Solutions

1. (a) The magnetic structure shown in Figure 1 is made of cast steel.

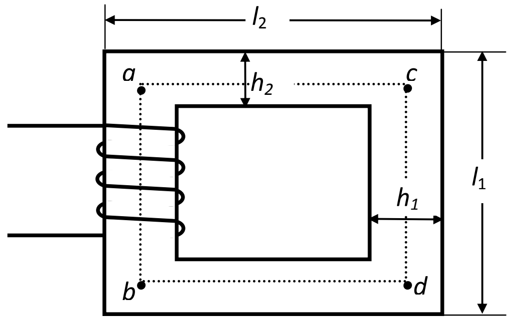


Figure 1

Use the *B-H* curve of the core shown in Figure 2 to find the permeability and the relative permeability of the core material at flux density levels of 0.6 T, and 1.2 T.

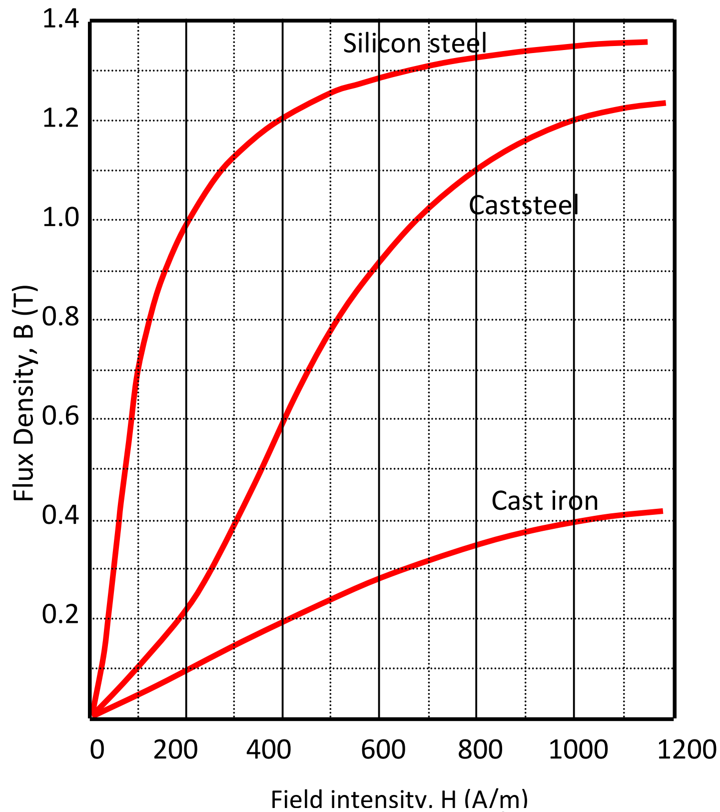


Figure 2 Typical magnetization curves of three materials

(b) The magnetic circuit shown in the Figure 3 has a cross section of 5 cm^2 and the relative permeability of 800. The coil has 400 turns and carries a current of 2.5 A. Ignoring the fringing, find:

(i) the flux density in each air gap, and hence their ratio,

(ii) what will be the ratio of these flux densities if the reluctance of the core were ignored?

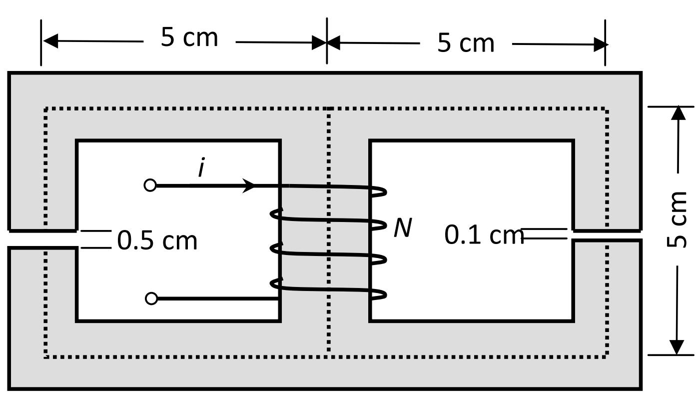


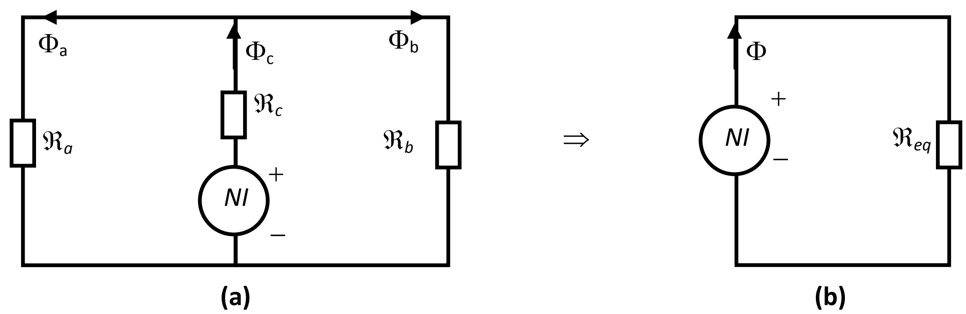
Figure 3. Magnetic circuit for Problem1 (b)

Solution

1 (a)

B	H	$\mu = B/H$	$\mu_r=\mu/\mu_0$
0.6	400	1.5×10^{-3}	1194
1.2	1000	1.2×10^{-3}	955

1(b) The equivalent magnetic circuit can be drawn as shown in the following figures.



Magnetic equivalent circuits for Q.1b

(i) The reluctances are computed as follows:

For the center core:

$$\Re_c = \frac{5\times10^{-2}}{800\times4\pi\times10^{-7}\times5\times10^{-4}}\ \mathrm{H^{-1}} = 0.995\times10^{5}\ \mathrm{H^{-1}}$$

For the right hand path:

$$\Re_b = \frac{0.1\times10^{-2}}{4\pi\times10^{-7}\times5\times10^{-4}} + \frac{14.9\times10^{-2}}{800\times4\pi\times10^{-7}\times5\times10^{-4}}\ \mathrm{H^{-1}} = 18.88\times10^{5}\ \mathrm{H^{-1}}$$

For the left hand path:

$$\Re_a = \frac{0.5\times10^{-2}}{4\pi\times10^{-7}\times5\times10^{-4}} + \frac{14.5\times10^{-2}}{800\times4\pi\times10^{-7}\times5\times10^{-4}}\ \mathrm{H^{-1}} = 82.46\times10^{5}\ \mathrm{H^{-1}}$$

$\Re_{eq} = \Re_c + (\Re_a // \Re_b) = 16.358\times 10^5\ \mathrm{H^{-1}}$

The flux values can be calculated as:

$\varphi_c = NI/\Re_{eq} = (400\mathrm{x}2.5)/16.358\times10^5 = 0.611$ mWb

$\varphi_a = [\Re_b / (\Re_a + \Re_b)]\ \varphi_c = 0.114$mWb

$\varphi_b = [\Re_a / (\Re_a + \Re_b)]\ \varphi_c = 0.497$mWb

Therefore the required flux densities are:

$B_a = \varphi_a/(5 \times 10^{-4}) = 0.228$ T

$B_b = \varphi_b/(5 \times 10^{-4}) = 0.994$ T, and

$B_b/B_a = 0.994/0.228 = 4.36$

(ii) If the core reluctances are ignored,

$B_b/B_a = \Re_a/\Re_b = \mathrm{gap}_a/\mathrm{gap}_b = 5:1$

2. When a voltage source with 220 V (rms) with frequency of 50 Hz is applied to an iron core inductor shown in Figure 4, the eddy current loss is 25 W out of the total iron loss of 60 W. What will be the total iron loss if the source voltage magnitude is kept fixed but the frequency is doubled? Assume that Steinmetz's index for iron core is equal to 2.

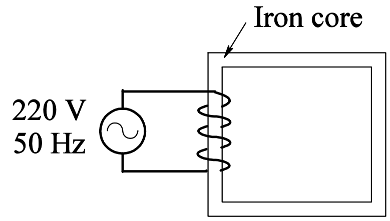


Figure 4

Solution

When 220 V and 50 Hz:

Total iron loss $P_{i_1} = 60$ W

Eddy current loss $P_{e_1} = 25$ W

∴ Hysteresis loss $P_{h_1} = P_{i_1} - P_{e_1} = 60 - 25 = 35$ W

Let $f_1 = 50$ Hz and the flux density for 220 V and 50 Hz is denoted by B_{m_1}.

At 220 V and 50 Hz:

Eddy current loss $P_{e_1} = K_e B_{m_1}^2 f_1^2 = 25$ W

At 220 V and 100 Hz ($= f_2$), we will have $B_{m_2} = \frac{1}{2} B_{m_1}$ (since $B_m \propto \frac{V}{f}$ and $f_2 = 2f_1$)

Eddy current loss $P_{e_2} = K_e B_{m_2}^2 f_2^2 = K_e \left(\frac{B_{m_1}}{2}\right)^2 (2f_1)^2 = K_e B_{m_1}^2 f_1^2$

$\therefore P_{e_2} = P_{e_1} = 25$ W

For Hysteresis loss, $P_h = K_h B_m^n f$ where n is Steinmetz's index and given as 2.

$$\frac{P_{h_2}}{P_{h_1}} = \frac{K_h B_{m_2}^2 f_2}{K_h B_{m_1}^2 f_1} = \frac{K_h \left(\frac{1}{2} B_{m_1}\right)^2 (2f_1)}{K_h B_{m_1}^2 f_1} = \frac{1}{2}$$

$\therefore P_{h_2} = 35/2 = 17.5$ W

Thus at 220 V and 100 Hz, the total iron loss $P_{i_2} = P_{e_2} + P_{h_2} = 25 + 17.5 = 42.5$ W

3. Calculate inductance of the inductor being realized as shown in Figure 5, ignoring reluctances of the iron core paths.

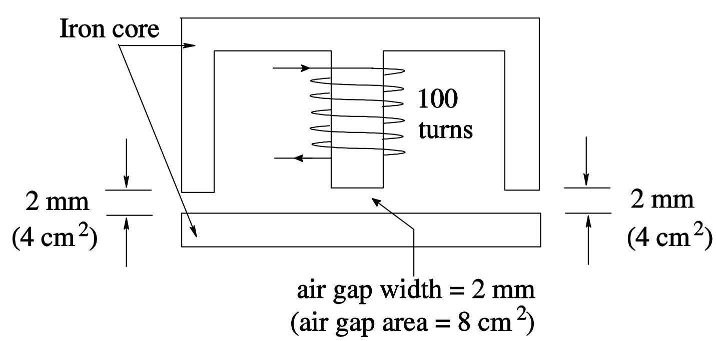
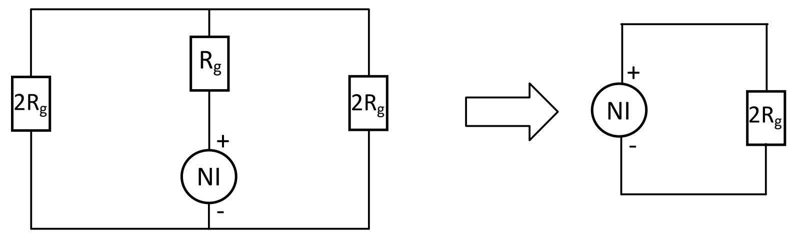


Figure 5

Solution

Let the reluctance of the ***central arm*** air gap be R_g. Since the lengths of all air gaps are same (= 2 mm) and

the area of the central arm air gap is 2 times that of each of the side air gaps. The magnetic equivalent circuit for the systemand its simplified version can be drawn as shown below:



$$\text{Reluctance } R_g = \frac{air\ gap\ length}{4\pi \times 10^{-7} \times air\ gap\ area} = \frac{2 \times 10^{-3}}{4\pi \times 10^{-7} \times 8 \times 10^{-4}} = \frac{2 \times 10^{8}}{4\pi \times 8} = 1.98 \times 10^{6} H^{-1}$$

$$\text{Thus, Inductance } L = \frac{N^2}{2R_g} = \frac{10^4}{2 \times 1.98 \times 10^6} = 0.25 \times 10^{-2} = 2.5\ mH$$