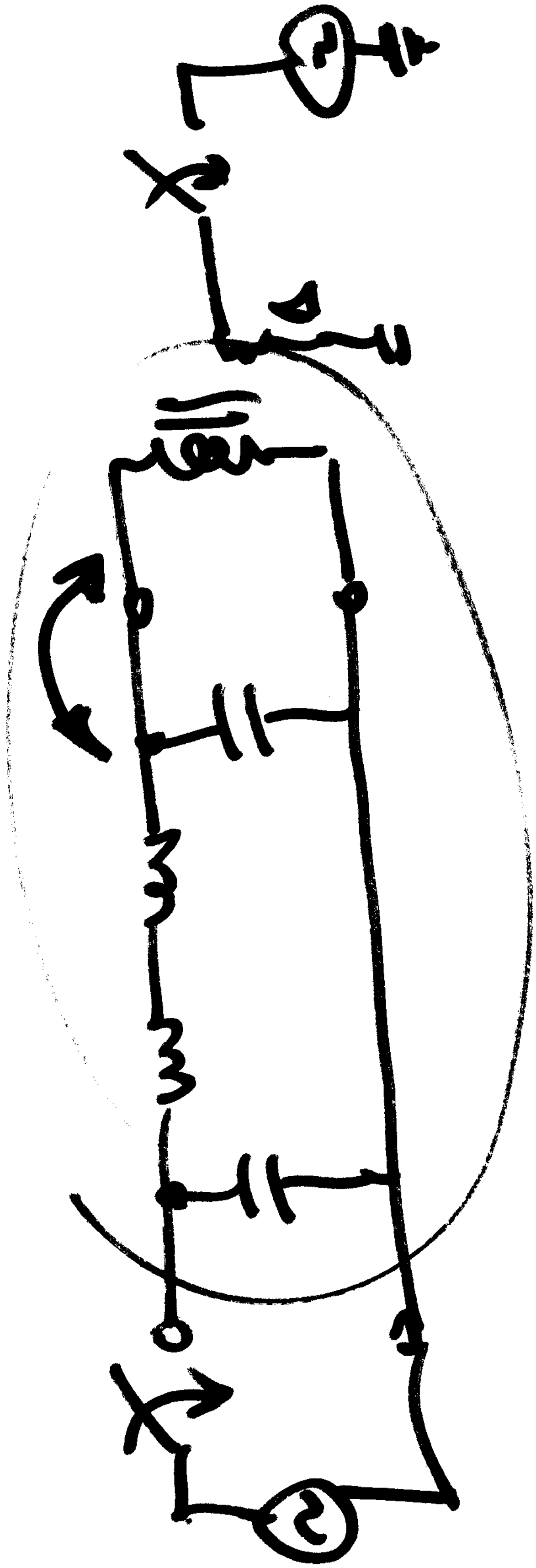
EE 5220 - Lecture 31 Mon Mar 25, 2024

Topics for Today:

- Course Info:
    - Web page: https://pages.mtu.edu/~bamork/ee5220/index.htm
    - Book, references, syllabus, more are on web page.
    - Software - Matlab. ATP/EMTP [License - www.emtp.org] ATP tutorials posted on our course web page
    - EE5220-L@mtu.edu (participation = min half letter grade)

- HW#9 - Probs. 9.2, 9.3, 9.4 due latest Wed 9am.
- Mid-term: will be based on homework & ATP skills, completed by Week 13.
- Term Project - Journal paper review - see review guidelines on web page.
- Transformer modeling - Section 11.1 of text, plus lecture notes
    - Magnetic materials: B-H characteristics
    - Transformer models for EMTP
        - Duality transformations gives correct equivalent circuit
        - Examples for core-form, “shell-form”, single-phase
        - Three phase modeling
- Next - take stock of available ATP transformer models
    - BCTRAN, XFMR models



Duality Transforms

- Ckts: Identical math structure but different physical structure.

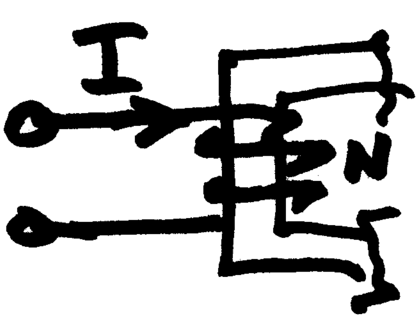
NODE EQN ⟷ MESH EQ

IN MAG CKTS – DUAL

MAG CKT ⟷ ELECT. EQUI

$\mathcal{R}$, N, ϕ, B, H,   V, E, L, I

↑ AMPERE'S CIRCUITAL LAW



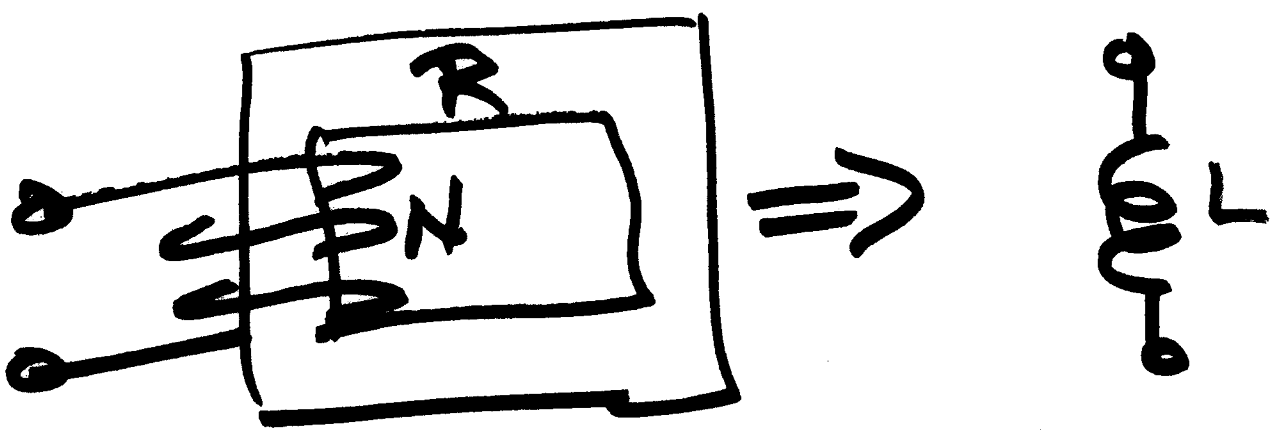
$$\boxed{NI = \phi \mathcal{R}} = MMF = \mathcal{F}$$

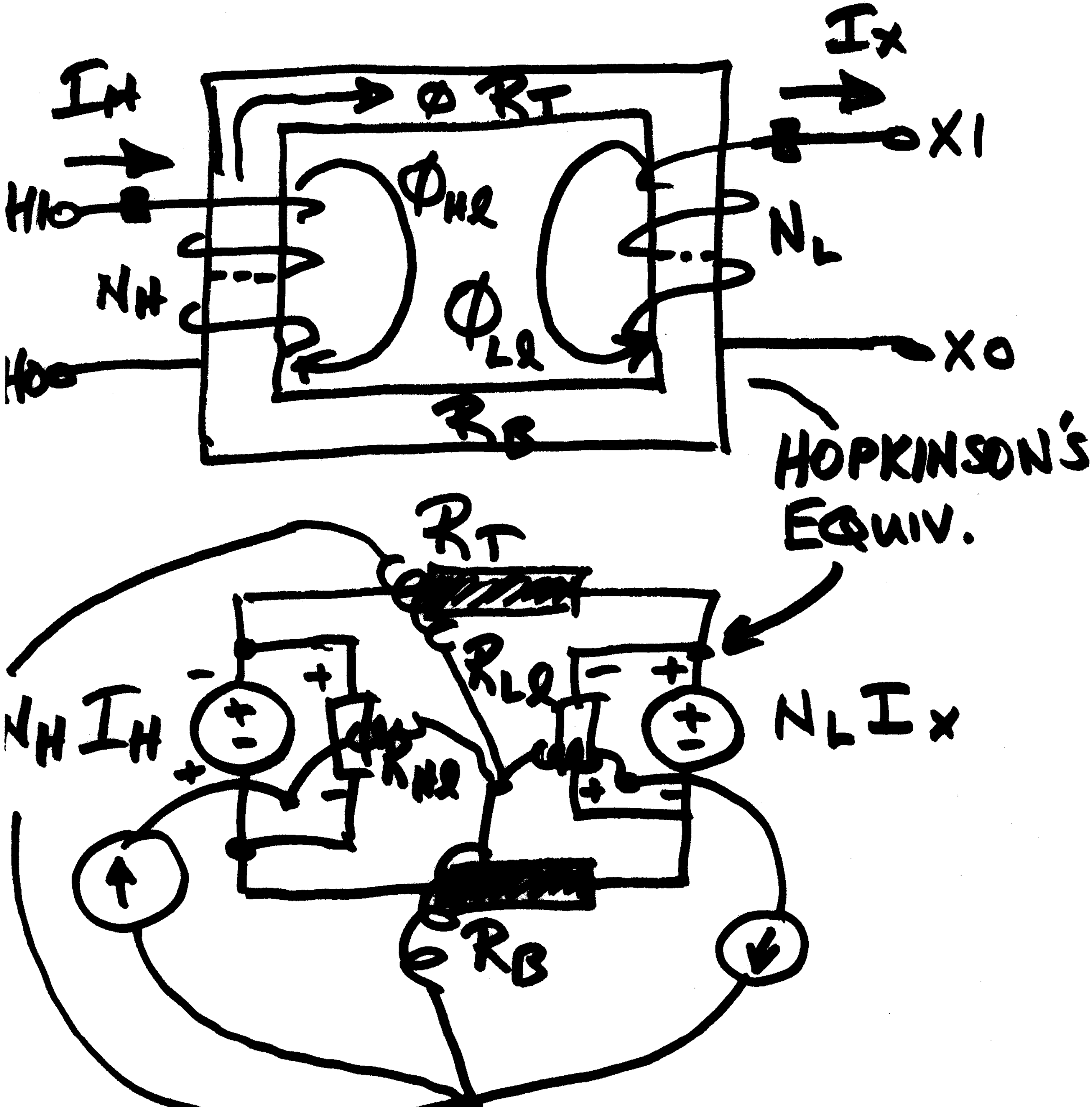
1) Create Lumped Mag Ckt

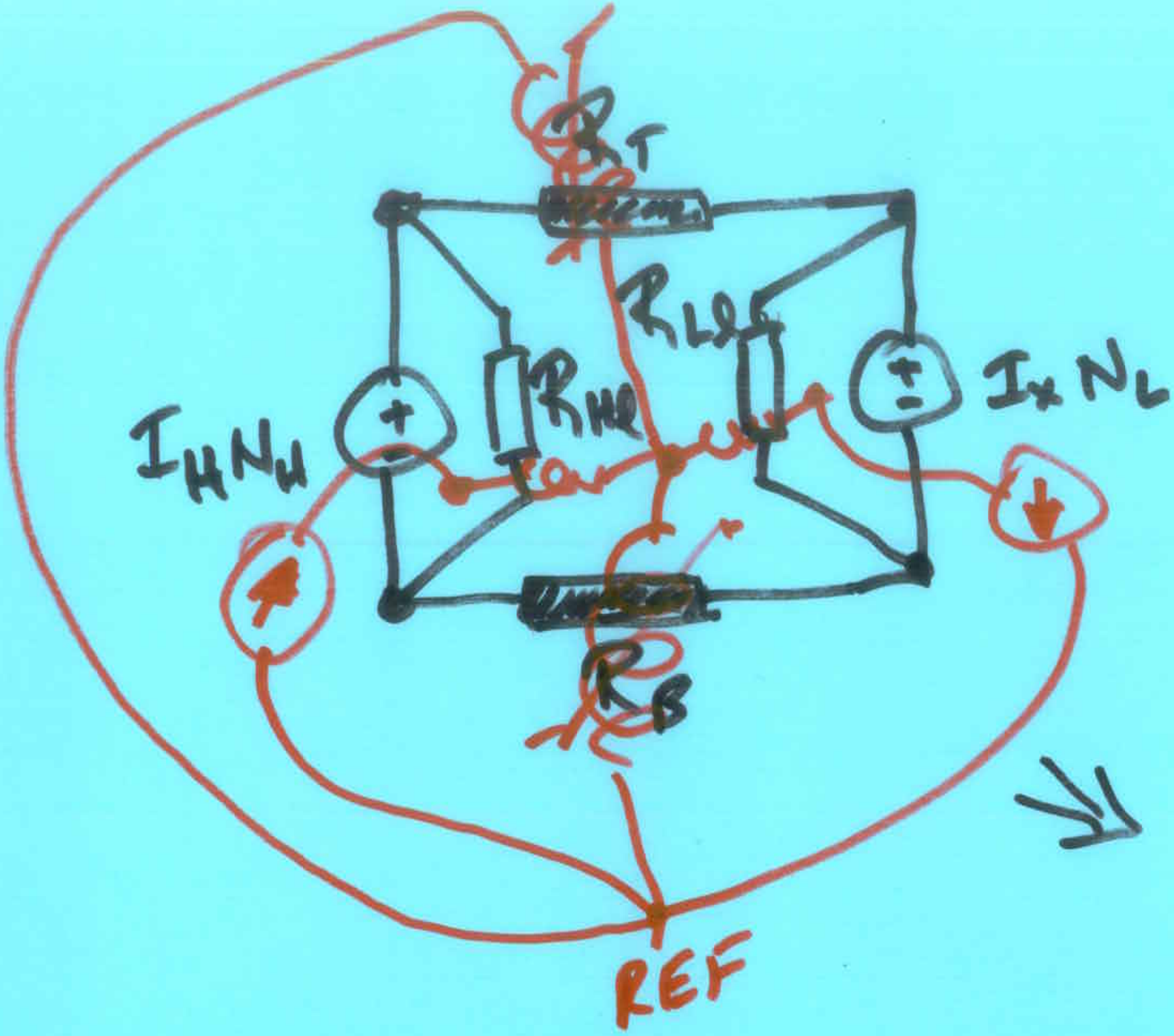
2) Transform

Mag Ckt		Elect Ckt
Mesh	⟷	Node
NODE	⟷	Mesh
$\mathcal{R}$	⟷	L

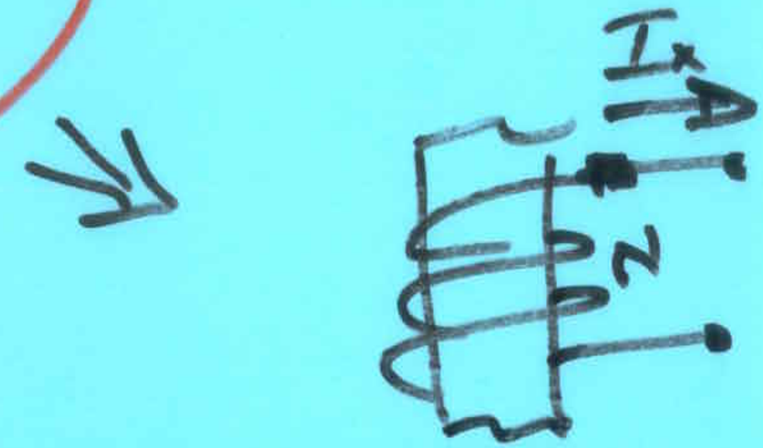
$L = \frac{N^2}{\mathcal{R}} = \frac{\lambda}{i}$



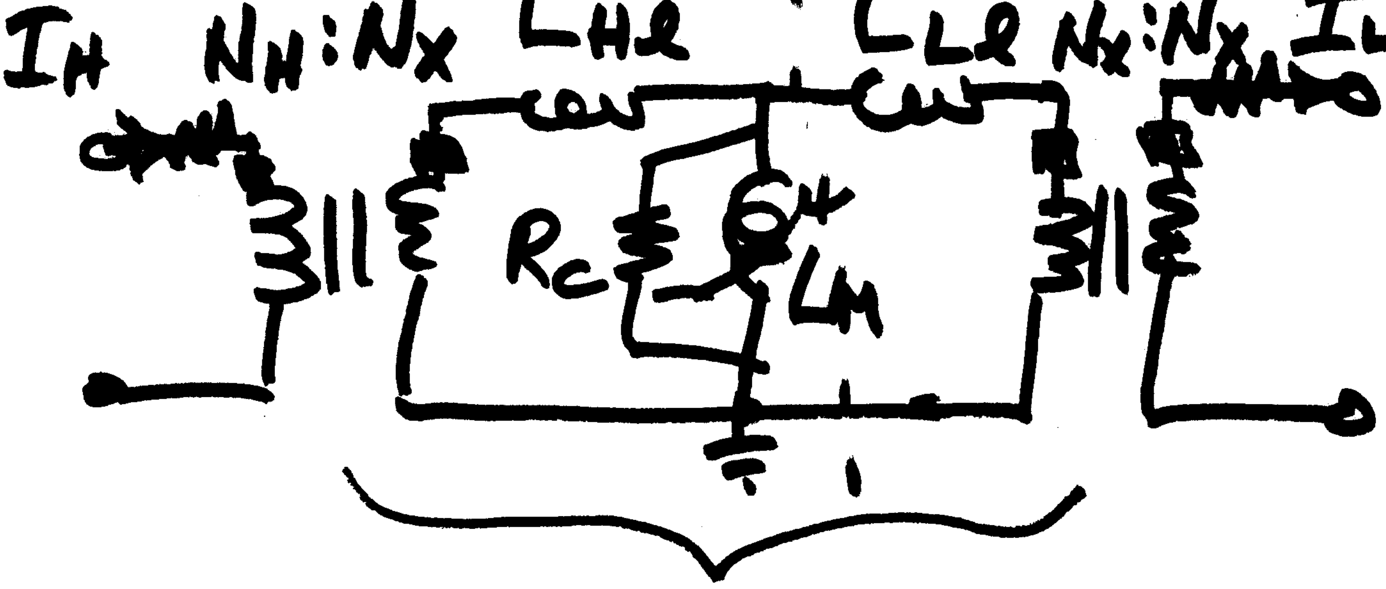

Ix
IH
φ RT
X1
H1
φHl
NL
NH
φLl
H0
X0
RB
HOPKINSON'S EQUIV.
RT
RLl
NH IH
NL Ix
RHl
RB



R_T
R_{LL}
R_{HL}
$I_H N_H$
$I_x N_L$
R_B
REF

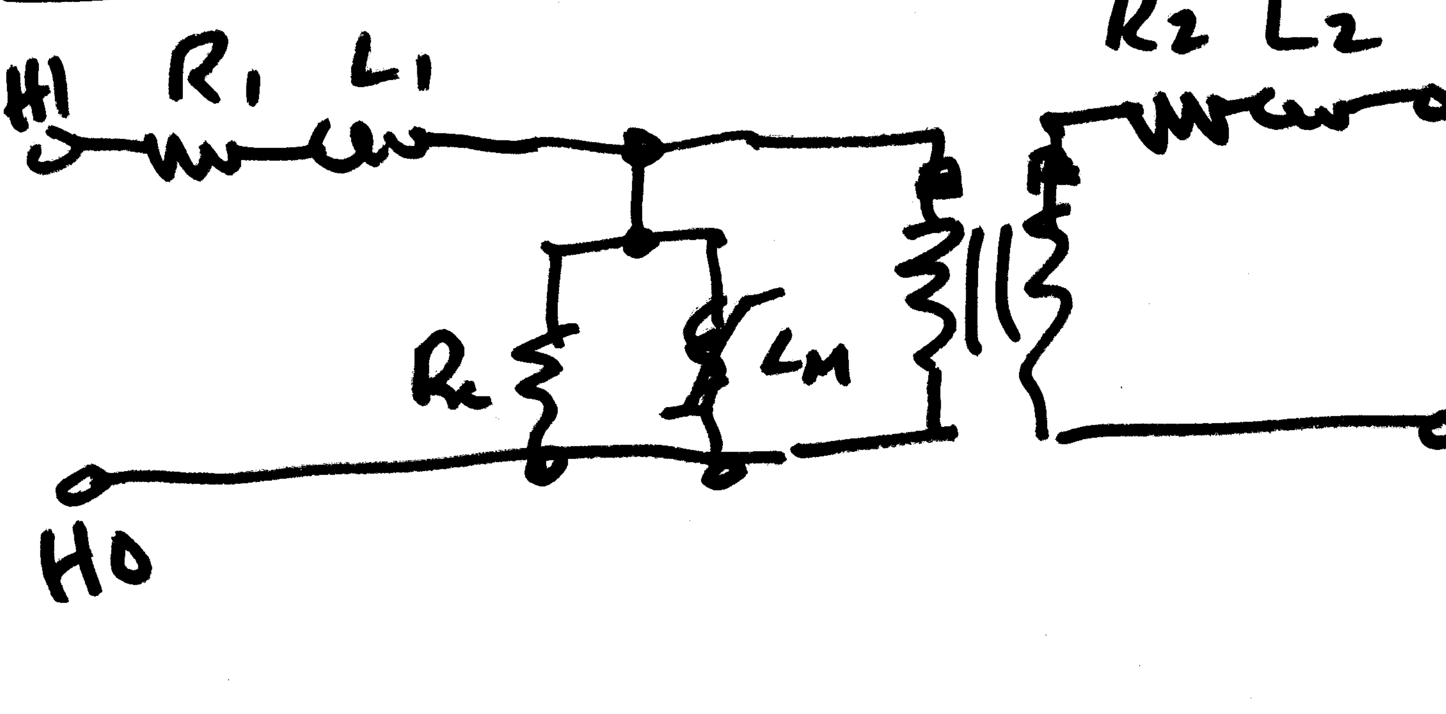


I_x
N



FLOATING

OTHER EXAMPLES



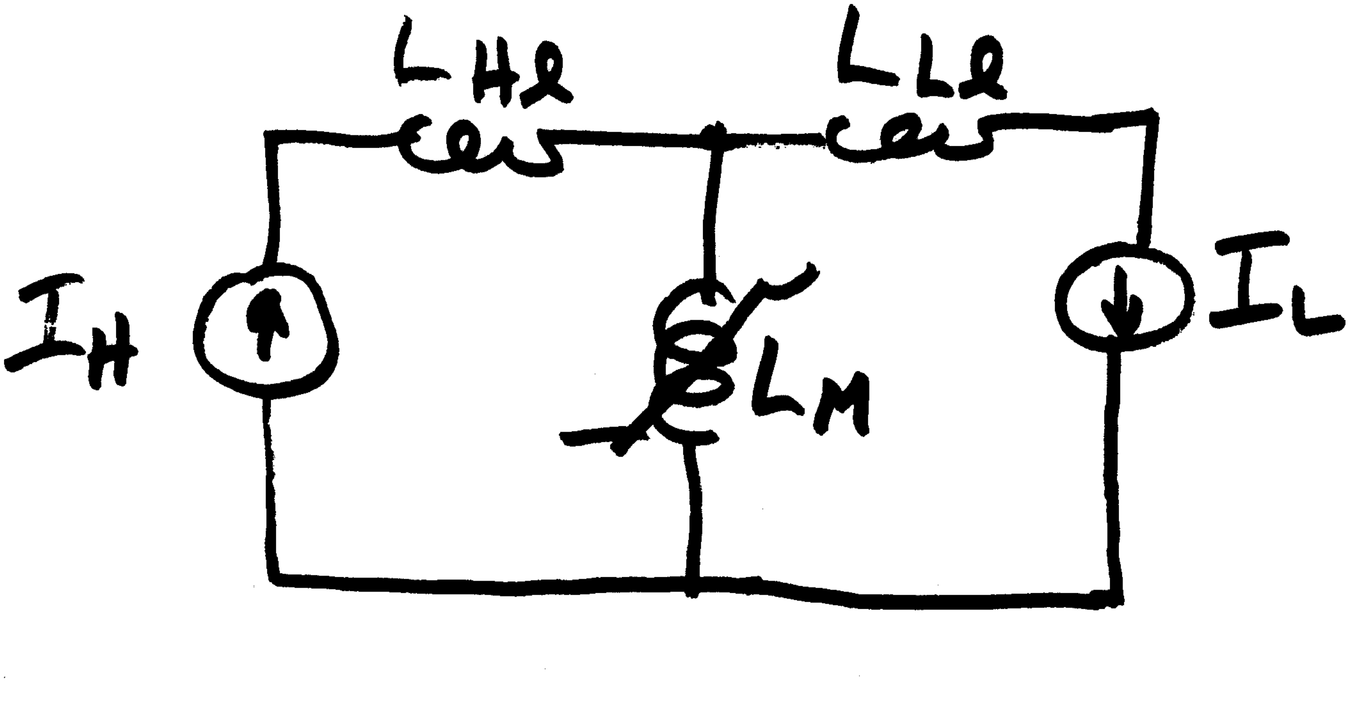
DUALITY TRANSF. "PAIRS"

NODE ⟷ MESH
MESH ⟷ NODE

$NI = MMF$ ⟷ I_{SOURCE}

$\mathcal{R}$ ⟷ $L = \frac{N^2}{\mathcal{R}}$

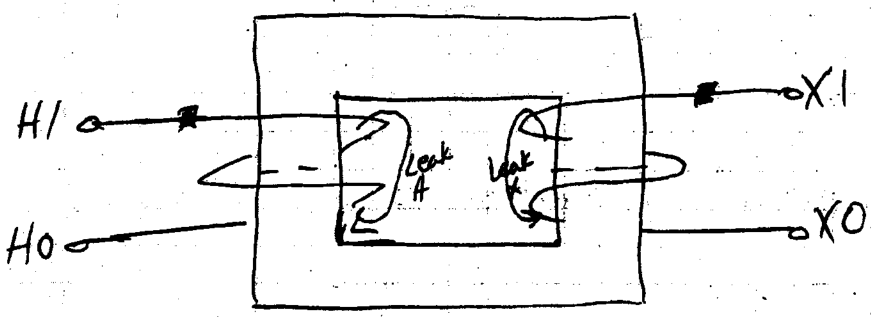
$$L = \frac{N^2}{\mathcal{R}}$$

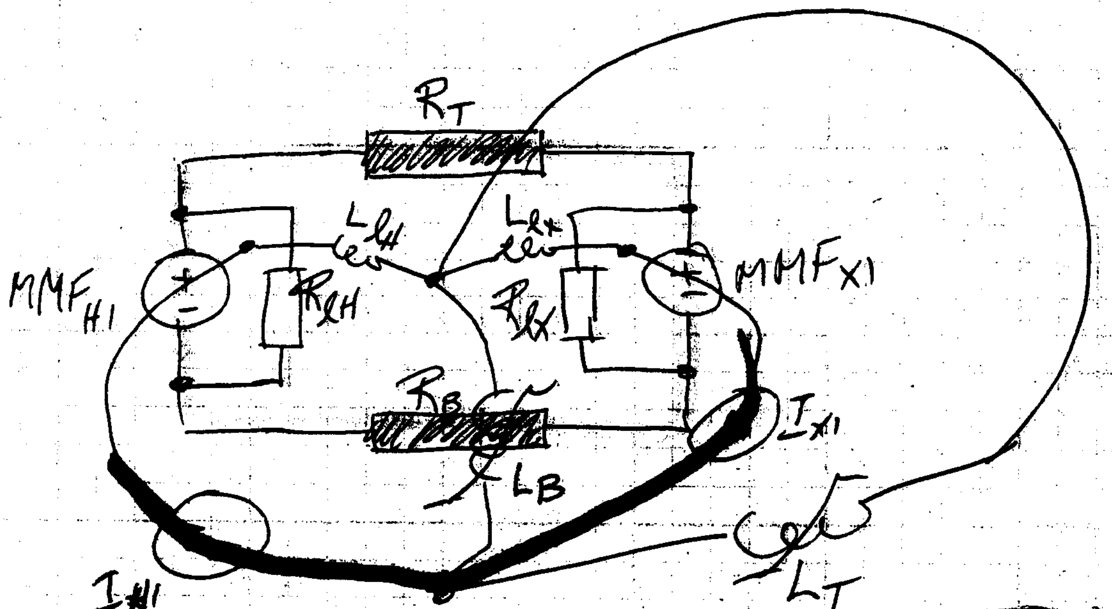


Duality Derivations:

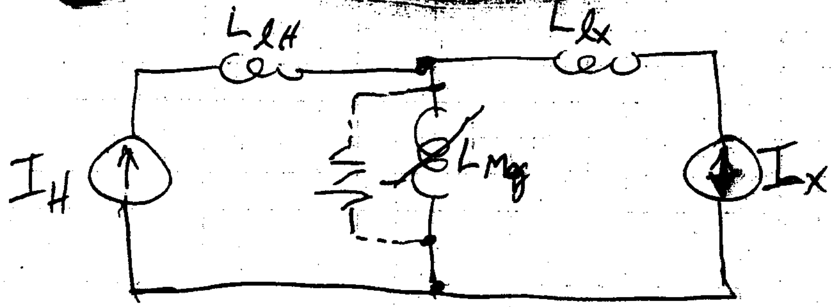
EX. 1

Simple XFMR:





Note! KVL around Mag ckt loop (MMFs) must have same relative signs as currents in KCL dual.



42-382 100 SHEETS 5 SQUARE
42-389 200 SHEETS 5 SQUARE
NATIONAL

Ex. 2

circuit calculations, but it is not generally adequate for transient modeling in the EMTP [3].

A cross section view of the CT used in this study is shown in Figure 2. It has a one turn primary and a toriodal core. Since it has concentric windings (the primary is effectively one turn) the circuit of Figure 1 is invalid. Therefore, a

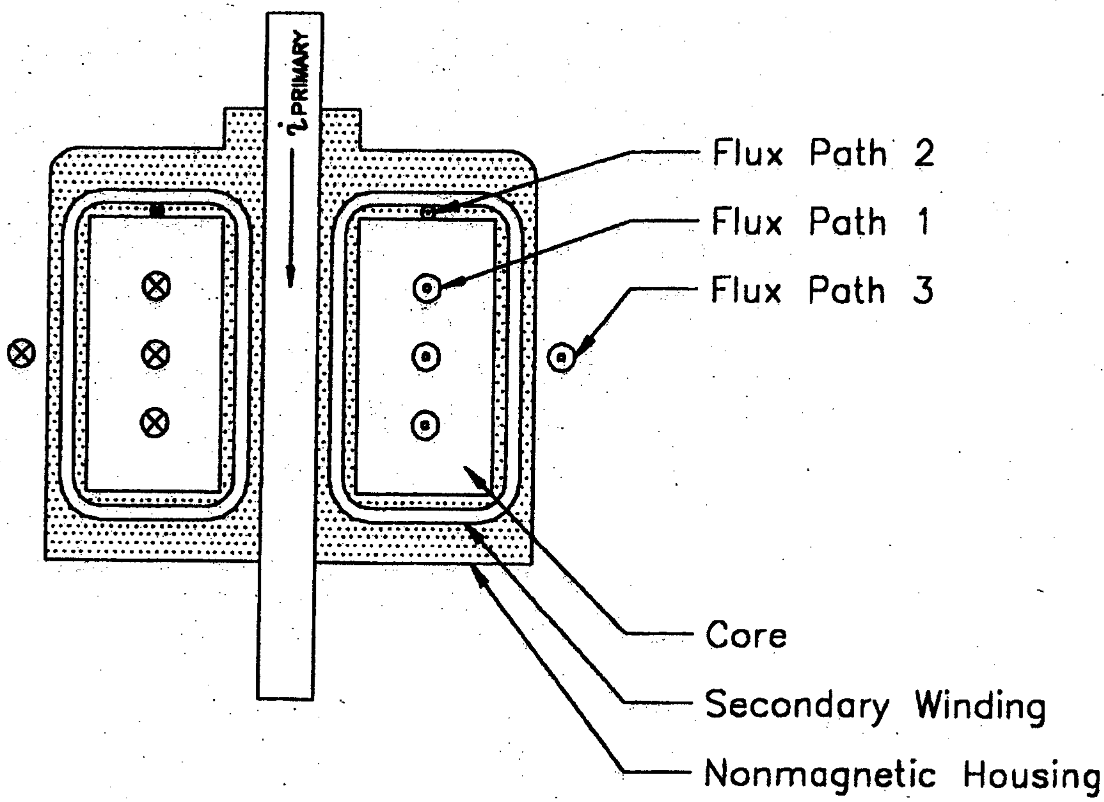


Figure 2. Cross section view of CT

This test is diffi
since it requires
tively low voltag
nonsinusoidal ab
digital oscillosco

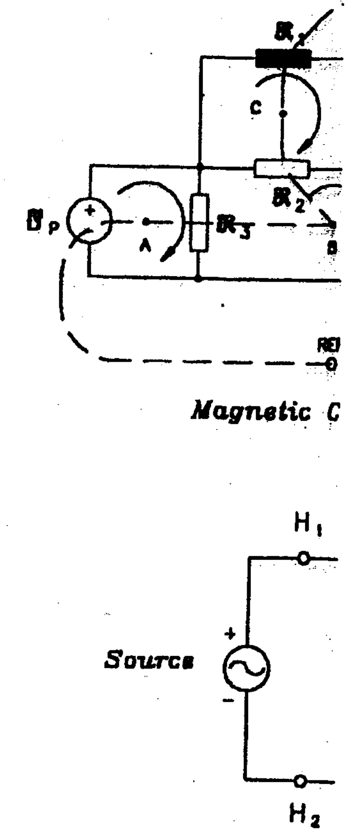
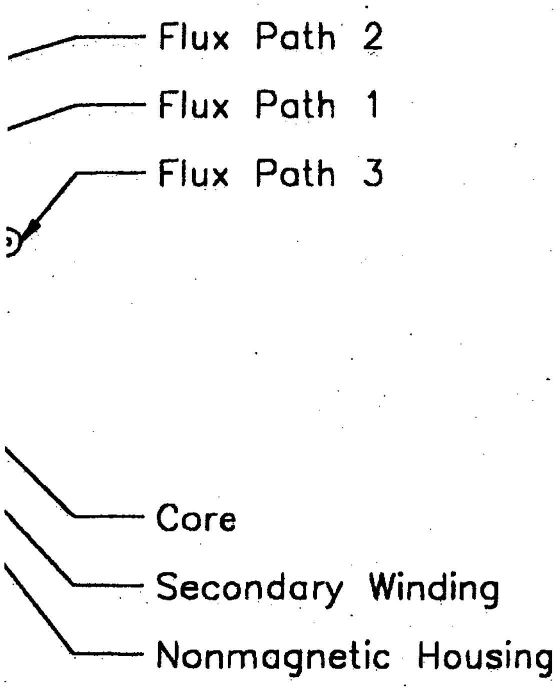


Figure 3. Duality l

; not generally adequate for
TP [3].

T used in this study is shown
primary and a toriodal core.
ıgs (the primary is effectively
:e 1 is invalid. Therefore, a



CT

This test is difficult to perform with a typical wattmeter, since it requires the measurement of real power at a relatively low voltage, and the currents for this CT became nonsinusoidal above 30 volts. To avoid this problem, a digital oscilloscope was used to record the voltage and

Ex. 2

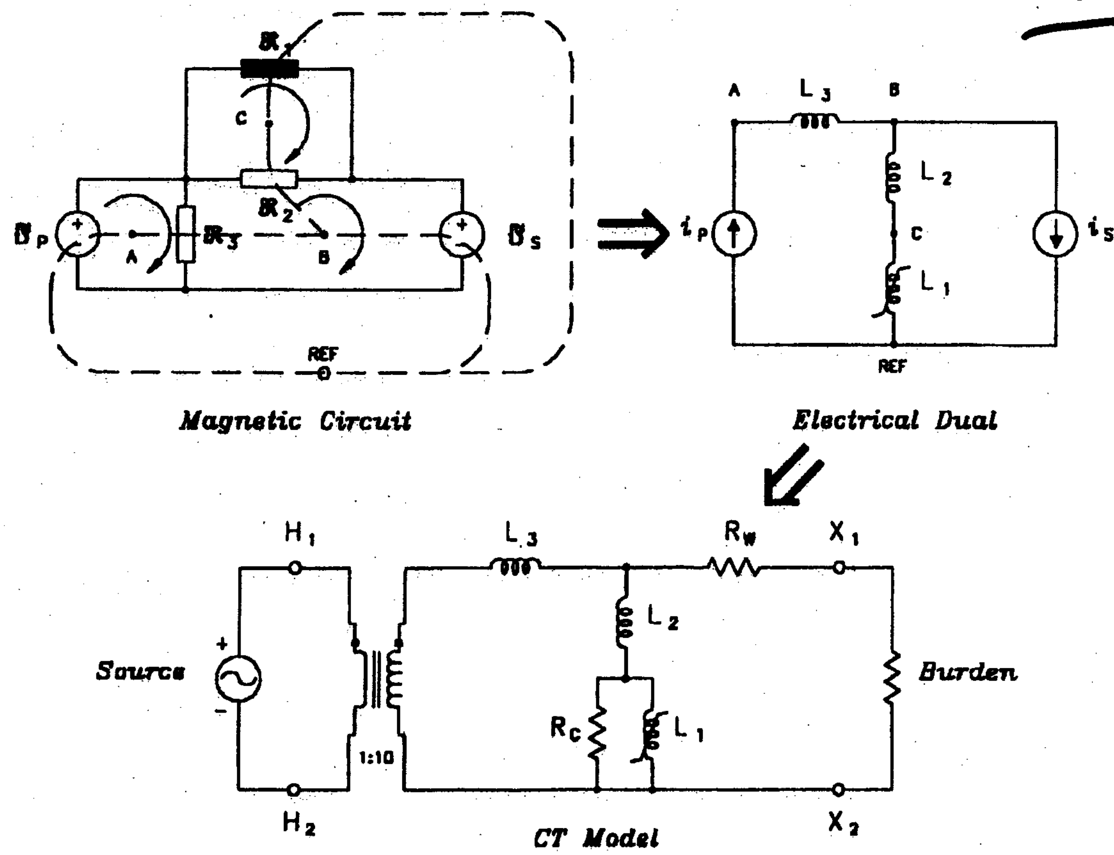
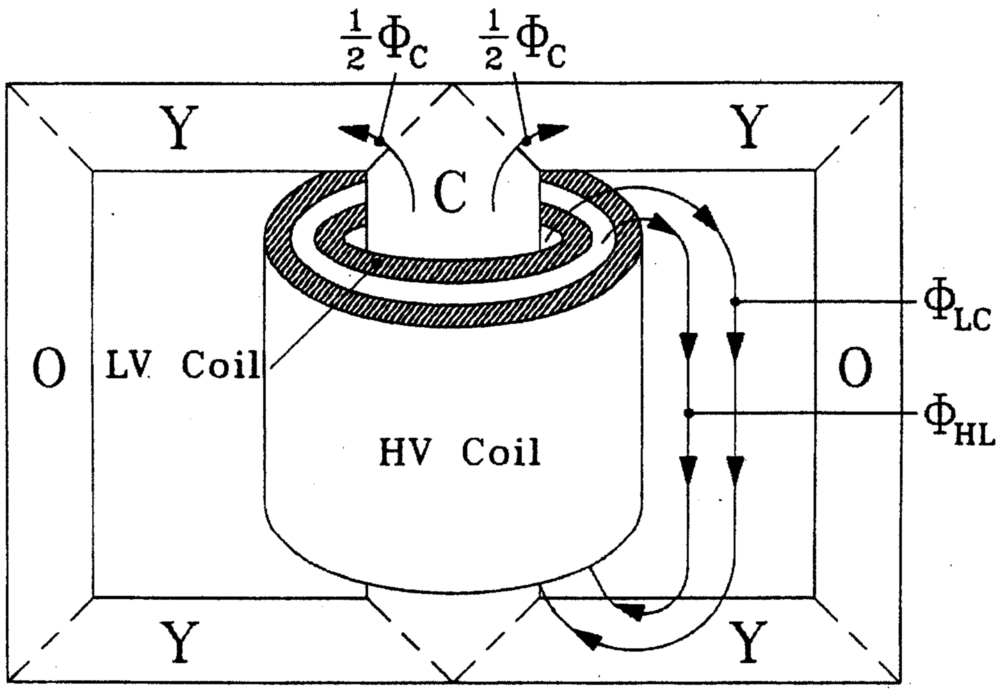
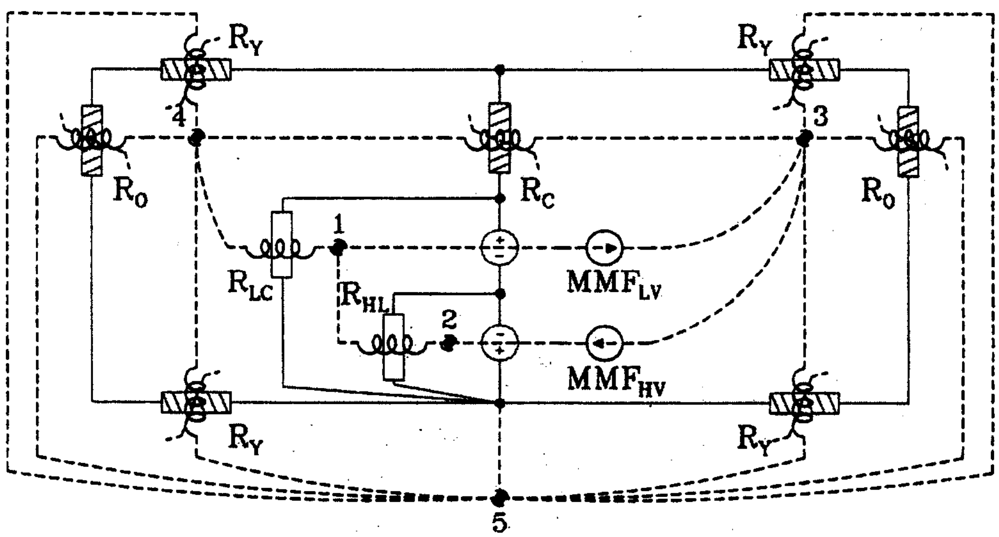
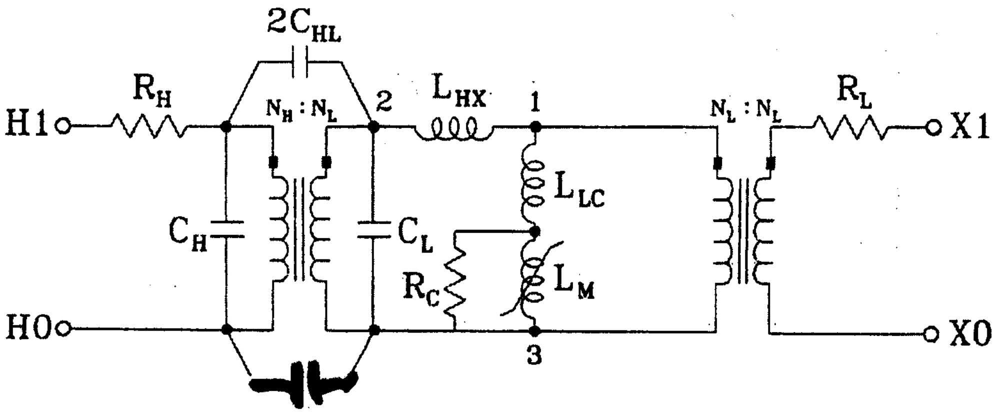


Figure 3. Duality Derivation for the CT

EX. 3







en
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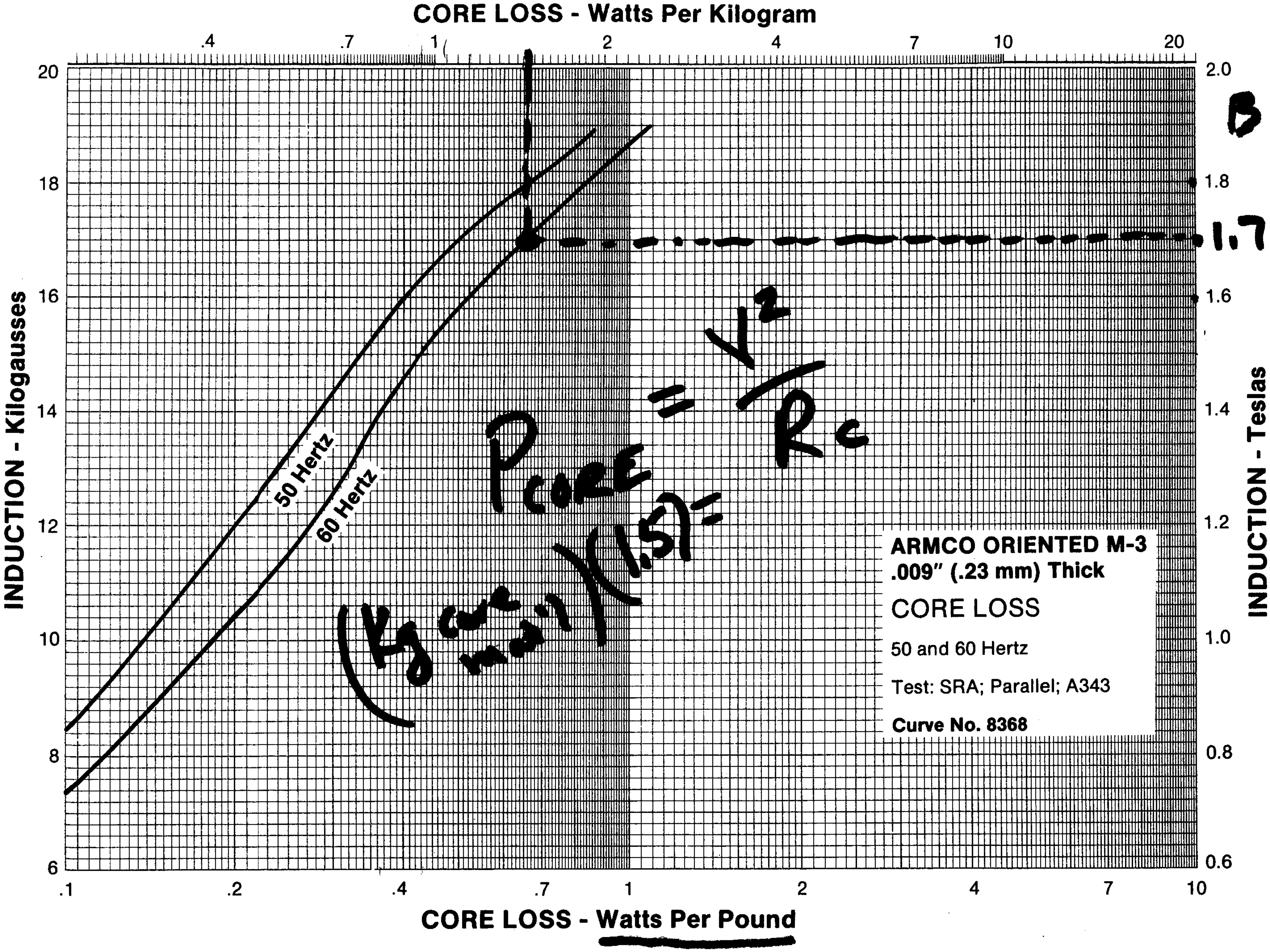
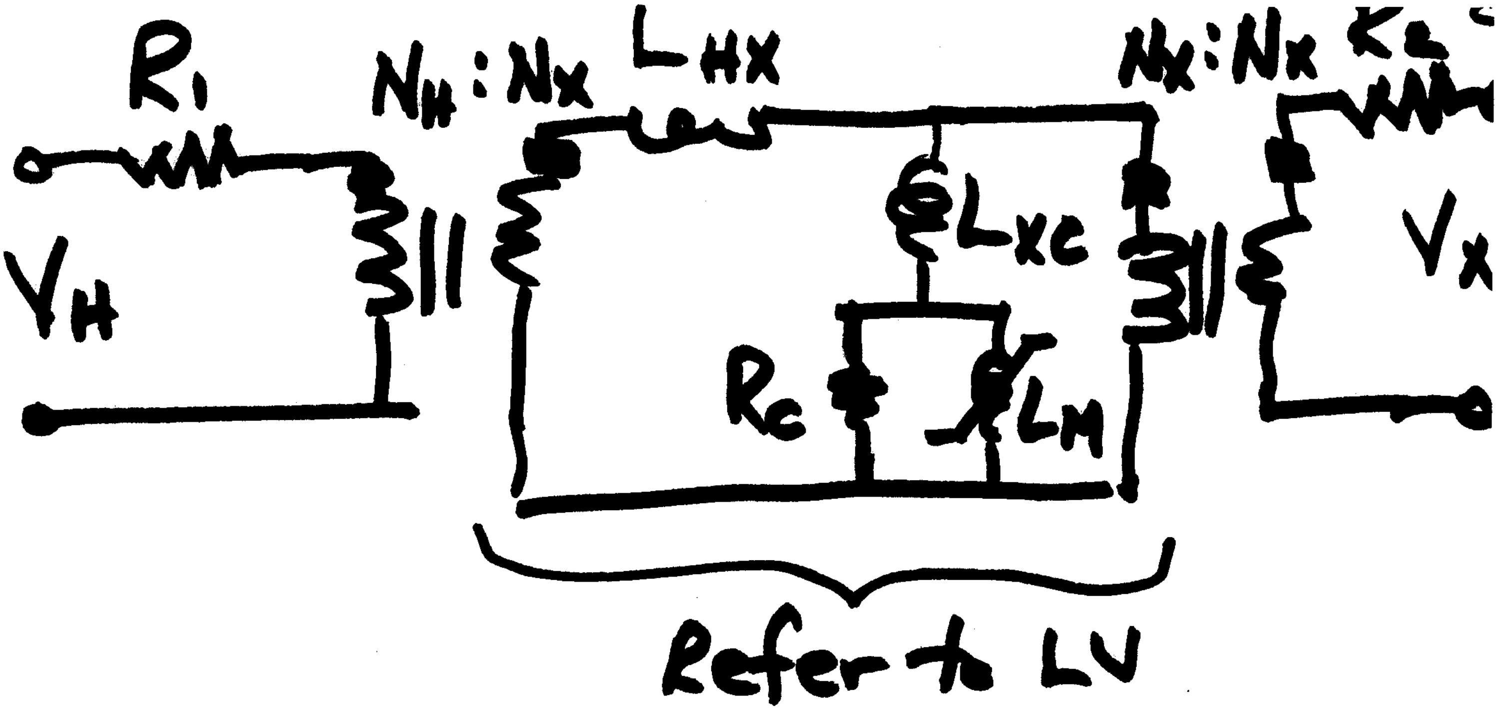
ce
nd
To
he
MF
es
be
he

- Find B_{MAX}
- Pick off P/kg from curve
- $P_{CORE,AVG}$ = Mass of Core × P/kg

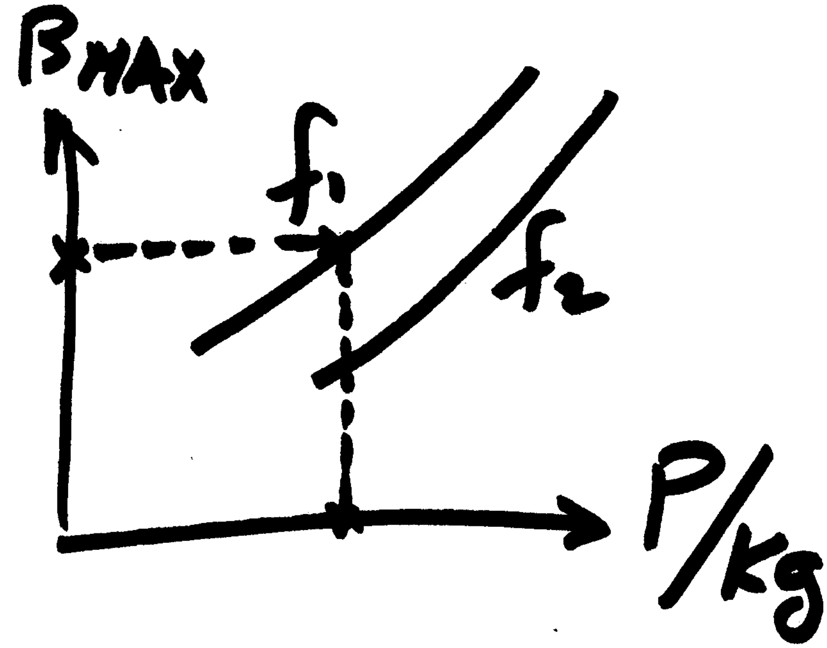
~~P_{AVG}~~ $P_C = \frac{V_x^2}{R_C}$

$$\Rightarrow R_C = \frac{V_x^2}{P_C}$$


CORE LOSS - Watts Per Kilogram
.4
.7
1
2
4
7
10
20
INDUCTION - Kilogausses
20
18
16
14
12
10
8
6
INDUCTION - Teslas
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
B
1.7
50 Hertz
60 Hertz
PCORE = V2/Rc
(Kg core mat'l)(1.5)=
ARMCO ORIENTED M-3
.009" (.23 mm) Thick
CORE LOSS
50 and 60 Hertz
Test: SRA; Parallel; A343
Curve No. 8368
.1
.2
.4
.7
1
2
4
7
10
CORE LOSS - Watts Per Pound



R_C:



$$B_{MAX} = \frac{E_P}{NA\omega}$$

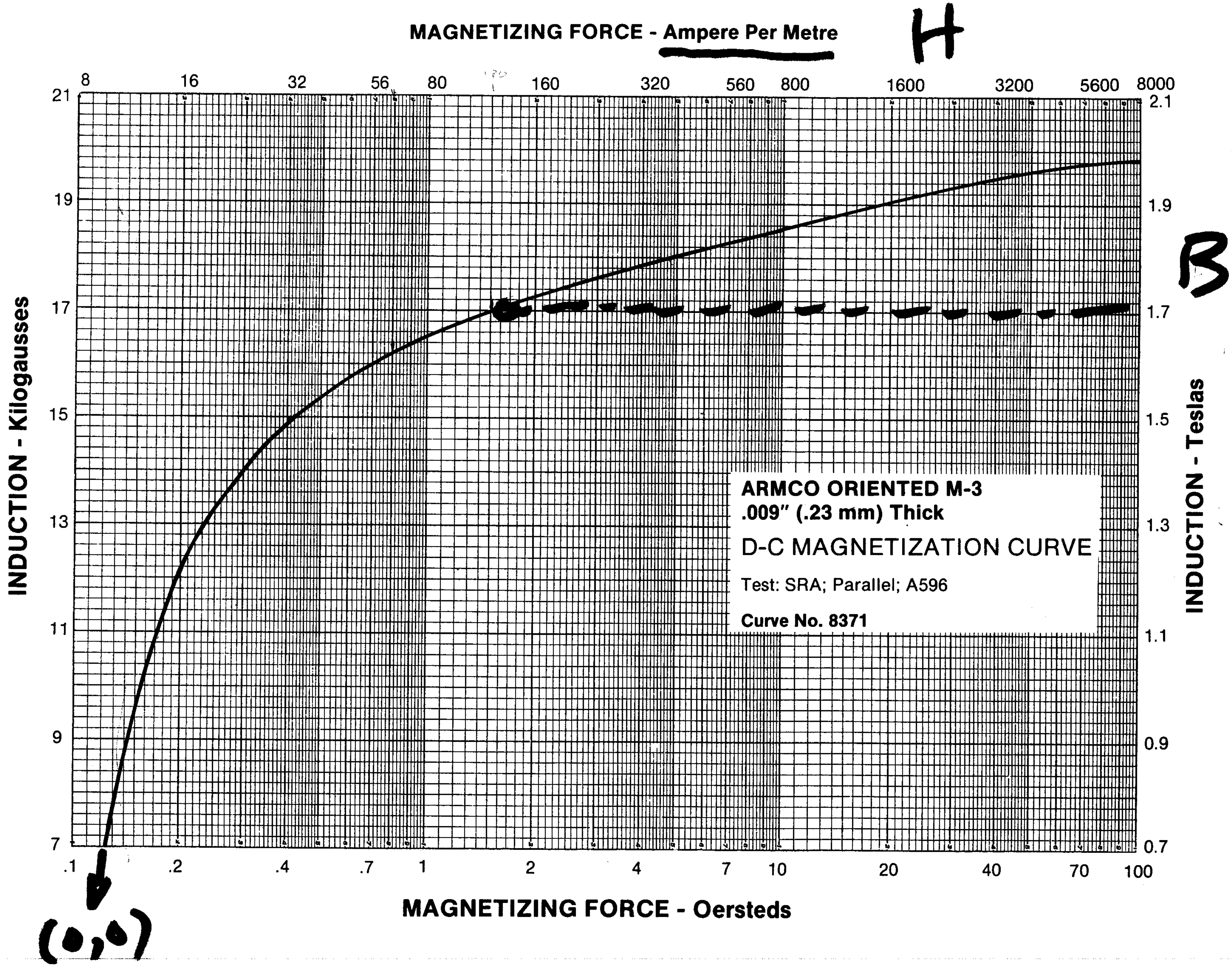
Bmax:

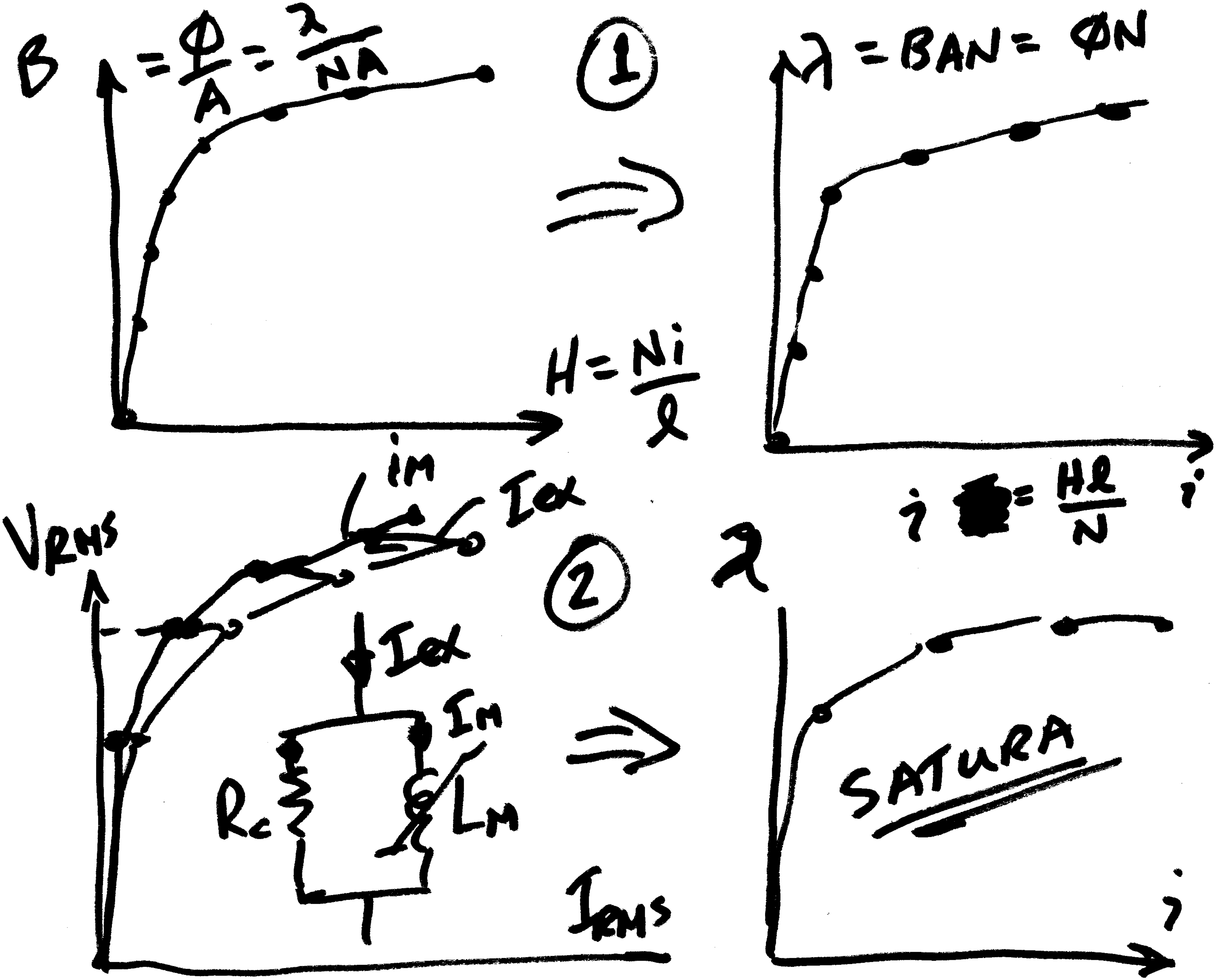
$$e = \frac{d\lambda}{dt} = N\frac{d\phi}{dt} = NA\frac{dB}{dt}$$

if sinusoidal:

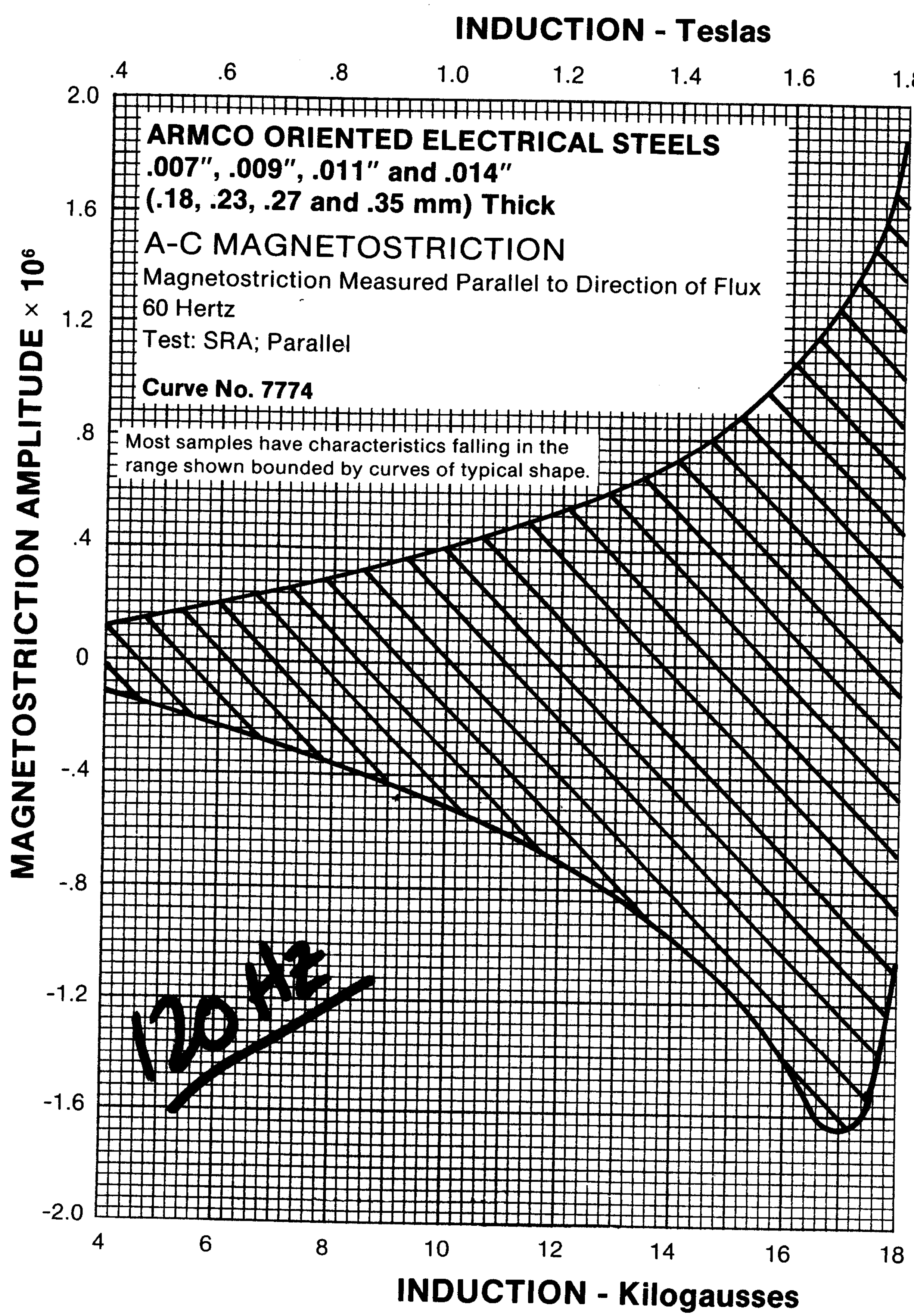
$$B = B_{MAX} \sin \omega t$$

$$e(t) = \underbrace{NAB_{MAX}\,\omega}_{E_P}\,\underbrace{\cos(\omega t)}$$


MAGNETIZING FORCE - Ampere Per Metre
8 16 32 56 80 160 320 560 800 1600 3200 5600 8000
INDUCTION - Kilogausses
21 19 17 15 13 11 9 7
INDUCTION - Teslas
2.1 1.9 1.7 1.5 1.3 1.1 0.9 0.7
.1 .2 .4 .7 1 2 4 7 10 20 40 70 100
MAGNETIZING FORCE - Oersteds
ARMCO ORIENTED M-3
.009" (.23 mm) Thick
D-C MAGNETIZATION CURVE
Test: SRA; Parallel; A596
Curve No. 8371
H
B
(0,0)



B = Φ/A = λ/NA
1
λ = BAN = ΦN
H = Ni/ℓ
i = Hℓ/N
i
iM
Iex
VRMS
2
λ
Iex
IM
Rc
LM
IRMS
SATURA
i


INDUCTION - Teslas
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
ARMCO ORIENTED ELECTRICAL STEELS
.007", .009", .011" and .014"
(.18, .23, .27 and .35 mm) Thick
A-C MAGNETOSTRICTION
Magnetostriction Measured Parallel to Direction of Flux
60 Hertz
Test: SRA; Parallel
Curve No. 7774
Most samples have characteristics falling in the
range shown bounded by curves of typical shape.
MAGNETOSTRICTION AMPLITUDE × 10⁶
2.0
1.6
1.2
.8
.4
0
-.4
-.8
-1.2
-1.6
-2.0
120 Hz
4
6
8
10
12
14
16
18
INDUCTION - Kilogausses