INDUCTANCE AND TRANSFORMER

EE 306 – SS2015

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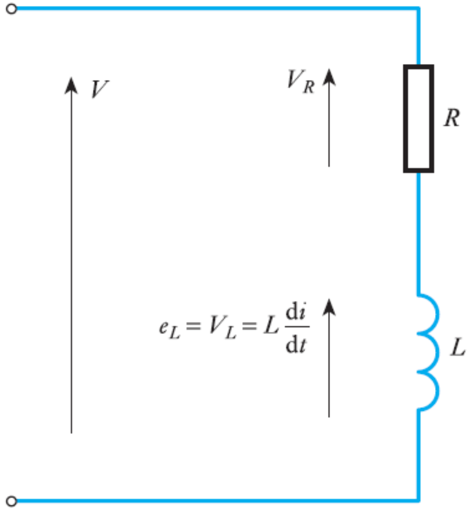
Basics

- Any circuit in which a change of current is accompanied by a change of flux, and therefore by an induced e.m.f., is said to be *inductive* or to possess *self-inductance* or merely *inductance*
- Unit of inductance is termed the *henry (H)*
  - *Circuit has an inductance of 1 henry (H) if e.m.f. of 1 volt is induced in circuit when the current varies uniformly at the rate of 1 ampere per second*

Self-inductance Symbol: L Unit: **henry (H)**

$$e = L \cdot \frac{di}{dt}$$



Factors Determining Inductance of Coil

- Coil uniformly wound on non-magnetic ring of uniform section

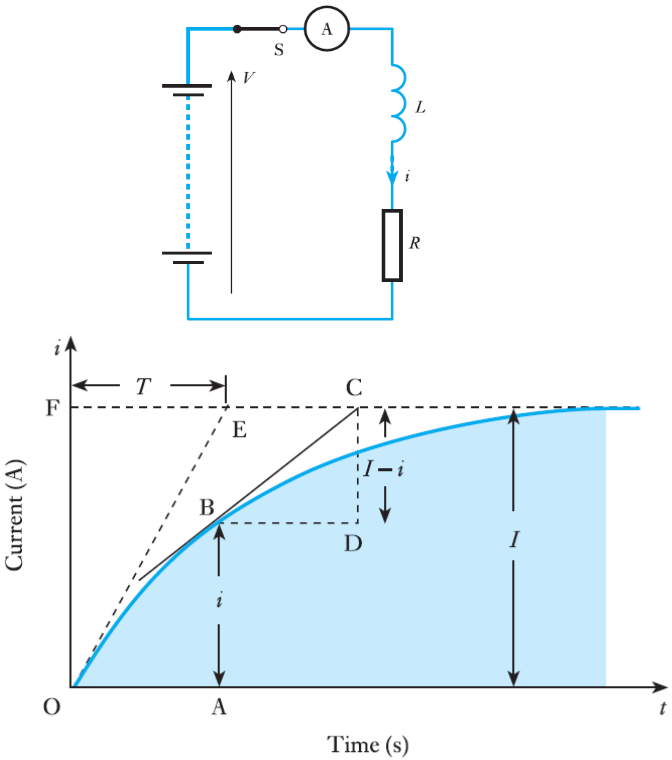
$$\text{Inductance} = L = 4\pi \times 10^{-7} \times \frac{AN^2}{l} \quad \text{henrys}$$

- Coil wound on closed ferromagnetic core (such as a ring)
  - μ_r represents the value of the relative permeability

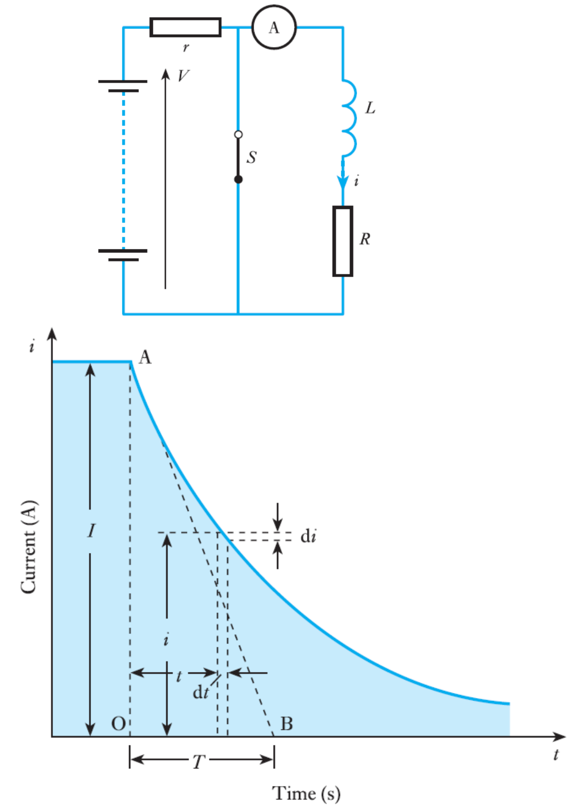
$$L = 4\pi \times 10^{-7} \times \frac{AN^2}{l} \times \mu_r \quad \text{henrys}$$

$$L\ (\text{henrys}) = \mu_0 \mu_r \times A\ (\text{metres}^2) \times \frac{N^2}{l\ (\text{metres})}$$

Growth and Decay in Inductive Circuit



$$i = I\left(1 - e^{-\frac{Rt}{L}}\right)$$



$$i = I e^{-\frac{Rt}{L}}$$

Time constant = $T = \frac{L}{R}$ seconds

Energy Stored in Inductor

- If current in coil having constant inductance of L henrys grows at uniform rate from zero to I amperes in t seconds:

$$W_f = \frac{1}{2}LI^2 \quad \text{joules}$$

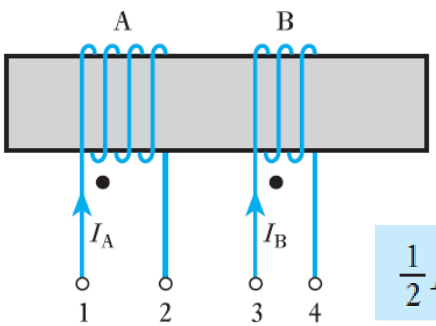
- Things can get complicated with complex inductors involving ferromagnetic cores and when current increase is nonuniform

Mutual Inductance

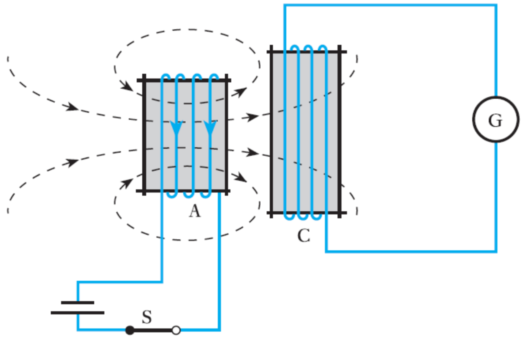
- If two coils A and C are placed relative to each other, then, when S is closed, some of the flux produced by the current in A becomes linked with C, and the e.m.f. induced in C circulates a momentary current through galvanometer G
- Since change of current in one coil is accompanied by change of flux linked with the other coil and therefore by an e.m.f. induced in the latter, the two coils are said to have *mutual inductance*

Mutual inductance Symbol: M Unit: **henry (H)**

$$\text{EMF induced in B} = M_{12} \cdot \frac{di}{dt} \text{ volts}$$



$$\tfrac{1}{2}L_A I_A^2 + \tfrac{1}{2}L_B I_B^2 \pm M_{12} I_A I_B \quad \text{joules}$$



Mutual Inductance

- Mutual inductance between two circuits is the same whichever circuit is taken as primary

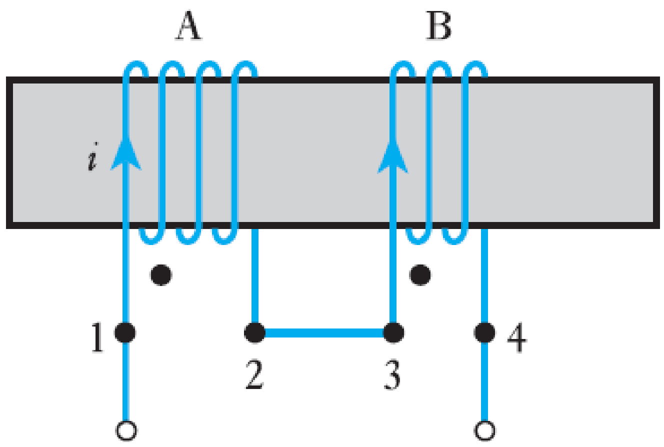
$$M_{12} = M_{21} = \text{(say) } M$$

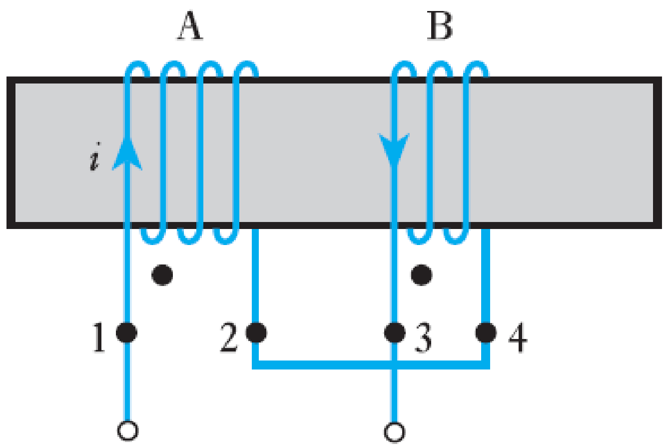
- Coupling

$$M = k\sqrt{(L_1 L_2)}$$

  - k is termed the coupling coefficient
  - Coils close together: *tightly coupled*
  - Coils far apart: *loosely coupled*

Coils Connected in Series





$$L_1 = L_A + L_B + 2M$$

$$L_2 = L_A + L_B - 2M$$

$$M = \frac{L_1 - L_2}{4}$$

Types of Inductors

- Inductors, unlike resistors and capacitors, cannot be considered as pure elements: always introduce inductance + resistance
- Inductors always involve coils of conductor wire
- Inductors fall into two categories: air core and ferromagnetic core
  - Inductance of air core is low but same regardless of current
  - Inductance of ferromagnetic core is high but changes with current
- Variable inductors: core mounted on screw
  - Move in and out of the coil, thus varying inductance
- Like capacitors, the weakness of inductors lies in the insulation
  - If insulation fails, one or more turns of coil are short-circuited

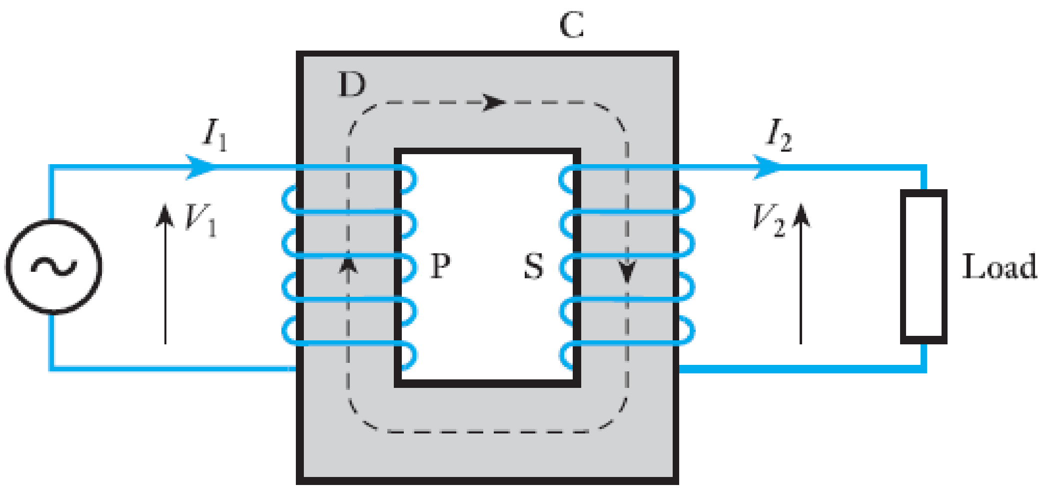

Inductor


Ferromagnetic-cored inductor


Variable inductor

Principle of Action of Ideal Transformer

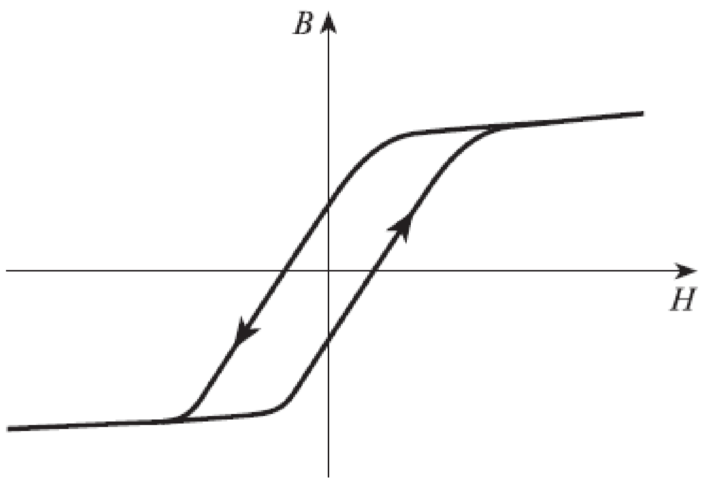
- General arrangement of a transformer includes two coils wound around steel core that consists of laminated sheets.
  - Vertical portions of core are referred to as limbs
  - Top and bottom portions are the yokes
  - Coils P and S are wound on the limbs
  - Coil P is connected to supply and is therefore termed primary
  - Coil S is connected to load and is termed secondary



$$\frac{I_1}{I_2} \simeq \frac{N_2}{N_1} \simeq \frac{V_2}{V_1}$$

Practical Transformer Issues

- Hysteresis losses
  - Requirement of supplying energy to magnetize core in each cycle
- Eddy currents
  - Varying flux in core induces e.m.f.s and hence currents in core material that give rise to I^2R losses (hence heat)
- Sum of the hysteresis and eddy-current losses is known as *core loss*



Summary

- Inductance depends on number of turns of the energizing coil, length and cross-sectional area of magnetic circuit and material of magnetic circuit
- Ferromagnetic-core inductors produce much higher inductances than other inductors
- Current in inductor cannot change instantaneously but has to rise or fall exponentially
- When magnetic field is set up by an inductor, it stores energy
- When magnetic field of one coil links with second coil, coils are said to be mutually linked and they have mutual inductance
- How well they are linked is indicated by the coupling coefficient
- Transformers effect changes of voltage with virtually no loss of power, input is called primary and the output is termed secondary
- Primary and secondary systems are connected by magnetic flux linkage

Suggested Readings and Exercises

- Hughes textbook – Chapters 8, 32.3
- Exercise 8 (Hughes)
  - Problems 2, 7, 9, 20, 22, 27, 35, 36