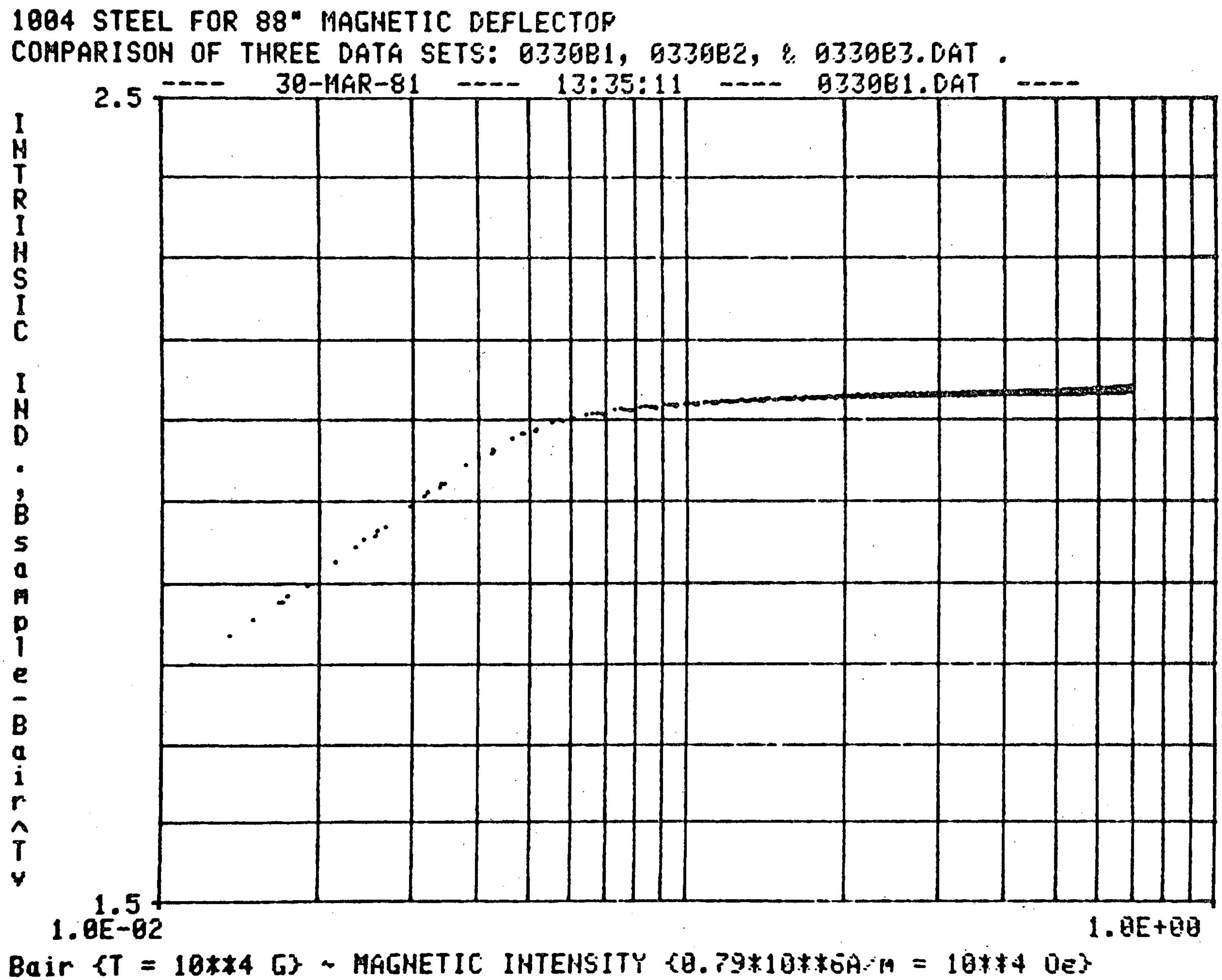

1004 STEEL FOR 88" MAGNETIC DEFLECTOR
COMPARISON OF THREE DATA SETS: 0330B1, 0330B2, & 0330B3.DAT .
---- 30-MAR-81 ---- 13:35:11 ---- 0330B1.DAT ----
2.5
1.5
INTRINSIC IND.,Bsample-Bair<T>
1.0E-02
1.0E+00
Bair {T = 10**4 G} ~ MAGNETIC INTENSITY {0.79*10**6A/m = 10**4 Oe}

FIGURE 7

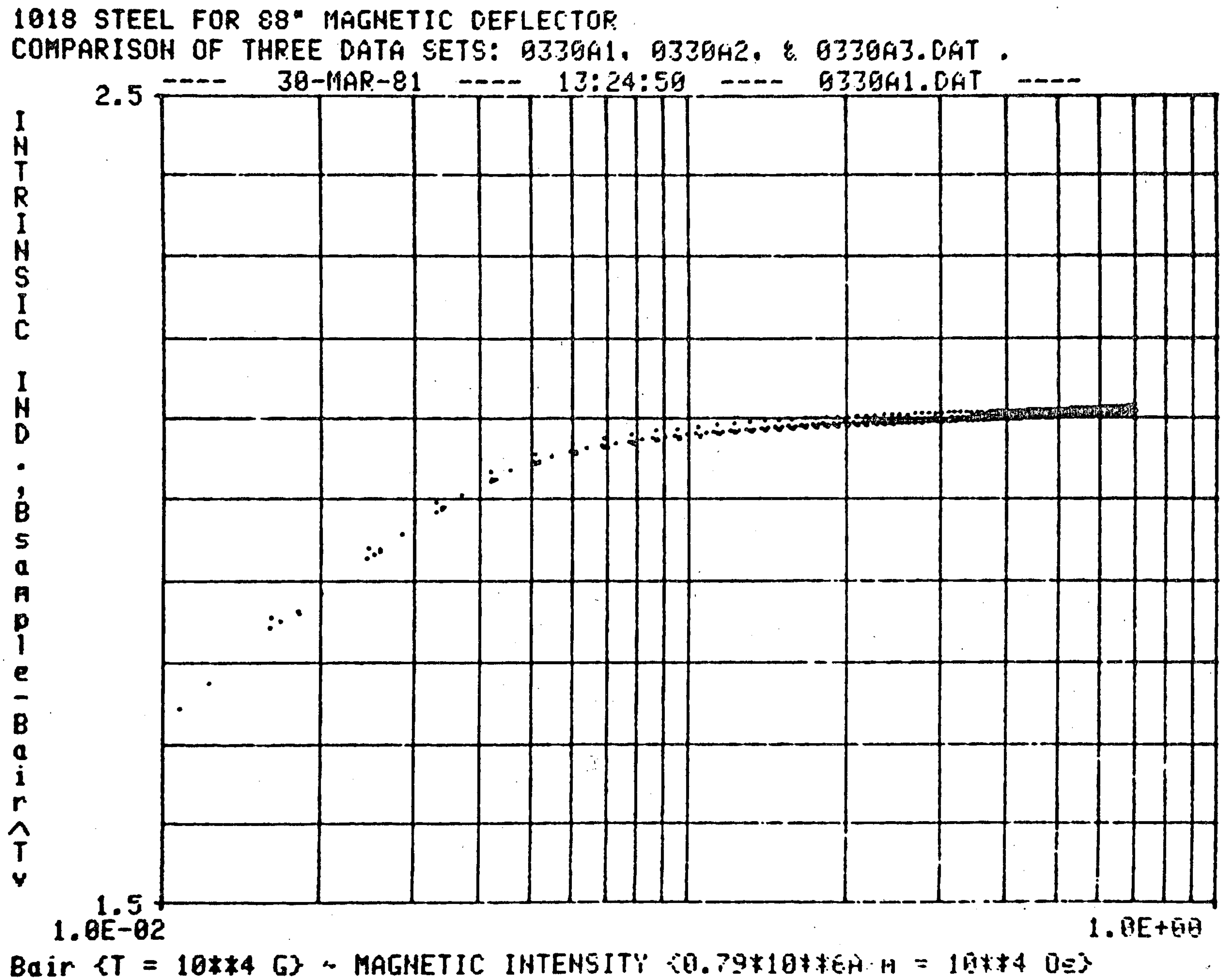

1018 STEEL FOR 88" MAGNETIC DEFLECTOR
COMPARISON OF THREE DATA SETS: 0330A1, 0330A2, & 0330A3.DAT .
---- 30-MAR-81 ---- 13:24:50 ---- 0330A1.DAT ----
2.5
1.5
INTRINSIC IND.,Bsample-Bair^T
1.0E-02
1.0E+00
Bair {T = 10**4 G} ~ MAGNETIC INTENSITY {0.79*10**6A m = 10**4 Oe}

FIGURE 8

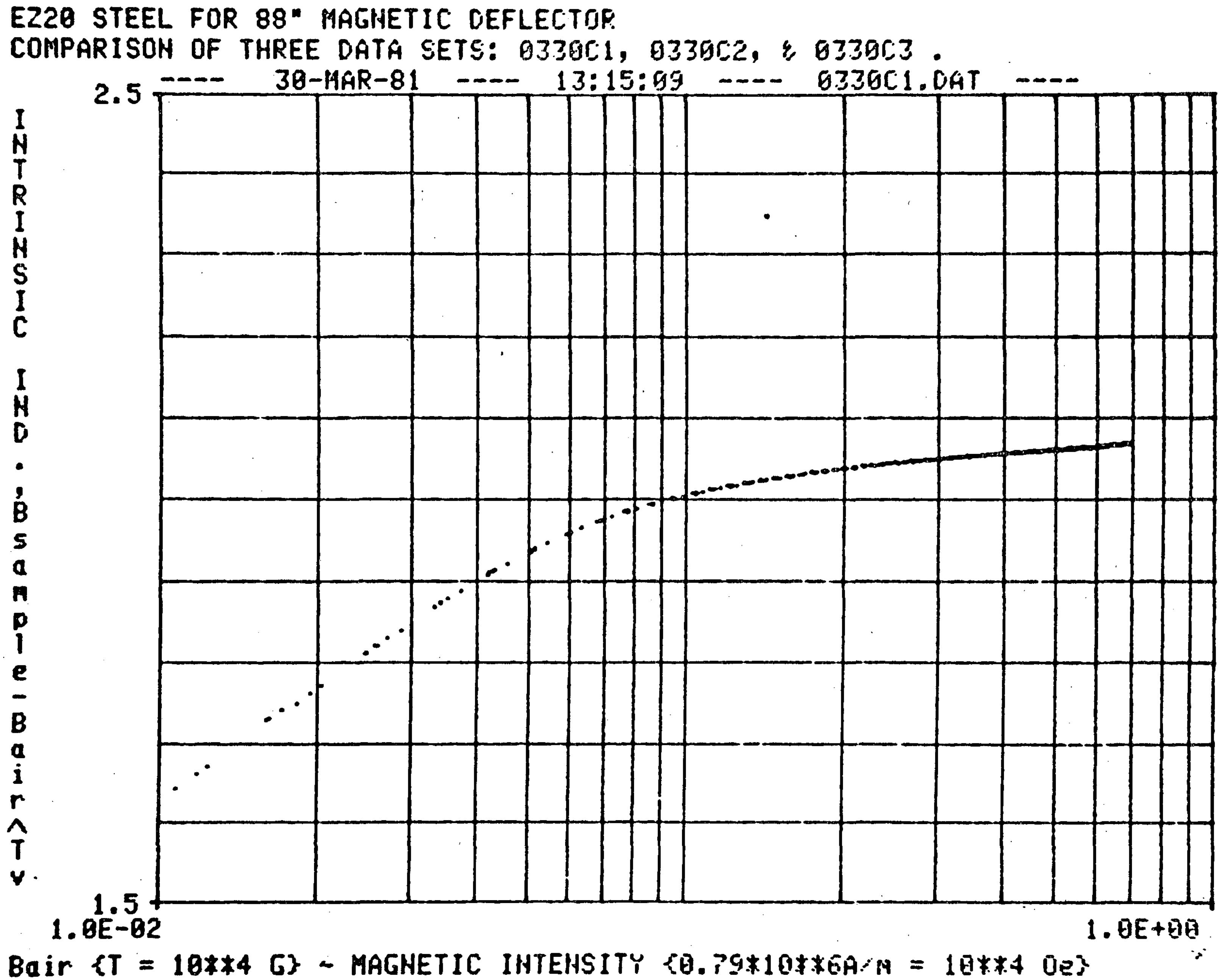

EZ20 STEEL FOR 88" MAGNETIC DEFLECTOR
COMPARISON OF THREE DATA SETS: 0330C1, 0330C2, & 0330C3 .
---- 30-MAR-81 ---- 13:15:09 ---- 0330C1.DAT ----
2.5
INTRINSIC IND.,Bsample-Bair^T v
1.5
1.0E-02
1.0E+00
Bair {T = 10**4 G} ~ MAGNETIC INTENSITY {0.79*10**6A/m = 10**4 Oe}

FIGURE 9

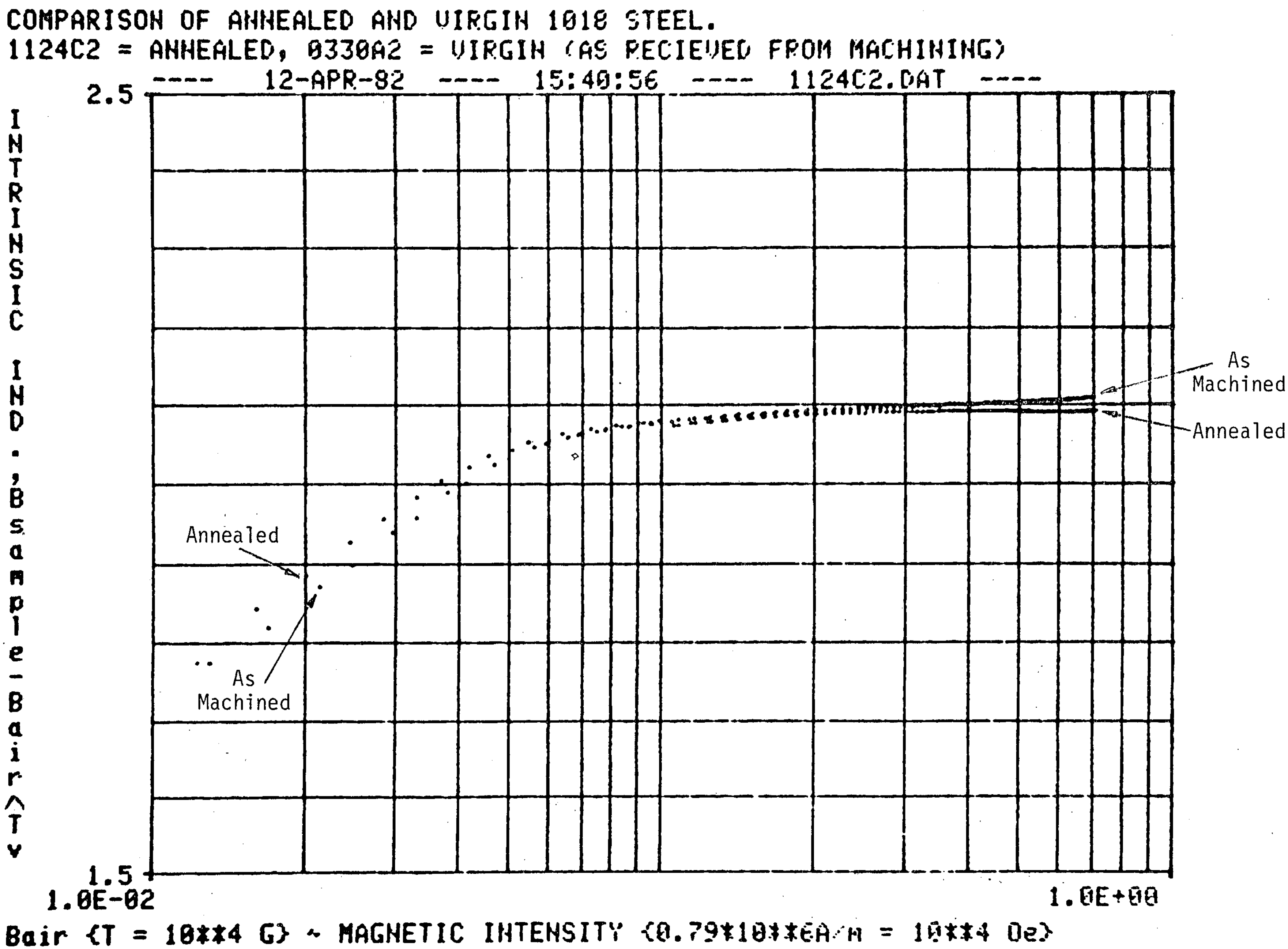

COMPARISON OF ANNEALED AND VIRGIN 1018 STEEL.
1124C2 = ANNEALED, 0330A2 = VIRGIN (AS RECIEVED FROM MACHINING)
---- 12-APR-82 ---- 15:40:56 ---- 1124C2.DAT ----
2.5
1.5
INTRINSIC IND.,Bsample-Bair(T)
1.0E-02
1.0E+00
Bair (T = 10**4 G) ~ MAGNETIC INTENSITY (0.79*10**6A/m = 10**4 Oe)
Annealed
As Machined
As Machined
Annealed

FIGURE 10

The units of the abscissas for all the curves were selected for ease in comparing our results with commercial data since (1) most commercial data is plotted with H (Oe) as the independent variable; (2) in the CGS system, the magnitudes of magnetic intensity and magnetic induction are equal (i.e., B = H) in a vacuum (and nearly so in air); and (3) the units of magnetic induction differ only by powers of 10 between the MKS and the CGS systems, i.e., 10^4 Gauss = 1 Tesla.

Appendix C contains one example of unprocessed (raw) data and all tabulated output from PROCC1, corresponding to data plotted in Figures 3 - 10. Appendix C is available on request.

DISCUSSION

Much of the discussion in reference 1 is still relevant. A significant improvement in our Phase II Data Acquisition System was made by the addition of graphics (reference 1, Section IV G3). We hope to be able to make similar improvements in conjunction with future jobs.

On April 6th, we reported our results (informally) to Don Elo and Lee Glasgow. On April 15th, Elo reported that E-Z CUT 20 had been selected as the material for fabricating the magnetic deflector. Since the saturation induction of 1004 was only 3% higher than that of E-Z CUT 20, other considerations, e.g., machinability, led to this selection.

REFERENCE

1. D.H. Nelson and M.I. Green, "LBL-SSRL Beamline Development - Permeability Measurements of Vanadium Permendur", LBL Engineering Note MT 307, Feb. 4, 1982.

Distribution:
D.J. Clark
T. Elioff
K. Halbach
E.C. Hartwig/L.J. Wagner/F.S. Goss
W.V. Hassenzahl
J.M. Haughian
E.H. Hoyer
A.M. Sessler
C.E. Taylor

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