Users Manual

HYSTERESIS LOOP TRACER

Model: HLT-111

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MOODY INTERNATIONAL
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ISO 9001 : 2000
Certified Company


HYSTERESIS LOOP TRACER
MODEL HLT-III
PHASE
H. BALANCE
IN PUT
AREA RATIO
DEMAG.
DC BALANCE
Y
E
X
G
MAG. FIELD
OFF
SOLENOID
ON
SCIENTIFIC EQUIPMENT
ROORKEE
SAMPLE HOLDER
SOLONOID

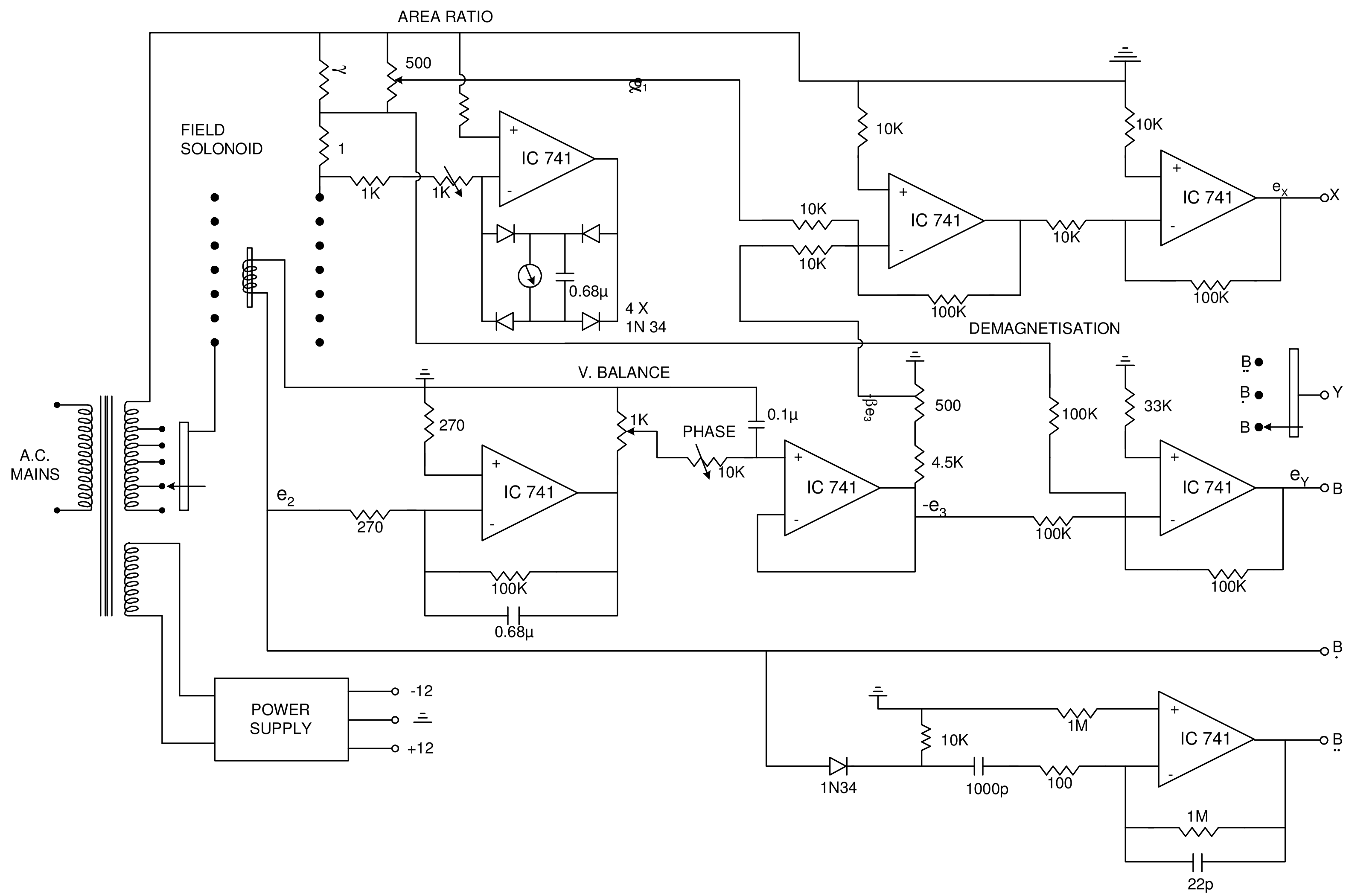
INTRODUCTION

A precise knowledge of various magnetic parameters of ferromagnetic substances and the ability to determine them accurately are important aspects of magnetic studies. These not only have academic significance but are also indispensable for both the manufacturers and users of magnetic materials.

The characteristics which are usually used to define the quality of the substance are coercivity, retentivity, saturation magnetisation and hysteresis loss. Furthermore, the understanding of the behaviour of these substances and improvement in their quality demand that the number of magnetic phases present in a system is also known.

The information about the aforementioned properties can be obtained from a magnetisation hysteresis loop which can be traced by a number of methods in addition to the slow and laborious ballistic galvanometer method. Among the typical representatives of AC hysteresis loop tracers some require the ring form of samples, while others can be used with thin films, wires or even rock and mineral samples. Toroidal or ring form samples are more convenient because of the absence of demagnetising effect due to closed magnetic circuits, but are not practicable to make all test samples in toroidal form with no free ends. Further every time the pickup and magnetising coils has to be wounded on them and hence are quite inconvenient and time consuming. In the case of open circuit samples, the free end polarities gives rise to demagnetising field which reduces the local field acting in the specimen and also makes the surrounding field non-uniform. Therefore, it becomes necessary to account for this effect lest the hysteresis loop is sheared. In case of conducting ferromagnetism, several additional problems arises due to eddy currents originating from the periodic changes in applied magnetic field. These currents give rise to a magnetic field in the sample which counteracts the variation of the external field and, in turn, renders the field acting in it non uniform and different from the applied field, both in magnitude and phase. Thus apart from resistive heating of the samples, because of the eddy currents the forward and backward paths traced near saturation will be different, which will lead to a small loop instead of a horizontal line in the magnetic polarisation (J) against field (H) plot. The intercept of the magnetic polarization axis, which corresponds to retentivity and saturation magnetic polarization tip will continue to increase with applied field upto very high values. Accordingly, retentivity (J_r) and saturation magnetic polarization (J_s) will be asymptotic values of the J-intercept and tip height respectively against H plots. Furthermore, the width of the loop along the direction of the applied field will depend on its magnitude and will continue to increase because shielding due to eddy currents is

CIRCUIT DIAGRAM OF MAGNETIC HYSTERESIS LOOP TRACER, HLT-111



proportional to the external field. Therefore, the true value to coercivity (JH_c) corresponding to no eddy currents situation, will be obtained by extrapolating the half loop width against field line to the H=0 axis. Obviously the effect of eddy currents will be more pronounced in thicker samples than in thin ones.

DESIGN PRINCIPLE

When a cylindrical sample is placed coaxially in a periodically varying magnetic field (say by the solenoid) the magnetisation in the sample also undergoes a periodic variation. This variation can be picked up by a pick up coil which is placed coaxially with the sample. Normally, the pickup coil is wound near the central part of the sample so that the demagnetisation factors involved are ballistic rather than the magnetometric.

For the uniform field H_a produced, the effective field H acting in the cylindrical sample will be

$H = H_a - NM$ where M is the magnetisation, or

$$H = H_a - \frac{NJ}{\mu_0} \qquad (1)$$

where N is the normalised demagnetisation factor including 4π and J is the magnetic polarization defined by

$$B = \mu_0 H + J \qquad (2)$$

with $B=\mu H$ or $\mu_0(H+M)$ as magnetic induction. The signal corresponding to the applied field, H_a, can be written as

$$e_1 = C_1 H_a \qquad (3)$$

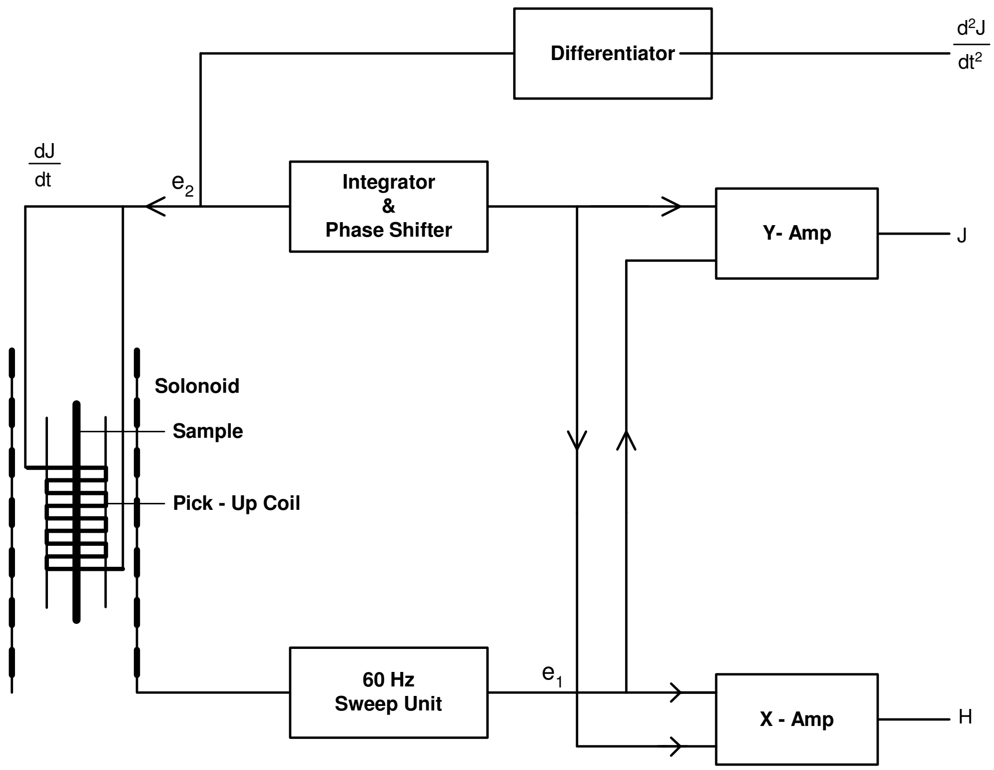
where C_1 is a constant.

Further the flux linked with the pickup coil of area A_c due to sample of area A_s will be

$$\phi = \mu_0(A_c - A_s)H' + A_s B$$

Here H' is the magnetic field, in the free from sample area of the pickup coil, will be different from H and the difference will be determined by the magnitude of demagnetising field. However, when the ratio of length of the sample rod to the diameter of the pickup coil is more than 10, the difference between H and H' is too small, so that

$$\phi = \mu_0(A_c - A_s)H + A_s B$$
$$= \mu_0 A_c H + A_s(B - \mu_0 H)$$



BLOCK DIAGRAM OF HYSTERISIS LOOP TRCER

$$\Rightarrow \phi = \mu_0 A_c H + A_s J \quad (4)$$

The signal e_2 induced in the pickup coil will be proportional to $\frac{d\phi}{dt}$

After integration the signal (e_3) will, therefore be

$$e_3 = C_3\phi = C_3\mu_0 A_c H + C_3 A_s J \quad (5)$$

Solving equations (1), (3) and (5) for J and H give

$$C_1C_3A_c\left(\frac{A_s}{A_c} - N\right)J = C_1e_3 - \mu_0 C_3 A_c e_1 \quad (6)$$

and
$$C_1C_3A_c\left(\frac{A_s}{A_c} - N\right)H = C_3A_se_1 - \frac{NC_1\,e_3}{\mu_0} \quad (7)$$

Based on these equations an electronic circuit may be designed to give the values of J and H and hence the hysteresis loop.

In case the sample contains a number of magnetically different constituents, the loop obtained will be the algebraic sum of individual loops of different phases. The separation of these is not easy in a J-H loop while in a second derivative of J, $\frac{d^2J}{dt^2}$, the identification can be made very clear.

EXPERIMENTAL DESIGN AND ANALYSIS

The aim is to produce electrical signals corresponding to J and H as defined in Eqs. (6) and (7) so that they can be displayed on CRO (cathode ray oscilloscope). Moreover, it should be able to display $\frac{d\phi}{dt}$ and $\frac{d^2\phi}{dt^2}$ as a function of H or usual time base of the CRO.

A detailed circuit diagram is shown in Fig. 2. The magnetic field has been obtained with a multilayered solenoid driven by the AC mains at 60 Hz and supplied through a variable transformer arrangement. The magnetic field has been calibrated with a Hall probe and is found to be within ±3% of the maximum value over a length of 5 cm. across the central region. The instantaneous current producing the field is passed through a resistor R_1 in series with the solenoid and measured with an AC ammeter. The resulting signal e_1 is applied across a 500Ω helipot and an adder amplifier through a 100 KΩ resistance.

The signal e_2 corresponding to the rate of change of flux is obtained from a pickup coil wound on a non conducting tube. Necessary arrangements have been made to place the sample coaxially with the pickup winding and in uniform magnetic field. The pick-up coil is connected to point B (Fig. 2) through twisted wires, where e_2 constitutes the input for further circuit. To obtain J, e_2 is fed to an adjustable gain integrator. Because of capacitive coupling of pickup coil and solenoid, self inductance of pickup coil and integration operation an additional phase will be introduced in the output signal e_3, whose sign can be made negative with respect to e_1 by interchanging the ends of the pickup coil. To render e_3 completely out of phase with e_1, a phase shifter consisting of a 1KΩ potentiometer and 1μF capacitor has been connected at the output of integrator. Amplitude attenuation due to this network is compensated by the gain of the integrator and is not important as addition of signals is performed afterwards.

The out of phase signals e_1 and e_3 are added at the input of a unity gain adder amplifier and its output which is proportional to J is applied to Y-input of a CRO. Fractions of these signals corresponding to the demagnetisation factor and area ratio form the input of another adder amplifier with gain 10 whose output after further amplification of 10 is fed to the X-input of CRO and gives H. It may be mentioned that the gains of the amplifier can be adjusted but should always be such that the operational amplifiers are not loaded to saturation.

The selector switch (SW) can change the Y-input of CRO to J, $\frac{dJ}{dt}$ or $\frac{d^2J}{dt^2}$. The $\frac{dJ}{dt}$ signal is taken directly from the pickup while $\frac{d^2J}{dt^2}$ is obtained through an operational amplifier differentiater.

Let us now analyze the circuit.

The magnetic field at the centre of the solenoid for current i flowing through it will be

$$H_a = Ki \qquad (8)$$

also $$e_1 = R_1 i \qquad (9)$$

with symbols defined above Eq. (9) reduces to Eq. (3) with $C_1=R_1/K$. Further, when the sample is placed in a pickup coil of n turns

$$e_2 = n\left(\frac{d\phi}{dt}\right)$$

$$= n\mu_0 A_c\left(\frac{dH}{dt}\right) + nA_s\left(\frac{dJ}{dt}\right) \qquad (10)$$

by substituting ϕ from Eq. (4), we get

$$-e_3 = -g_1\int e_2 dt$$

$$= -g_1 n\mu_0 A_c H - g_1 n A_s J \qquad (11)$$

Where g_1 is the gain of the integrator and phase shifter combination. The sum of e_1 and $-e_3$ after amplification becomes.

$$e_y = -g_y(e_1 - e_3)$$

$$= -g_y\left(C_1 H - g_1 n\mu_0 A_c H + C_1 \frac{NJ}{\mu_0} - g_1 n A_s J\right) \qquad (12)$$

Using Eq. (1), (3) and (11), g_y is the gain of this amplifier. If we adjust $C_1 = g_1 n\mu_0 A_c$, then

$$e_y = g_y\, g_1 n A_c \left(\frac{A_s}{A_c} - N\right) J \qquad (13)$$

Fraction α and β of e_1 and $-e_3$ respectively, are added together at the input of the first amplifier for the X-input. If g_x be the total gain of both amplifiers we get

$$e_x \quad = g_x(e_1 - Be_3)$$

$$= g_x g_1 n\mu_0 A_c(-B)H + g_x g_1 n A_c\left(N - B\frac{A_s}{A_c}\right)J \qquad (14)$$

after substituting $C_1 = g_1 n\mu_0 A_c$, J will be eliminated from the right hand side of (14). By adjusting $\alpha$and β such that

$$\alpha = \frac{A_s}{A_c} \text{ and } \beta = N \qquad (15)$$

we get $e_x = g_x g_1 n\mu_0 A_c\left(\frac{A_s}{A_c} - N\right)H$ (16)

Equation (13) and (16) can be written as

$$H = G_0 \frac{e_x}{\left(\frac{A_s}{A_c} - N\right)} \qquad (17)$$

and $$J = \frac{\mu_0\, g_x\, e_y}{g_y\left(\frac{A_s}{A_c} - N\right)} \qquad (18)$$

Where

$$\frac{1}{G_0} = g_x g_1 n \mu_0 A_c \qquad (19)$$

Equations (17) and (18) define the magnetic quantities H and J in terms of electrical signals e_x and e_y respectively.

METHOD

Calibration

When an empty pickup coil is placed in the solenoid field, the signal e_2 will only be due to the flux linking with coil area. In this case J = 0, α = 1, N = 0 so that $H = H_a$ and Eqs. (13) and (16) yield

$$e_y = 0 \quad \text{and} \quad e_x = G_0^{-1} H_a \qquad (20)$$

i.e. on CRO it will be only a horizontal straight line representing the magnetic field H_a. This situation will, obviously, be obtained only when the condition for (13) is satisfied. Thus without a sample in the pickup coil a good horizontal straight line is a proof of complete cancellation of signals at the input of the Y-amplifier. This can be achieved by adjusting the gain of the integrator and also the phase with the help of network meant for this purpose. From known values of H_a and the corresponding magnitude of e_x, we can determine G_0 and hence calibrate the instrument. The dimensions of a given sample define the values of demagnetisation factor and the area ratio pertaining to the pickup coil. The demagnetisation factor can be obtained from the Appendix. These values are adjusted with the value of 10 turn helipots provided for this purpose. The value of the area ratio can be adjusted upto three decimal places whereas that of N upto four (Zero to 0.1 max.). The sample is now placed in the pickup coil. The plots of J, $\frac{dJ}{dt}$ and $\frac{d^2J}{dt^2}$ against H can be studied by putting the selector switch at appropriate positions. The graph of these quantities can also be obtained from time base by using the internal time base of CRO.

Since eddy currents are present in conducting ferromagnetic materials, the resulting J-H loop has a small loop in the saturation portion due to difference in phases for the forward paths. Moreover, these plots do not show horizontal lines at saturation and hence their shapes can't be employed as a criterion to adjust the values of demagnetisation factor.

The values of loop width, intercept on the J-axis and saturation position are determined in terms of volts for different applied fields. Plots of these against magnetic field are then used to extract the value of coercivity, retentivity and saturation magnetic polarization. The first corresponds to the intercept of the width against currents straight line on the Y-axis and it is essentially the measure of the width under no shielding effects. On the other hand, the remaining two parameters are derived from asymptotic extensions of the corresponding plots because these refer to the situation when shielding effects are insignificant. Caution is necessary in making the straight line fit for loop widths as a function of current data as the points for small values of magnetic current have some what lower magnitudes. This is due to the fact that incomplete saturation produces lower coercivity values in the material. The geometrically obtained values of potentials are, in turn, used to find the corresponding magnetic parameters through equations (17) and (18).

If the area ratio for a particular sample is so small that the loop does not exhibit observable width, the signal e_x can be enhanced by multiplying α and β by a suitable factor and adjusting the two helipots accordingly. The ultimate value of the intercept can be normalised by the same factor to give the correct value of coercivity.

Observations

For this equipment diameter of pickup coil = 3.21mm

g_x = 100

g_y = 1

Sample : Commercial Nickel

Length of sample : 39 mm

Diameter of sample : 1.17 mm

Therefore,

Area ratio $\left(\frac{A_s}{A_c}\right) = 0.133$

Demagnetisation factor (N) = 0.0029 (Appendix)

Calibration

Settings : Without sample. Oscilloscope at D.C. Time base EXT. H Bal., Phase and DC Bal. adjusted for horizontal straight line in the centre. Demagnetisation at zero and Area ratio 0.40 at magnetic field 200gauss (rms)

e_x = 64mm, or

= 7.0V (if read by applying on Y input of CRO)

For Area ratio 1

e_x = 160mm, or

= 17.5V

From Eq. (20)

$$G_0(\text{rms}) = \frac{200}{160} = 1.25\text{gauss/mm}$$

$$G_0(\text{peak to peak}) = 1.25\text{x}2.82$$

$$= 3.53\text{gauss/mm},$$

also

$$G_0(\text{rms}) = \frac{200}{17.5} = 11.43 \text{ gauss/volt}$$

$$G_0(\text{peak to peak}) = 11.43\text{x}2.82$$

$$= 32.23\text{gauss/volt}$$

By adjusting N and $\frac{A_s}{A_c}$ as given above the J-H loop width is too small. Thus both are adjusted to three times i.e. 0.399 and 0.0087 respectively (full value of area ratio pot. = 1.000 and full value of demag. pot. = 0.100)

(a) Coercivity

S.No.	Mag. Field (rms) (Gauss)	2xLoop width (mm)
1.	30	7.0
2.	62	9.0
3.	94	11.0
4.	138	12.5
5.	179	14.0
6.	226	15.5
7.	266	16.75
8.	302	18.0
9.	336	18.75

(b) Saturation magnetisation

S.No.	Mag. Field (rms) (Gauss)	Tip to tip height (mv)
1.	29	205
2.	61	370
3.	96	400
4.	137	420
5.	176	430
6.	223	440
7.	264	445
8.	298	450
9.	331	450

(c) Retentivity

S.No.	Mag. Field (rms) (Gauss)	2xIntercept (mV)
1.	29	170
2.	61	260
3.	95	265
4.	136	270
5.	175	270
6.	219	275
7.	263	275
8.	302	275
9.	335	275

From the graphs Fig. (4) and (5)

Loop width = 2.9mm (after dividing by the multiplying factor 3)

2xIntercept = 280mV

Tip to tip height = 457.5mV

CALCULATIONS

(a) Coercivity

Since e_x = ½ x loop width = ½ x 2.9 = 1.45 mm

$$H = \frac{G_0\, e_x}{\left(\frac{A_s}{A_c} - N\right)} = \frac{3.53 \times 1.45}{(0.133 - 0.0029)} = 39.3\text{Oe} \quad \text{from equation (17)}$$

(b) Saturation magnetisation

$$\mu_s = \frac{J_s}{4\pi} \qquad \text{due to equation (2)}$$

$(e_y)_s$ = ½ x tip to tip height = 457.5/2 = 228.75mV

$$\mu_s = \frac{J_s}{4\pi} = \frac{G_0\, \mu_0\, g_x\, (e_y)_s}{g_y \left(\frac{A_s}{A_c} - N\right) \times 4\pi} \qquad \text{from equation (18)}$$

$$= \frac{32.23 \times 1 \times 100 \times 0.229}{1 \times (0.133 - 0.0029) \times 12.56} = 452 \text{ gauss}$$

(c) Retentivity

$$\mu_r = \frac{J_r}{4\pi} \qquad \text{due to equation (2)}$$

$(e_y)_r$ = ½ x (2xIntercept) = ½ x 280= 140mV

$$\mu_r = \frac{J_r}{4\pi} = \frac{G_0\, \mu_0\, g_x\, (e_y)_r}{g_y \left(\frac{A_s}{A_c} - N\right) \times 4\pi} = \frac{32.23 \times 1 \times 100 \times 0.140}{1 \times (0.133 - 0.0029) \times 12.56} = 276\text{gauss}$$

Note : The above observation and calculation are given as a typical example. Test results of individual unit are supplied with the unit separately

QUESTIONS

1. Explain the difference in J-H loop of hard and soft iron samples**?**
2. Why the loop width graph was extrapolated to zero magnetic field**?**
3. Why the asymptotes were drawn for finding J_s and J_r**?**

APPENDIX

Demagnetizing Factors for Ellipsoids of Revolution For prolate spheroids, c is the polar axis

C/a	$N_c/4$	C/a	$N_c/4$	C/a	$N_c/4$
1.0	0.333 333	4.0	0.075 407	20	0.006 749
1.1	308 285	4.1	72 990	21	6 230
1.2	286 128	4.2	70 693	22	5 771
1.3	266 420	4.3	68 509	23	5 363
1.4	248 803	4.4	66 431	24	4 998
1.5	0.232 981	4.5	0.064 450	25	0.004 671
1.6	218 713	4.6	62 562	30	3 444
1.7	205 794	4.7	60 760	35	2 655
1.8	194 056	4.8	59 039	40	2 116
1.9	183 353	4.9	57 394	45	1 730
2.0	0.173 564	5.0	0.050 821	50	0.001 443
2.1	164 585	5.5	48 890	60	1 053
2.2	156 326	6.0	43 230	70	0 805
2.3	148 710	6.5	38 541	80	0 637
2.4	141 669	7.0	34 609	90	0 518
2.5	0.135 146	7.5	0.031 275	100	0.000 430
2.6	129 090	8.0	28 421	110	363
2.7	123 455	8.5	25 958	120	311
2.8	118 203	9.0	23 816	130	270
2.9	113 298	9.5	21 939	140	236
3.0	0.108 709	10	0.020 286	150	0.000 209
3.1	104 410	11	17 515	200	125
3.2	100 376	12	15 297	250	083
3.3	096 584	13	13 490	300	060
3.4	093 015	14	11 997	350	045
3.5	0.089 651	15	0.010 749	400	0.000 036
3.6	86 477	16	09 692	500	24
3.7	83 478	17	08 790	600	17
3.8	80 641	18	08 013	700	13
3.9	77 954	19	07 339	800	10

From 'Introduction to Magnetic Materials' by B.D. Cullity (Addison - Wesley Pub. Co.)1972.

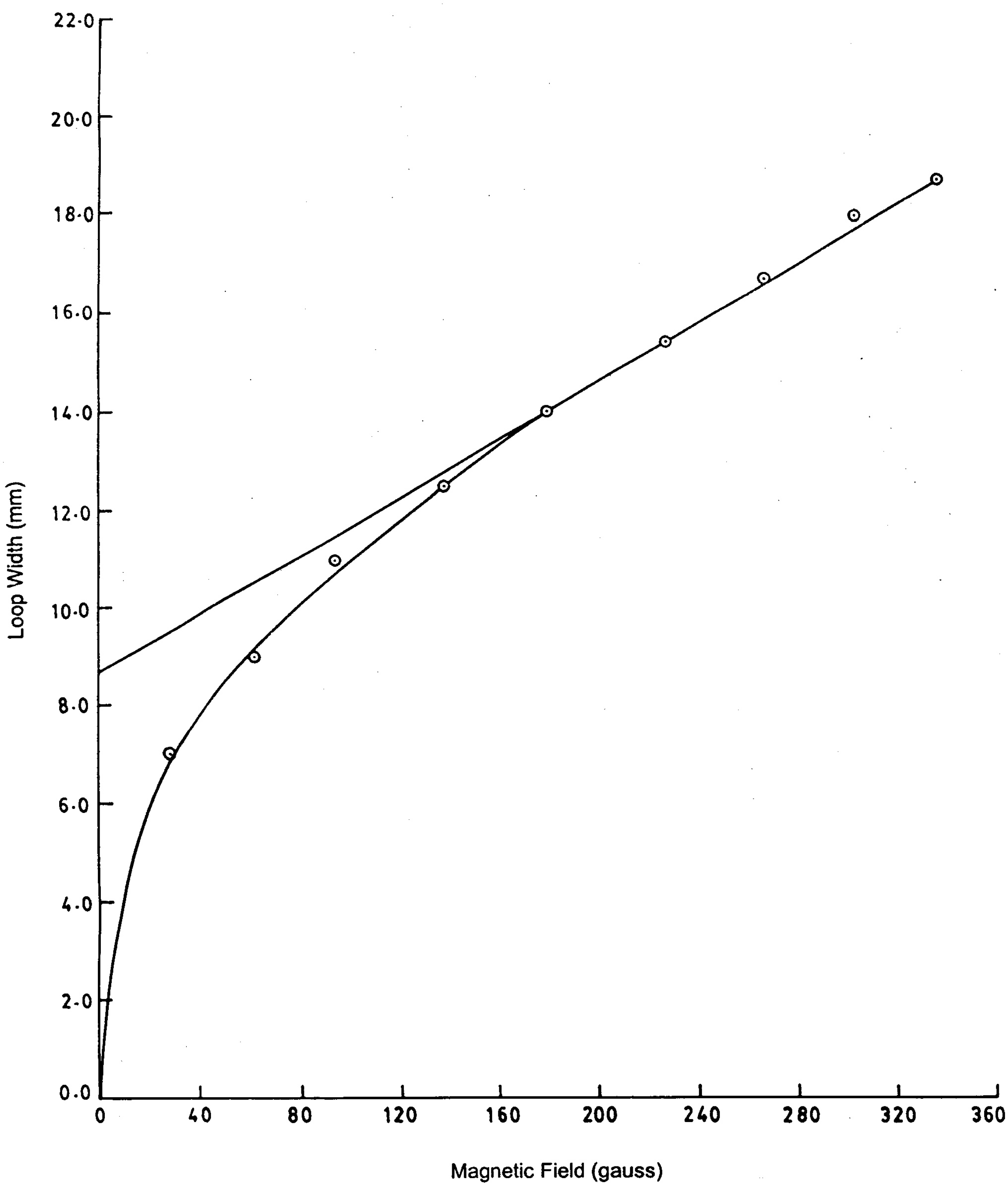


Fig. 4 Dependence of Loop Width on Magnetic Field. The Intercept of Straight Line fit gives Coercivity from equation

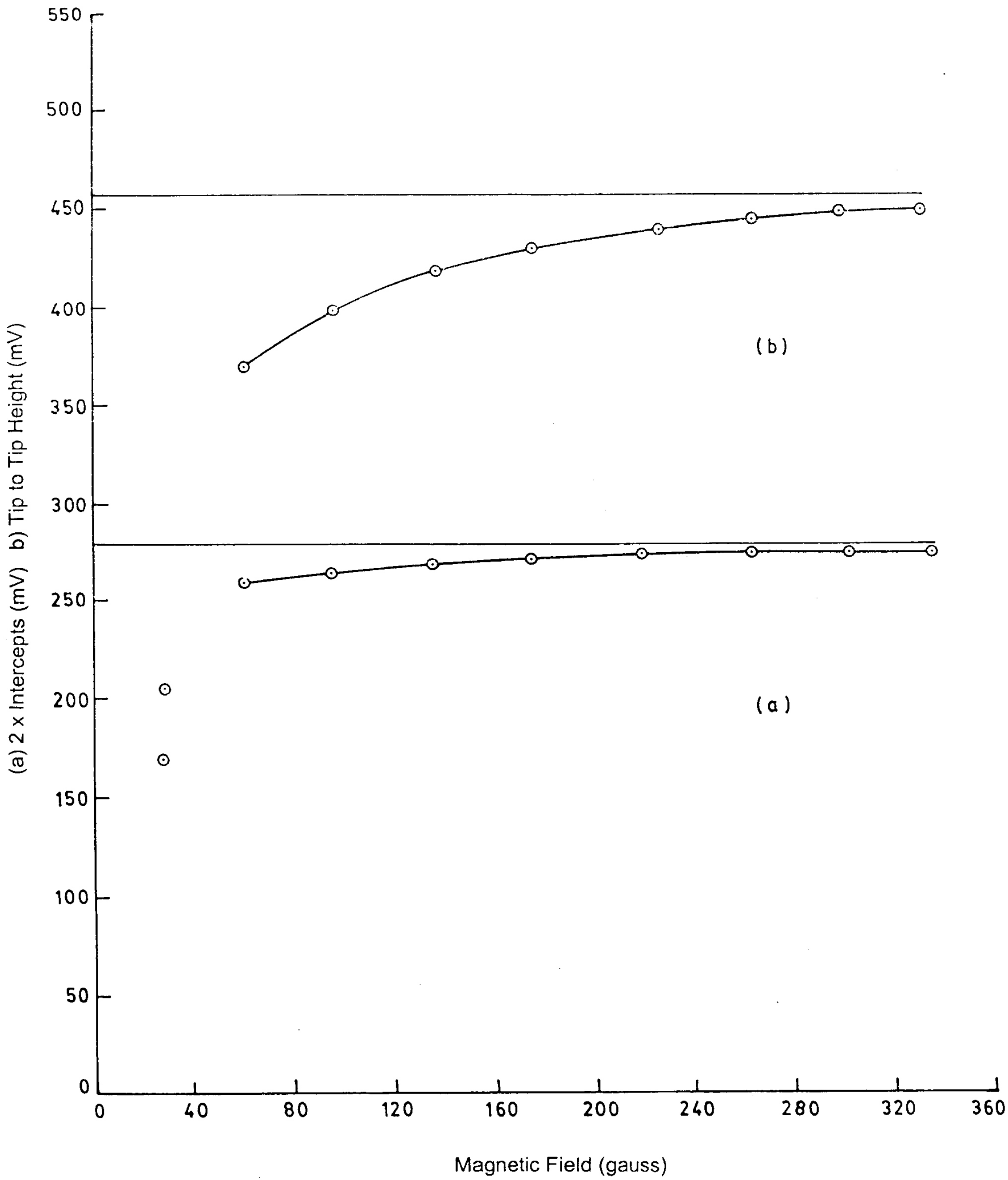
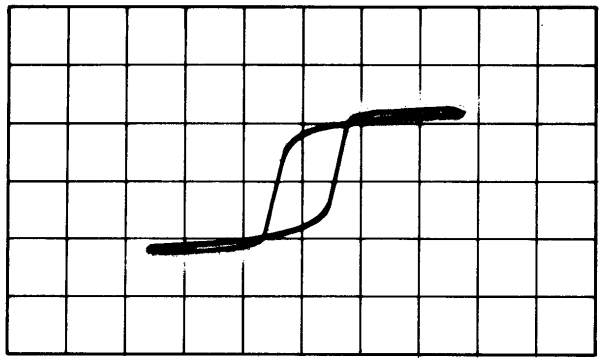
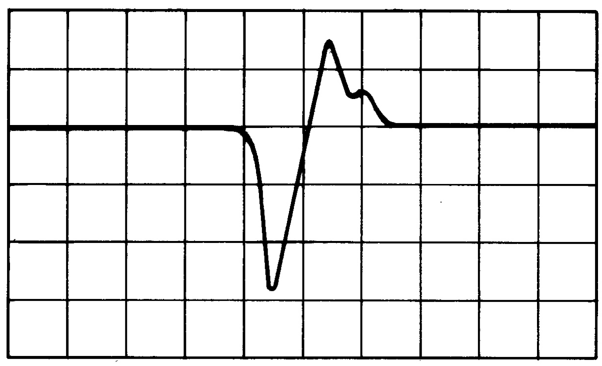


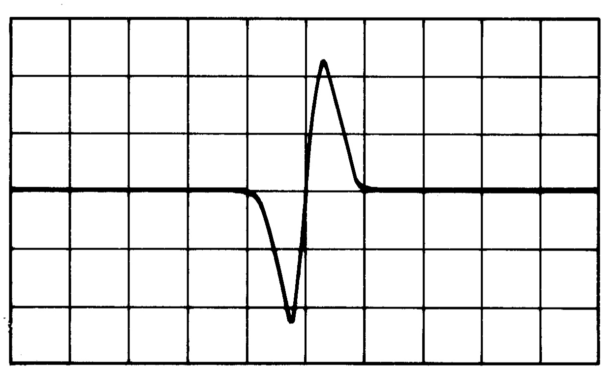
Fig. 5 Dependence of (a) Twice the Intercept on the Y-axis, and (b) Tip to Tip Separation of J-H Plot for Commercial Nickel on Magnetic Field.



J-H LOOP



$\frac{d^2J}{dt^2}$ SHOWING TWO MAGNETIC PHASE



$\frac{d^2J}{dt^2}$ SHOWING A SINGLE MAGNETIC PHASE IN THE SAMPLE