KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

ELECTRICAL ENGINEERING DEPARTMENT

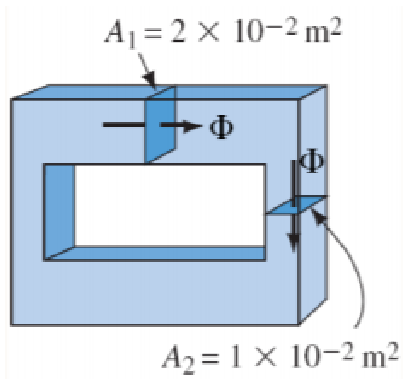
EE 306 – Term 181

HW # 2: Magnetic Circuits

Key Solutions

Problem # 1:

In the figure below, the flux density at cross section A_1 is $B_1 = 0.4$T, determine B_2.

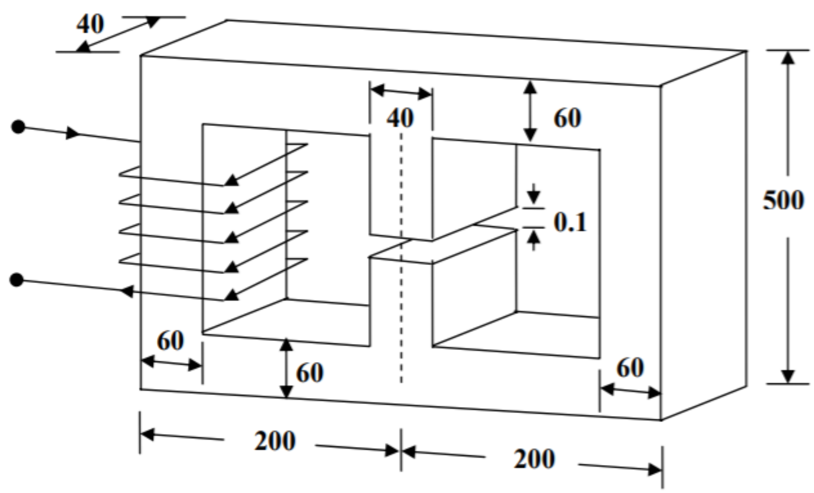


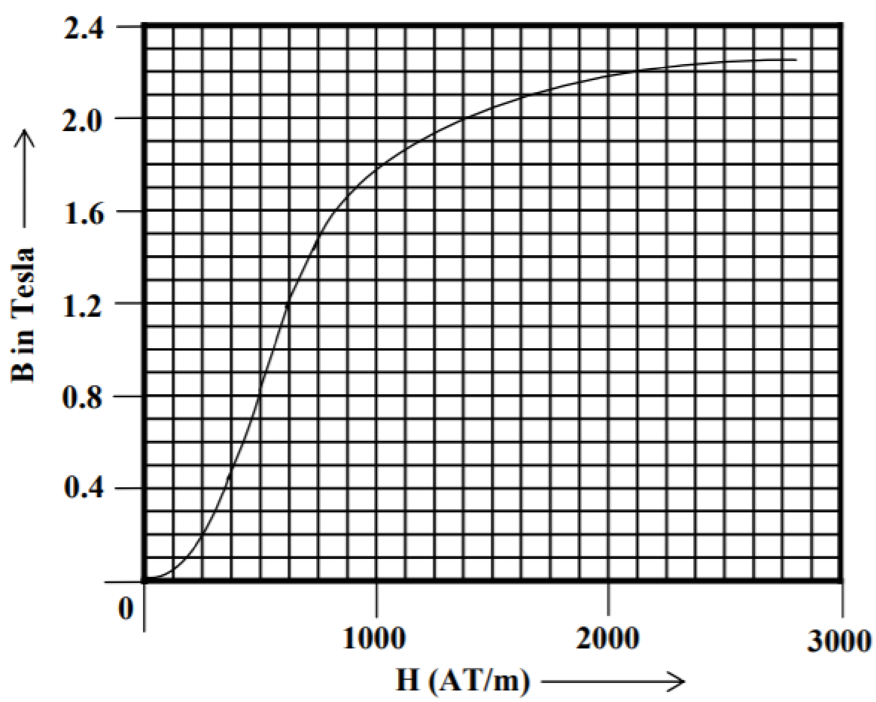
Solution $\Phi = B_1 \times A_1 = (0.4\,\text{T})(2 \times 10^{-2}\,\text{m}^2) = 0.8 \times 10^{-2}$ Wb. Since all flux is confined to the core, the flux at cross section 2 is the same as at cross section 1. Therefore,

$$B_2 = \Phi/A_2 = (0.8 \times 10^{-2}\,\text{Wb})/(1 \times 10^{-2}\,\text{m}^2) = 0.8\,\text{T}$$

Problem # 2:

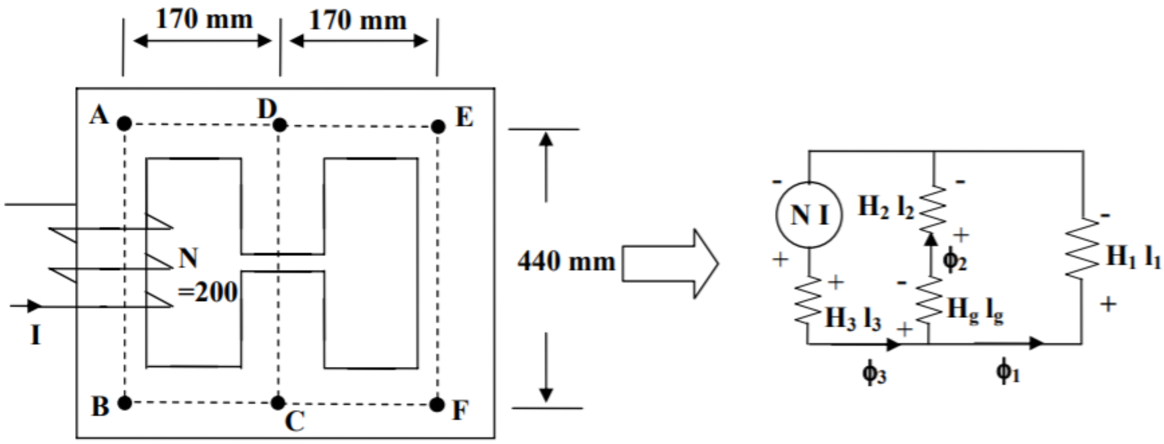
A 3-legs core and its *B-H* curve are shown below. All dimensions are in mm. Calculate the required current to be passed in the coil having 200 turns in order to establish a flux of 1.28 mWb in the air gap. Neglect fringing effect and leakage flux.





Solution:

The equivalent magnetic circuit is



$\phi_g = \phi_2 \;=\; 1.28 \times 10^{-3}$

Cross sectional area of central limb $A_2 \;=\; 16 \times 10\text{-}4 \text{ m}^2$

$$\text{Flux density } B_g = B_2 \;=\; \frac{1.28\times10^{-3}}{16\times10^{-4}}\text{T} \;=\; 0.8 \text{ T}$$

$$\therefore, H_g = \frac{B_g}{\mu_0} \;=\; \frac{0.8}{4\pi\times10^{-7}}\text{AT/m} \;=\; 63.66 \times 10^4 \text{ AT/m}$$

mmf required for gap $H_g l_g \;=\; 63.66 \times 10^4 \times 1 \times 10^{-4}$ AT $=$ 63.66 AT

flux density, $B_2 \;=\; 0.8$ T $\because$ fringing & leakage neglected

corresponding H from graph, $H_2 \;\approx\; 500$ AT /m

Mean iron length, $l_2 \;=\; (440 - 0.1)$ mm $\approx$ 0.44 m

mmf required for iron portion, $H_2 l_2 \;=\; 220$ AT

Total mmf required for iron & air gap, $=$ (220 + 63.66) AT

$$mmf_{CD} = 283.66 \text{ AT.}$$

Due to parallel connection, mmf acting across path 1 is same as mmf acting across path 2. Our intention here, will be to calculate ϕ_1 in path 1.

mean length of the path, $l_1 \;=\; l_{DE} + l_{EF} + l_{FC} \;=\; 2 \times 170 + 440$ mm $=$ 0.78 m

$$\because H_1 \;=\; \frac{283.66}{0.78} \;=\; 363.67 \text{ AT /m}$$

corresponding flux density from graph, $B_1 \;\approx\; 0.39$ T

$\therefore$ flux, $\phi_1 \;=\; B_1 A_1 \;=\; 0.39 \times 24 \times 10^{-4} \;=\; 0.94 \times 10^{-3}$ Wb calculate the mmf necessary to drive ϕ_3 in path 3 as follows.

$$\text{flux in path 3, } \phi_3 = \phi_1 + \phi_2 = 2.22 \times 10^{-3} \text{ Wb}$$

$$\text{flux density, } B_3 = \frac{\phi_3}{A_3} = \frac{2.22 \times 10^{-3}}{24 \times 10^{-4}} = 0.925 \text{ T}$$

$$\text{corresponding H from graph, } H_3 \approx 562.5 \text{ AT /m}$$

$$\text{total mmf required for path 3} = H_3 l_3 = 562.5 \times 0.78 \text{ AT} = 438.7 \text{ AT}$$

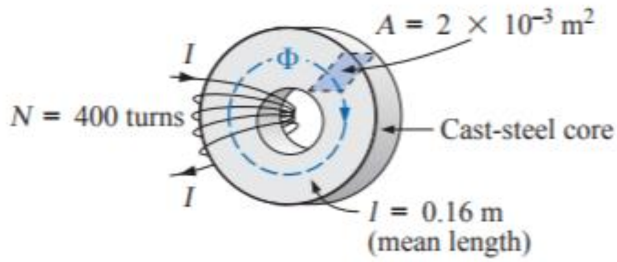
$$\therefore \text{ mmf to be supplied by the coil, } NI = 283.66 + 438.7 \text{ AT}$$

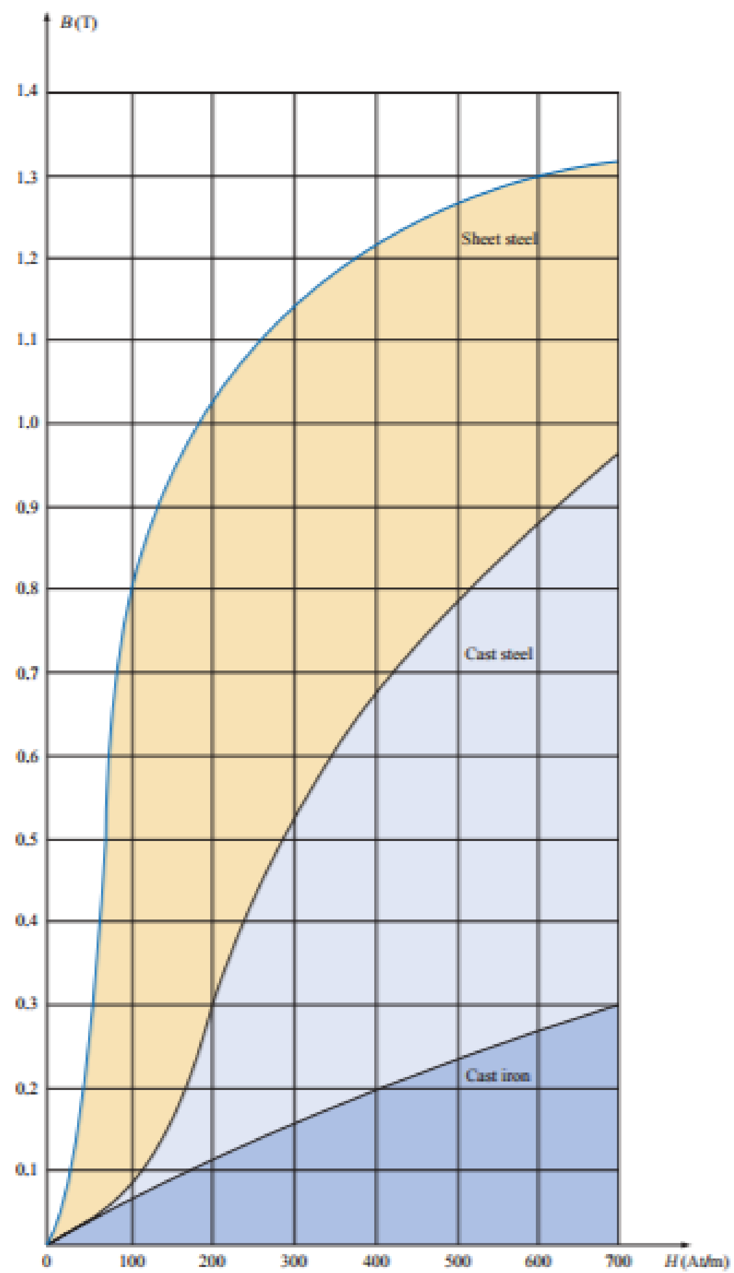
$$\text{or } 200I = 722.36 \text{ AT}$$

$$\therefore \text{ exciting current needed, } I = \frac{722.36}{200} \text{A} = 3.61 \text{ A}$$

Problem # 3:

For the magnetic circuit and the corresponding magnetizing-curve (*B*-*H* curves) shown below



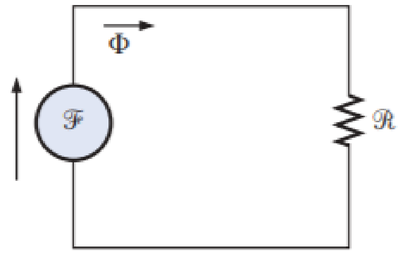


a. Find the value of I required to develop a magnetic flux of $\Phi = 6 \times 10^{-4}$ Wb.

b. Determine μ and μ_r for the material under these conditions.

Solution:

The magnetic circuit can be represented as



a. The flux density is

$$B = \frac{\Phi}{A} = \frac{6 \times 10^{-4}\ \text{Wb}}{2 \times 10^{-3}\ \text{m}^2} = 0.3\ \text{T}$$

Using the cast-steel *B-H* curve

$H = 200$ At/m ; I = (200 x 0.16) / 400 = 0.08 A

b. The permeability of the material is

$$\mu = \frac{B}{H} = \mathbf{1.5 \times 10^{-3}\ Wb/A \cdot m}$$

The relative permeability is

$$\mu_r = \frac{\mu}{\mu_o} = \mathbf{1193.7}$$

Problem # 4:

An electromagnet has a magnetic-circuit that can be regarded as comprising three parts in series, each of uniform cross-sectional area.
(i) a length of 8 cm and cross-section area of 0.511 cm^2.
(ii) a length of 6 cm and cross-sectional area of 0.9 cm^2.
(iii) an air-gap of length 0.5 mm and cross-sectional area of 1.5 cm^2.
Parts (i) and (ii) are of a material having a magnetic characteristic given by the following table:

H (AT/m)	100	210	340	500	800	1500
B (wb/m^2)	0.2	0.4	0.6	0.8	1.0	1.2

Determine the current necessarv in a coil of 4000 turns wound on part (ii) to produce in the air-gap a flux density of 0.3 wb/m^2.

Solution:

Part	l cm	A cm^2	Φ μwb	B	H
i	8	0.511	45	0.88	620
ii	6	0.9	45	0.5	275
gap	0.05	1.5	45	.3	$.24 \times 10^6$

$\Phi_g = .3 \times 1.5 \times 10^{-4} = 45\mu$, all part are in series

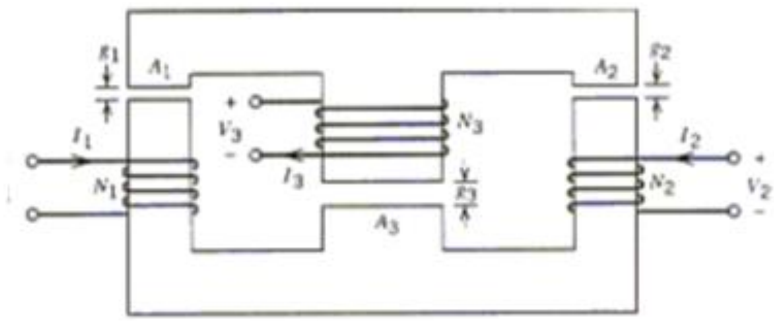
$AT = \Sigma Hl = 620 * 0.08 + 275 * 0.06$

$+ .2387 \times 10^6 \times 0.05 \times 10^{-2} = 185.5$

$I = AT/4000 = 46.4$ mA.

Problem # 5:

The magnetic circuit shown has an infinitely permeable magnetic core.

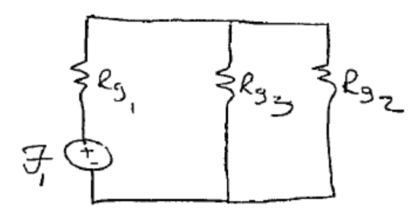


$g_1 = 5$ mm	$A_1 = 5$ cm^2	$N_1 = 80$ turns
$g_2 = 5$ mm	$A_2 = 5$ cm^2	$N_2 = 100$ turns
$g_3 = 10$ mm	$A_3 = 10$ cm^2	$N_3 = 125$ turns

A current of 12 A flows in the first coil N_1. The second and third coils N_2 and N_3 respectively, are unexcited. Determine the flux densities in each of the air gaps g_1, g_2, and g_3.

Solution:

$$\mathcal{F}_1 = 80 \times 12 = 960 \text{ At}$$



$$R_{g_2} = R_{g_1} = \frac{5 \times 10^{-3}}{\mu_0 \times 5 \times 10^{-4}} = 7.958 \times 10^{6} \text{ At/wb}$$

$$R_{g_3} = \frac{10 \times 10^{-3}}{\mu_0 \times 10 \times 10^{-4}} = 7.958 \times 10^{6} \text{ At/wb}$$

$$R_t = R_{g_1} + \frac{R_{g_2} R_{g_3}}{R_{g_2} + R_{g_3}} = 11.937 \times 10^{6} \text{ At/Wb}$$

$$\Phi_1 = \frac{\mathcal{F}_1}{R_t} = \frac{960}{11.937 \times 10^{6}} = 80.4 \times 10^{-6} \text{ Wb} \qquad B_1 = \frac{\Phi_1}{A_1} = .161 \text{ T}$$

$$\Phi_2 = \Phi_3 = \frac{1}{2}\Phi_1 = 40.2 \times 10^{-6} \text{ Wb} \qquad B_2 = 0.08 \text{ T}$$

$$B_3 = 0.04 \text{ T}$$

Problem # 6:

The core loss of a magnetic core is 2000 W at 50 Hz. Keeping the flux density constant, the frequency of the supply is raised to 75 Hz resulting in core loss of 3200 W. Compute separately hysteresis and eddy current losses at both the frequencies.

Solution:

For constant B_{max}

$W_h = Af$ and $W_e = Bf^2$

$W_t = W_h + W_e = Af + Bf^2$

at 50 Hz: $2000 = A \times 50 + B \times 50^2$ — (1)

$3200 = A \times 75 + B \times 75^2$ — (2)

solving 1 & 2 for A and B

$A = 34.667$ and $B = 0.10667$

at 50 Hz

$W_h =$ **1733.35 W**

$W_e =$ **266.65 W**

at 75 Hz

$W_h =$ **2600 W**

$W_e =$ **600 W**