CHAPTER 6

ELECTROMAGNETIC INDUCTION

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Faraday's Law of Electromagnetic Induction

- ***The magnitude of the induced emf in a circuit is equal to the time rate of change of magnetic flux through the circuit.***
- Mathematically

$$\varepsilon = -\frac{d\Phi_B}{dt}$$

- If there are N turns

$$\varepsilon = -N\frac{d\Phi_B}{dt}$$

- The negative sign indicates the direction of emf.

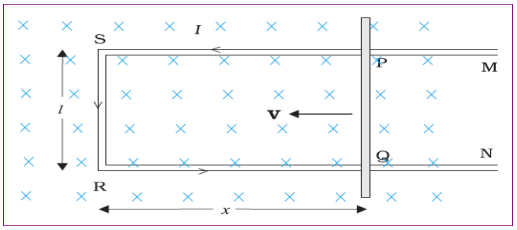
Ways to increase the induced emf

- By increasing the number of turns, N.
- By changing magnetic flux.
- The magnetic flux can be varied by
  - Changing magnetic field, B
  - Changing area, A.
  - Changing the angle, θ.
  - Rotating the coil in a magnetic field.
  - Shrinking or stretching the coil in a magnetic field.

Motional Electromotive Force

- The emf induced by the motion of a conductor in a magnetic field is called motional emf.

Expression of motional emf



- The magnetic flux Φ_B enclosed by the loop PQRS is

$\Phi_B = Blx$, where B – magnetic field

- Since *x is changing with time, the rate of change* of flux Φ_B will induce an emf given by

$$\varepsilon = \frac{-d\Phi_B}{dt} = -\frac{d}{dt}(Blx)$$
$$= -Bl\frac{dx}{dt} = Blv$$

- The induced emf **Blv** is called motional emf.

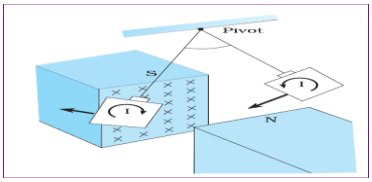
Eddy Currents

- Eddy currents are the **surface currents** produced when **bulk pieces of conductors** are subjected to **changing magnetic field**.
- Eddy currents flow in closed loops within conductors, in planes perpendicular to the magnetic field.

- This effect was discovered by physicist Foucault, and hence this current is also known as **Foucault current.**
- The direction of eddy currents is given by Lenz's law.

Demonstration of eddy currents

Experiment 1



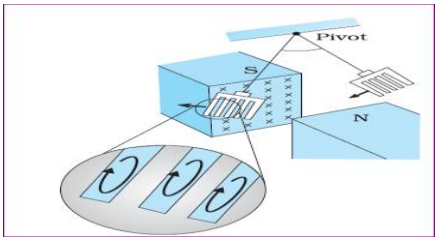
- When a copper plate is allowed to swing like a simple pendulum between the pole pieces of a strong magnet, it is found that the motion is damped and the plate comes to rest in the magnetic field.

Reason :

- As the plates moves the magnetic flux associated with it changes and eddy currents are induced on its surface.
- Directions of eddy currents are opposite when the plate swings into the region between the poles and when it swings out of the region.

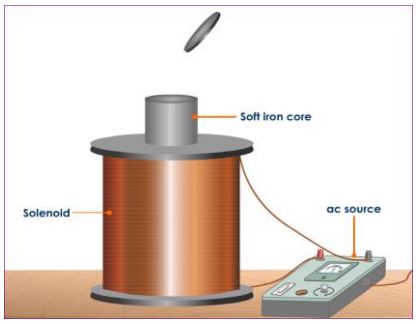
- Hence the plate comes to rest.

Experiment II



- If rectangular slots are made in the copper plate the area available to the flow of eddy currents is less.
- The pendulum plate with holes or slots reduces electromagnetic damping and the plate swings more freely.

Experiment III



- When a metallic disc is placed on one end of a solenoid connected to an ac source and with a soft iron core in it, the disc is thrown up into air.

Reason

- The disc is subjected to a changing magnetic field and eddy currents are formed on it.
- The direction of the induced currents is as per Lenz's law and hence the disc is thrown up into air.

Disadvantages of eddy currents

- The eddy currents dissipate energy in the form of heat.
- Eddy currents are minimized by using laminations.
- Eddy currents are undesirable, in most of the electrical devices like transformer, induction coil, choke coil etc. Eddy currents produce heating in these devices, which is wastage of energy.

Applications of Eddy currents

- Magnetic braking in trains
- Electromagnetic damping in galvanometers.
- Induction furnace
- Electric power meters
- Metal detectors
- Induction cookers
- Speedometer
- Induction motors

AC Generator

- An ac generator converts mechanical energy into electrical energy.
- Nicola Tesla is credited with the development of an ac generator.
- Modern day generators produce electric power as high as 500 MW.
- The frequency of rotation is **50 Hz** in India. In certain countries such as USA, it is **60 Hz.**

Principle/Theory

- A.C. generator works on the principle of **electro-magnetic induction**.
- The rotation of the coil causes the magnetic flux through it to change, so an emf is induced in the coil.
- When the coil is rotated with a constant angular speed ω, the angle θ between the magnetic field vector **B** and the area vector **A** of the coil at any instant t is **θ = ωt**
- The flux at any time *t is*

$$\Phi_B = BA\cos\theta = BA\cos\omega t$$

- From Faraday's law, the induced emf for the rotating coil of *N turns is* then,

$$\varepsilon = -N\frac{d\Phi_B}{dt} = -NBA\frac{d}{dt}(\cos\omega t)$$

- Thus, the instantaneous value of the emf is

$$\varepsilon = NBA\omega \sin\omega t$$

- where ***NBAω*** *is the* ***maximum value*** *of the emf, which occurs when* **sin ωt = ±1.**
- If we denote *NBAω as* ε_0*, then*

$$\varepsilon = \varepsilon_0 \sin \omega t$$

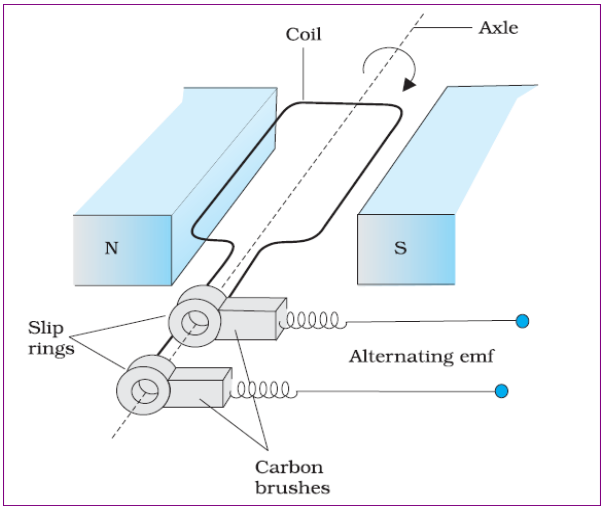
- The direction of the current changes periodically and therefore the current is called ***alternating current (ac).***
- Since ω = 2πν

$$\varepsilon = \varepsilon_0 \sin 2\pi \nu t$$

- Where ν is the frequency of revolution of the generator's coil.

Construction

- An AC Generator consists of a coil mounted on a rotor shaft.
- The axis of rotation of the coil is perpendicular to the direction of the magnetic field.
- The coil (called armature) is mechanically rotated in the uniform magnetic field by some external means.
- The ends of the coil are connected to an external circuit by means of **slip rings** and brushes.

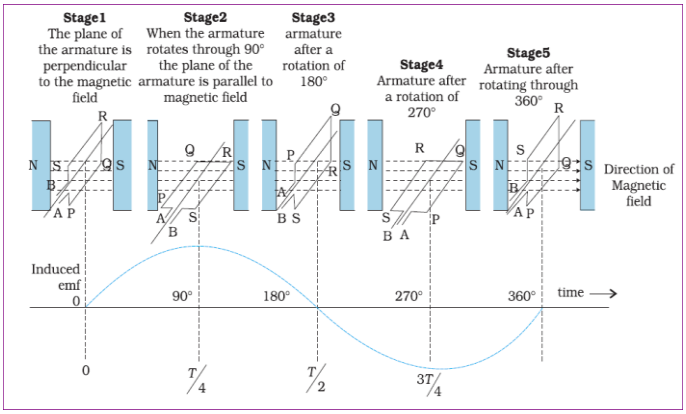


Working

- When the armature coil is mechanically rotated in a uniform magnetic field, the magnetic flux through the coil changes and hence an emf is induced in the coil.

$$\varepsilon = \varepsilon_0 \sin \omega t$$

- The ends of the coil are connected to external circuit by means of slip rings and brushes.



- In most generators, the coils are held stationary and it is the electromagnets which are rotated.

Hydro-electric generators.

- The mechanical energy required for rotation of the armature is provided by water falling from a height.

Thermal generators

- Water is heated to produce steam using coal or other sources.
- The steam at high pressure produces the rotation of the armature.

Nuclear power generators

- Nuclear fuel is used to heat water to produce steam.

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