Pulsed Magnetic Field Measurement on Main Accelerator Extraction Magnets

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On November 13 and 14, 1974, a C-type and an H-type magnet were measured for their integrated field values well above the 500-GeV level. In July 1974, these same magnets were measured in a DC mode up to the 400-GeV level. Due to high field and consequently high current required, a Tektronix Digital Processing Oscilloscope (DPO), and a PDP-11/05 were used to take ramp data.

Setup

The $\int Bdl$ measurement was made using one turn of 4-mil tungsten wire (with an effective width of 5.004") separated by precision glass spaces. The wire tension was set at 1 kg on each half of the loop. The test set-up is shown in Fig. 1. The sketched wire holders were positioned about 30 inches beyond the ends of the magnet in order to clear the fringe field. The holders were aligned by sight only, due to the relative flatness of the field.

The output of the stretched wire search coil was fed into an integrator. This search coil and integrator system is the same one which was used for the previous mode measurement.

Procedure

The output of the integrator was connected into the y-axis of the Tektronix Digital Processing Oscilloscope. The output of the current transductor was connected to the x-axis of the same scope.

It was essential to use differential input amplifiers for both axes to reduce noises. The used equipment is listed in Table I with a list of magnet parameters.

The magnets were powered by a Trans-Rex power supply ramped up to approximately 2600 amps in 5.88 sec. The current waveform is shown in Fig. 2. This ramp was slow enough to provide a low current slew rate allowing the field to follow the current closely, while at the same time it is fast enough to avoid excessive heating of the magnet. The current from the power supply was measured using the internal current transductor which is very accurate.

Data

Measurements of integrated field values were made at x = 0.0" and x = ±0.350" on both magnets at y = 0.0".

The output voltage of the integrated field value $\int Bdl$ and the current value I were input into y and x axis of the DPO respectively. The input data were stored in the DPO, and processed by a BASIC program in the PDP-11. The program listing is shown in Table II.

The integrated field values are listed in Tables III and IV and their computer displays are shown in Figs. 3 and 4 for C-type and H-type magnets. These data were averaged over four runs, and interpolated over the five nearest consecutive pairs of data, using the on-line program listed.

The C-type magnet shows an ever increasing quadrupole term above 1400 A. This is mainly due to the saturation of the pole tips.

The H-type magnet shows a field shape, which is low at the center compared to the data at ±0.35", up to 1800A. This is mainly due to the shimming of pole pieces. Above 2000A the center values at x = 0.0" are higher than the others. This may be due to the saturati

at the end. The detailed behavior of the difference is shown in Figs. 5 and 6, which is also processed by the on-line program. The minus side shows a bigger difference above 2000Å of about a factor 2 over the plus side, which is due to the saturation of the pole piece.

Table I

Magnet Parameters

Magnet	C-type	H-type
Physical Length	125.875"	126.0"
Gap	0.650"	0.625"
Turns	8	12
Resistance to core	300 KΩ	∞
*L_s @ 1 kHz	.542 mh	1.94 mh
*Q @	2.3	3.35
D.C. Resistance	31.5 mΩ	14.5 mΩ

*from GR 1650-B Impedance Bridge NAL #7139

Equipment Used:

1-Tektronix DPO	NAL #16211
1-Tektronix 7A13 Differential Comparator	NAL #16144
1-Tektronix 7A22 Differential Amplifier	NAL #16214
1-PDP 11/05 Computer w/tu-60 Casette Drive	NAL #16216
1-Tektronix 4010-1 CRT Terminal	NAL #13637
1-Tektronix 4610 Hard copy unit	NAL #16215
1-Krohn-Nite 5300 Function Generator	NAL #15042
1-Trans-Rex 500-5 Power Supply	NAL #11547
1-Integrator #4-MOD 1 (c = 0.1 mf)	Property of Magnet Measurement
1 turn tungsten wire	0.004"
2-Glass spacers	0.500 ±0.001"
2-Setco x-y Positioning tables (Type P1-Model 100)	#87172 and #87171

Table II Program Listing

```
REMARK  DPO TEK BASIC (CASSETTE) V01-01
  10 DIMENSION BI(511)
  11 DIMENSION BA(11)
  12 DIMENSION XP(511)
  13 DIMENSION XZ(511)
  14 DIMENSION XM(511)
  15 FOR I=0 TO 511
  16 LET XZ(I)=0.00
  17 LET XP(I)=0.00
  18 LET XM(I)=0.00
  19 NEXT I
  20 PRINT "^E^L"
  21 PRINT "TYPE IN X-COORDINATE OF PROBE WHERE DATA WAS TAKEN.
  25 INPUT X
  26 PRINT "^E^L"
  30 LET J=0
  40 LET A=PA
  50 LET B=PB
  60 LET C=PC
  70 LET D=PD
  90 LET BI=(A+B+C+D)/4.00
 100 LET BI=BI*7.934
 125 PRINT "BI(0)=";BI(0)
 126 WAIT
 127 PRINT "^E^L"
 130 FOR I=1 TO 511
 140 LET BI(I)=BI(I)-BI(0)
 150 NEXT I
 160 LET BI(0)=0.00
 170 FOR I=40 TO 491 STEP 41
 180 LET BV=(BI(I-1)+BI(I+1))/2.00
 190 LET BW=(BI(I-2)+BI(I+2))/2.00
 200 LET BX=(BI(I-3)+BI(I+3))/2.00
 210 LET BY=(BI(I-4)+BI(I+4))/2.00
 220 LET BZ=(BI(I-5)+BI(I+5))/2.00
 230 LET BA(J)=(BV+BW+BX+BY+BZ)/5.00
 240 LET J=J+1
 245 NEXT I
 250 PRINT "^E^L"
 251 PRINT "H MAGNET"
 252 PRINT "NOV. 14,1974"
 253 PRINT "PROBE POSITIONED AT X=";X
 255 PRINT "    "
 256 PRINT "    "
 260 LET J=0
 270 FOR I=40 TO 491 STEP 41
 275 PRINT "    "
 280 LET K=(J+1)*200
 290 PRINT "I=";K;" AMPS","AVERAGE B=";BI(I),"INTERPOLATED B=";BA(J)
 300 LET J=J+1
 310 NEXT I
 340 PRINT "^E^W^E^L"
 350 PRINT "^E^L"
 360 PRINT BI
 364 WAIT
 365 LET A=BI
 366 LET PA=A
 368 PRINT "^E^L"
 369 GRAPH PA:PRINT "^E^W^E^L"
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 370 IF X>0.0 THEN GOTO 430
 375 IF X<0.00 THEN GOTO 420
 380 IF XZ(511)=0.00 THEN GOTO 410
 390 LET XZ=(XZ+BI)/2.0
 400 GOTO 20
 410 LET XZ=BI
 420 GOTO 20
 430 IF XP(511)=0.00 THEN GOTO 460
 440 LET XP=(XP+BI)/2.00
 450 GOTO 20
 460 LET XP=BI
 470 GOTO 20
 480 IF XM(511)=0.00 THEN GOTO 510
 490 LET XM=(XM+BI)/2.0
 500 GOTO 20
 510 LET XM=BI
 520 GOTO 20
 530 STOP
 550 LET B=XZ-XP
 560 LET PB=B
 565 PRINT "^L^L"
 570 PRINT "B FIELD AT ZERO MINUS B FIELD AT PLUS SIDE "
 580 GRAPH PB:PRINT "^L^W^L^L
 590 LET C=XZ-XM
 600 LET PC=C
 605 PRINT "^L^L"
 610 PRINT "B FIELD AT ZERO MINUS B FIELD AT MINUS SIDE."
 620 GRAPH PC:PRINT "^L^W^L^L"
 625 FOR I=0 TO 10
 628 PRINT "^L^L"
 630 INTEGRATE B,PA
 635 DIFFERENTIATE A,PB,3
 642 PRINT "RESPOND '0' FOR MORE SMOOTHING; ELSE TYPE '1'"
 643 GRAPH PB
 645 INPUT R0
 650 IF R0=1 THEN GOTO 660
 655 NEXT I
 660 GRAPH PB
 661 PRINT "^L^W^L^L"
 662 FOR I=0 TO 10
 663 INTEGRATE C,PD
 665 DIFFERENTIATE D,PC,3
 666 PRINT "^L^L"
 670 PRINT "RESPOND '0' FOR MORE SMOOTHING; ELSE TYPE '1'"
 672 GRAPH PC
 675 INPUT RS
 680 IF RS=1 THEN GOTO 688
 685 NEXT I
 688 GRAPH PC
 689 PRINT "^L^W^L^L"
 690 STOP
READY
*
```
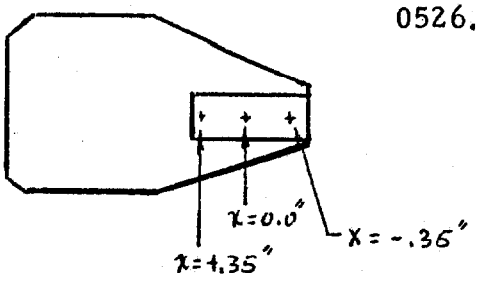
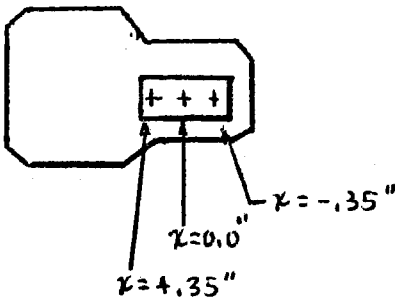



C Magnet

I (Amp)	∫Bdl (kG-m)		
	x = -0.35"	x = 0.0"	x = +0.35"
200	3.88	3.86	3.85
400	7.80	7.88	7.83
600	11.78	11.82	11.83
800	15.68	15.75	15.74
1000	19.59	19.67	19.68
1200	23.46	23.55	23.59
1400	27.12	27.23	27.34
1600	30.30	30.49	30.75
1800	33.07	33.40	33.82
2000	35.71	36.09	36.72
2200	38.14	38.59	39.40
2400	40.39	40.89	41.83

Table III Integrated Field Values for C-Type Magnet



H Magnet

I (Amp)	∫Bdl (kG-m) x = -0.35"	x = 0.0"	x = +0.35"
200	6.12	6.02	6.15
400	12.33	12.14	12.33
600	18.48	18.35	18.47
800	24.68	24.50	24.65
1000	30.83	30.74	30.82
1200	36.99	36.83	36.96
1400	42.67	42.57	42.62
1600	47.54	47.43	47.48
1800	51.63	51.61	51.66
2000	55.16	55.22	55.17
2200	58.11	58.25	58.17
2400	60.50	60.72	60.16

Table IV Integrated Field Values for H-type Magnet

Fig. 1 TEST SET-UP

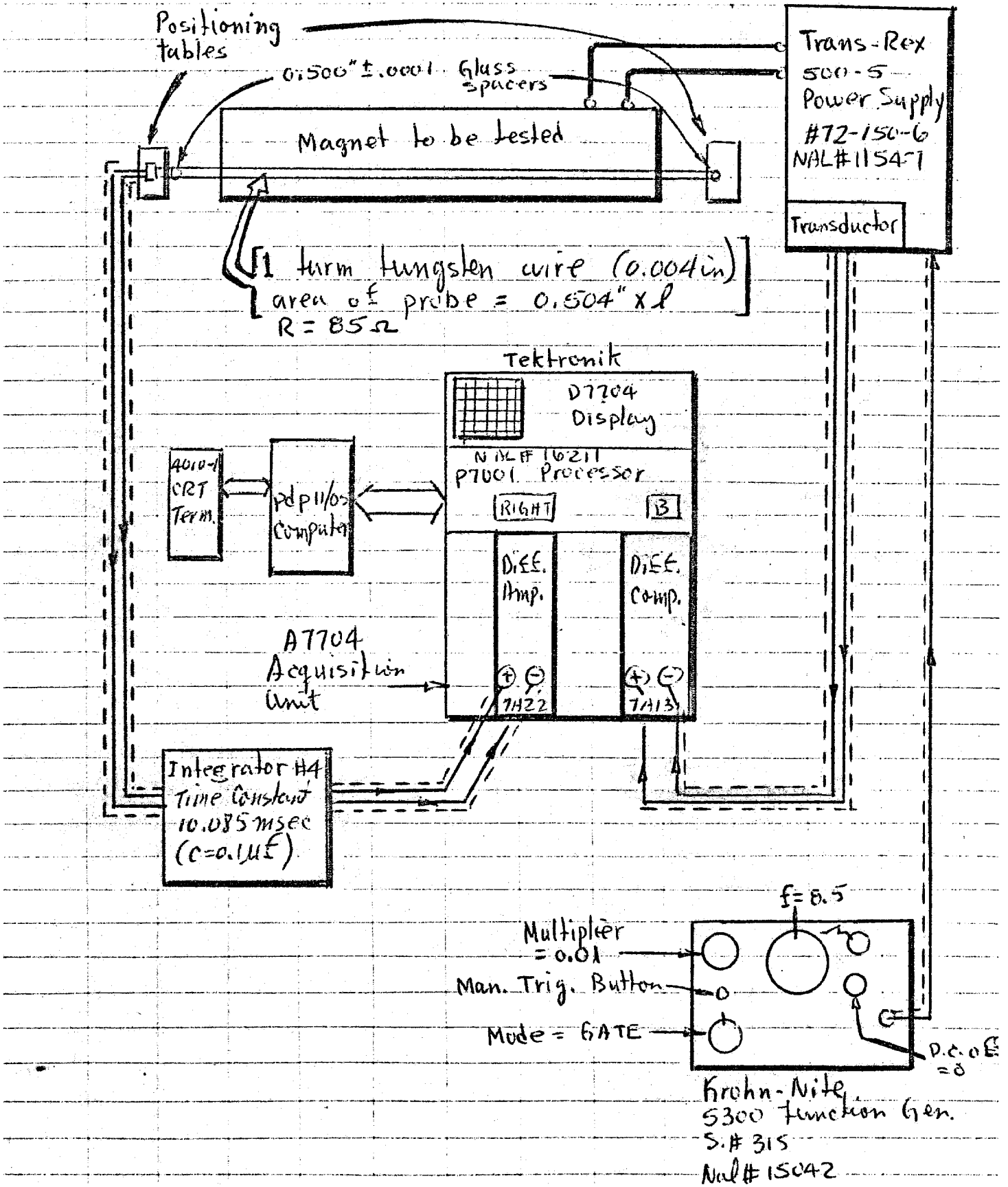
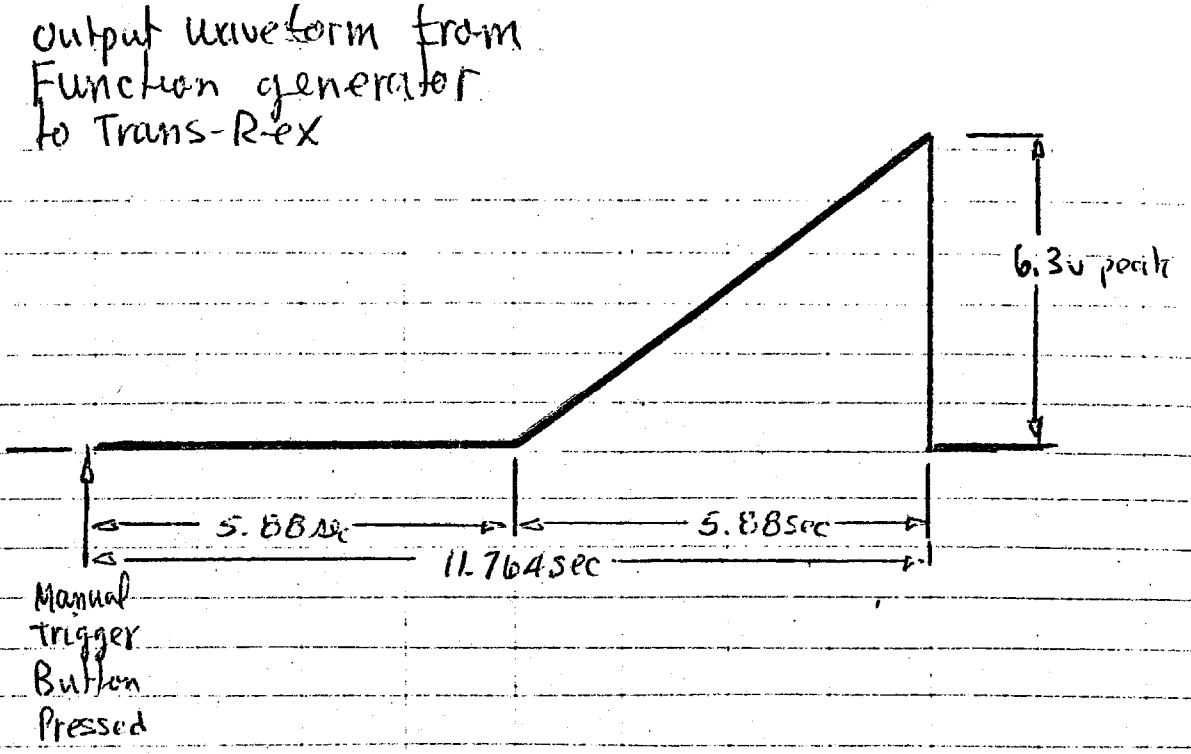
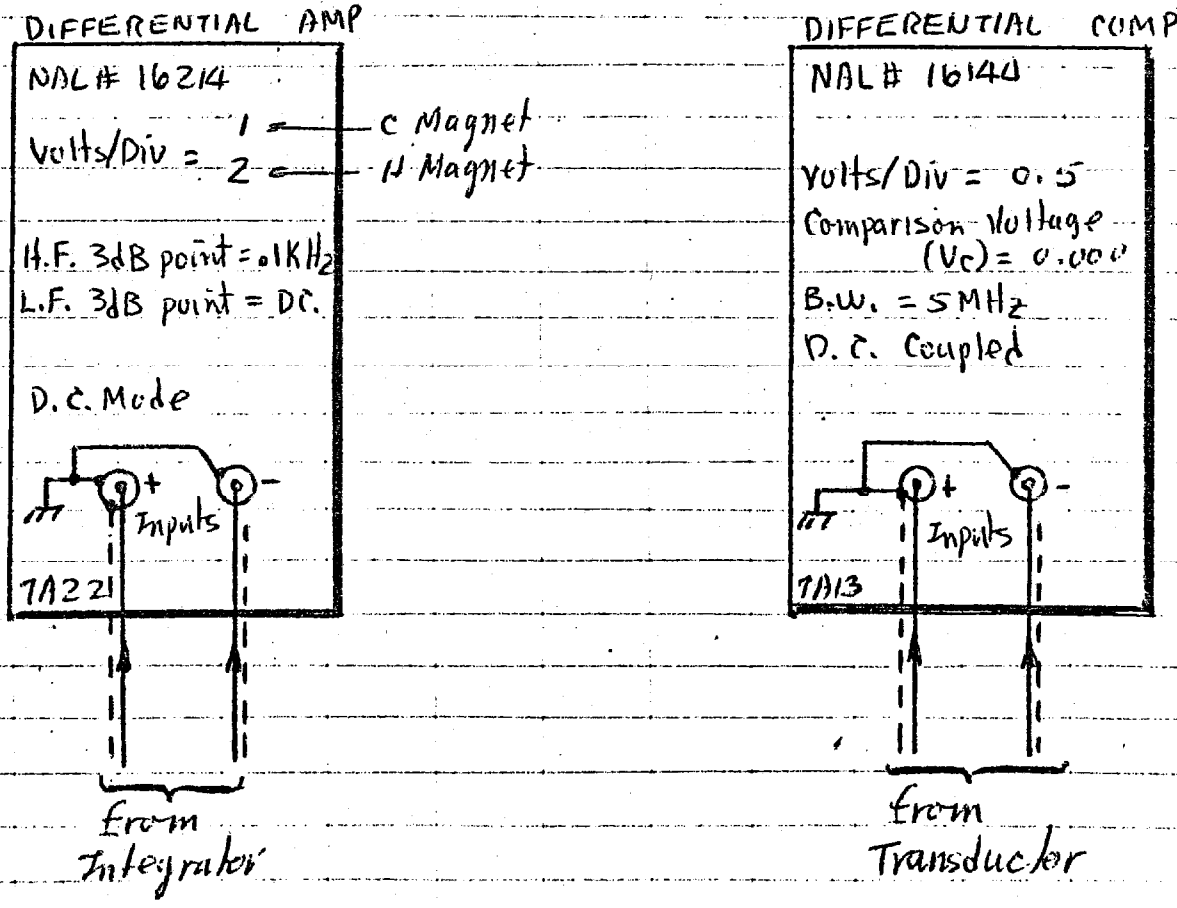


Fig. 2 Current Wave-Form & Plug-In's



PLUG-IN Detail



C-type Magnet

*GRA FA

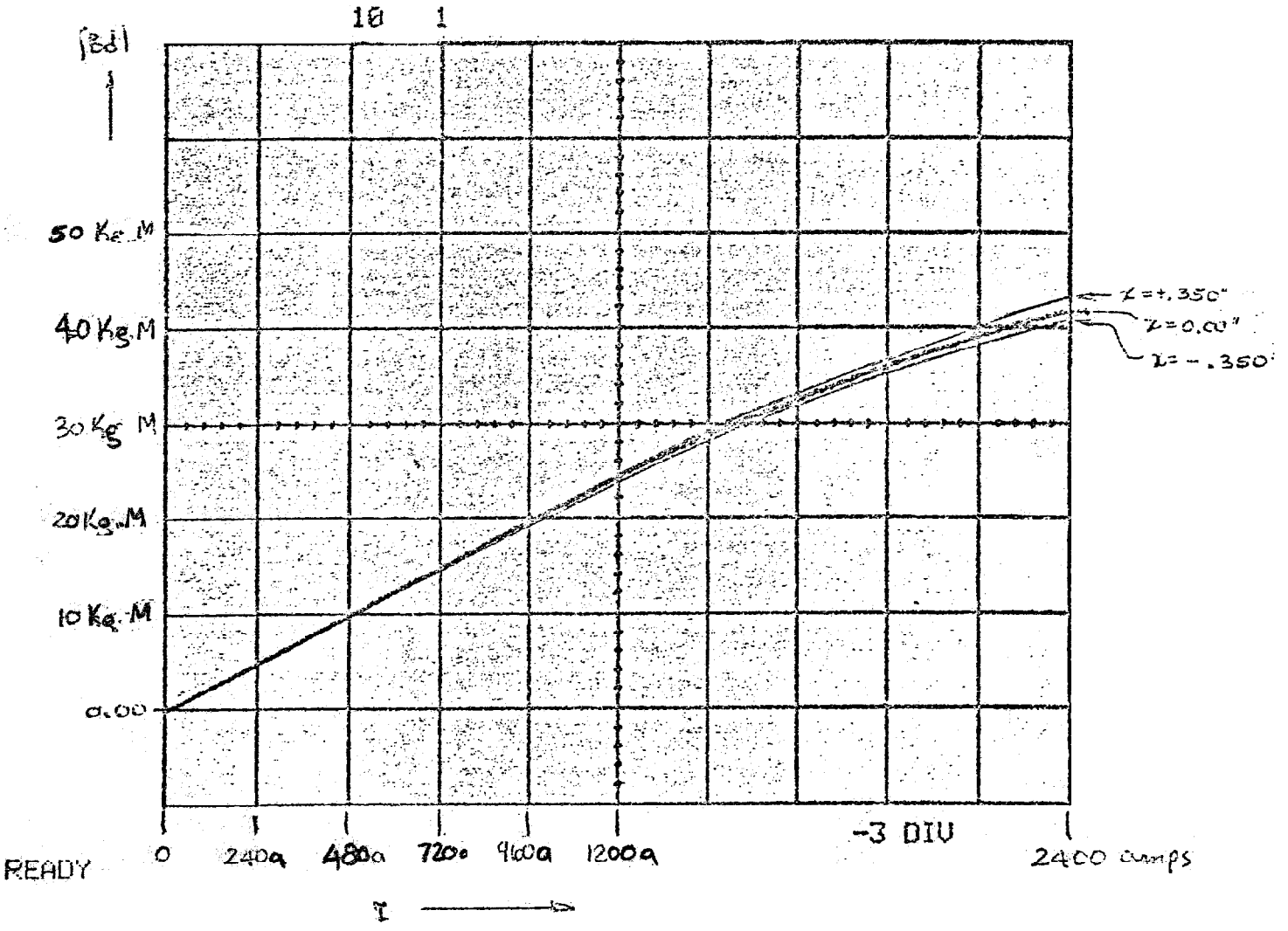


Fig 3. Excitation Curve of C-type Magnet for Integrated Field Value

H-type Magnet

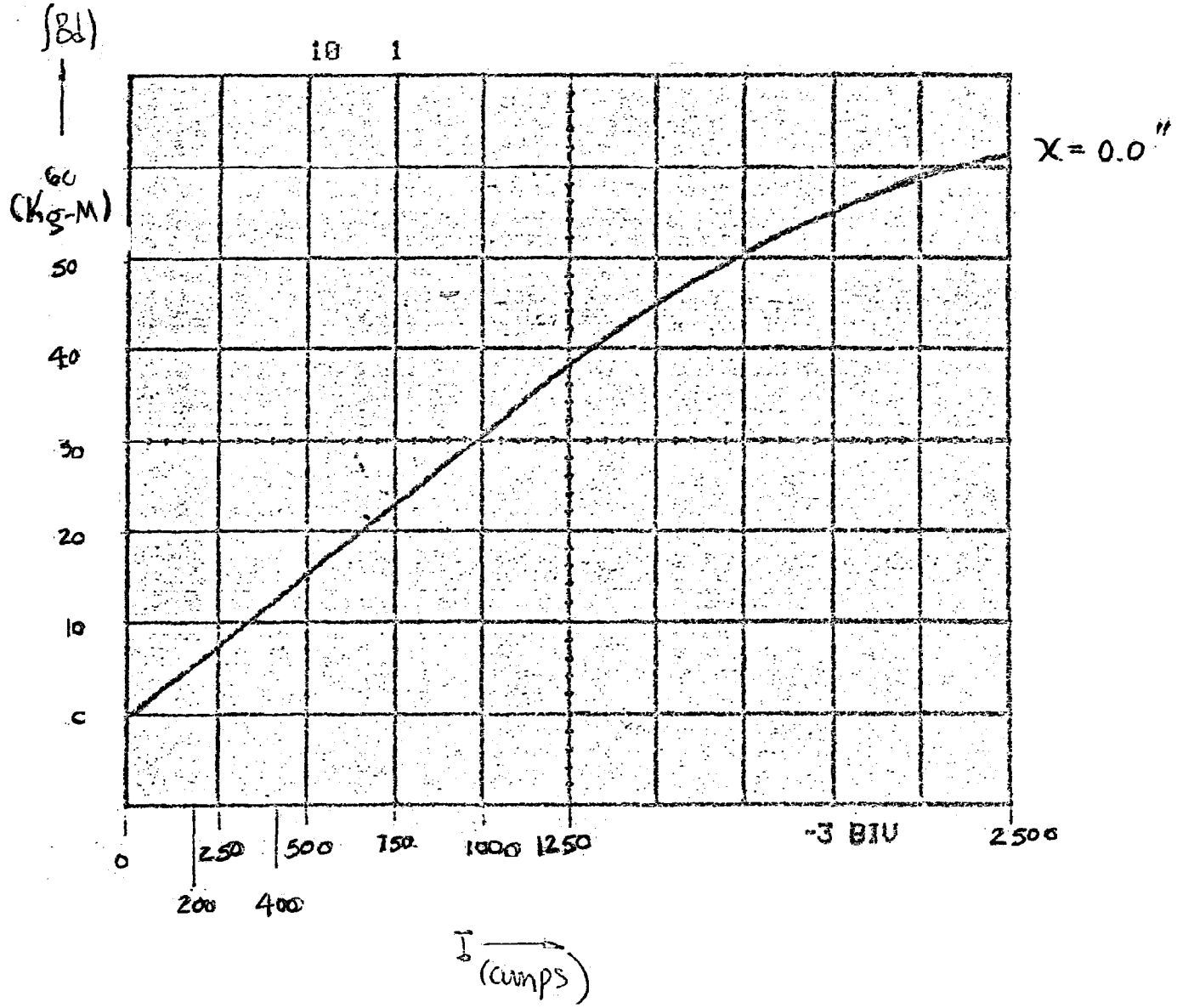


Fig 4 Excitation Curve of H-type Magnet for Integrated Field Value

B field @ zero - B field @ plus side
(Smoothed)

differentiation factor = 2^3

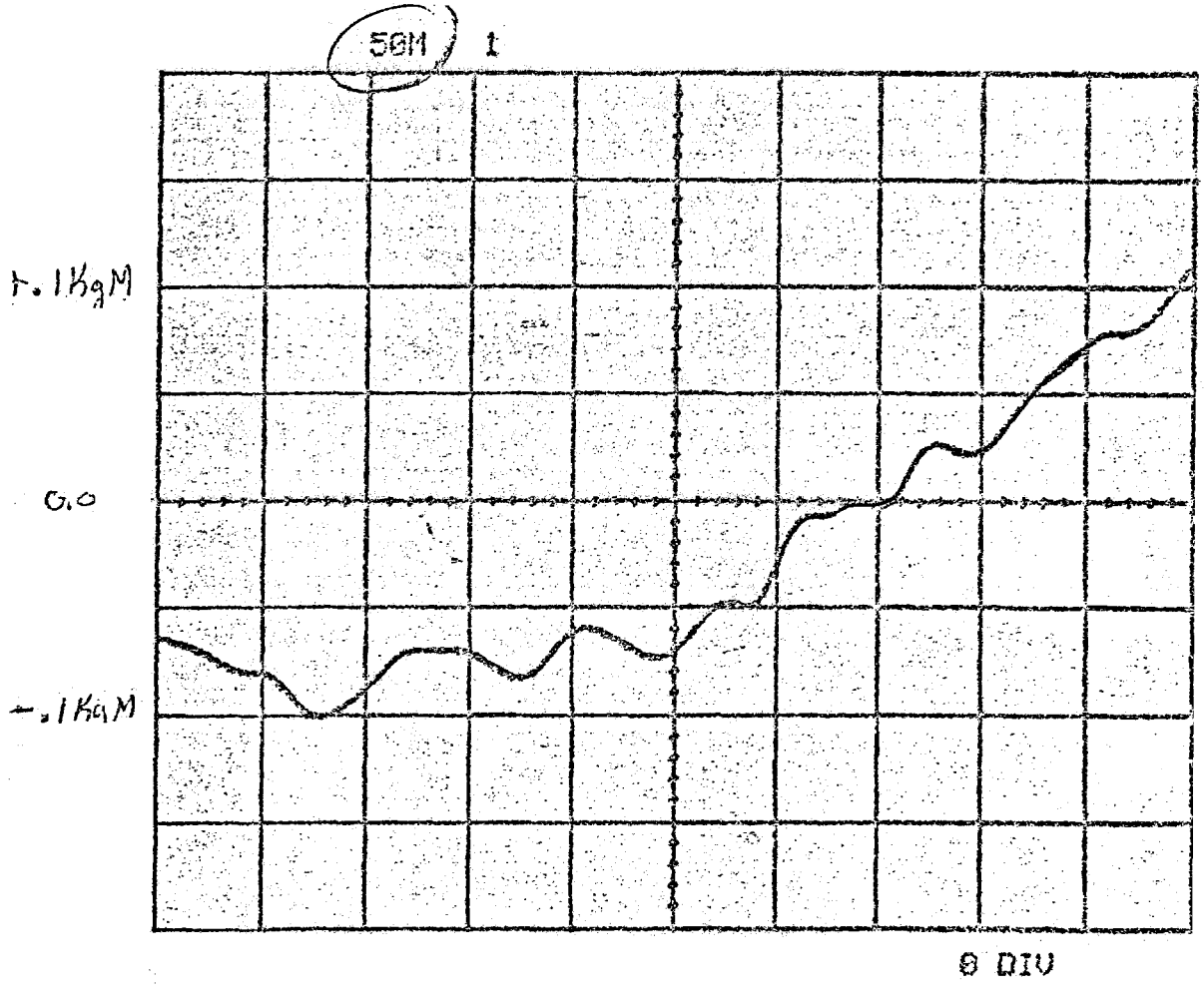


Fig 5 Difference of Integrated Field Values
between $x = 0.0"$ and $+0.35"$

B field @ zero − B field @ minus side
(smoothed)

differention factor = z^3

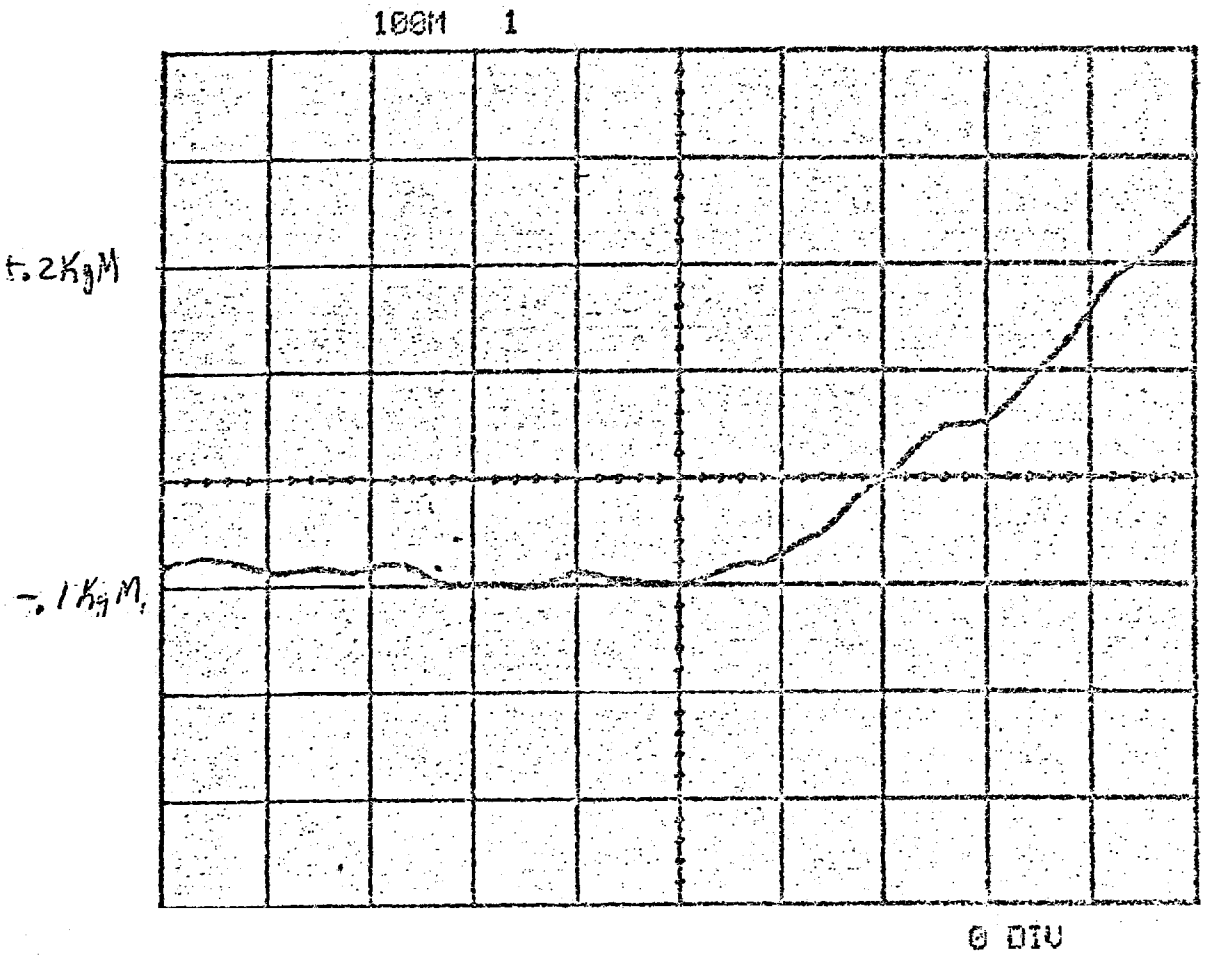


Fig 6. Difference of Integrated Field Values
between $x = 0.0"$ and $x = -0.35"$