Transformers

- Transformers
  - Basic Principle
  - Equivalent Circuit
  - Parameter Estimation
- Permanent Magnets

Transformers

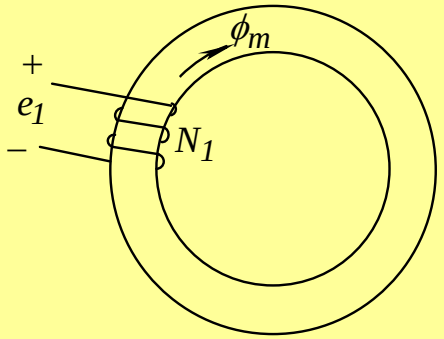
- Tightly coupled coils (low leakage inductance)
- Essential for power transmission and distribution
- Helpful in understanding induction machines

Transformers - Development

- Single coil

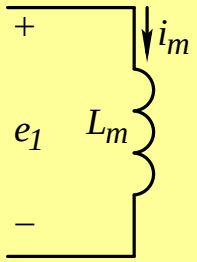
  Assuming zero resistance and zero leakage inductance

$$e_1 = N_1 \frac{d\phi_m}{dt}$$



ϕ_m determined completely by applied voltage:

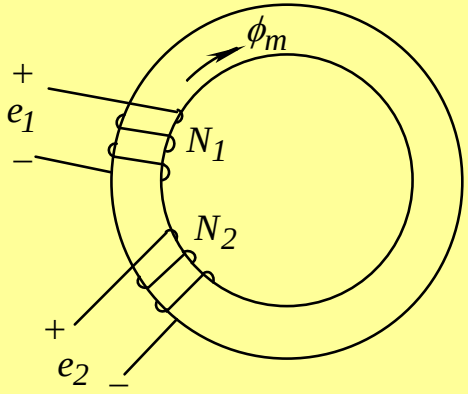
$$\phi_m = \frac{1}{N_1} \int e_1 \, d\tau$$



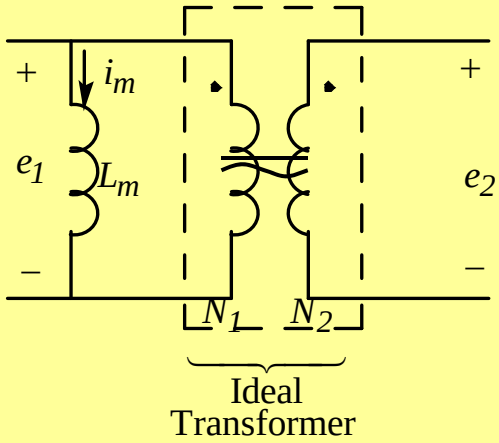
- Two coils

$$e_2(t) = N_2 \frac{d\phi_m}{dt} \qquad \& \quad e_1(t) = N_1 \frac{d\phi_m}{dt}$$

$$\Rightarrow \frac{e_1(t)}{e_2(t)} = \frac{N_1}{N_2}$$



Transformer Model



- Dot polarity
- Magnetizing inductance

Transformer with Secondary Loaded

- ϕ_m determined by e_1 alone

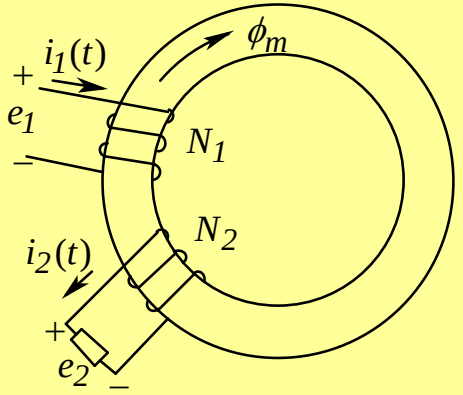
  hence i_2 in secondary induces

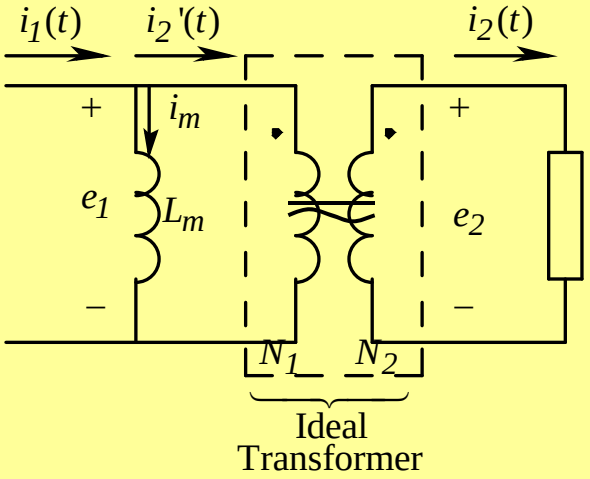
  i_2' in the primary such that

$$N_1 i_2' = N_2 i_2$$

$$\Rightarrow \frac{i_2'}{i_2} = \frac{N_2}{N_1}$$

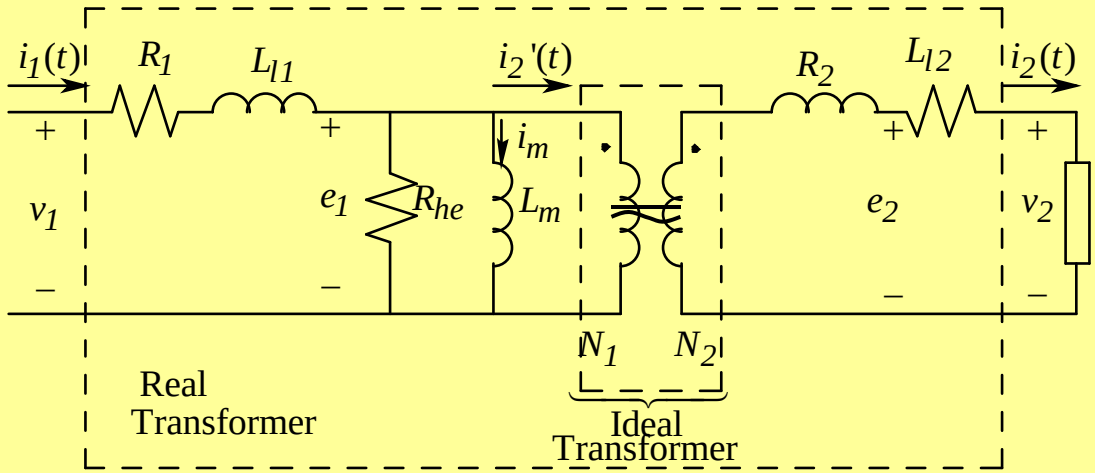
$$i_1(t) = \underbrace{i_2'(t)}_{\text{relflected load current}} + \underbrace{i_m(t)}_{\text{magnetizing current}}$$



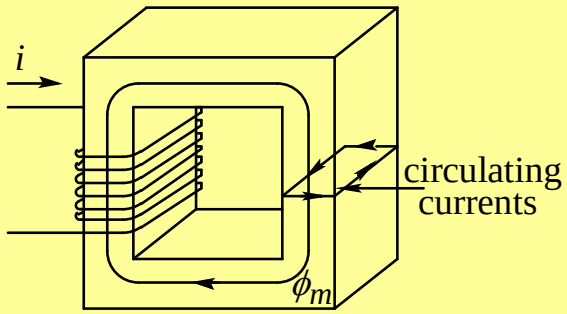


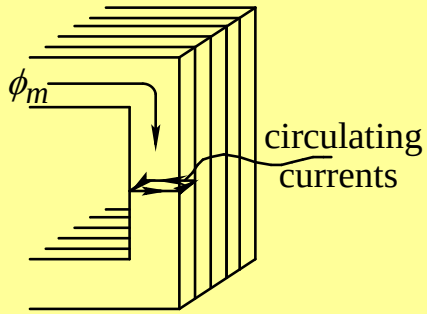
Real Transformers

- ☐ Add leakages
- ☐ Core loss
  - hysteresis
  - eddy currents
- ☐ Winding resistances

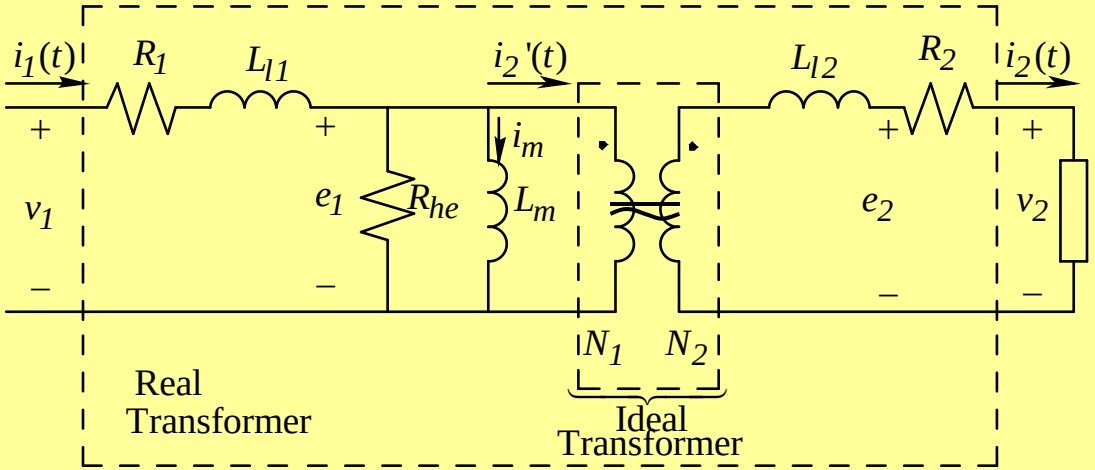


- ☐ Laminations to reduce eddy current loss





Determining Transformer Model Parameters



- Open circuit test
  - Core loss, R_{he}
  - Magnetizing inductance, L_m

- Short circuit test
  - Winding resistance, R_1, R_2
  - Leakage inductance, L_{l1}, L_{l2}

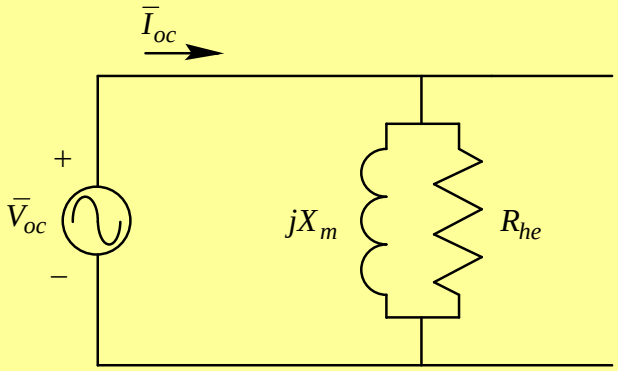
Open Circuit Test

- Secondary unloaded (open circuit)
- Rated voltage applied to primary
- Measure
  - To find R_{he}

$$R_{he} = \frac{V_{oc}^2}{P_{oc}}$$

  - To find L_m

$$|R_{he}||jX_m| = \frac{V_{oc}}{I_{oc}}$$



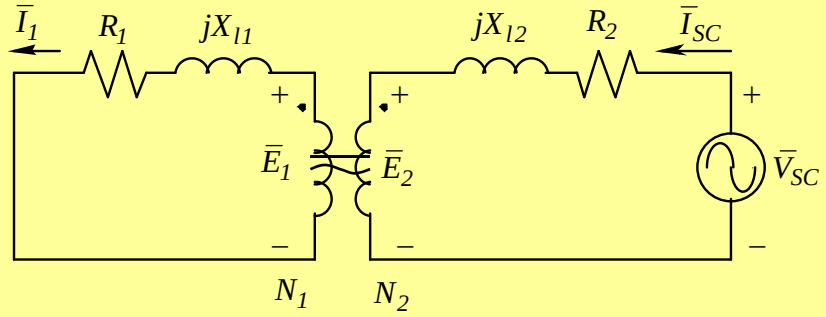
Short Circuit Test

- One winding shorted

  small voltage applied to other winding
- Measure V_{SC}, and I_{SC}, and P_{SC}

  - To find R_1 and R_2

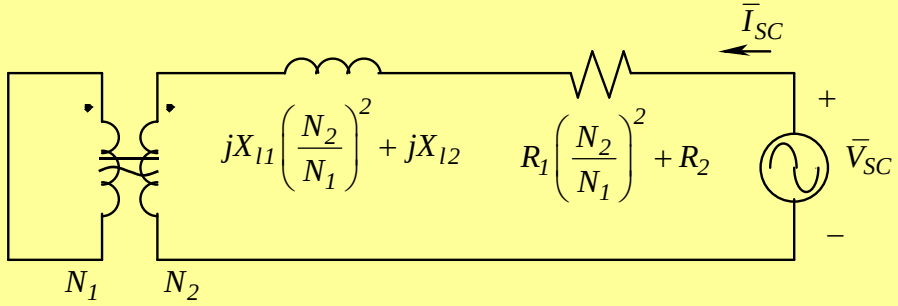
$$R_2 = \frac{1}{2}\frac{P_{SC}}{I_{SC}^2} \qquad R_1 = R_2\left(\frac{N_1}{N_2}\right)^2$$



  - To find L_{l1} and L_{l2}

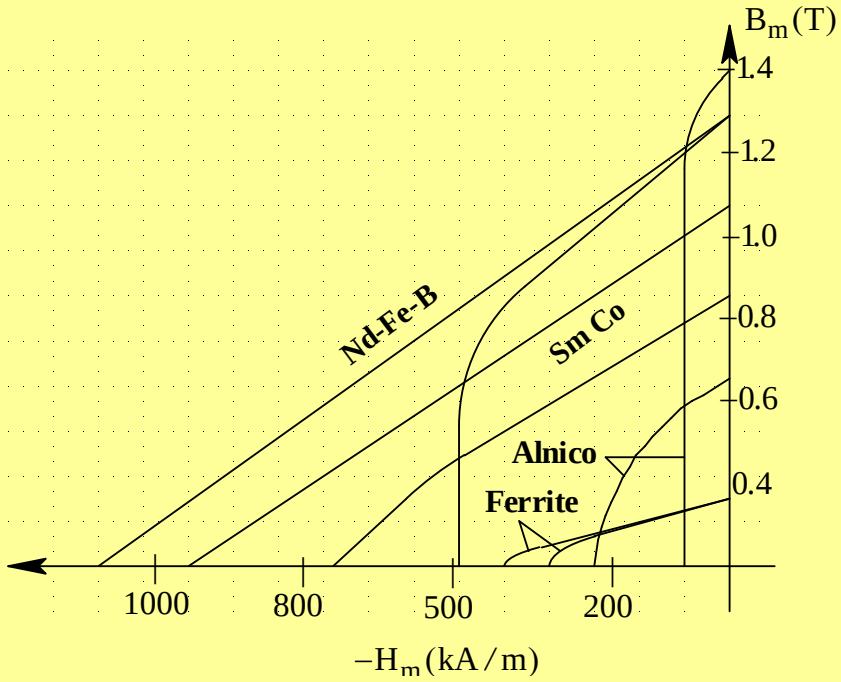
$$|2R_2 + j2X_{l2}| = \frac{V_{SC}}{I_{SC}}$$

$$X_{l1} = X_{l2}\left(\frac{N_1}{N_2}\right)^2$$



Permanent Magnets

- Typically used in smaller motors
- Applicable power range increasing due to new materials
- In simplest analysis, treated simply as a source of magnetic flux



Summary

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  - Parameter Estimation
- Permanent Magnets