Advanced Topics in Electrical Machines PE/PE/H/T/316B

PRP

Course outcomes (CO)

After successful completion of this course, the students would be able to:

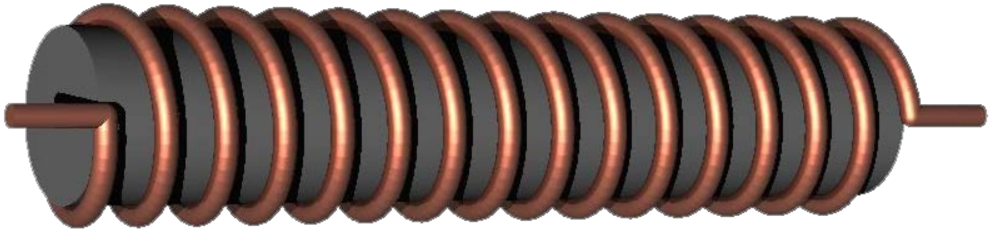
CO1	Describe generalized theory of electrical machines, linear transformation between rotating axes and pseudo-stationary axes variables, Parks Transformation
CO2	Analyze the effects of saturation, harmonics and solid iron rotor/pole shoe on the performance of synchronous machines and Appraise stability and asynchronous operation of synchronous machine
CO3	Examine the heating and cooling of large power transformers and effects of surge voltage on electrical machines
CO4	Investigate type tests, routine tests and special tests of electrical machines

Recapitulation of Electromagnetism

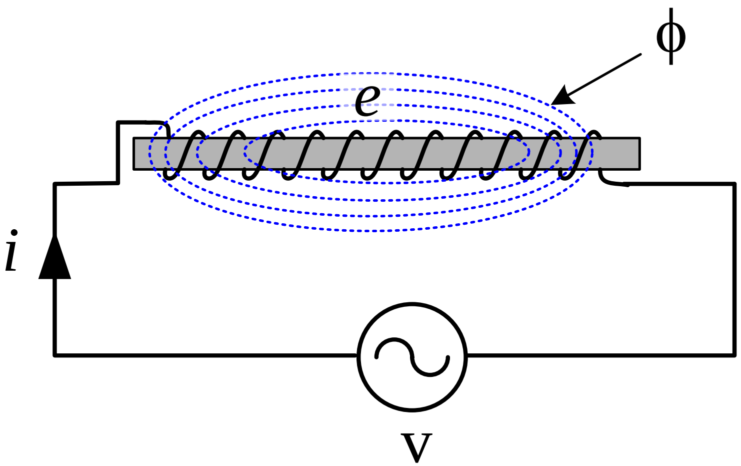
Day 1

ILOs – Day1

- Recapitulate basic electromagnetism principles & relations
  - Flux
  - Flux linkage
  - Mutual flux
  - Leakage flux



Flux & flux linkage - **Electromagnet**



- Coil with N number of turns
- AC supply voltage *v*
- Current *i* through coil is also AC
- Magnetic flux created by the current carrying coil is ϕ Wb

$$\phi = \frac{MMF}{\text{Reluctance}} = \frac{Ni}{S}$$

$$S = \frac{l}{\mu_0 \mu_r A}$$

- l = length of magnetic path
- A = cross sectional area of the iron core
- μ_0 = Absolute permeability (of air)
- μ_r = Relative permeability (of the core)

Flux & flux linkage – Electromagnetic induction

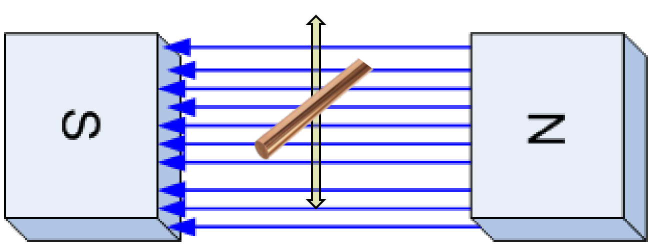
- Faraday' laws of electromagnetic induction
  - 1st law: **Whenever there is change in magnetic flux linking with a conductor, an EMF is induced in the conductor**
  - 2^{nd} law: **The amount of EMF induced in the conductor is proportional to the rate of change of flux linking with the conductor**
- Lenz's law:
  - **The direction of induced EMF is such that the current set up by it produces a magnetic field that opposes the change in original flux**

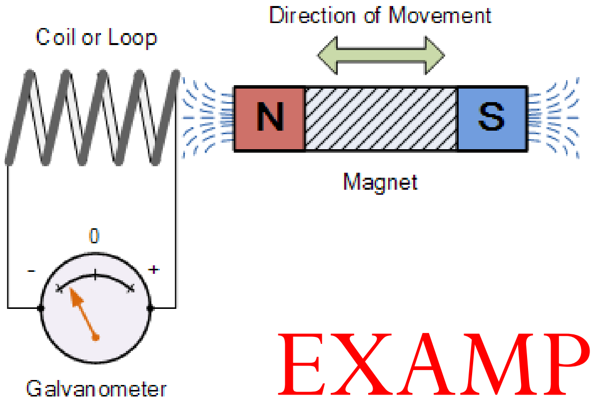
$$e = -\frac{d\psi}{dt} = -N\frac{d\phi}{dt}$$

- **Thus, whenever there is a relative change between magnetic flux and a coil, EMF is induced in the coil.**

Flux & flux linkage – Electromagnetic induction

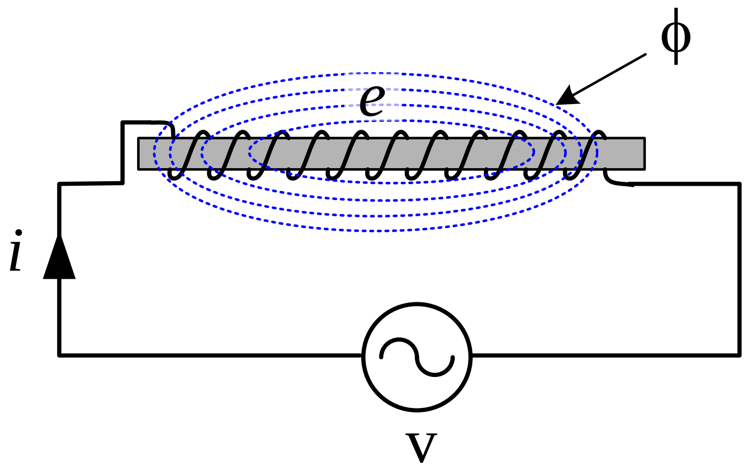
- Dynamically induced EMF
  - **The magnetic field is stationery and constant, but the conductor physically moves in the magnetic field**
  - **The conductor remains stationery but the magnet or the magnetic field moves physically**
- Statically induced EMF
  - **Both magnet as well as the conductor is stationery, but the magnetic field itself is time-varying**





EXAMPLES????

Flux & flux linkage - **Self induced EMF**



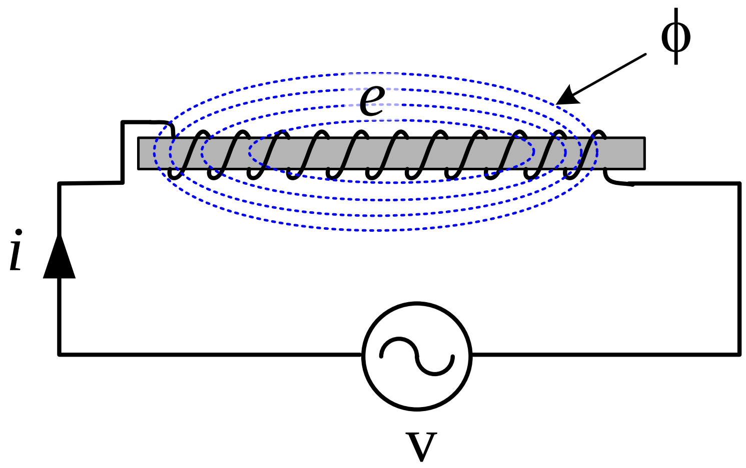
$$\phi = \frac{MMF}{\text{Reluctance}} = \frac{Ni}{S}$$

- Since the supply current is AC, the magnetic flux ϕ produced by the coil is also AC
- This flux links with the coil also
- Since this flux is varying with time, an EMF will be induced in the coil itself
- This EMF is called ***self-induced EMF***
- Direction of this EMF will be such that it opposes the supply voltage

$$e = -\frac{d\psi}{dt} = -N\frac{d\phi}{dt}$$

- ψ = Flux linkage = $N\phi$

Flux & flux linkage - **Self induced EMF**



$$e = -\frac{d\psi}{dt} = -N\frac{d\phi}{dt}$$

In terms of self-inductance L of the coil:

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

Where self inductance, $L = N\frac{d\phi}{di}$

When absolute values of flux and current are known: $L = N\frac{\phi}{i}$

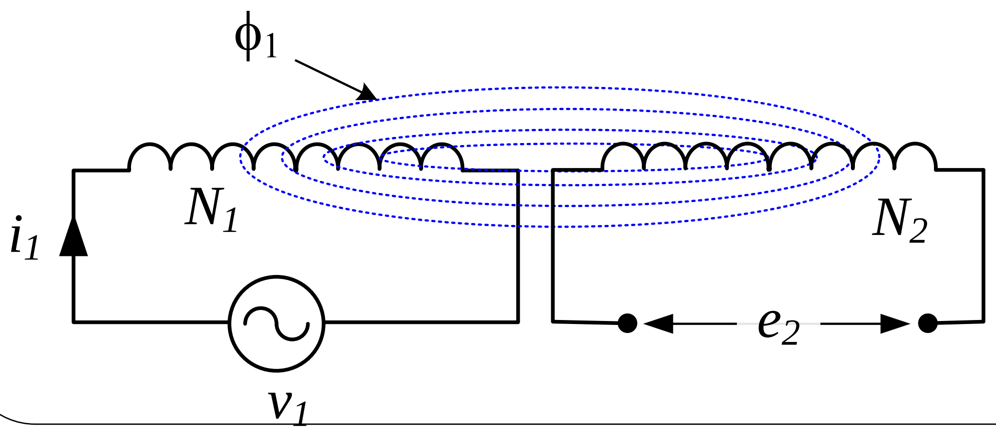
$$L = N\frac{\phi}{i} = N\frac{Ni}{Si} = \frac{N^2}{S}$$

Flux & flux linkage - **Mutually induced EMF**

- Two coils (with turns N_1 and N_2) are placed close to each other
- An alternating voltage v_1 is applied to the first coil
- An alternating flux ϕ_1 is produced by the current i_1 in the first coil

$$\phi_1 = \frac{MMF}{\text{Reluctance}} = \frac{N_1 i_1}{S}$$

- This time varying flux ϕ_1 links with the second coil
- A EMF e_2 is induced in the second coil
- This EMF is called ***mutually induced EMF***



$$e_2 = -\frac{d\psi}{dt} = -N_2 \frac{d\phi_1}{dt}$$

Flux & flux linkage - **Mutually induced EMF**

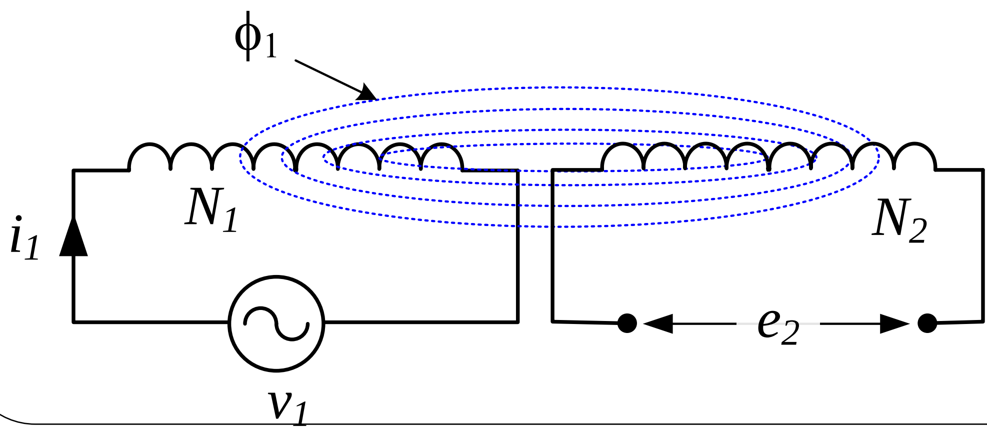
$$e_2 = -\frac{d\psi}{dt} = -N_2\frac{d\phi_1}{dt}$$

In terms of mutual-inductance *M* between the two coils:

$$e_2 = -M\frac{di_1}{dt} \quad \text{Where, } M = N_2\frac{d\phi_1}{di_1}$$

$$M = N_2\frac{\phi_1}{i_1} = N_2\frac{N_1 i_1}{S i_1}$$

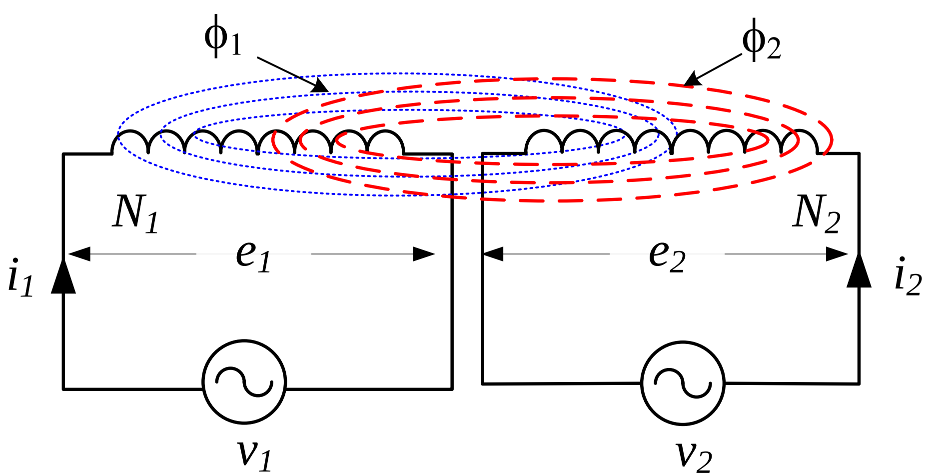
$$M = \frac{N_1 N_2}{S}$$



The action of mutual induction is reversible, i.e. any change in current in the second coil will also cause similar EMF to be induced in the first coil.

Flux & flux linkage – **Coupled circuits**

- When the second circuit is closed
- Current flows through it
- The second coil produces another flux that takes part in further electromagnetic induction processes
- In general, if two or more coils are placed close to each other so that magnetic flux produced by each of them can link with the others, those inter-linked (magnetically) circuits are called coupled circuits.



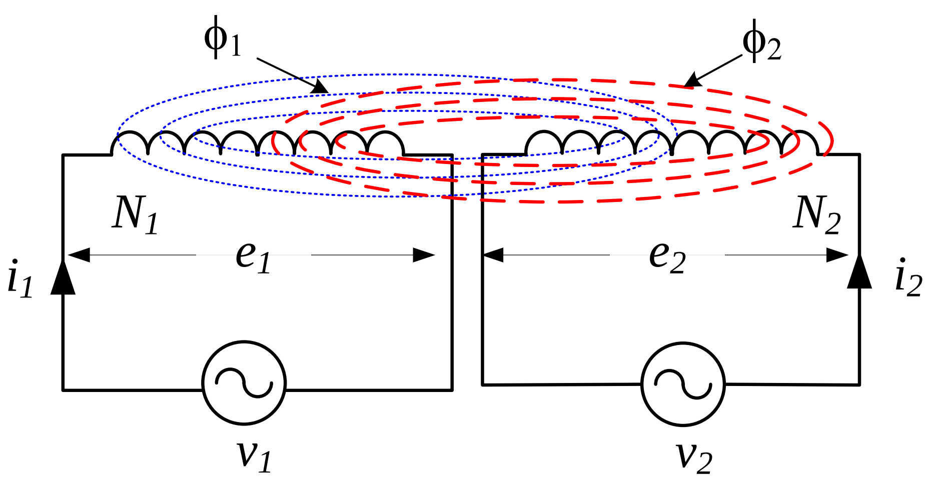
Flux & flux linkage – **Coupled circuits**

- Now each coil has its own flux, and a second flux that comes from the second coil
- So, each coil will have both **self** as well as **mutually induced EMF**

$$e_1 = -\left(L_1 \frac{di_1}{dt} + M \frac{di_2}{dt} \right)$$

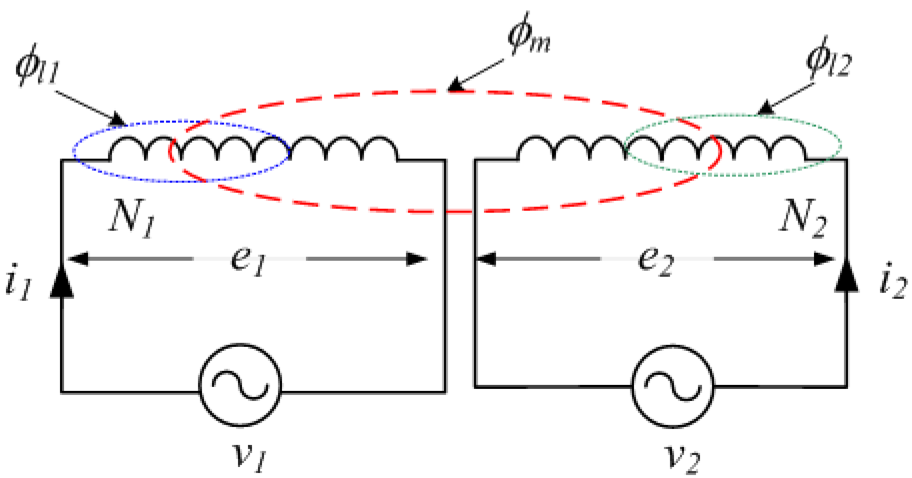
$$e_2 = -\left(L_2 \frac{di_2}{dt} + M \frac{di_1}{dt} \right)$$

Where, L_1 and L_2 are self-inductances of the two coils respectively, and M is the mutual inductance between them.



Flux & flux linkage – **Leakage flux**

- If the flux from one coil does not link the second coil completely
- Such fluxes that do not link both coils simultaneously are **leakage flux**
- ϕ_{l1} is the leakage flux linking the first coil alone
- ϕ_{l2} is the leakage flux linking the second coil alone
- ϕ_m is the mutual flux linking both the coils



Flux & flux linkage – **Leakage flux**

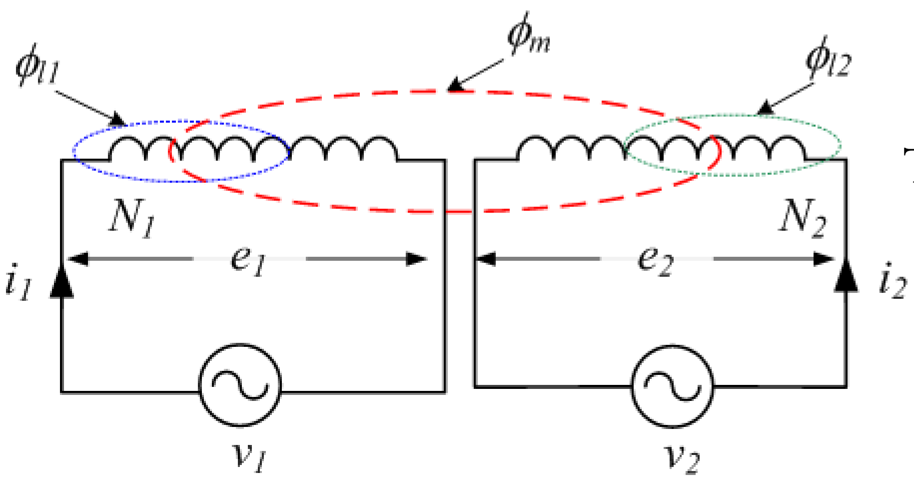
- Self inductance of the first coil:

$$L_1 = \frac{\text{Total flux linkages with } 1^{\text{st}} \text{ coil}}{\text{Total current in } 1^{\text{st}} \text{ coil}} = \frac{(\text{Mutual} + \text{leakage}) \text{ flux linkages with } 1^{\text{st}} \text{ coil}}{\text{Total current in } 1^{\text{st}} \text{ coil}}$$

$$= \frac{\phi_m N_1 + \phi_{l1} N_1}{i_1} = \frac{\phi_m N_1}{i_1} + \frac{\phi_{l1} N_1}{i_1} = \frac{\phi_m N_2}{i_1} \cdot \frac{N_1}{N_2} + \frac{\phi_{l1} N_1}{i_1} = M \cdot \frac{N_1}{N_2} + l_1$$

Where M is the mutual inductance and l_1 is leakage inductance of the 1st coil

Assuming identical coils (or converting to per unit system), $N_1 = N_2$



$$L_1 = M + l_1$$

Thus, self inductance = Mutual inductance + leakage inductance

Similarly, $$L_2 = M + l_2$$

Activity

GATE EE2013

Leakage flux in an induction motor is

(A) flux that leaks through the machine

(B) flux that links both stator and rotor windings

(C) flux that links none of the windings

(D) flux that links the stator winding or the rotor winding but not both