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Exercises

Question 6.1:

Predict the direction of induced current in the situations described by the following Figs. 6.18(a) to (f).

(a)





Answer

The direction of the induced current in a closed loop is given by Lenz's law. The given pairs of figures show the direction of the induced current when the North pole of a bar magnet is moved towards and away from a closed loop respectively.



Using Lenz's rule, the direction of the induced current in the given situations can be predicted as follows:

- (a) The direction of the induced current is along qrpq.
- (b) The direction of the induced current is along prqp.
- (c) The direction of the induced current is along yzxy.
- (d) The direction of the induced current is along zyxz.
- (e) The direction of the induced current is along xryx.
- (f) No current is induced since the field lines are lying in the plane of the closed loop.

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Question 6.2:

A 1.0 m long metallic rod is rotated with an angular frequency of 400 rad s^{-1} about an axis normal to the rod passing through its one end. The other end of the rod is in contact with a circular metallic ring. A constant and uniform magnetic field of 0.5 T parallel to the axis exists everywhere. Calculate the emf developed between the centre and the ring. Answer

Length of the rod, I = 1 m

Angular frequency, $\omega = 400 \text{ rad/s}$

Magnetic field strength, B = 0.5 T

One end of the rod has zero linear velocity, while the other end has a linear velocity of lω. $v = \frac{l\omega + 0}{\omega}$

Average linear velocity of the rod,

Emf developed between the centre and the ring,

$$e = Blv = Bl\left(\frac{l\omega}{2}\right) = \frac{Bl^2\omega}{2}$$
$$= \frac{0.5 \times (1)^2 \times 400}{2} = 100 \text{ V}$$

Hence, the emf developed between the centre and the ring is 100 V.

Question 6.3:

A long solenoid with 15 turns per cm has a small loop of area 2.0 cm² placed inside the solenoid normal to its axis. If the current carried by the solenoid changes steadily from 2.0 A to 4.0 A in 0.1 s, what is the induced emf in the loop while the current is changing? Answer

Number of turns on the solenoid = 15 turns/cm = 1500 turns/m Number of turns per unit length, n = 1500 turns The solenoid has a small loop of area, A = 2.0 cm² = 2 \times 10⁻⁴ m² Current carried by the solenoid changes from 2 A to 4 A. Change in current in the solenoid, di = 4 - 2 = 2 A

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Change in time, dt = 0.1 sInduced emf in the solenoid is given by Faraday's law as: $e = \frac{d\phi}{dt}$... (i) Where, ϕ = Induced flux through the small loop = BA ... (ii) B = Magnetic field ... (iii) $\mu_0 ni$ μ_0 = Permeability of free space $= 4\pi \times 10^{-7} \text{ H/m}$ Hence, equation (i) reduces to: $e = \frac{d}{dt}(BA)$ $=A\mu_0n\times\left(\frac{di}{dt}\right)$ $= 2 \times 10^{-4} \times 4\pi \times 10^{-7} \times 1500 \times 2$ $= 7.54 \times 10^{-6}$ V

Hence, the induced voltage in the loop is 7.54×10^{-6} V

Ouestion 6.4:

A rectangular wire loop of sides 8 cm and 2 cm with a small cut is moving out of a region of uniform magnetic field of magnitude 0.3 T directed normal to the loop. What is the emf developed across the cut if the velocity of the loop is 1 cm s⁻¹ in a direction normal to the (a) longer side, (b) shorter side of the loop? For how long does the induced voltage last in each case?

Answer

Length of the rectangular wire, I = 8 cm = 0.08 mWidth of the rectangular wire, b = 2 cm = 0.02 mHence, area of the rectangular loop,

A = Ib $= 0.08 \times 0.02$ $= 16 \times 10^{-4} \text{ m}^2$ Magnetic field strength, B = 0.3 T Velocity of the loop, v = 1 cm/s = 0.01 m/s (a) Emf developed in the loop is given as: e = Blv $= 0.3 \times 0.08 \times 0.01 = 2.4 \times 10^{-4} \text{ V}$ Velocity 0.02 = 2 s0.01Hence, the induced voltage is 2.4×10^{-4} V which lasts for 2 s. (b) Emf developed, e = Bbv $= 0.3 \times 0.02 \times 0.01 = 0.6 \times 10^{-4} \text{ V}$ Velocity = 8 s

Hence, the induced voltage is 0.6×10^{-4} V which lasts for 8 s.

Question 6.6:

A circular coil of radius 8.0 cm and 20 turns is rotated about its vertical diameter with an angular speed of 50 rad s⁻¹ in a uniform horizontal magnetic field of magnitude 3.0×10⁻² T. Obtain the maximum and average emf induced in the coil. If the coil forms a closed loop of resistance 10Ω , calculate the maximum value of current in the coil. Calculate the average power loss due to Joule heating. Where does this power come from?

Answer

Max induced emf = 0.603 VAverage induced emf = 0 VMax current in the coil = 0.0603 A

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Average power loss = 0.018 W (Power comes from the external rotor) Radius of the circular coil, r = 8 cm = 0.08 mArea of the coil, $A = \pi r^2 = \pi \times (0.08)^2 m^2$ Number of turns on the coil, N = 20Angular speed, $\omega = 50 \text{ rad/s}$ Magnetic field strength, $B = 3 \times 10^{-2} T$ Resistance of the loop, R = 10 Ω Maximum induced emf is given as: $e = N\omega AB$ = $20 \times 50 \times \pi \times (0.08)^2 \times 3 \times 10^{-2}$ we ational Sector = 0.603 VThe maximum emf induced in the coil is 0.603 V. Over a full cycle, the average emf induced in the coil is zero.

Maximum current is given as:

$$I = \frac{e}{R} = \frac{0.603}{10} = 0.0603 \text{ A}$$

Average power loss due to joule heating:

$$P = \frac{eI}{2}$$

= $\frac{0.603 \times 0.0603}{2} = 0.018 \text{ W}$

The current induced in the coil produces a torque opposing the rotation of the coil. The rotor is an external agent. It must supply a torque to counter this torque in order to keep the coil rotating uniformly. Hence, dissipated power comes from the external rotor.

Ouestion 6.7:

A horizontal straight wire 10 m long extending from east to west is falling with a speed of 5.0 m s⁻¹, at right angles to the horizontal component of the earth's magnetic field, 0.30×10^{-4} Wb m⁻².

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- (a) What is the instantaneous value of the emf induced in the wire?
- (b) What is the direction of the emf?
- (c) Which end of the wire is at the higher electrical potential?

Answer

Length of the wire, I = 10 m

Falling speed of the wire, v = 5.0 m/s

Magnetic field strength, $B = 0.3 \times 10^{-4} \text{ Wb m}^{-2}$

(a) Emf induced in the wire, e = Blv

$$= 0.3 \times 10^{-4} \times 5 \times 10^{-1}$$

$$=1.5 \times 10^{-3} V$$

- (b) Using Fleming's right hand rule, it can be inferred that the direction of the induced emf is from West to East.
- (c) The eastern end of the wire is at a higher potential.

Question 6.8:

Current in a circuit falls from 5.0 A to 0.0 A in 0.1 s. If an average emf of 200 V induced, give an estimate of the self-inductance of the circuit.

Answer

Initial current, $I_1 = 5.0 A$

Final current, $I_2 = 0.0 A$

Change in current, $dI = I_1 - I_2 = 5$ A

Time taken for the change, t = 0.1 s

Average emf, e = 200 V

For self-inductance (L) of the coil, we have the relation for average emf as:

$$e = L \frac{\frac{di}{dt}}{L}$$
$$L = \frac{e}{\left(\frac{di}{dt}\right)}$$
$$= \frac{200}{\frac{5}{0.1}} = 4 \text{ H}$$

Hence, the self induction of the coil is 4 H.

Question 6.9:

A pair of adjacent coils has a mutual inductance of 1.5 H. If the current in one coil changes from 0 to 20 A in 0.5 s, what is the change of flux linkage with the other coil?

... (1)

Answer

Mutual inductance of a pair of coils, $\mu = 1.5$ H

Initial current, $I_1 = 0 A$

Final current $I_2 = 20 A$

Change in current, $dI = I_2 - I_1 = 20 - 0 = 20$ A

Time taken for the change, t = 0.5 s

Induced emf,
$$e = \frac{d\phi}{dt}$$

Where $d\phi$ is the change in the flux linkage with the coil.

Emf is related with mutual inductance as:

$$e = \mu \frac{dI}{dt} \qquad \dots (2)$$

Equating equations (1) and (2), we get

$$\frac{d\phi}{dt} = \mu \frac{dI}{dt}$$
$$d\phi = 1.5 \times (20)$$
$$= 30 \text{ Wb}$$



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Hence, the change in the flux linkage is 30 Wb.

Question 6.10:

A jet plane is travelling towards west at a speed of 1800 km/h. What is the voltage difference developed between the ends of the wing having a span of 25 m, if the Earth's magnetic field at the location has a magnitude of 5 \times 10⁻⁴ T and the dip angle is 30°.

Answer

Speed of the jet plane, v = 1800 km/h = 500 m/s

Wing spanof jet plane, I = 25 m

Earth's magnetic field strength, $B = 5.0 \times 10^{-4} T$

Angle of dip, $\delta = 30^{\circ}$

Vertical component of Earth's magnetic field,

 $B_V = B \sin \delta$

$$= 5 \times 10^{-4} \sin 30^{\circ}$$

$$= 2.5 \times 10^{-4}$$
 T

Voltage difference between the ends of the wing can be calculated as:

 $e = (B_V) \times I \times v$

 $= 2.5 \times 10^{-4} \times 25 \times 500$

Hence, the voltage difference developed between the ends of the wings is 3.125 V.