CHAPTER

6 Electromagnetic Induction

Magnetic Flux

$\phi = \vec{B} \cdot \vec{A} = BA \cos\theta$ weber for uniform $\vec{B}$.

$\phi = \int \vec{B} \cdot d\vec{A}$ for non uniform $\vec{B}$.

Faraday's Laws of Electromagnetic Induction

(i) An induced emf is setup whenever the magnetic flux linking that circuit changes.

(ii) The magnitude of the induced emf in any circuit is proportional to the rate of change of the magnetic flux linking the circuit, $\varepsilon \propto \frac{d\phi}{dt}$.

Lenz's Laws

The direction of an induced emf is always such as to oppose the cause producing it.

Law of EMI

$e = -\frac{d\phi}{dt}$. The negative sign indicated that the induced emf opposes the change of the flux.

Motional EMF

When a conductor is moved across a magnetic field, an electromotive force (emf) is produced in the conductor. If the conductors forms part of a closed circuit then the emf produced causes an electric current to flow round the circuit. Hence an emf (and thus a current) is induced in the conductor as a result of its movement across the magnetic field. This is known as motional emf.

EMF Induced across a moving Straight Conductor in Uniform Magnetic Field

$E = BLv \sin\theta$ volt where $\left(\text{is } \vec{L} \perp \vec{v} \text{ and } \vec{B}\right)$

B = flux density in wb/m^2;

L = length of the conductor (m);

v = velocity of the conductor (m/s);

θ = angle between direction of motion of conductor & B.

Coil Rotation in Magnetic Field Such that Axis of Rotation is Perpendicular to the Magnetic Field

Instantaneous induced emf. $E = NAB\omega \sin \omega t = E_0 \sin \omega t$, where

N = number of turns in the coil; A = area of one turn ;

B = magnetic induction; ω = uniform angular velocity of the coil;

E_0 = maximum induced emf.

Self Induction and Self Inductance

The property of the coil or the circuit due to which it opposes any change of the current coil or the circuit is known as **Self-Inductance**. It's unit is Henry.

Coefficient of Self inductance $L = \frac{\phi_s}{i}$ or $\phi_s = Li$

L depends only on;

(i) Shape of the loop and

(ii) Medium

i = current in the circuit.

ϕ_s = magnetic flux linked with the circuit due to the current i.

self induced emf $e_s = \frac{d\phi_s}{dt} = -\frac{d}{dt}(Li) = -L\frac{di}{dt}$ (if L is constant)

Mutual Induction

If two electric circuits are such that the magnetic field due to a current in one is partly or wholly linked with the other, the two coils are said to be electromagnetically coupled circuits . Then any change of current in one produces a change of magnetic flux in the other and the latter opposes the change by inducing an emf within itself. This phenomenon is called **Mutual Induction.**

Induced emf in the latter circuit due to a change of current in the former is called **Mutually Induced EMF**.

The circuit in which the current is changed, is called the primary and the other circuit in which the emf is induced is called the secondary.

The co-efficient of mutual induction (mutual inductance) between two electromagnetically coupled circuit is the magnetic flux linked with the secondary per unit current in the primary.

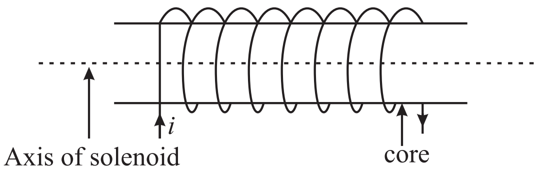
Mutual inductance $= M = \frac{\phi_m}{I_p} = \frac{\text{flux linked with secondary}}{\text{current in the primary}}$

Mutually induced emf $(E_m) = \frac{d\phi_m}{dt} = -\frac{d}{dt}(MI) = -M\frac{dI}{dt}$

M depends on

(1) geometry of loops (2) medium (3) orientation and distance between the loops.

Solenoid



There is a uniform magnetic field along the axis the solenoid (ideal : length >> diameter)

$B = \mu\, ni$ where;

μ = magnetic permeability of the core material;

n = number of turns in the solenoid per unit length;

i = current in the solenoid;

Self inductance of a solenoid $L = \mu n^2 Al$;

A = area of cross section of solenoid.

Super Conducting Loop in Magnetic Field

$R = 0$; $\varepsilon = 0$. Therefore ϕ_{total} = constant. Thus through a superconducting loop flux never changes.

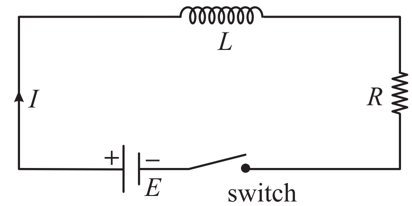
Energy Stored in an Inductor:

$$U = \frac{1}{2} LI^2.$$

Energy of interaction of two loops $U = I_1\phi_2 = I_2\phi_1 = MI_1I_2$, where M is mutual inductance.

Growth of a Current in an L—R Circuit

$I = \frac{E}{R}(1 - e^{-Rt/L})$. [If initial current = 0]

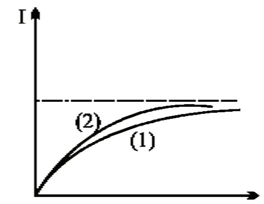


$\frac{L}{R}$ = time constant of the circuit.

$I_0 = \frac{E}{R}$.

(i) L behaves as open circuit at $t = 0$ [If $i = 0$]

(ii) L behaves as short circuit at $t = \infty$ always.



Curve (1) $\longrightarrow \frac{L}{R}$ Large

Curve (2) $\longrightarrow \frac{L}{R}$ Small

Decay of Current

Initial current through the inductor = I_0; Current at any instant $i = I_0 e^{-Rt/L}$