

POSTAL Book Package

2023

Electrical Engineering

Conventional Practice Sets

Electric Machines

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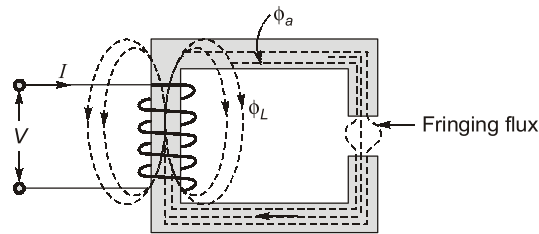
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Magnetic Circuits, Electromechanical Energy Conversion

Q1 Explain the difference between fringing flux and leakage flux.

Solution:

Consider the magnetic circuit given below:



Of the total flux generated by the coil, some flux Φ_L does not follow the intended path of the magnetic circuit. This flux cannot be used for any purpose. This flux is called as the leakage flux.

When the flux enters the airgap, it acquires a bulging shape. The amount of the bulging is direction proportional to the length of the airgap. Bulging increases, the effective area of the airgap and reduces flux density in it. This effect is called as fringing and the flux in the bulge is called as fringing flux.

Q2 The flux linkage (λ) and circuit (i) is related as $\psi = (\sqrt{i}) / g$. When $i = 2$ A and g (airgap length) = 10 cm, then determine the magnitude of mechanical force on the moving part.

Solution:

Energy in magnetic system,

$$W_f = \int_0^{\psi} i(\psi) d\psi$$

$$\psi = (\sqrt{i})/g \quad (\text{Given})$$

$$W_f = \int_0^{\psi} \psi^2 \cdot g^2 \cdot d\psi = g^2 \frac{\psi^3}{3}$$

Now, mechanical force,

$$F_f = -\frac{\partial W_f(\psi, g)}{\partial g}$$

$$F_f = -\frac{\partial}{\partial g} \left[\frac{g^2 \psi^3}{3} \right] = -\frac{2}{3} \psi^3 g$$

$$\therefore i = 2 \text{ A}, g = 10 \text{ cm}, \psi = 10\sqrt{2}$$

Hence,

$$|F_f| = \frac{2}{3} \times (10\sqrt{2})^3 \times 0.1 = 188.56 \text{ N}$$

Q3 In an electromagnetic relay, functional relation between the current in the exciting coil, the position of armature x and the flux linkage Ψ is given by

$$i = 2\Psi^3 + 3\Psi(1 - x + x^2), \quad x > 0.5$$

Find the force on the armature as a function of Ψ .

Solution:

$$i = 2\Psi^3 + 3\Psi(1 - x + x^2)$$

Field energy stored,

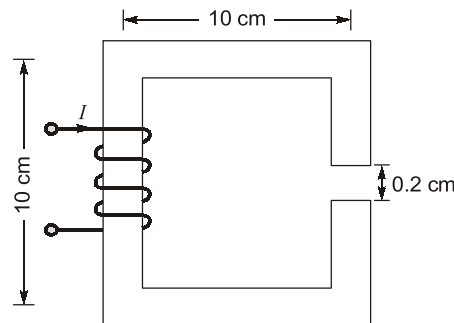
$$W_f(\Psi, x) = \int_0^\Psi i(\Psi) d\Psi = \int_0^\Psi [2\Psi^3 + 3\Psi(1 - x + x^2)] d\Psi = \frac{2\Psi^4}{4} + 3\frac{\Psi^2}{4}(1 - x + x^2)$$

Magnetic force is given by,

$$\begin{aligned} \therefore f_e &= \frac{\partial W_f(\Psi, x)}{\partial x} = -\frac{\partial}{\partial x} \left[\frac{\Psi^4}{2} + \frac{3\Psi^2}{2}(1 - x + x^2) \right] \\ &= -\left[0 + \frac{3\Psi^2}{2}(0 - 1 + 2x) \right] = \frac{3\Psi^2}{2}(1 - 2x) \end{aligned}$$

For $x > 0.5$, f_e is negative, therefore f_e acts to decrease the field energy stored at constant flux linkage.

Q4 The magnetic circuit shown below has uniform cross-sectional area and air gap of 0.2 cm. The mean path length of the core is 40 cm. Assume that leakage and fringing fluxes are negligible. When the core relative permeability is assumed to be infinite, the magnetic flux density computed in the air gap is 1 tesla. With same Ampere-turns, if the core relative permeability is assumed to be 1000 (linear), then determine the flux density in the air gap.



Solution:

Air gap length, $l_{ag} = 0.2 \text{ cm}$,
Mean length of magnetic path, $l_m = 40 \text{ cm}$
Given, $B_0 = 1 \text{ Tesla}$

$$\phi = \frac{\text{mmf}}{\mathfrak{R}}$$

For same mmf, $\phi \propto \frac{1}{\mathfrak{R}}$

$$\text{In case-1: } \mathfrak{R}_1 = \frac{l_m}{\mu_0 A} = \frac{l_{ag}}{\mu_0 A} + \frac{l_m}{\mu_0 \mu_r A}$$

As $\mu_r = \infty$

$$\therefore \mathfrak{R}_1 = \frac{0.2 \times 10^{-2}}{\mu_0 A}$$

In case-2:

$$\begin{aligned}\mathfrak{R}_2 &= \frac{l_{ag}}{\mu_0 A} + \frac{l_m}{\mu_0 \mu_r A} \\ &= \frac{0.2 \times 10^{-2}}{\mu_0 A} + \frac{40 \times 10^{-2}}{1000 \mu_0 A} = \frac{0.24 \times 10^{-2}}{\mu_0 A}\end{aligned}$$

As, flux, $\phi = BA$

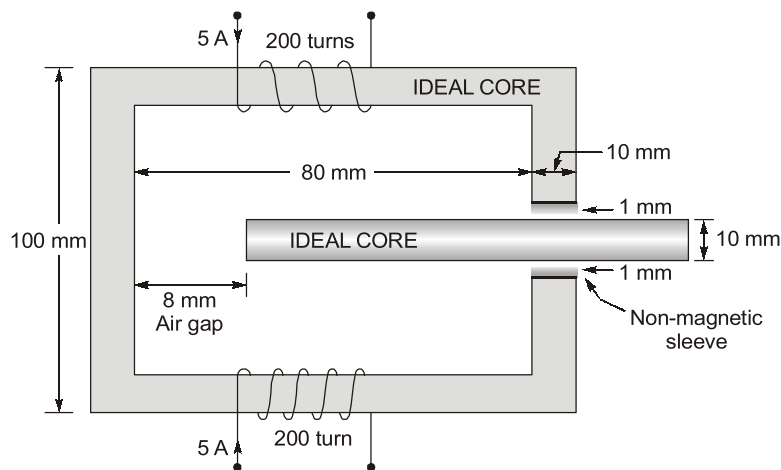
for uniform cross section area, $\phi \propto B$

Therefore, $B \propto \frac{1}{\mathfrak{R}}$

$$\therefore B_2 = \frac{B_1 \times \mathfrak{R}_1}{\mathfrak{R}_2}$$

$$B_2 = \frac{0.2 \times 10^{-2} / \mu_0 A}{0.24 \times 10^{-2} / \mu_0 A} = 0.833 \text{ T}$$

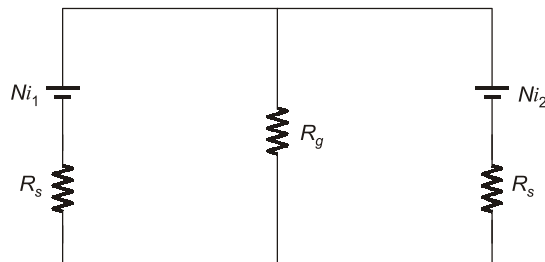
Q5 A magnetic circuit formed by an ideal core material as shown in below figure. Determine the magnetic flux density in the air gap.



Solution:

Since, the core is ideal, therefore the reluctance of the mean magnetic path of core is zero.

The equivalent circuit is,



where

R_s = reluctance of non-magnetic sleeve

R_g = reluctance of air gap

MMF, $Ni_1 = Ni_2 = 200 \times 5 = 1000 \text{ AT}$

Length of non-magnetic sleeve,

$$l_s = 1 \text{ mm}$$

Length of air gap, $l_g = 8 \text{ mm}$

Reluctance of non-magnetic sleeve,

$$\mathfrak{R}_s = \frac{l_s}{\mu_0 \mu_r A}$$

$$\mathfrak{R}_s = \frac{1 \times 10^{-3}}{4\pi \times 10^{-7} \times A} \quad (\mu_r = 1)$$

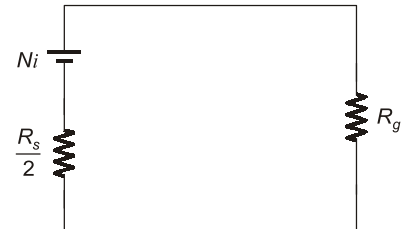
$$\mathfrak{R}_g = \frac{l_g}{\mu_0 A_g} = \frac{8 \times 10^{-3}}{4\pi \times 10^{-7} \times a}$$

Total reluctance of magnetic circuit,

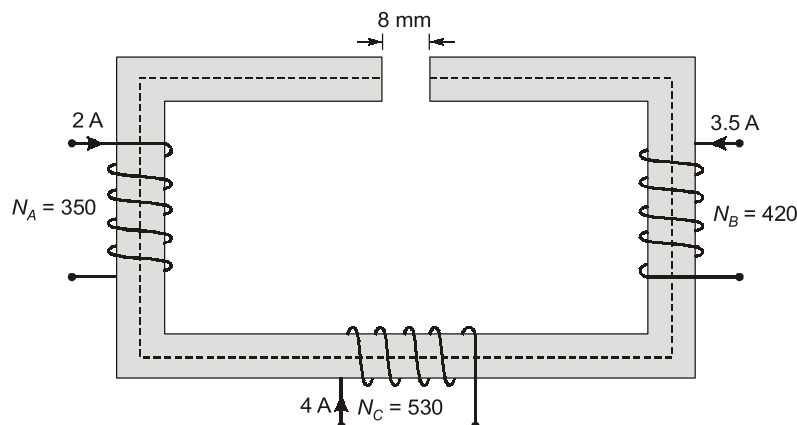
$$\mathfrak{R}_{eq} = \frac{\mathfrak{R}_s}{2} + \mathfrak{R}_g = \frac{1 \times 10^{-3}}{2 \times 4\pi \times 10^{-7} \times A} + \frac{8 \times 10^{-3}}{4\pi \times 10^{-7} \times A}$$

$$\mathfrak{R}_{eq} = \frac{8.5 \times 10^{-3}}{4\pi \times 10^{-7} \times A}$$

Magnetic flux density, $B = \frac{\phi}{A} = \frac{mmf}{\mathfrak{R}_{eq} \times A} = \frac{1000}{\frac{8.5 \times 10^{-3} \times A}{4\pi \times 10^{-7} \times A}} = 0.1478 \text{ Wb/m}^2$

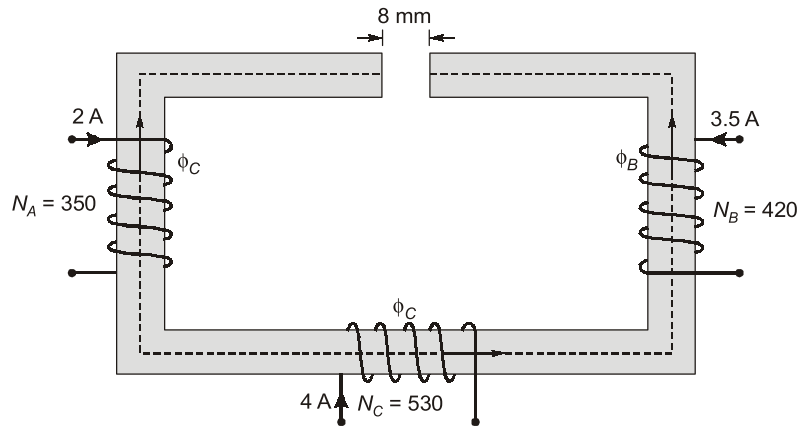


Q.6 An iron core has mean length of a magnetic circuit of 120 cm, cross-section of 4 cm × 4 cm and relative permeability of 2470. A cut of size 8 mm in the core has been made. The three coils, A, B and C on the core have number of turns 350, 420 and 530 respectively and the respective currents flowing are 2 A, 3.5 A and 4 A. The direction of currents is shown in figure below. Find the air gap flux. Neglecting of flux.



Solution:

As shown in figure, the flux produce by coil B and C are in the same direction but that by coil A is in opposite direction.



Hence net available ampere turns

$$= AT_B + AT_C - AT_A$$

$$= 420 \times 3.5 + 530 \times 4 - 350 \times 2 = 2890 \text{ AT}$$

Mean length of iron path, $l_i = 120 \text{ cm} = 1.2 \text{ m}$

Area of cross-section, $A = 4 \times 10^{-2} \times 4 \times 10^{-2} = 16 \times 10^{-4} \text{ m}^2$

Relative permeability of iron path,

$$\mu_r = 2470$$

$$\text{Reluctance of iron path, } \mathfrak{R}_i = \frac{l_i}{\mu_0 \mu_r A} = \frac{1.2}{4\pi \times 10^{-7} \times 2470 \times 16 \times 10^{-4}} = 2.4163 \times 10^5 \text{ AT/Wb}$$

Length of air gap, $l_g = 8 \times 10^{-3} \text{ m}$

$$\text{Reluctance of air gap, } \mathfrak{R}_g = \frac{l_g}{\mu_0 \mu_r A} = \frac{8 \times 10^{-3}}{4\pi \times 10^{-7} \times 1 \times 16 \times 10^{-4}} = 3.978 \times 10^6 \text{ AT/Wb}$$

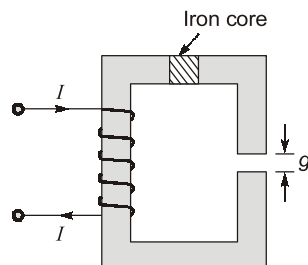
Total reluctance of the circuit

$$\mathfrak{R} = \mathfrak{R}_i + \mathfrak{R}_g = 4.219 \times 10^6 \text{ AT/Wb}$$

$$\text{Flux in the air gap, } \phi = \frac{\text{Total available AT}}{\text{Total Reluctance}} = \frac{2890}{4.219 \times 10^6} = 684.894 \times 10^{-6} \text{ Wb}$$

$$\phi = 0.685 \text{ mWb}$$

Q.7 For the magnetic circuit of figure below, length of iron path = 120 cm, $g = 0.5 \text{ cm}$, area of cross-section of iron = $5 \times 5 \text{ cm}^2$, $\mu_r = 1500$, $I = 2 \text{ A}$, $N = 1000$ turns.



Calculate and compare the field-energy stored and field-energy density in iron as well as in airgap. Neglect fringing and leakage flux.

Solution:

$$\text{Total reluctance} = \frac{\text{Length of iron path}}{\mu_0 \mu_r \times \text{Area}} + \frac{\text{Gap length}}{\mu_0 \times \text{Area}}$$

$$= \frac{120 \times 10^{-2}}{4\pi \times 10^{-7} \times 1500 \times 25 \times 10^{-4}} + \frac{0.5 \times 10^{-2}}{4\pi \times 10^{-7} \times 25 \times 10^{-4}}$$

$$= \frac{10^9}{4\pi \times 25} \left[\frac{120}{1500} + \frac{0.5}{1} \right] = 1.8462 \times 10^6 \text{ A/Wb}$$

Flux,

$$\phi = \frac{NI}{\mathfrak{R}} = \frac{1000 \times 2}{1.8462 \times 10^6} \text{ mWb} = 1.0833 \text{ mWb}$$

Field energy stored in iron = $\frac{1}{2} \phi^2 \times \text{reluctance offered by iron path}$

$$= \frac{1}{2} [1.0833 \times 10^{-3}]^2 \times \frac{120 \times 10^{-2}}{4\pi \times 10^{-7} \times 1500 \times 25 \times 10^{-4}}$$

$$= 0.14942 \text{ J}$$

Field energy stored in Air gap ,

$$= \frac{1}{2} \phi^2 (\mathfrak{R}_{\text{airgap}})$$

$$= \frac{1}{2} (1.0833 \times 10^{-3})^2 \times \frac{0.5 \times 10^{-2}}{4\pi \times 10^{-7} \times 25 \times 10^{-4}} = 0.93387 \text{ J}$$

Energy density in iron core = $\frac{\text{Energy stored in iron}}{\text{Volume of iron}} = \frac{0.14942}{120 \times 10^{-2} \times 25 \times 10^{-4}} = 49.81 \text{ J/m}^3$

Energy density of air gap = $\frac{\text{Energy stored in air gap}}{\text{Volume of air gap}} = \frac{0.93387}{0.5 \times 10^{-2} \times 25 \times 10^{-4}} = 74709.6 \text{ J/m}^3$

$$\frac{\text{Energy stored in air gap}}{\text{Energy stored in iron}} = \frac{0.93387}{0.14942} = 6.25$$

$$\frac{\text{Energy density in air gap}}{\text{Energy density in iron}} = \frac{74709.6}{49.807} = 1499.98 \gg 1500$$

This example demonstrates that most of the field energy is stored in the air gap.

Q8 For the electromagnetic device shown in figure, the cross-sectional area normal to the flux is A and the reluctance is offered by air gap alone. Compute the average force on the movable member in terms of N , x , A , L etc.

When,

(i) $i = I_m \cos \omega t$

(ii) $v = V_m \cos \omega t$

