CHAPTER NO. 15(ELECTROMAGNETIC INDUCTION)

Question 15.1:- An emf of 0.45 V is induced between the ends of a metal bar moving through a magnetic field of 0.22 T. What field strength would be needed to produce an emf of 1.5 V between the ends of the bar, assuming that all other factors remain the same?

Solution:- **First case:**

Induced emf = ε_1 = 0.45 V

Magnetic field = B_1 = 0.22 T

Second case:

Induced emf = ε_2 = 1.5 V

Magnetic field = B_2

All other factors i.e. v, L and sin θ are same. We will use the relation of motional emf for both cases.

$\varepsilon_1 = -\, v\, B_1\, L \sin\theta$

$\varepsilon_2 = -\, v\, B_2\, L \sin\theta$

Diving both equations gives $\frac{\varepsilon_1}{\varepsilon_2} = \frac{-v\, B_1\, L \sin\theta}{-v\, B_2\, L \sin\theta} = \frac{B_1}{B_2}$

Put the values $\frac{0.45}{1.5} = \frac{0.22}{B_2}$

$B_2 = (1.5)(0.22)/(0.45)$

$B_2 = 0.73$ T

Question 15.2:- The flux density B in a region between the poles faces of a horse-shoe magnet is 0.5 Wb m^{-2} directed vertically downward. Find the emf induced in a straight wire 5.0 cm long, perpendicular to B when it is moved in a direction at angle of 60^o with the horizontal with a speed of 100 cm s^{-1}.

Solution:- Magnetic flux density = B = 0.5 Wb m^{-2} vertically downwards (-ve y-axis)

Length of wire = L = 5.0 cm = 0.05 m

Speed of wire = v = 100 cm s^{-1} = 1 m s^{-1}

Angle between horizontal and direction of movement of wire = α = 60^o

The angle between velocity and magnetic flux density = $\theta = 90^o - \alpha = 90^o - 60^o = 30^o$

Induced emf = $\varepsilon = -\, v\, B\, L \sin\theta = -\,(1)\,(0.5)\,(0.05) \sin 30^o$

$\varepsilon = -1.25 \times 10^{-2}$ V ∴ -ve sign indicates the induced emf opposes the change which produced it.

Magnitude of induced emf = $+1.25 \times 10^{-2}$ V

Question 15.3:- A coil of wire has 100 loops. Each loop has an area of 1.5×10^{-3} m^2. A magnetic field is perpendicular to the surface of each loop at all times. If the magnetic field is changed from 0.05 T to 0.06 T in 0.1 s, find the average emf induced in the coil during this time.

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Solution:- Number of turns = N = 100

Area of each loop = A = 1.5 x 10^{-3} m^2

Initial magnetic field = B_1 = 0.05 T

Final magnetic field = B_2 = 0.06 T

Change in magnetic field = ΔB = B_2 – B_1 = 0.06 – 0.05 = 0.01 T

Time taken to change the field = Δt = 0.1 s

Angle between magnetic field and surface of loop = α = 90^o

Angle between magnetic field and area vector of loop = θ = 90^o – α = 0^o

Induced emf = ε = $-N\frac{\Delta\phi}{\Delta t} = -N\frac{\Delta B\ A\cos\theta}{\Delta t}$

$\varepsilon = -(100)\frac{(0.01)(1.5\ x\ 10^{-3})\cos 0^o}{0.1}$

ε = -1.5 x 10^{-3} V ∴ -ve sign indicates the induced emf opposes the change which produced it.

Magnitude of induced emf = +1.5 x 10^{-3} V

Question 15.4:- A circular coil has 15 turns or radius 2 cm each. The plane of the coil lies at 40^o to a uniform magnetic field of 0.2 T. If the field in increased by 0.5 T in 0.2 s, find the magnitude of induced emf.

Solution:- Number of turns = N = 15

Radius of each turn = r = 2 cm = 0.02 m

Initial magnetic field = B = 0.2 T

Change in magnetic field = ΔB = 0.5 T

Time taken to change magnetic field = Δt = 0.2 s

Angle between plane of coil and magnetic field = α = 40^o

Angle between area vector of coil and magnetic field = θ = 90^o – α = 90^o – 40^o = 50^o

Area of each loop = A = π r^2 = (3.14) $(0.02)^2$ = 0.001256 m^2 = 1.26 x 10^{-3} m^2

Induced emf = ε = $-N\frac{\Delta\phi}{\Delta t} = -N\frac{\Delta B\ A\cos\theta}{\Delta t}$

$\varepsilon = -(15)\frac{(0.5)(1.26\ x\ 10^{-3})\cos 50^o}{0.2}$

ε = -1.8 x 10^{-2} V ∴ -ve sign indicates the induced emf opposes the change which produced it.

Magnitude of induced emf = +1.8 x 10^{-2} V

Question 15.5:- Two coils are placed side by side. An emf of 0.8 V is observed in one coil when the current is changing at the rate of 200 A s^{-1} in the other coil. What is the mutual inductance of the coils.

Solution:- Induced emf in secondary coil = ε_s = 0.8 V

Time rate of change of current in primary coil = $\Delta I_p/\Delta t$ = 200 A s^{-1}

We know that $\varepsilon_s = M\ \Delta I_p/\Delta t$

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$M = \frac{\varepsilon_s}{\Delta I_p/_{\Delta t}} = 0.8/200 = 0.004$

M = 4 mH

Question 15.6:- A pair of adjacent coils has a mutual inductance of 0.75 H. If the current in the primary changes from 0 A to 10 A in 0.025 s, what is the average induced emf in the secondary? What is the change in flux in it if the secondary has 500 turns?

Solution:- Mutual inductance = M = 0.75 H

Initial current = I_1 = 0 A

Final current = I_2 = 10 A

Change in current = ΔI_p = 10 – 0 = 10 A

Time taken to change the current = Δt = 0.025 s

Number of turns in secondary coil = N_s = 500

We know that $\varepsilon_s = M\ \Delta I_p/\Delta t$

$\varepsilon_s = (0.75)(10)/(0.025)$

ε_s = 300 V

We also know that magnitude of average induced emf is $\boldsymbol{\varepsilon_s = N_s \frac{\Delta\phi_s}{\Delta t}}$

$\Delta\phi_s = \varepsilon_s\ \Delta t\ /\ N_s$

$\Delta\phi_s = (300)\ (0.0.25)\ /\ (500)$

$\Delta\phi_s = 1.5 \times 10^{-2}$ Wb

Question 15.7:- A solenoid has 250 turns and its self inductance is 2.4 mH. What is the flux through each turn when the current is 2 A? What is the induced emf when the current changes at 20 A s^{-1}?

Solution:- Number of turns of solenoid = N = 250

Self inductance = L = 2.4 mH = 0.0024 H

Current = I = 2 A

For a solenoid of N turns, $N\ \phi = L\ I$

$\phi = LI/N = (0.0024)(2)/250 = 0.0000192$ Wb

$\phi = 1.92 \times 10^{-5}$ Wb

Rate of change of current = $\Delta I/\Delta t = 20\ A\ s^{-1}$

Magnitude of induced emf = $\varepsilon = L\ \Delta I/\Delta t = (0.0024)(20) = 0.048$ V

ε = 48 mV

Question 15.8:- A solenoid of length 8.0 cm and cross sectional area 0.5 cm^2 has 520 turns. Find the self inductance of the solenoid when the core is air. If the current in the solenoid

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increases through 1.5 A in 0.2 s, find the magnitude of induced emf in it. ($\mu_o = 4\pi \times 10^{-7}$ Wb A^{-1} m^{-1})

Solution:- Length of solenoid = l = 8.0 cm = 0.08 m

Area of cross section = A = 0.5 cm^2 = 0.5 x 10^{-4} m^2

Number of turns = N = 520

Change in current = ΔI = 1.5 A

Time taken to change the current = Δt =0.2 s

Self inductance of coil = $L = \mu_o n^2 A l = \mu_o (\frac{N}{l})^2 A l = \mu_o N^2 \frac{A}{l} = (4\pi \times 10^{-7}) (520)^2 \frac{(0.5 \times 10^{-4})}{0.08}$

<u>**$L = 2.12 \times 10^{-4}$ H**</u>

Magnitude of induced emf in the coil is ε = L ΔI/Δt

$\varepsilon = (2.12 \times 10^{-4})(1.5)/(0.2)$

<u>**$\varepsilon = 1.6 \times 10^{-3}$ V**</u>

Question 15.9:- When current through a coil changes from 100 mA to 200 mA in 0.005 s, an induced emf of 40 mV is produced in the coil. (a) What is the self inductance of the coil? (b) Find the increase in the energy stored in the coil.

Solution:- Initial current = I_1 = 100 mA = 0.1 A

Final current = I_2 = 200 mA = 0.2 A

Change in current = $\Delta I = I_2 - I_1$ = 0.2 – 0.1 = 0.1 A

Time taken to change the current = Δt = 0.005 s

Average induced emf = ε = 40 mV = 0.04 V

(a) ε = L ΔI/Δt

L = ε Δt/ΔI = (0.04)(0.005)/(0.1) = 0.002 H

<u>**L = 2 mH**</u>

(b) Increase in energy stored = ΔE = Final energy – Initial energy = $\frac{1}{2} L I_2^2 - \frac{1}{2} L I_1^2$

$\Delta E = \frac{1}{2} L (I_2^2 - I_1^2) = \frac{1}{2} (0.002) [(0.2)^2 - (0.1)^2]$

<u>**ΔE = 0.03 J**</u>

Question 15.10:- Like any field, the earth's magnetic field stores energy. Find the magnetic energy stored in the space where strength of earth's magnetic field is 7 x 10^{-5} T, if the space occupies an area 10 x 10^8 m^2 and has a height of 750 m.

Solution:- Earth's magnetic field = B = 7 x 10^{-5} T

Area of space = A = 10 x 10^8 m^2

Height of space = l = 750 m

Energy stored in earth's magnetic field = $U_B = \frac{1}{2} \frac{B^2}{\mu_o} (Al) = \frac{1}{2} \frac{(7 \times 10^{-5})^2}{4 \times 3.14 \times 10^{-7}} (10 \times 10^8 \times 750)$

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$U_B = 1.46 \times 10^9$ J

Question 15.11:- A square coil of side 16 cm has 200 turns and rotates in a uniform magnetic field of magnitude 0.05 T. If the peak emf is 12 V, what is the angular velocity of the coil?

Solution:- Length of one side of square coil = l = 16 cm = 0.16 m

Number of turns of coil = N = 200

Applied magnetic field = B = 0.05 T

Peak emf = ε = 12 V

We know the peak emf of generator coil is ε = N ω A B

$$\omega = \frac{\varepsilon}{N\,A\,B} = \frac{\varepsilon}{N\,l^2\,B} = \frac{12}{(200)(0.16)^2\,(0.05)}$$

$\omega = 47$ rad s^{-1}

Question 15.12:- A generator has a rectangular coil consisting of 360 turns. The coil rotates at 420 rev per min in 0.14 T magnetic field. The peak value of emf produced by the generator is 50 V. If the coil is 5.0 cm wide, find the length of the side of the coil.

Solution:- Length of rectangular coil = l

Width of square coil = W = 5.0 cm = 0.05 m

Number of turns of coil = N = 360

Angular velocity of coil = ω = 420 rev per min = $420\,\frac{2 \times 3.14}{60}$ rad s^{-1} = 44 rad s^{-1}

Applied magnetic field = B = 0.14 T

Peak emf = ε = 50 V

We know the peak emf of generator coil is ε = N ω A B

ε = N ω (l x W) B

$$l = \frac{\varepsilon}{N\,\omega\,W\,B} = \frac{50}{360 \times 44 \times 0.05 \times 0.14} = 0.45 \text{ m}$$

l = 45 cm

Question 15.13:- It is desired to make an ac generator that can produce an emf of maximum value 5 kV with 50 Hz frequency. A coil of area 1 m^2 having 200 turns is used as armature. What should be the magnitude of the magnetic field in which the coil rotates?

Solution:- Peak emf of generator = ε = 5 kV = 5000 V

Frequency = 50 Hz

Area of coil = A = 1 m^2

Number of turns of coil = N = 200

Applied magnetic field = B

Peak emf induced in generator coil is ε = N ω A B = N (2 π f) A B

$$B = \frac{\varepsilon}{N\,(2\,\pi\,f)A} = \frac{5000}{(200)\,(2)\,(3.14)(50)(1)}$$

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$B = 0.08$ T

Question 15.14:- The back emf in a motor is 120 V when the motor is turning at 1680 rev per min. What is the back emf when the motor turns 3360 rev per min?

Solution:- Initial back emf of the coil = ε_1 = 120 V

Initial angular frequency of rotation = ω_1 = 1680 rev per min

Final back emf of the coil = ε_2

Final angular frequency of rotation = ω_2 = 3360 rev per min

$\varepsilon_1 = N \omega_1 A B$

$\varepsilon_2 = N \omega_2 A B$

$\frac{\varepsilon_2}{\varepsilon_1} = \frac{\omega_2}{\omega_1}$

$\varepsilon_2 = \varepsilon_1 \omega_2 / \omega_1 = (120)(3360)/(1680)$

$\varepsilon_2 = 240$ V

Question 15.15:- A DC motor operates at 240 V and has a resistance of 0.5 Ω. When the motor is running at normal speed, the armature current is 15 A. Find the back emf in the armature.

Solution:- Applied emf = V = 240 V

Resistance of coil = R = 0.5 Ω

Armature current = I = 15 A

Back emf = ε

$V = \varepsilon + I R$

$\varepsilon = V - I R = 240 - (15)(0.5)$

$\varepsilon = 232.5$ V

Question 15.16:- A copper ring has a radius of 4.0 cm and resistance of 1.0 mΩ. A magnetic field is applied over the ring, perpendicular to its plane. If the magnetic field increases from 0.2 T to 0.4 T in a time interval of 5×10^{-3} s, what is the current in the ring during this interval?

Solution:- Radius of copper ring = r = 4.0 cm = 0.04 m

Area of cross section = $A = \pi r^2 = (3.14)(0.04)^2 = 5.02 \times 10^{-3}$ m^2

Resistance of copper ring = R = 1.0 mΩ = 0.001 Ω

Initial magnetic field = B_1 = 0.2 T

Final magnetic field = B_2 = 0.4 T

Change in magnetic field = $\Delta B = 0.4 - 0.2 = 0.2$ T

Time interval = $\Delta t = 5 \times 10^{-3}$ s

Angle between plane of coil and magnetic field = $\alpha = 90^o$

Angle between area vector and magnetic field = $\theta = 90^o - \alpha = 0^o$

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Magnitude of induced emf = ε = $N\frac{\Delta\phi}{\Delta t} = N\frac{\Delta B\, A\cos\theta}{\Delta t}$

ε = $(1)\frac{(0.2)(5.02\ x\ 10^{-3})\cos 0^o}{5\ x\ 10^{-3}}$ = 0.201 V

I = ε/R = 0.201/0.001

<u>I = 201 A</u>

Question 15.17:- A coil of 10 turns and 35 cm^2 area is in a perpendicular magnetic field of 0.5 T. The coil is pulled out of the field in 1.0 s. Find the induced emf in the coil as it is pulled out of the field.

Solution:- Number of turns of coil = N = 10

Area of coil = A = 35 cm^2 = 35 x 10^{-4} m^2

Initial magnetic field = B_1 = 0.5 T

Final magnetic field = B_2 = 0 T

Change in magnetic field = ΔB = $B_2 - B_1$ = -0.5 T

Time taken to change magnetic field = Δt = 1.0 s

Angle between plane of coil and magnetic field = α = 90^o

Angle between area vector and magnetic field = θ = $90^o - \alpha = 0^o$

Induced emf = ε = $-N\frac{\Delta\phi}{\Delta t} = -N\frac{\Delta B\, A\cos\theta}{\Delta t}$

ε = $-(10)\frac{(-0.5)(35\ x\ 10^{-4})\cos 0^o}{1.0}$ = 0.0175 V

<u>ε = 1.75 x 10^{-2} V</u>

Question 15.18:- An ideal step down transformer is connected to main supply of 240 V. It is desired to operate a 12 V, 30 W lamp. Find the current in the primary and the transformation ratio.

Solution:- Primary voltage = V_P = 240 V

Secondary Voltage = V_S = 12 V

Output power = P_{out} = 30 W

(a) We know that $P_{in} = P_{out}$

$V_P I_P = P_{out}$

$I_P = P_{out}/V_P$ = 30/240

<u>I_P = 0.125 A</u>

(b) $\frac{N_S}{N_P} = \frac{V_S}{V_P}$

$\frac{N_S}{N_P} = \frac{12}{240}$

$\boldsymbol{\frac{N_S}{N_P} = \frac{1}{20}}$

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