Development of Electronic Hysteresigraph for DC Magnetic Testing of Soft Magnetic Materials

by

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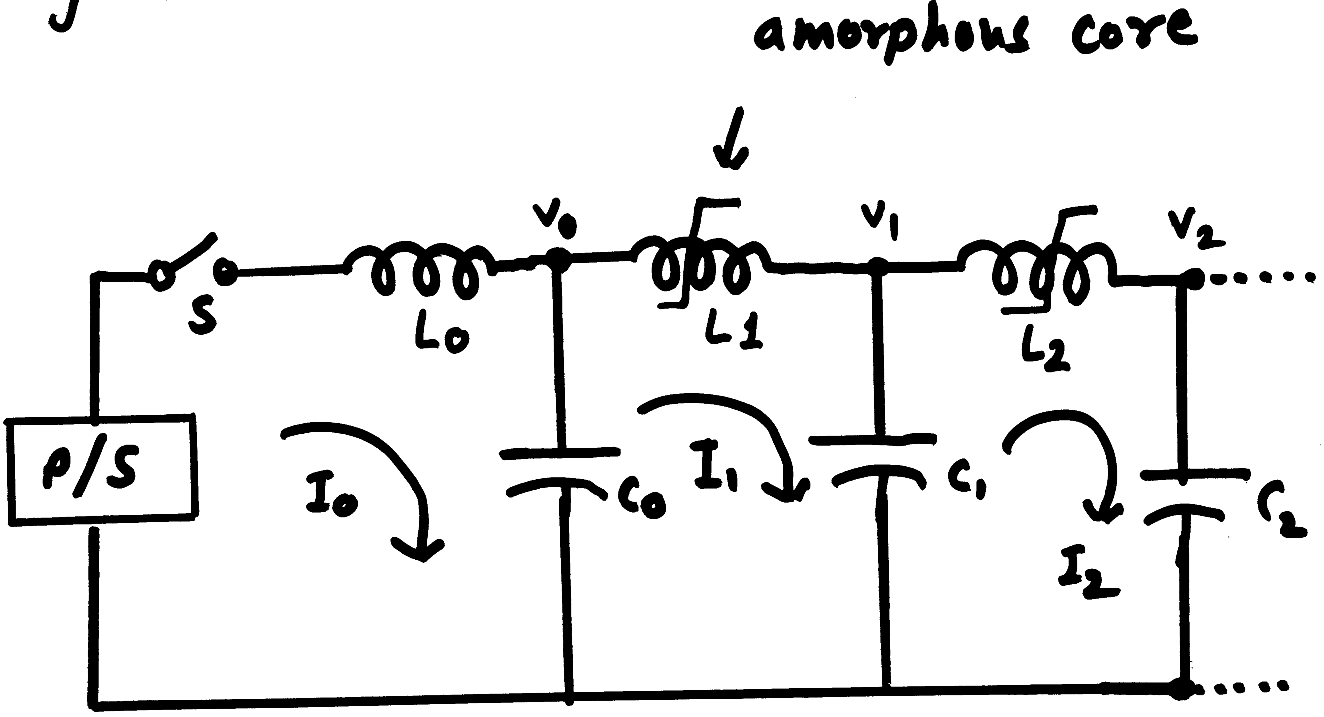
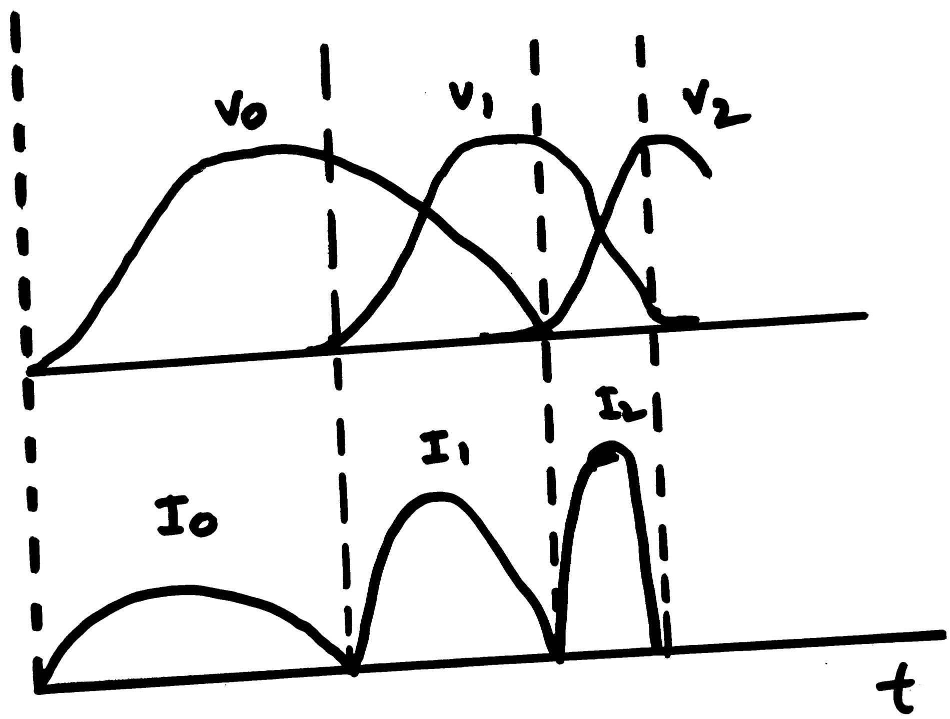
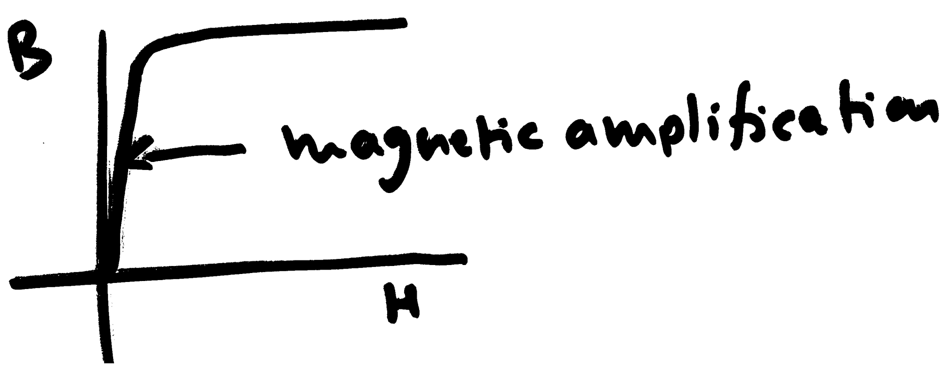
Magnetic Switches:







Brief Background: We have undertaken dev. of Magnetic Pulse compressors for Pulse P/S to be used in Accel and Laser systems.

* Initial stages of Magnetic switches - uses amorphous cores for obtaining Pulses ~ 1 μs ~ 100 ns, due to large ΔB, high pulse current is generated
* Further, to compress the pulses in the order of 50 ns, we used NiZn ferrite toroids.
* Therefore, we developed electronic hyst eqpt to measure hyst parameters of magnetic materials.

Electronic Hysteresisgraph

* An automatic device for DC magnetic testing of soft Magnetic materials

Principle of Device

* It is based on the classical method, but the Ballistic Galvanometer has been replaced by an electronic Integrator, and a semiconductor switch,
* Electronic Hysteresis graph method is proposed for determining the dc magnetic materials

Main features of electronics hysteresis graph equipment.

(a) Ability to trace Magnetic curve keeping induction flux derivative (dB/dt) constant which minimize the error due to the eddy currents in the test specimen.

(b) The low drift of integrating circuit, which allows tracing Hystersis loop of specimen in 100 sec.

Instrument Description

The hysteresigraph employs a instrumentation amplifiers, power amplifiers (current), Bistable circuits (timing), electronic integrator, dB/dt control loop & PC base data acquisition system.

The block diagram of the instrument is shown in fig.1
Electronic hysteresis graph instrument consist of

1. B loop : Amplifier and integrator for magnetic induction
2. Magnetizing current loop: Current Amplifier, integrator and Bistable circuit for a perfect symmetry of the hysteresis loop, stability of excitation levels (dB/dt constant)
3. Digital storage oscilloscope: - For tracing of hysteresis loop Accuracy: 1 %
4. ADC: - Computerized data acquisition system software for calculation of magnetic properties of soft magnetic material
   Data presentation on PC has accuracy of ADC (12 Bit) H & B ~ 0.1%

Instrument Operation:

* Magnetic test sample: Three windings,
  - N_p: magnetizing field
  - N_b: develop voltage proportional to the time derivative of the induction field (dB/dt)
  - N_c: supplies control loop: → Magnetizing Current loop - maintaining dB/dt constant.

* Secondary Ciriuit (B- Ciriuit): →

  Field change gives rise to an induced voltage in N_b, which is integrated drives the Y axis

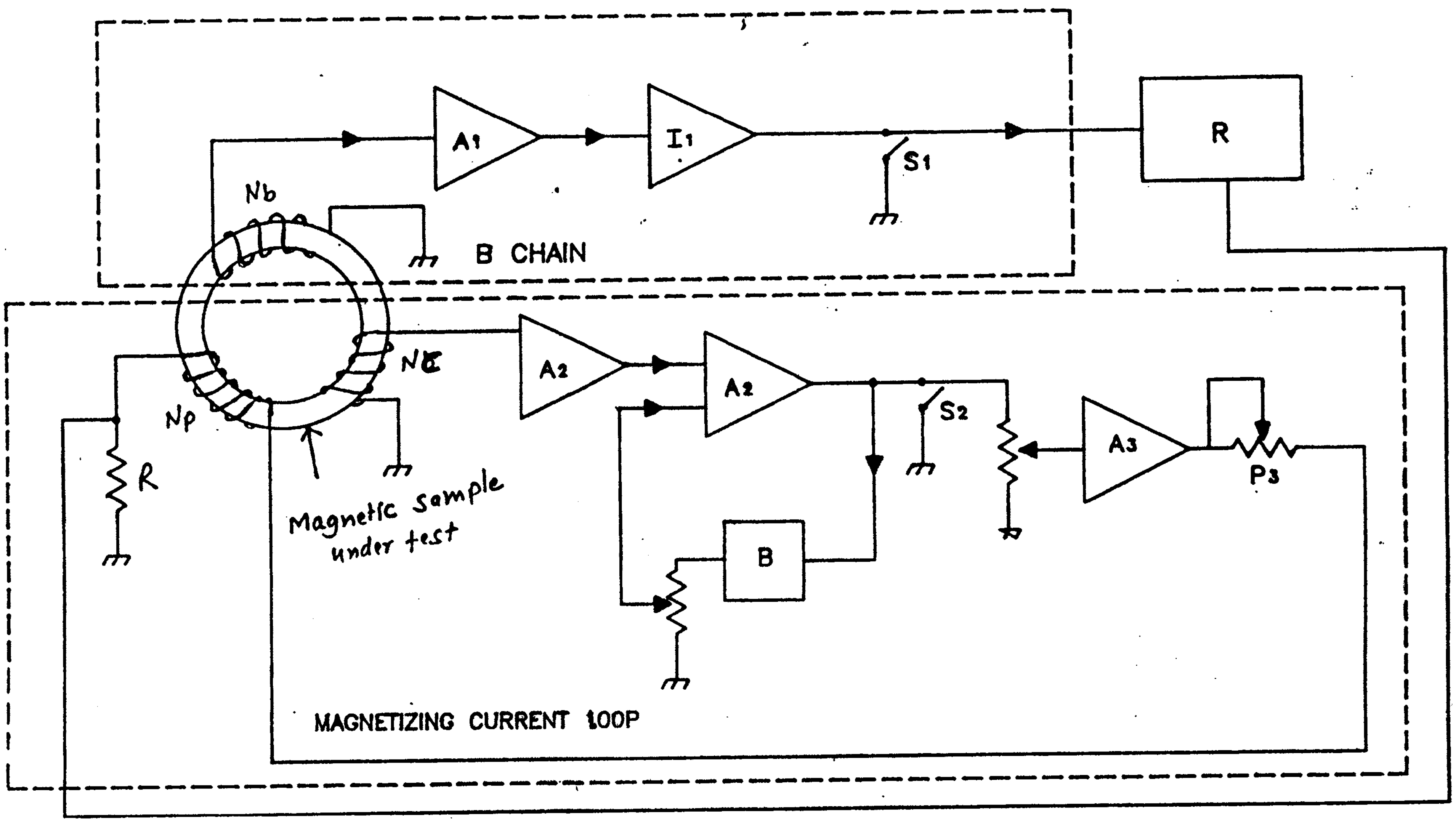
$$V_o = N_b \frac{\partial \phi}{\partial t} = N_b A \frac{dB}{dt} \rightarrow B$$

* Magnetization Ciriuit:

  The magnetization current is supplied by the power amplifier which is driven by the integrator. The output of this integrator is the integral of the algebric sum of two voltages -

  i) Constant voltage coming from Bistable circuit

  ii) Voltage proportional to the induced voltage in N_c.

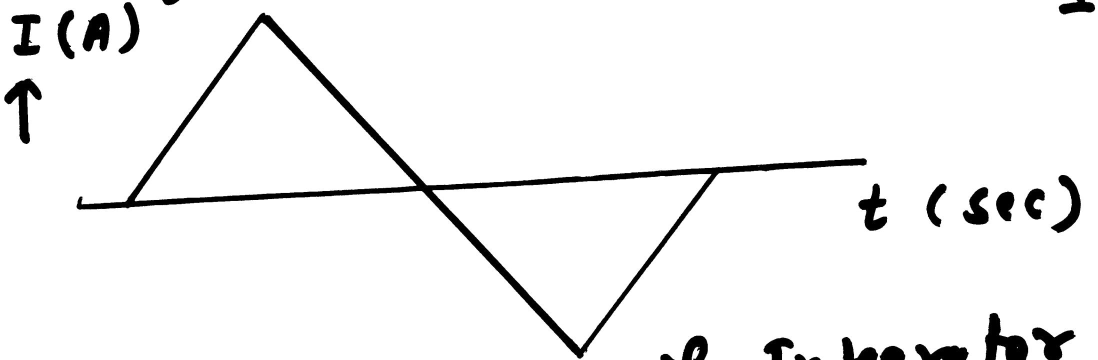


FIG—1 BLOCK DIAGRAM OF THE HYSTERSISGRAPH INSTRUMENT

* Magnetizing current loop: $\frac{dB}{dt}$ constant

- Initially, in the absence of voltage V_c the output of Power Amplifier (A) is a traingular waveform

± 10 Amp



The output voltage of Integrator IT-2 is the integral of a constant voltage, increases linearily with time. when this voltage reaches a fixed level it switches the bistable ciruit, whose polarity is reversed.

Thus the output voltage of Integrator (IT-2) becomes linearly decreasing function of time. when a fixed negative level (-5V) is reached then polarity of Bistable ct reversed — again increases with time until a fixed voltage (+5V)

and so on.

when the winding N_c is connected to the integrator (IT-2), it controls the rate of change of the magnetizing field maintaining a constant dB/dt. Actually the gain of IT-2 is very high, the difference between voltages in the inputs A & B of IT-2 vanishes.
Thus, the induced voltage in N_c is constant and so dB/dt.

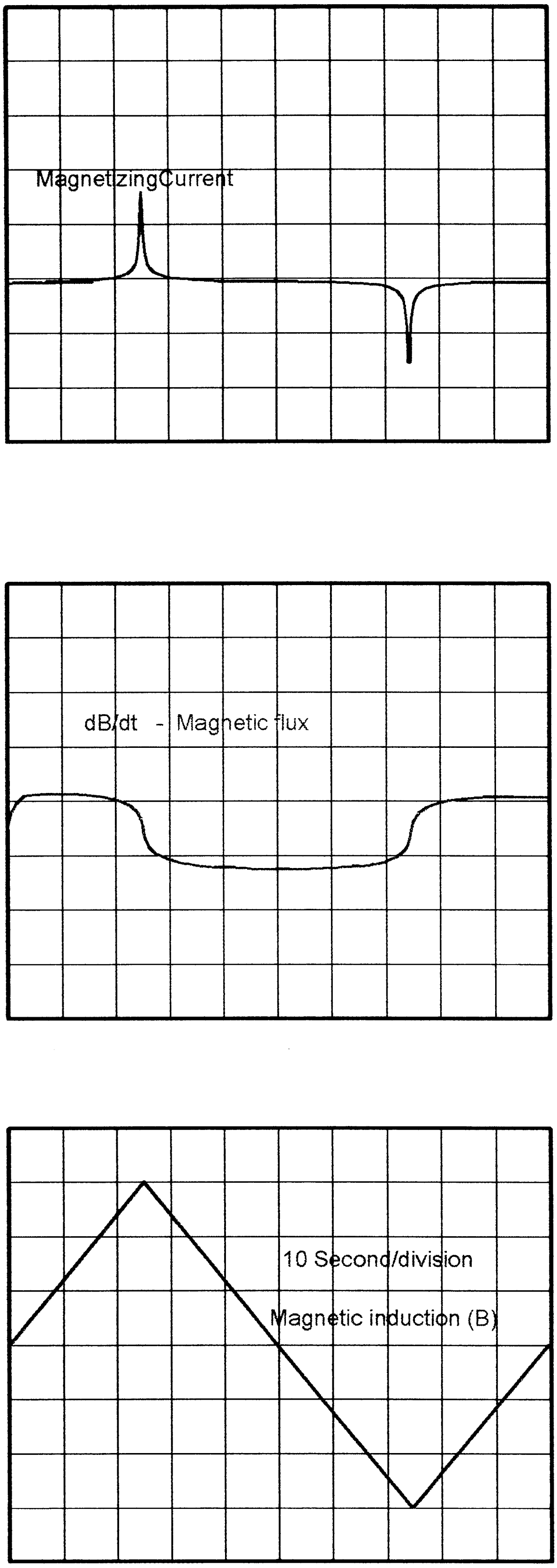


Fig: Waveform showing dB/dt constant during Hysteresis graph

Equipment Components:

1. Integrator
2. Bistable Circuit
3. Power Amplifiers

Integrator: Based on a d.c amplifier Small drift & a high open loop gain

Bistable Circuit: voltage comparator having two stable states, each being excited when its input assumes two fixed values, which, for a sym loop must be equal & opposite.

These states give, at the output of B, two voltages, which, in order to obtain the same dB/dt in two halves of the loop, must be equal & opposite.

Power Amplifiers & Bistable Ciriuit

: Designed & built by Industries (India)
for CAT, Indore

Measurements:

1. First Magnetization Curve:

Specimen demagnetized: started from saturation point, during demagnetization process I decreased step by step until lowest value of interest (say ~ 150 Gauss). During demagnetization reads integrated signals not current.

set I from power amplifier → $\frac{dB}{dt}$

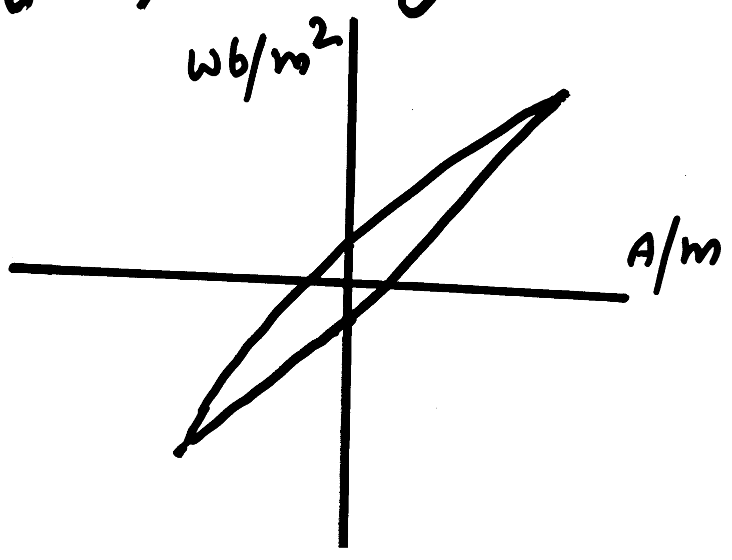
2. Hysteresis Loop

select Max current to saturate the material. computer software.

B_s, B_r & H_c

3. Initial permeability (μ_i)

The specimen - demagnetized. The μ_i obtained by making a small loop

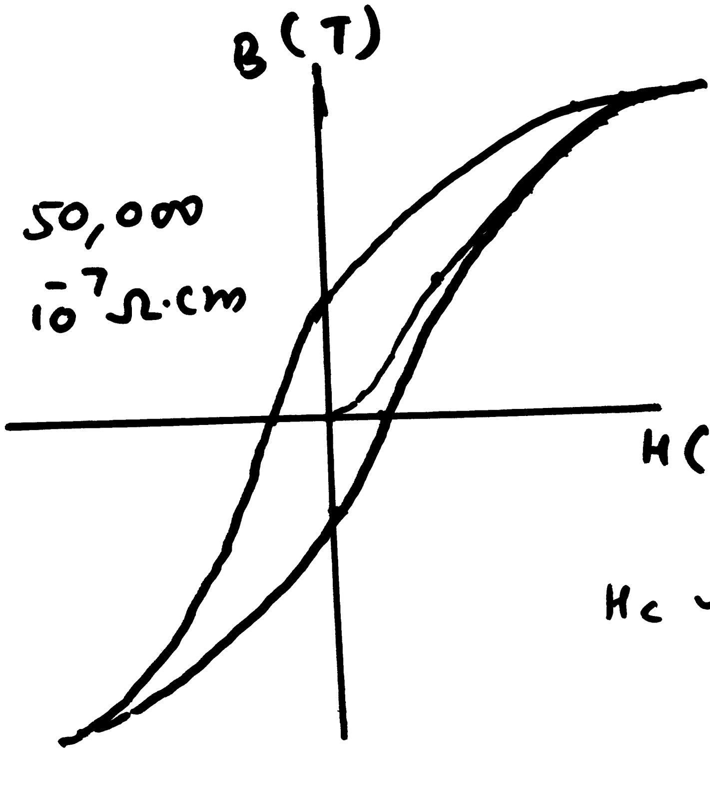


EXPERIMENTAL RESULTS:

Soft magnetic materials: supermalloy, permalloy, metallic ribbon wound cores Ni-Fe alloy wound cores, etc.

μ_i : 50,000

ρ : $10^{-7}\ \Omega\cdot cm$



B_m : ~ 1.6 T

H_c ~ 0.5 Oe

Hysteresis Loop : supermalloy (Midhani 78B)

Loop was traced in 3 min.

Accuracy and Sensitivity of Equipment

Accuracies : B & H Scale

- **B accuracy**
  Limited by

i)Measurement time: select to avoid error due to eddy currents

* This can be controlled by maintaining dB/dt constant in hysteresis operation.

* Reducing rate of change of magnetizing field

ii) Drift of Amplifiers,stability of gain of amplifier & linearity of Integrator

Magnetic samples :

i) Laminated magnetic materials : NiFe wound core duration of measurement ~ 100 second enough to avoid eddy current error for tracing hysteresis loop.

ii) Metglas- Amorphous ribbons duration of measurements~ 4 to 5 minutes is required to trace the hysteresis loop.

$\mu_{Max} \sim 100000$

The overall accuracy for B measurement is bout 0.5% obtained

Accuracy and sensitivity

Detail measurements are in process for flux density & coercivity of various, reference materials over a range of different magnetic field strengths.

However, Accuracy of measurement lie between 1% to 0.1% for hysteresis loop parameters (Bs, Br, Hc,)

Test Sample Results

Ref. material sample	Coercivity A/m		Max. Permeability		Saturation flux density Tesla (A/m)	
	[redacted] CERN	[redacted] CAT	[redacted] CERN	[redacted] CAT	[redacted] CERN	[redacted] CAT
1. CERN Steel 54/1125/1	84.77	82.4	4500	4380	2.048	2.033
2. CERN Steel 9268/1	43.2	45	6000	5800	2.017	2.010
3. Ni-Zn-Co Ferrite, 250L	40.0	42	250 NPL	240	0.305 NPL	0.30
4. Decarburized Steel (Raymond Steel)	Measurement 257 at CERN	Observed at CAT 262	2200	2140	2.02	2.01

Performance factor

Minimum flux change per second, which can be measured

Performance factor ~ function of the required accuracy and

duration of measurement ~ 100 second

Drift: 0.01 μV

Maximum flux change, $\Delta\phi = 0.01 \times 10^{-6} \times 100$

$\sim 1 \times 10^{-6}$ web

Maximum value of drift – correspond to a flux change of 1×10^{-8} web/sec.

Performance factor: Minimum flux change per second ~ 1×10^{-8} web/sec.

With 0.5% accuracy, PF: ~ 5×10^{-6} web/sec. Obtained

Specimen dimension: low carbon steel

50 mm OD × 45 mm ID × 100 Ht

Cross sectional area: 25 mm^2

No. of turns: 100

Maximum induction ~ 2.1 Web/m^2

Flux change during a half cycle is 2.5×10^{-5} web

The error due to the drift during the same time: 0.01 μv × 50 ~ 0.5×10^{-6} web, the error being about 0.1 % (at saturation)

Magnetic Field distribution :→

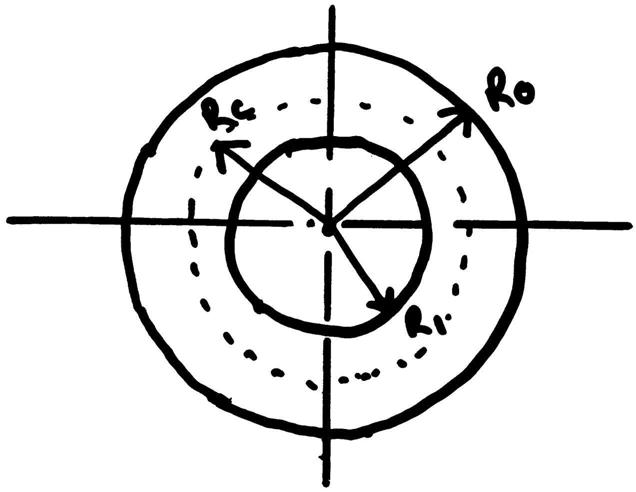


Fig : Ring Specimen

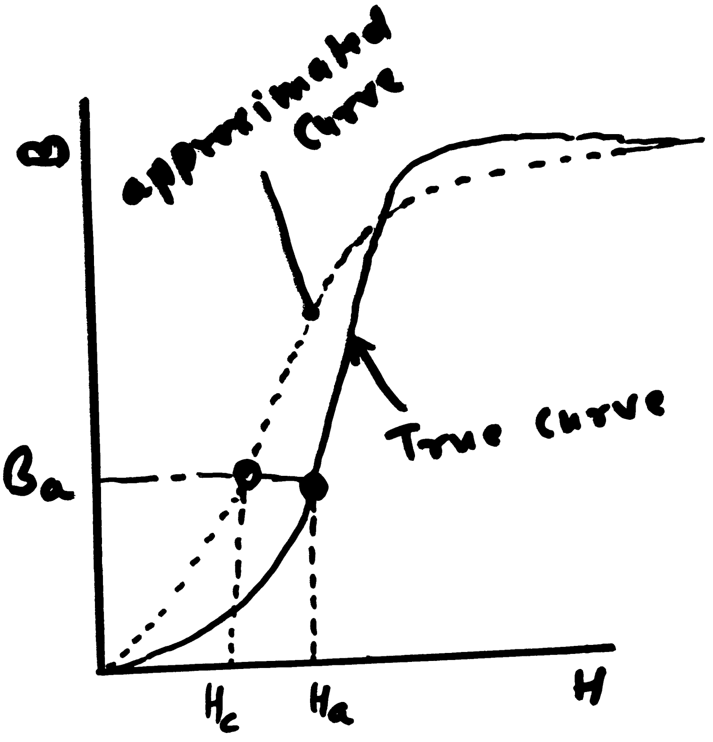
Field H in the ring specimen varies as a function of the radius, its mean value $\bar{H}$ is given by

$$\bar{H} = \frac{1}{R_0 - R_1} \int_{R_1}^{R_0} \frac{NI}{2\pi R} \, dR = \frac{NI}{2\pi R_c}$$

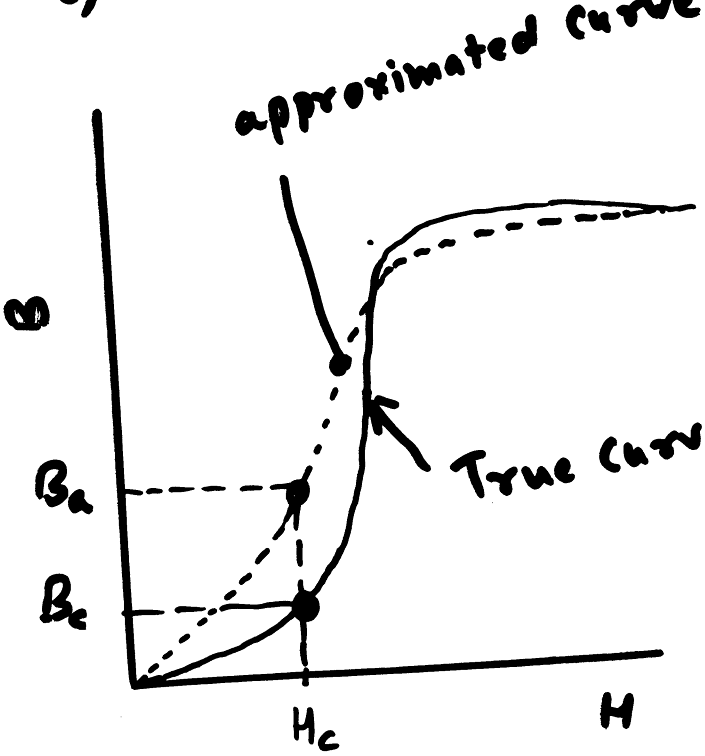
where $R_c = \dfrac{R_0 - R_1}{\ln R_0 - \ln R_1}$

Magnetic Flux distribution:

* B(R) can not be measured, but the average flux density, B(a) can be measured using a search coil.
* The average values of the magnetizing field and of the flux density will not correspond to each other
  → as the distribution of H and B are not described by the same fn.



Error in H



Error in B

Error in H : Magnetic field H_c on the mean radius $R_c = \frac{R_0 + R_1}{2}$ is used

Actually we should mease H_a on mean magnetic path corresponding to B_a.

Error in B : Measure B_a corresponding to H_c.

Flux density B on the centre radius $R_c = \frac{R_0 + R_1}{2}$

Actually we should measure B_c.