1. Magnetic Circuits

Tuesday, October 27, 2020 3:47 AM

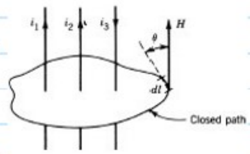
1.1 Magnetic Circuits

i–H Relation

- Conductor → current i, Magnetic Field Intensity H
- Ampere Circuit law: line integral of H around closed path = I total enclosed

$\oint H\,dl = \sum i = i_1 + i_2 - i_3$

$\oint H \cdot dl \cos\theta = \sum i$



- For single conductor: $\oint H \cdot dl = i \rightarrow dl = 2\pi r$

B–H Relation

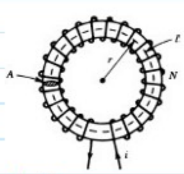
- H produces magnetic flux density B

$B = \mu H \rightarrow \mu = \mu_0 \mu_r$

Magnetic Equivalent Circuit

- Magnetic flux mostly in core material, flux outside → leakage flux

$\oint H \cdot dl = Ni \rightarrow F = Ni$ (magnetomotive force mmf)



$H = \frac{N}{l} i$ At/m

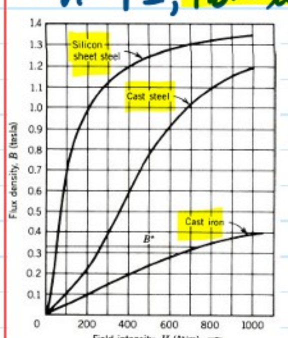
$B = \frac{\mu N i}{l}$ T

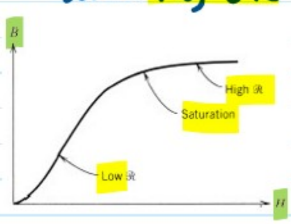
- flux in cross-section of toroid: $\varphi = \int B\,dA = BA = \frac{F}{R}$ wb

Reluctance: $R = \frac{l}{\mu A}$

Magnetization Curve

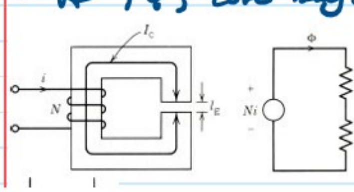
- If ↑I, ↑B ~ linearly when ↓H, but saturates at ↑H
  - when ↑B, ↓R and when ↓B, ↑R





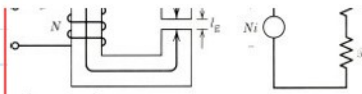
Air gaps

- Airgaps needs ↑mmf than core
- If ↑φ, core may saturate, but airgap unsaturated ∵ B-H air → linear



$R_c = \frac{l_c}{\mu_c A_c}$ $R_g = \frac{l_g}{\mu_0 A_g}$

$\varphi = \frac{F}{R}$ $F = Ni = H_c l_c + H_g l_g$



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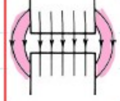
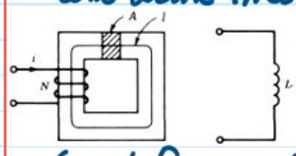


- Magnetic flux lines overflow → fringing
- If ↓l_g, neglect ∴ $A_g = A_c \to B_g = B_c = \frac{\varphi}{A_c}$

Inductance

- Coil wound inductor → flux linkage of coil



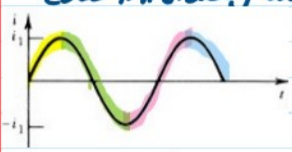
Flux linkage $\lambda = N\varphi$

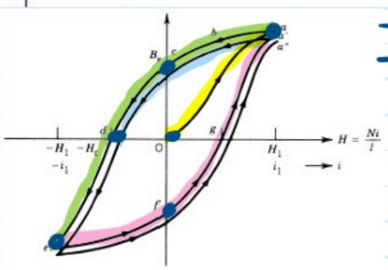
Inductance $L = \frac{\lambda}{i} = \frac{N\varphi}{i} = \frac{N^2}{R_T}$

- Can define inductance w/ dimensions (A, l), or magnetic reluctance

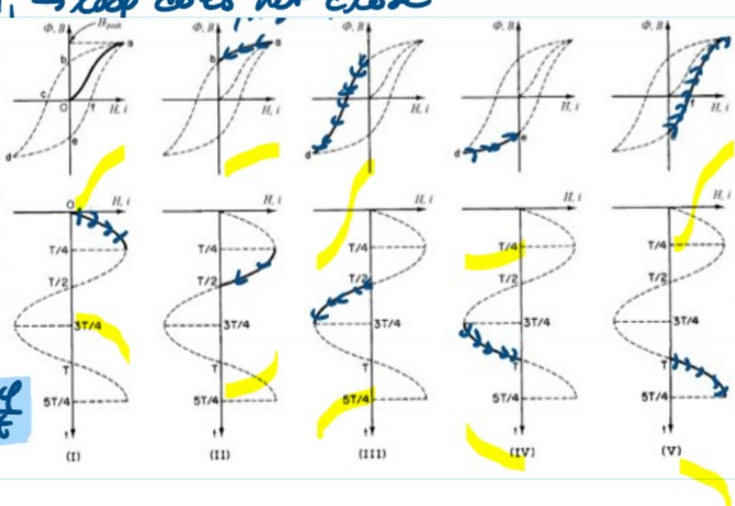
1.2 Hysteresis

- Core initially unmagnetized, slowly ↑i, ↑H



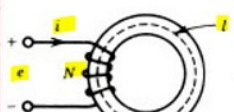


- ↑H, @ a, ↓H until H=0
- But core has retained flux density B_r → Residual flux density
- ↑H reversed → flux decreases, @ $-H_c$, residual flux = 0
- ↑H reversed → ↑B reverse ↳ coercive force
- ↓H to 0 then ↑H_1 → loop does not close



Hysteresis loss

- E_{in} > $E_{returned}$, E loss → core
  ↳ Hysteresis loss
- Size Hysteresis loop ∝ Hysteresis loss
  - Faraday's law: $e = N\frac{d\varphi}{dt}$



$P_{in} = ie = i\frac{d\lambda}{dt}$

$dW = \oint P_{in}\, dt = \oint i \frac{d\lambda}{dt}$

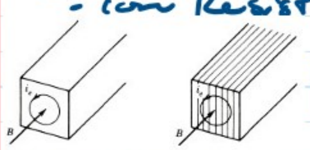
$dW_h = \oint i\, d\lambda \to F = Ni,\ \lambda = N\varphi = NB_cA_c$

$= \oint \left(\frac{H_c l_c}{N}\right)(NA_c\, dB_c) = \underbrace{l_c A_c}_{V} \underbrace{\oint H_c\, dB_c}_{A} = V_{core} \times$ Area B-H loop $= V_{core} \times W_h$

Power loss: $P_h = K_h \cdot f \cdot (B_{c,max})^n \to K_h$ & n determined exp.

Eddy Current Loss

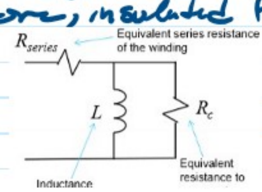
- flux density changes rapidly in core
- Voltage induced, ie eddy current flows around path
  ∵ core Resistance, power loss i^2R



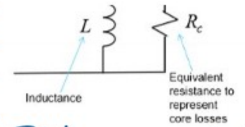
Reducing Eddy Currents:

1. ↑ core resistivity
2. laminated core, insulated from eachother

Power loss: $P_e = K_e f^2 (B_{c,max})^2$
↳ K_e determined exp.



↳ K_c determined exp.



Core Loss

- Core losses = hysteresis loss + Eddy current loss

  $P_c = P_h + P_e$

- core loss can be computed from Area of dynamic B-H loop

  $P_c = V_{core} \cdot f \oint_{\text{dynamic loop}} H \cdot dB$ → volume core × frequency × Area dynamic loop