

UNIT - 4 ELECTROMAGNETIC INDUCTION AND ALTERNATING CURRENT

PART - IV 5 MARK QUESTIONS AND ANSWERS

1. Explain the applications of eddy currents (or) Foucault currents.

Induction stove :

- It is used to cook food quickly and safely with less consumption. Below the cooking zone, there is a tightly wound coil of insulated wire.
- A suitable cooking pan is placed over the cooking zone. When the stove is switched on, 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 heat due to Joule heating which is used to cook the food.

Eddy current brake :

- This type of brakes are 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 induces eddy currents in the rails which oppose the movement of the train. This is eddy current linear brake.

Eddy current testing :

- It is one of the 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 it, and the presence of defects causes the change in phase and amplitude of the eddy current.

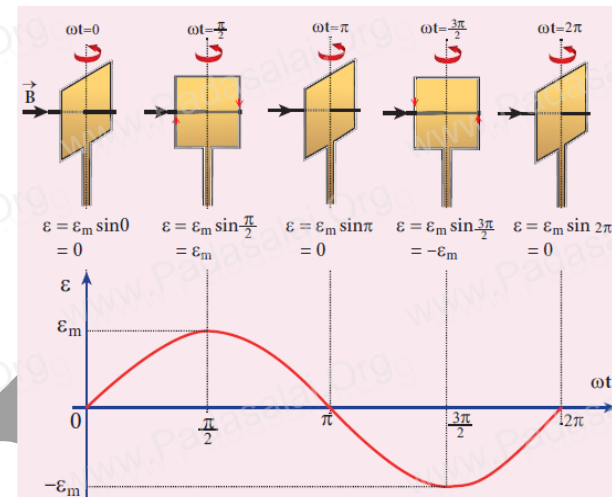
Thus the defects present in the specimen are identified.

Electromagnetic 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.
- The damping force due to the flow of eddy current brings the armature to rest immediately and the galvanometer shows a steady deflection.
- This is called electromagnetic damping.

2. Show mathematically that the rotation of a coil in a magnetic field over one rotation induces an alternating emf of one cycle.

- Consider a rectangular coil of 'N' turns kept in a uniform magnetic field 'B'.
- The coil rotates in anti-clockwise direction with an angular velocity ' ω ' about an axis. Initially let the plane of the coil be perpendicular to the field ($\theta = 0$) and the flux linked with the coil has its maximum value. (i.e.) $\Phi_m = B A$
- In time 't', let the coil be rotated through an angle $\theta (= \omega t)$, then the total flux linked is $N \Phi = N B A \cos \omega t = N \Phi_m \cos \omega t$



According to Faraday's law, the emf induced at that instant is,

$$\begin{aligned}\epsilon &= -\frac{d}{dt}(N\Phi_B) = -\frac{d}{dt}(N\Phi_m \cos \omega t) \\ &= -N\Phi_m (-\sin \omega t) \omega \\ &= N\Phi_m \omega \sin \omega t\end{aligned}$$

When $\theta = 90^\circ$, then the induced emf becomes maximum and it is given by,

$$\begin{aligned}\epsilon_m &= N\Phi_m \omega \\ \epsilon_m &= NBA\omega \quad \text{since } \Phi_m = BA\end{aligned}$$

Therefore the value of induced emf

$$\epsilon = \epsilon_m \sin \omega t$$

Thus the induced emf varies as sine function of the time angle and this is called sinusoidal emf or alternating emf. If this alternating voltage is given to a closed circuit, a sinusoidally varying current flows in it, called alternating current and is given by, $i = I_m \sin \omega t$ where, $I_m \rightarrow$ peak value of induced current.

3. Elaborate the standard construction details of AC generator.

Construction :

- AC generator (alternator) is an energy conversion device.
- It converts mechanical energy used to rotate the coil or field magnet in to electrical energy.
- It works on the principle of electro magnetic induction. It consists of two major parts namely stator and rotor.
- In commercial alternators, the armature winding is mounted on stator and the field magnet on rotor

Stator : It has three components

(i) Stator frame :

- It is used for holding stator core and armature windings in proper position.
- It provides best ventilation with the help of holes provided in the frame itself.

(ii) Stator core (Armature) :

- It is made up of iron or steel alloy. It is a hollow cylinder and is laminated to minimize eddy current loss.
- The slots are cut on inner surface of the core to accommodate armature windings.

(iii) Armature windings :

- It the coil wound on slots provided in the armature core. One or more than one coil may be employed.
- Two types of windings are commonly used.

Rotar :

- It consists magnetic field windings.
- The magnetic poles are magnetized by DC source. The ends of field windings are connected to a pair of slip rings, attached to a common shaft about which rotor rotates.

- Slip rings rotate along with rotor.
- To maintain connection ,two brushes are used which continuously slide over the slip rings

- There are two types, namely

(i) Salient pole rotor :

- The word salient means projecting.
- This rotor has a number of projecting poles having their bases riveted to the rotor.
- It is mainly used in low-speed alternators

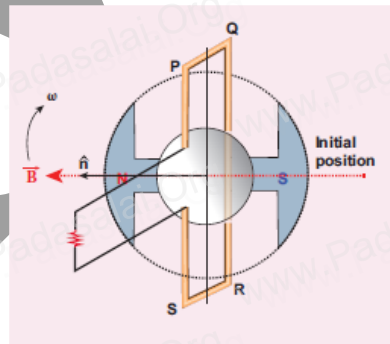
(ii) Cylindrical pole rotor :

- This rotor consists of a smooth solid cylinder. It is suitable for very high speed alternators.
- The frequency of alternating emf induced is directly proportional to the rotor speed.
- In order to maintain the frequency constant, the rotor run at a constant speed.

4. Explain the working of a single - phase AC generator with necessary diagram.

Single phase AC generator :

In a single phase AC generator, the armature conductors are connected in series so as to form a single circuit which generates a single-phase alternating emf and hence it is called single-phase alternator.



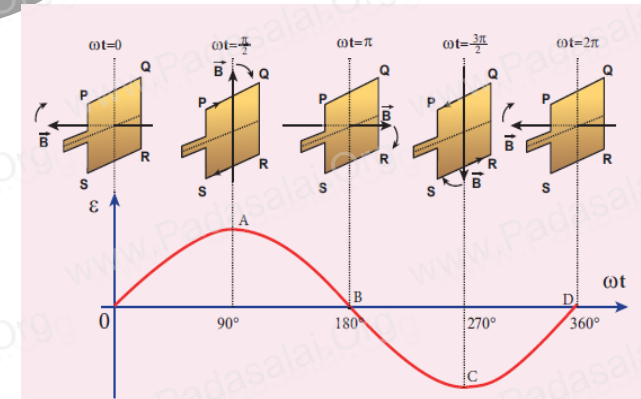
Principle : Electro magnetic induction

Construction :

Consider a stator core consisting of 2 slots in which 2 armature conductor PQ and RS are mounted to form single - turn rectangular loop PQRS. Rotor has 2 salient poles with field windings which can be magnetized by means of DC source.

Working :

- The loop PQRS is stationary and is perpendicular to the plane of the paper.
- Assume the initial position of the field magnet is horizontal. At that instant, the magnetic field is perpendicular to the plane of the loop PQRS.
- The induced emf is zero represented by origin 'O' in the graph
- Let the magnetic field rotate in clock-wise direction.

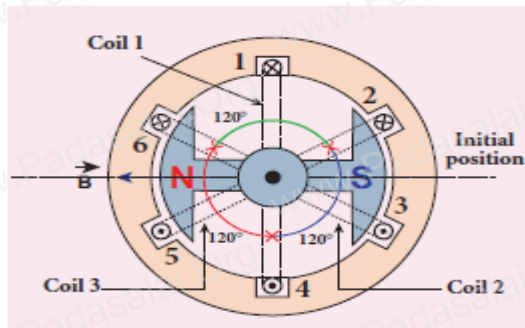


- When the field magnet rotates through 90° the magnetic field becomes parallel to PQRS.
- The induced emf's across PQ and RS would become maximum.
- According to Fleming's right hand rule, the current flows along PQRS.
- The point A in the graph represents this maximum emf.

- When field magnet rotates 180° the field is again perpendicular to PQRS and the induced emf becomes zero. This is represented by point B.
- When field magnet rotates 270° , the field is again parallel to PQRS, the induced emf is maximum but the direction is reversed. Thus the current flows along SRQP. This is represented by point C.
- On completion of 360° , the induced emf becomes zero and it is represented by the point D.
- From the graph, it is clear that, when field magnet completes one rotation, the emf induced in PQRS is alternating in nature.

5. How are the three different emfs generated in a three-phase AC generator? Show the graphical representation of these three emfs.

Three phase AC generator :

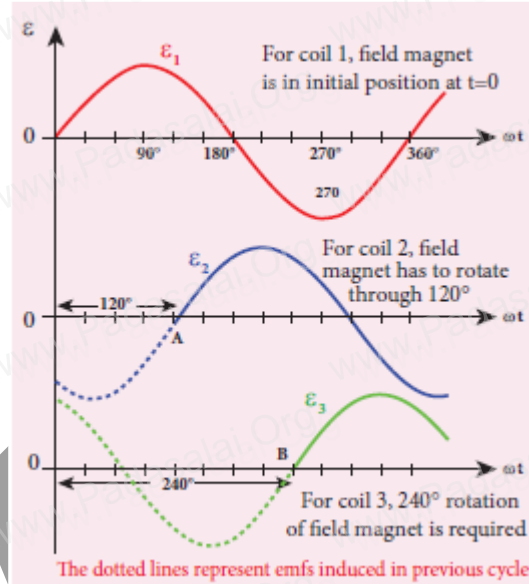


- If the AC generator consists three separate coils, which would give three separate emfs, then it is called three-phase generators.

Construction :

- It has 6 slots, cut in its inner rim. Each slot is 60° away from one another. six armature conductors are mounted in these slots.
- The conductors 1 - 4, 2 - 5 and 3 - 6 are joined in series to form coils 1, 2 and 3

- So these coils are rectangular in shape and are 120° apart from one another.



- The initial position of the field magnet is horizontal and field direction is perpendicular to the plane of the coil - 1.
- When it rotated from that position in clock-wise direction, alternating emf 'ε1' in coil - 1 begins a cycle from origin 'O'.
- When it rotated through 120° , alternating emf 'ε2' in coil - 2 starts at point 'A'.
- When it rotated through 240° , alternating emf 'ε3' in coil - 3 starts at point 'B'.
- Thus these emfs produced in the three phase AC generator have 120° phase difference between one another.

6. Explain the principle, construction and working of transformer.

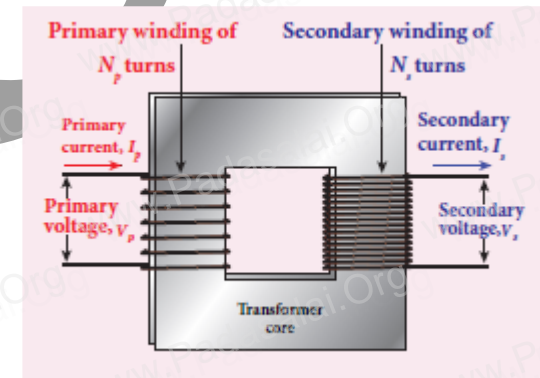
Transformer :

- It is a stationary device used to transform electrical power from one circuit to another without changing its frequency.

- It is done with either increasing or decreasing the applied alternating voltage with corresponding decrease or increase of current in the circuit.
- If the transformer converts an alternating current with low voltage in to an alternating current with high voltage, it is called **step-up transformer**.
- If the transformer converts an alternating current with high voltage in to an alternating current with low voltage, it is called **step-down transformer**.

Principle : Mutual induction between two coils.

Construction :



- It consists of two coils of high mutual inductance wound over the same transformer core made up of silicone steel.
- To avoid eddy current loss, the core is generally laminated
- The alternating voltage is applied across primary coil (P), and the output is taken across secondary coil (S)
- The assembled core and coils are kept in a container which is filled with suitable medium for better insulation and cooling purpose.

Working :

✚ The alternating voltage given to the primary coil, set up an alternating magnetic flux in the laminated core.

✚ As the result of flux change, emf is induced in both primary and secondary coils.

✚ The emf induced in the primary coil ' ϵ_P ' is almost equal and opposite to the applied voltage ' V_P ' and is given by,

$$v_p = \epsilon_p = -N_p \frac{d\Phi_B}{dt} \quad \text{----- (1)}$$

The emf induced in the secondary coil ' ϵ_s ' is,

$$v_s = \epsilon_s = -N_s \frac{d\Phi_B}{dt} \quad \text{----- (2)}$$

Dividing equation (1) by (2),

$$\frac{v_s}{v_p} = \frac{N_s}{N_p} = K \quad \text{----- (3)}$$

Where, K is transformation ratio

For an ideal transformer,
input power = output power

$$V_p i_p = V_s i_s$$

$$\frac{v_s}{v_p} = \frac{N_s}{N_p} = \frac{i_p}{i_s} \quad \text{----- (4)}$$

From equation (3) and (4), we have

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} = \frac{I_p}{I_s} = K \quad \text{----- (5)}$$

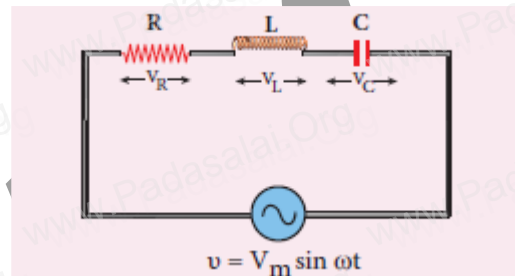
(i) If $K > 1$ (or) $N_s > N_p$, then $V_s > V_p$ and $i_s < i_p$
This is step up transformer in which voltage increased and the corresponding current is decreased.

(ii) If $K < 1$ (or) $N_s < N_p$, then $V_s < V_p$ and $i_s > i_p$
This is step down transformer in which voltage decreased and the corresponding current is increased.

Efficiency of a transformer :

The efficiency (η) of a transformer is defined as the ratio of the useful output power to the input power.

$$\eta = \frac{\text{Output power}}{\text{Input power}} \times 100\%$$

7. Derive an expression for phase angle between the applied voltage and current in a series RLC circuit.**Series RLC circuit :**

✚ Consider a circuit containing a resistor of resistance ' R ', an inductor of inductance ' L ' and a capacitor of capacitance ' C ' connected across an alternating voltage source.

✚ The applied alternating voltage is given by $v = V_m \sin \omega t$ ----- (1)

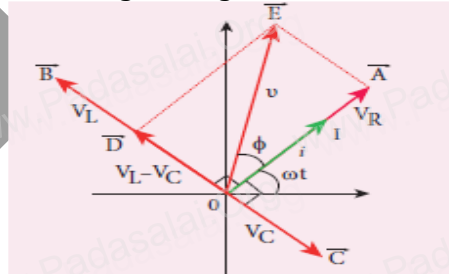
Let ' i ' be the current in the circuit at that instant. Hence the voltage developed across R, L and C are

$$V_R = i R \text{ (} V_R \text{ is in phase with } i \text{)}$$

$$V_L = i X_L \text{ (} V_L \text{ leads } i \text{ by } \pi/2 \text{)}$$

$$V_C = i X_C \text{ (} V_C \text{ lags } i \text{ by } \pi/2 \text{)}$$

The phasor diagram is given below.



If $V_L > V_C$, then the net voltage drop across LC combination is $(V_L - V_C)$ which is represented by \overline{AD}

By parallelogram law, the diagonal \overline{OE} gives the resultant voltage ' v '

$$\therefore v = \sqrt{V_R^2 + (V_L - V_C)^2}$$

$$v = \sqrt{i^2 R^2 + (i X_L - i X_C)^2}$$

$$v = i \sqrt{R^2 + (X_L - X_C)^2}$$

$$\text{(or)} \quad i = \frac{v}{\sqrt{R^2 + (X_L - X_C)^2}} \quad \text{---- (4)}$$

$$\text{(or)} \quad i = \frac{v}{Z} \quad \text{---- (5)}$$

Where, $Z = \sqrt{R^2 + (X_L - X_C)^2}$ is called impedance of the circuit, which refers to the effective opposition to the circuit current by the series RLC circuit.

From the phasor diagram, the phase angle between ' v ' and ' i ' is found out by

$$\tan \phi = \frac{V_L - V_C}{V_R} = \frac{X_L - X_C}{R} \quad \text{---- (6)}$$

Special cases :

(i) When $X_L > X_C$, the phase angle ϕ is **positive**. It means that v leads i by ϕ .

$$\text{(i.e.) } v = V_m \sin \omega t \text{ \& } i = I_m \sin(\omega t - \phi)$$

This circuit is inductive.

(ii) When $X_L < X_C$, the phase angle ϕ is **negative**.

It means that v lags behind i by ϕ .

$$\text{(i.e.) } v = V_m \sin \omega t \text{ \& } i = I_m \sin(\omega t + \phi)$$

This circuit is capacitive

(iii) When $X_L = X_C$, the phase angle ϕ is **zero**. It means that v in phase with i

$$\text{(i.e.) } v = V_m \sin \omega t \text{ \& } i = I_m \sin \omega t$$

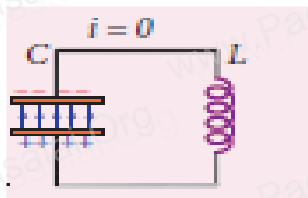
This circuit is resistive

8. What are called LC oscillations? Explain the generation of LC oscillations.**LC oscillations :**

Whenever energy is given to a circuit containing a pure inductor of inductance L and a capacitor of capacitance C, the energy oscillates back and

forth between the magnetic field of the inductor and the electric field of the capacitor. Thus the electrical oscillations of definite frequency are generated. These oscillations are called LC oscillations.

Generation of LC - oscillations :



Stage - 1 :

Consider the capacitor is fully charged with maximum charge Q_m . So that the energy stored in the capacitor is maximum

$$U_E = Q_m^2 / 2C$$

As there is no current in the inductor, $U_B = 0$

Therefore the total energy is wholly electrical.

Stage - 2 :

The capacitor now begins to discharge through the inductor that establishes current 'i' clockwise direction.

This current produces a magnetic field around the inductor and energy stored in the inductor which is given by

$$U_B = Li^2 / 2$$

As the charge in the capacitor decreases, the energy stored in it also decreases and is given by

$$U_E = q^2 / 2C$$

Total energy is the sum of electrical and magnetic energies.

Stage - 3 :

When the charge in the capacitor becomes zero, its energy becomes zero (i.e.) $U_E = 0$

In this stage maximum current (I_m) flows through inductor and its energy becomes maximum. (i.e.) $U_E = LI_m^2 / 2$

Thus the total energy is wholly magnetic.

Stage - 4 :

Even though the charge in the capacitor is zero, the current will continue to flow in the same direction.

Since the current flow is in decreasing magnitude, the capacitor begins to charge in the opposite direction.

Thus a part of the energy is transferred from the inductor back to the capacitor.

The total energy is the sum of the electrical and magnetic energies.

Stage - 5 :

When the current in the circuit reduces to zero, the capacitor becomes fully charged in the opposite direction.

Thus the energy stored in the capacitor becomes maximum and the energy stored in the inductor is zero.

So the total energy is wholly electrical.

Stage - 6 :

This state of the circuit is similar to the initial state but the difference is that the capacitor is charged in opposite direction.

So it will start discharge through inductor in anti-clockwise direction.

The total energy is the sum of the electrical and magnetic energies.

Stage - 7 :

The processes are repeated in opposite direction and finally the circuit returns to the initial state.

Thus when the circuit goes through these stages, an alternating current flows in the circuit.

As this process is repeated again and again, the electrical oscillations of definite frequency are generated.

These are known as LC oscillations.

9. Compare the electromagnetic oscillations of LC circuit with the mechanical oscillations of block spring system to find the expression for angular frequency of LC oscillations mathematically.

Electrical system	Mechanical system
Charge q	Displacement x
Current $i = \frac{dq}{dt}$	Velocity $v = \frac{dx}{dt}$
Inductance L	Mass m
Reciprocal of capacitance $\frac{1}{C}$	Force constant k
Electrical energy $= \frac{1}{2} \left(\frac{1}{C} \right) q^2$	Potential energy $= \frac{1}{2} k x^2$
Magnetic energy $= \frac{1}{2} Li^2$	Kinetic energy $= \frac{1}{2} mv^2$
Electromagnetic energy $U = \frac{1}{2} \left(\frac{1}{C} \right) q^2 + \frac{1}{2} Li^2$	Mechanical energy $E = \frac{1}{2} k x^2 + \frac{1}{2} mv^2$

Angular frequency of LC oscillations:

The electro magnetic energy is

$$U = \frac{1}{2} \left[\frac{1}{C} \right] q^2 + \frac{1}{2} Li^2 = \text{constant}$$

Differentiate,

$$\frac{dU}{dt} = \frac{1}{2C} \left(2q \frac{dq}{dt} \right) + \frac{1}{2} L \left(2i \frac{di}{dt} \right) = 0$$

$$\frac{dU}{dt} = \frac{q}{C} \frac{dq}{dt} + L \frac{dq}{dt} \left[\frac{d}{dt} \left(\frac{dq}{dt} \right) \right] = 0 \quad \left[\because i = \frac{dq}{dt} \right]$$

$$L \frac{d^2 q}{dt^2} + \frac{q}{C} = 0 \quad \text{----- (1)}$$

Its solution is, $q(t) = Q_m \cos(\omega t + \phi)$

Differentiate with respect to 't'

$$i(t) = \frac{dq}{dt} = \frac{d}{dt} [Q_m \cos(\omega t + \phi)]$$

$$i(t) = -Q_m \omega \sin(\omega t + \phi) = -I_m \sin(\omega t + \phi)$$

Again differentiate with respect to 't',

$$\frac{d^2 q}{dt^2} = -Q_m \omega^2 \cos(\omega t + \phi) = -I_m \omega \cos(\omega t + \phi)$$

Put this in equation (1), the angular frequency of LC oscillations is,

$$\omega = \frac{1}{\sqrt{LC}}$$