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UNIT-3

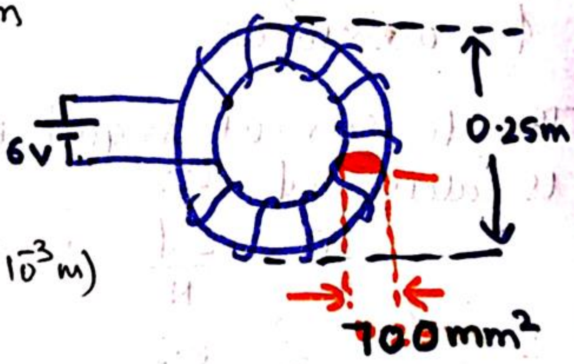
Tutorial sheet-1

Q1:→ A coil of insulated wire of 500 turns and of resistance 4Ω is closely wound on an iron ring. The ring has a mean diameter of 0.25 m and a uniform cross-sectional area of $700\ mm^2$. Calculate the total flux in the ring when a d.c. supply at 6 V is applied to the ends of the winding. Assume a relative permeability of 550.

Solution :- Given : $N = 500$ $V_{dc} = 6V.$
$R = 4\Omega$

diameter of ring ; $d = 0.25m$

area of cross-section of ring $a = 700 mm^2$



$a = 700 \times (10^{-3})^2 = 700 \times 10^{-6}$

$\boxed{a = 7 \times 10^{-4} m^2}$ $(\because 1mm = 10^{-3}m)$

The mean length of magnetic circuit is given by:

$l = \pi d = \pi \times 0.25\ m.$

The magnetic [redacted] field strength (H) is given by:

$$H = \frac{IN}{l}$$

$$I = \frac{V}{R} = \frac{6V}{4\Omega} = 1.5A$$

$$H = \frac{1.5 \times 500}{\pi \times 0.25} = 955\ A/m$$

The flux density given by: $B = \mu_0 \mu_r H$

$B = 4\pi \times 10^{-7} \times 550 \times 955$

$B = 0.66\ T.$

$\phi = Ba = 0.66 \times 7 \times 10^{-4}$ wb

$\boxed{\phi = 0.462 \times 10^{-3}\ Wb}$ [redacted]

Q2 :- A magnetic core, in the form of a closed ring, has a mean length of 20 cm and a cross-section of 1 cm². The relative permeability of iron is 2400. Calculate the value of direct current required to establish the flux of 0.2 mwb in a coil of 2000 turns wound over the iron ring.

Solution :- Given: $l = 20\,cm$ (mean length)

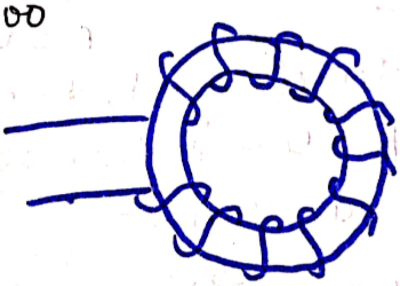
$a = 1\,cm^2$ $\qquad l = 20 \times 10^{-2} = 0.2\,m$

$a = 1 \times (10^{-2})^2\,m^2 = 1 \times 10^{-4}\,m^2$

relative permeability $\mu_r = 2400$

$N = 2000$

$\phi = 0.2 \times 10^{-3}\,wb$



The dc current required is calculated as:

$$I = \frac{S\phi}{N}$$; where S = reluctance of magnetic circuit.

$$S = \frac{l}{\mu_0 \mu_r a} = \frac{0.2}{4\pi \times 10^{-7} \times 2400 \times 1 \times 10^{-4}}$$

$$S = 6.63 \times 10^5\ A/wb$$

$$I = \frac{6.63 \times 10^5 \times 0.2 \times 10^{-3}}{2000} = 66.3 \times 10^{-3}\,A = 66.3\,mA$$ Ans.

Q3: For the iron ring wound with 2000 turns of a coil. Consider that an air gap of 1mm is cut through the core perpendicular to the direction of flux. What current is required to maintain the flux in this gap?

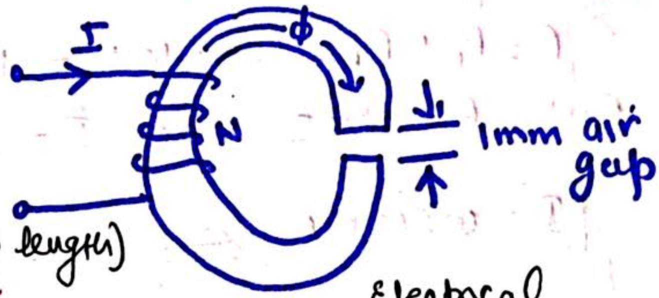
Solution:

$N = 2000$

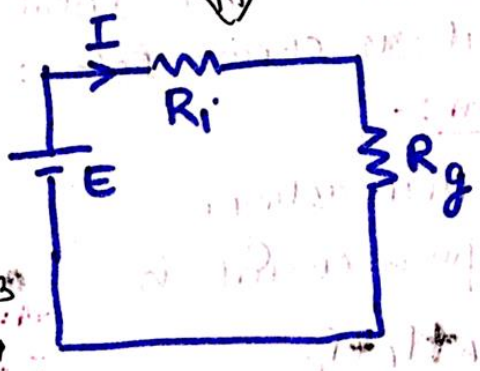
$\mu_r = 2400$

$a = 1\,cm^2 = 1 \times 10^{-4}\,m^2$

$l_g = 1mm = 1 \times 10^{-3} m$ (air gap length)



Electrical Equivalent



Calculation of MMF for the iron path.

l_i = original mean length − air gap length

$l_i = 0.2 - .001 = 0.199\,m$

Flux density $B_i = \frac{\phi}{a_i} = \frac{0.2 \times 10^{-3}}{1 \times 10^{-4}}$

$\boxed{B_i = 2T}$

Magnetic field strength, $H_i = \frac{B_i}{\mu_0 \mu_{r_i}} = \frac{2}{4\pi \times 10^{-7} \times 2400}$

$H_i = 663\,A/m$

MMF for the iron path; $F_i = H_i l_i = 663 \times 0.199$

$F_i = 132\,A$

Calculation of MMF for the air gap:

MMF for air gap is given by: $F_a = H_a l_a$

H_a = magnetic field strength in air gap

l_a = air gap length $= l_g = 1mm = 1 \times 10^{-3} m$

$H_a = \frac{B_a}{\mu_0} = \frac{2}{4\pi \times 10^{-7}} = 0.1591 \times 10^{7}\,A/m$

$\therefore F_a = 0.1591 \times 10^{+7} \times 1 \times 10^{-3} = 1591\,A$

Total ~~flux~~ mmf for the complete magnetic circuit 4

$F = F_i + F_a = 132 + 1591 = 1723\,A$

But $F = N \times I$ or $I = \frac{F}{N} = \frac{1723}{2000} = 0.862\,A$

$\boxed{I = 862\,mA}$ ⟸ Ans.

Q5: An iron ring of mean length 1.2 m and cross-section area $0.005\,m^2$ is wound with a coil of 900 turns. If a current of 2A in the coil produces a flux density in the ring of 1.1 T. calculate:

(a) MMF

(b) Total flux in the ring

(c) Magnetic field strength

(d) relative permeability of the iron at this flux density.

Solution:

Given:

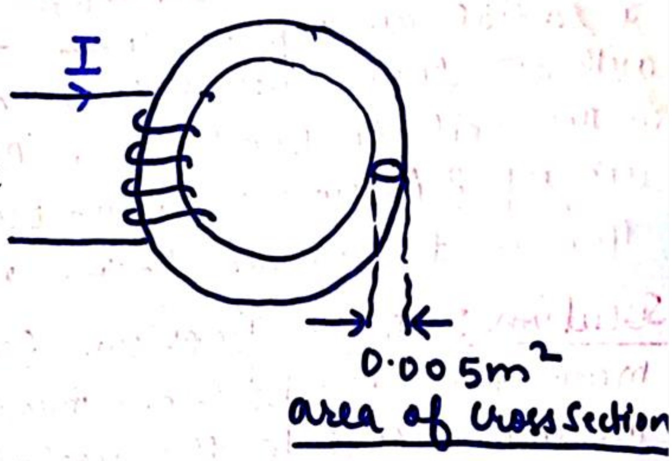
Mean length, $l = 1.2\,m$

$a = 0.005\,m^2$ (cross section area).

$N = 900$

$I = 2A$

Flux density, $B = 1.1\,T$



(a) M.M.F in the circuit:

$$F = N \times I = 900 \times 2 = 1800\,A$$

(b) Total flux in the ring.

$$\text{Flux density} = \frac{\text{flux}}{\text{area of cross-section}} = \frac{\phi}{a}$$

$$\boxed{\phi = Ba} \qquad \phi = 1.1 \times 0.005 = 0.0055\,Wb$$

$$\boxed{\phi = 5.5\,mWb}$$

(c) Magnetic field strength (H)

$$H = \frac{NI}{l} = \frac{900 \times 2}{1.2} = \frac{1800}{1.2} = 1500$$

$$\boxed{H = 1500\,A/m}$$

(d) Relative permeability of the iron at this flux density :→ The flux density and field strength are related as: $B = \mu_0 \mu_r H$

$$\mu_r = \frac{B}{\mu_0 H} = \frac{1.1}{4\pi \times 10^{-7} \times 1500} = 583 \text{ Ans.}$$

Q6 :- An iron ring has a mean length of 1.5m and a cross-sectional area of 0.01 m^2. It has a radial air gap of 4 mm. The ring is uniformly wound with 250 turns. What direct current would be needed in the coil to produce a flux of 0.8 mWb in the air gap? Assume relative permeability of iron as 400 and leakage factor as 1.25. (6)

Solution: In this problem, leakage factor is given, which means that this problem involves leakage flux. So, we will calculate the useful flux in the airgap and then the total flux produced by the coil.

Given parameters:

l (mean length) $= 1.5\,m$

area of cross section, $a = 0.01\,m^2$

length of air gap, $l_a = 4\,mm$

$l_a = 4\times10^{-3}\,m$

⇒ mmf of airgap :

useful flux in airgap;

$\phi_a = 0.8\,mWb = 0.8\times10^{-3}\,Wb.$

Flux density, $B_a = \dfrac{\phi_a}{a_a}$

$a_a = a = 0.01\,m^2$

$B_a = \dfrac{0.8\times10^{-3}}{0.01} = 0.08\,T$

field strength, $H_a = \dfrac{B_a}{\mu_0} = \dfrac{0.08}{4\pi\times10^{-7}}$

$H_a = 0.006366\times10^{7} = 63661.9\,A/m$

Air gap length $l_a = 4\times10^{-3}\,m.$

mmf of airgap; $F_a = H_a l_a$

$F_a = 63661.9\times4\times10^{-3} = 254.647\,A$

Total flux produced by the coil

$= \text{useful flux} \times \text{leakage factor}$

$= \phi_a \times \lambda = 0.8\times10^{-3}\times1.25$

$\phi_T = 1\times10^{-3}\,Wb$

So; Total flux in the iron path = Total flux produced by coil

$\phi_i = \phi_T = 1\times10^{-3}\,Wb.$

flux density, $B_i = \dfrac{\phi_i}{a_i} = \dfrac{1\times10^{-3}}{0.01}$

$\boxed{B_i = 0.1\,T}$

field strength, $H_i = \dfrac{B_i}{\mu_0\mu_r} = \dfrac{0.1}{4\pi\times10^{-7}\times400}$

$H_i = 198.94\,A/m$

⇒ MMF for the iron $= F_i$

$F_i = H_i l_i = 198.94\times(1.5-0.004)$

$F_i = 297.61\,A$

Total MMF, $F = F_i + F_a = 552.257\,A$

current required;

$I = \dfrac{F}{N} = \dfrac{552.257}{250} = \boxed{2.21\,A}$

Ans.

Example 7. *A cast steel electromagnet has an air gap length of 3 mm and an iron path of length 40 cm. Find the number of ampere-turns necessary to produce a flux density of 0.7 Wb/m^2 in the gap. Neglect leakage and fringing. Assume ampere-turns required for air gap to be 70% of the total ampere-turns.*

Solution. Air-gap length, $l_g = 3 \text{ mm} = 3 \times 10^{-3}$ m

Flux density in air gap, $B_g = 0.7$ Wb/m^2

$$\therefore \quad \text{Magnetising force, } H_g = \frac{B_g}{\mu_0 \mu_r} = \frac{0.7}{4\pi \times 10^{-7} \times 1} = 5.57 \times 10^5 \text{ AT/m}$$

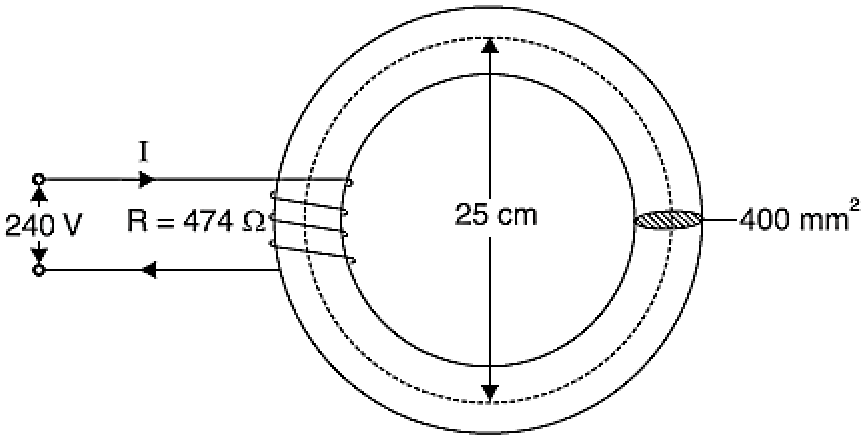
$$AT \text{ required for air gap, } AT_g = H_g \times l_g = 5.57 \times 10^5 \times 3 \times 10^{-3} = 1671 \text{ AT}$$

It is given that : AT_g = 70% of total AT

$$\therefore \quad \text{Total } AT = \frac{AT_g}{0.7} = \frac{1671}{0.7} = \mathbf{2387\ AT}$$

Example 8. *An iron ring has a cross-sectional area of 400 mm^2 and a mean diameter of 25 cm. It is wound with 500 turns. If the value of relative permeability is 250, find the total flux set up in the ring. The coil resistance is 474 Ω and the supply voltage is 240 V.*

Solution. The conditions of the problem are represented in Figure below:



Current through the coil, $I = V/R = 240/474 = 0{\cdot}506$ A

Mean length of magnetic circuit is given by ;

$$l = \pi \times (25 \times 10^{-2}) = 0{\cdot}7854 \text{ m}$$

$$\text{Magnetising force, } H = \frac{NI}{l} = \frac{500 \times 0.506}{0.7854} = 322.13 \text{ AT/m}$$

$$\text{Flux density, } B = \mu_0 \mu_r H = (4\pi \times 10^{-7}) \times 250 \times 322{\cdot}13 = 0{\cdot}1012 \text{ Wb/m}^2$$

$$\therefore \quad \text{Flux in the ring, } \phi = B \times a = 0{\cdot}1012 \times (400 \times 10^{-6}) = \mathbf{40{\cdot}48 \times 10^{-6}\ Wb}$$

Example 9. *A circular iron ring has a mean circumference of 1·5 m and a cross-sectional area of 0·01 m^2. A saw-cut of 4 mm wide is made in the ring. Calculate the magnetising current required to produce a flux of 0·8 mWb in the air gap if the ring is wound with a coil of 175 turns. Assume relative permeability of iron as 400 and leakage factor 1·25.*

Solution. $\phi_g = 0{\cdot}8 \times 10^{-3}$ Wb ; $a = 0{\cdot}01$ m^2 ; $l_i = 1{\cdot}5$m ; $l_g = 4 \times 10^{-3}$ m

AT for air gap

$$B_g = \frac{\phi_g}{a} = \frac{0.8\times10^{-3}}{0.01} = 0.08 \text{ Wb/m}^2$$

$$H_g = \frac{B_g}{\mu_0} = \frac{0{\cdot}08}{4\pi\times10^{-7}} = 63662 \text{ AT/m}$$

$$\therefore \quad AT_g = H_g \times l_g = 63662 \times (4 \times 10^{-3}) = 254{\cdot}6 \text{ AT}$$

AT for iron path

$$\phi_i = \phi_g \times \lambda = 0{\cdot}8 \times 10^{-3} \times 1{\cdot}25 = 10^{-3} \text{ Wb}$$

$$B_i = \phi_i/a = 10^{-3}/0{\cdot}01 = 0{\cdot}1 \text{ Wb/m}^2$$

$$H_i = \frac{B_i}{\mu_0\mu_r} = \frac{0{\cdot}1}{4\pi\times10^{-7}\times400} = 199 \text{ AT/m}$$

$$\therefore \quad AT_i = H_i \times l_i = 199 \times 1{\cdot}5 = 298{\cdot}5 \text{ AT}$$

$$\therefore \quad \text{Total } AT = 254{\cdot}6 + 298{\cdot}5 = 553{\cdot}1 \text{ AT}$$

$$\therefore \quad \text{Magnetising current, } I = 553{\cdot}1/N = 553{\cdot}1/175 = \mathbf{3{\cdot}16\ A}$$

Example 10. *A rectangular iron core is shown in Figure 1. It has a mean length of magnetic path of 100 cm, cross-section of 2 cm × 2 cm, relative permeability of 1400 and an air gap of 5 mm cut in the core. The three coils carried by the core have number of turns N_a = 335, N_b = 600 and N_c = 600 and the respective currents are 1·6 A, 4 A and 3 A. The directions of the currents are as shown in Fig. 1. Find the flux in the air gap.*

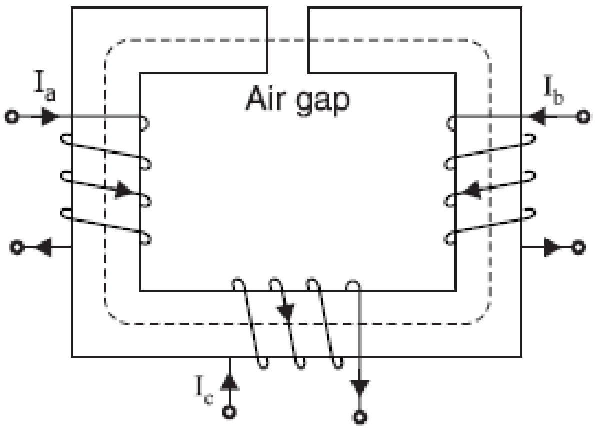


Figure 1

Solution. By applying right-hand rule for the coil, it is easy to see that fluxes produced by currents *Ia* and *Ib* are in the clockwise direction through the iron core while the flux produced by current *Ic* is in the anticlockwise direction through the core.

$$\therefore \quad \text{Net m.m.f.} = N_a I_a + N_b I_b - N_c I_c = 335 \times 1{\cdot}6 + 600 \times 4 - 600 \times 3 = 1136 \text{ AT}$$

$$\text{Reluctance of air gap} = \frac{l_g}{\mu_0 a} = \frac{5 \times 10^{-3}}{4\pi \times 10^{-7} \times 4 \times 10^{-4}} = 9{\cdot}946 \times 10^6 \text{ AT/Wb}$$

$$\text{Reluctance of iron path} = \frac{l_i}{\mu_0 \mu_r a} = \frac{(100 - 0{\cdot}5) \times 10^{-2}}{4\pi \times 10^{-7} \times 1400 \times 4 \times 10^{-4}} = 1{\cdot}414 \times 10^6 \text{ AT/Wb}$$

$$\therefore \quad \text{Total reluctance} = (9{\cdot}946 + 1{\cdot}414) \times 10^6 = 11{\cdot}36 \times 10^6 \text{ AT/Wb}$$

The statement of the example suggests that there is no leakage flux. Therefore, flux in the air gap is the same as in the iron core.

$$\therefore \quad \text{Flux in air gap} = \frac{\text{Net m.m.f.}}{\text{Total reluctance}} = \frac{1136}{11{\cdot}36 \times 10^6} = 100 \times 10^{-6} \text{ Wb} = \mathbf{100\ \mu Wb}$$