UNIT 4
ELECTROMAGNETIC INDUCTION AND ALTERNATING CURRENT

Warm greetings:

Dear students

Welcome all. In this section of physics class you get to learn about eddy current and it’s applications. In this class we are going to discuss the following topics.

- **Motional emf from Lorentz force**
- **Eddy current**
- **Applications f eddy current**

Motional emf from Lorentz force:

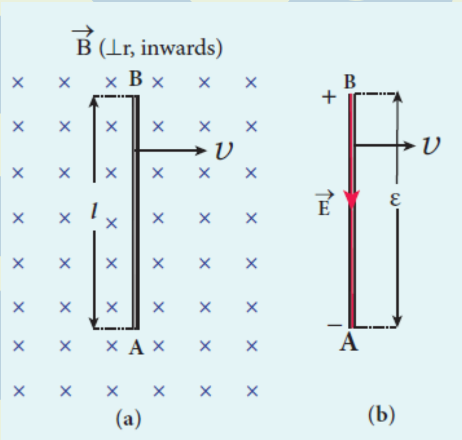

Figure 4.9 Motional emf from Lorentz force

- Consider a straight conducting rod *AB* of length *l* in a uniform magnetic field $\vec{B}$ which is directed perpendicularly into the plane of the paper as shown in Figure 4.9(a).
- The length of the rod is normal to the magnetic field. Let the rod move with a constant velocity $\vec{v}$ towards right side.
- When the rod moves, the free electrons present in it also move with same velocity $\vec{v}$ in $\vec{B}$.

- As a result, the Lorentz force acts on free electrons in the direction from B to A and is given by the relation

$$\vec{F}_B = -e(\vec{v} \times \vec{B}) \qquad (4.4)$$

- The action of this Lorentz force is to accumulate the free electrons at the end *A*. This accumulation of free electrons produces a potential difference across the rod which in turn establishes an electric field $\underset{E}{\rightarrow}$ directed along *BA* (Figure 4.9(b)).
- Due to the electric field $\underset{E}{\rightarrow}$, the coulomb force starts acting on the free electrons along *AB* and is given by

$$\vec{F}_E = -e\vec{E} \qquad (4.5)$$

- The magnitude of the electric field $\underset{E}{\rightarrow}$ keeps on increasing as long as accumulation of electrons at the end *A* continues.
- The force $\underset{FB}{\rightarrow}$ also increases until equilibrium is reached.
- At equilibrium, the magnetic Lorentz force $\underset{FB}{\rightarrow}$ and the coulomb force $\underset{FE}{\rightarrow}$ balance each other and no further accumulation of free electrons at the end *A* takes place. i.e.,

$$|\vec{F}_B| = |\vec{F}_E|$$

$$|-e\,(\vec{v} \times \vec{B})| = |-e\vec{E}|$$

$$vB \sin 90° = E$$

$$vB = E \qquad (4.6)$$

The potential difference between two ends of the rod is

$$V = El$$

$$V = vBl$$

- Thus the Lorentz force on the free electrons is responsible to maintain this potential difference and hence produces an emf

$$\varepsilon = Blv \qquad (4.7)$$

- As this emf is produced due to the movement of the rod, it is often called as **motional emf**.
- If the ends A and B are connected by an external circuit of total resistance *R*, then current $i = \frac{\varepsilon}{R} = \frac{Blv}{R}$ flows in it.
- The direction of the current is found from right-hand thumb rule.

EDDY CURRENTS:

According to Faraday's law of electromagnetic induction, an emf is induced in a conductor when the magnetic flux passing through it changes. However, the conductor need not be in the form of a wire or coil.

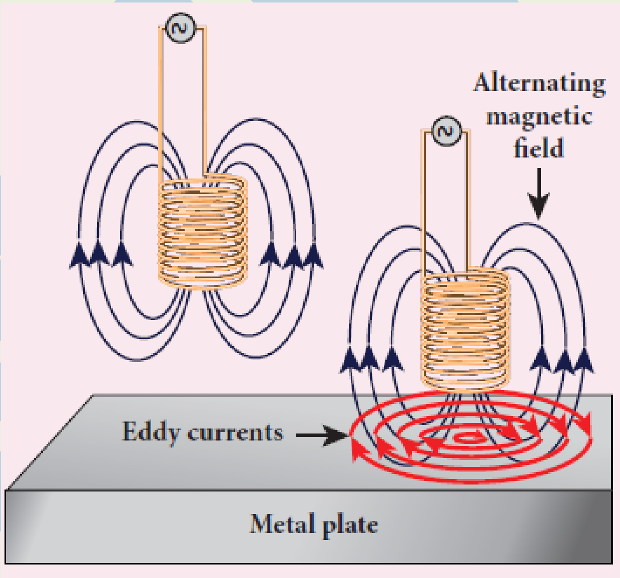

Figure 4.10 Eddy currents

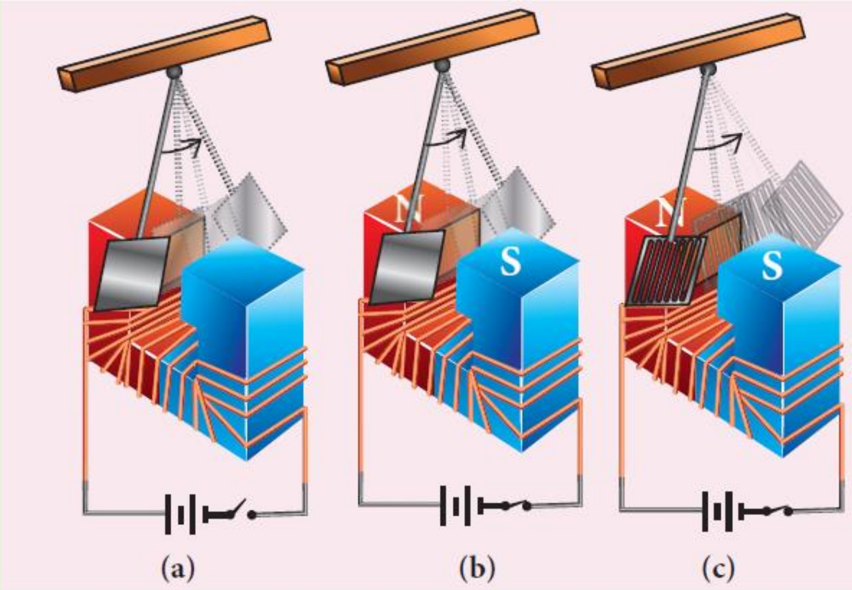

Figure 4.11 Demonstration of eddy currents

Even for a conductor in the form of a sheet or plate, an emf is induced when magnetic flux linked with it changes. But the difference is that there is no definite loop or path for induced current to flow away. As a result, the induced currents flow in concentric circular paths (Figure 4.10). As these electric currents resemble eddies of water, these are known as **Eddy currents**. They are also called **Foucault currents**.

Demonstration:

- Here is a simple demonstration for the production of eddy currents. Consider a pendulum that can be made to oscillate between the poles of a powerful electromagnet (Figure 4.11(a)).
- First the electromagnet is switched off, the pendulum is slightly displaced and released. It begins to oscillate and it executes a large number of oscillations before stopping. The air friction is the only damping force.
- When the electromagnet is switched on and the disc of the pendulum is made to oscillate, eddy currents are produced in it which will oppose the oscillation.
- A heavy damping force of eddy currents will bring the pendulum to rest within a few oscillations (Figure 4.11(b)).
- However if some slots are cut in the disc (Figure 4.11(c)), the eddy currents are reduced. The pendulum now will execute several oscillations before coming to rest.
- This clearly demonstrates the production of eddy current in the disc of the pendulum.

Drawbacks of Eddy currents:

When eddy currents flow in the conductor, a large amount of energy is dissipated in the form of heat. The energy loss due to the flow of eddy current is inevitable but it can be reduced to a greater extent with suitable measures.

The design of transformer core and electric motor armature is crucial in order to minimise the eddy current loss. To reduce these losses, the core of the transformer is made up of thin laminas insulated from one another (Figure 4.12 (a)) while for electric motor the winding is made up of a group of wires insulated from one another (Figure 4.12 (b)). The insulation used does not allow huge eddy currents to flow and hence losses are minimized.

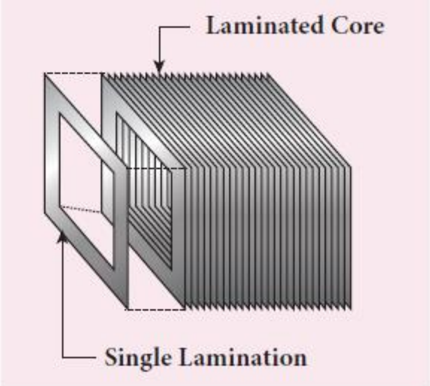

Figure 4.12 (a) Insulated laminas of the core of a transformer

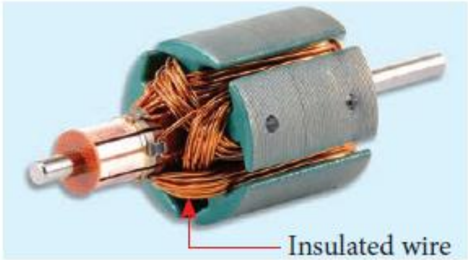

Figure 4.12 (b) Insulated winding of an electric motor

Application of eddy currents:

Though the production of eddy current is undesirable in some cases, it is useful in some other cases. A few of them are

i. Induction stove

ii. Eddy current brake

iii. Eddy current testing

iv. Electromagnetic damping

i. Induction stove:

- ✓ Induction stove is used to cook the food quickly and safely with less energy consumption. Below the cooking zone, there is a tightly wound coil of insulated wire.
- ✓ The cooking pan made of suitable material, is placed over the cooking zone.
- ✓ When the stove is switched on, an alternating current flowing in the coil produces high frequency alternating magnetic field which induces very strong eddy currents in the cooking pan.
- ✓ The eddy currents in the pan produce so much of heat due to Joule heating which is used to cook the food (Figure 4.13).

Note: The frequency of the domestic AC supply is increased from 50–60 Hz to around 20–40 KHz before giving it to the coil in order to produce high frequency alternating magnetic field.

ii. Eddy current brake:

- ✓ This eddy current braking system is generally used in high speed trains and roller coasters.
- ✓ Strong electromagnets are fixed just above the rails. To stop the train, electromagnets are switched on. The magnetic field of these magnets induces eddy currents in the rails which oppose or resist the movement of the train. This is Eddy current linear brake (Figure 4.14(a)).
- ✓ In some cases, the circular disc, connected to the wheel of the train through a common shaft, is made to rotate in between the poles of an electromagnet.
- ✓ When there is a relative motion between the disc and the magnet, eddy currents are induced in the disc which stop the train. This is Eddy current circular brake (Figure 4.14(b))

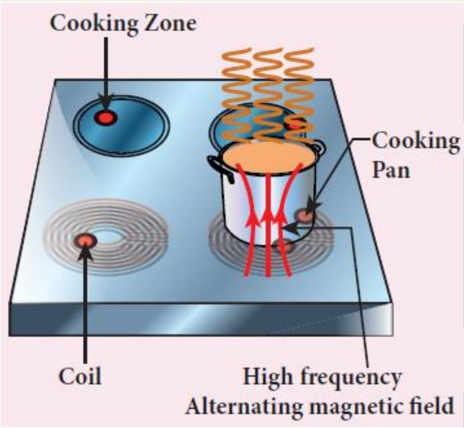

Figure 4.13 Induction stove

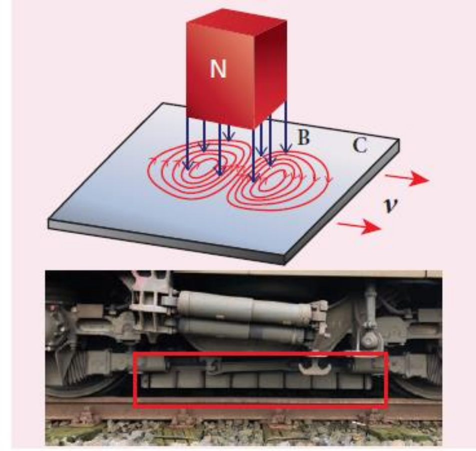

Figure 4.14(a) Linear Eddy current brake

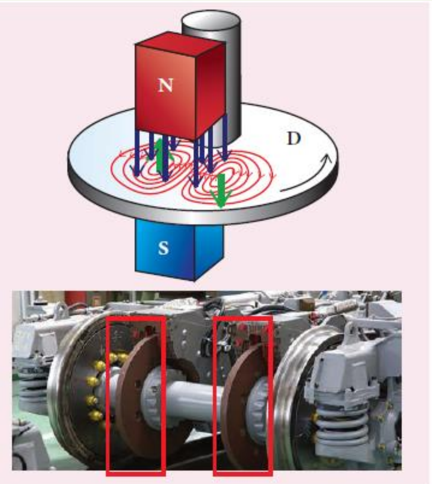

Figure 4.14(b) Circular Eddy current brake

iii. Eddy current testing:

- It is one of the simple non–destructive testing methods to find defects like surface cracks, air bubbles present in a specimen.
- A coil of insulated wire is given an alternating electric current so that it produces an alternating magnetic field.
- When this coil is brought near the test surface, eddy current is induced in the test surface.
- The presence of defects causes the change in phase and amplitude of the eddy current that can be detected by some other means.
- In this way, the defects present in the specimen are identified (Figure 4.15).

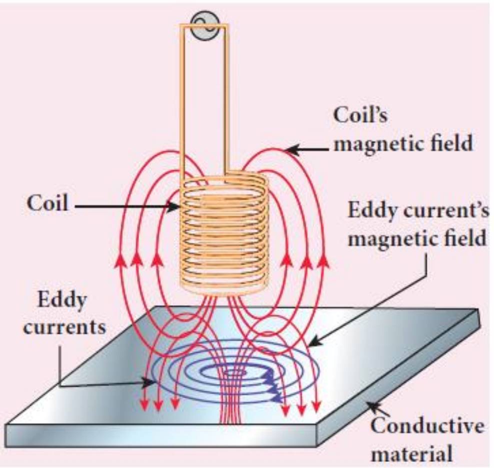

Figure 4.15 Eddy current testing

iv. Electro magnetic damping:

- The armature of the galvanometer coil is wound on a soft iron cylinder. Once the armature is deflected, the relative motion between the soft iron cylinder and the radial magnetic field induces eddy current in the cylinder (Figure 4.16).
- The damping force due to the flow of eddy current brings the armature to rest immediately and then galvanometer shows a steady deflection. This is called electromagnetic damping.

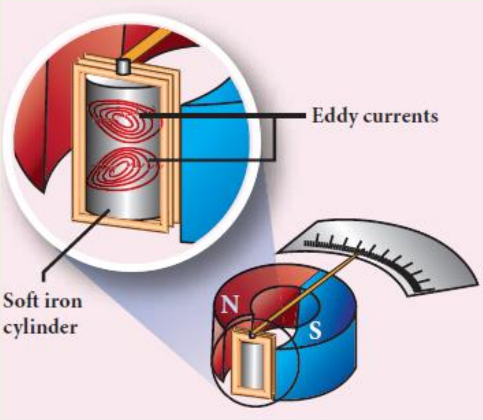

Figure 4.16 Electromagnetic damping