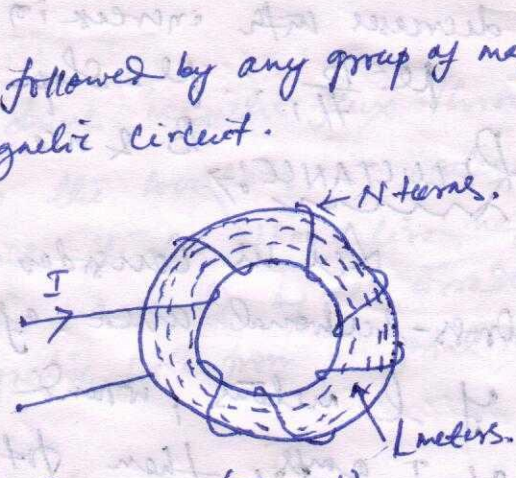
MAGNETIC CIRCUIT

MAGNETIC CIRCUIT :→

The Complete closed path followed by any group of magnetic flux lines is referred to as a magnetic circuit.



MAGNETOMOTIVE FORCE AND MAGNETIC FIELD STRENGTH :→

MMF, $F = NI$ AT or A.

Magnetic field strength, $H = \frac{NI}{l}$ AT/m or A/m. $= \frac{F}{l}$.

where, N = Nos. of turns of the coil.
I = Current flowing through the coil
l = Mean length of the magnetic circuit.

PERMEABILITY OF FREE SPACE OR MAGNETIC CONSTANT :→

Permeability of free space or air or other non-magnetic material $\mu_0 = \frac{B}{H} = 4\pi \times 10^{-7}$ H/m.

where, B = flux density in wb/m² or Tesla (T).

RELATIVE PERMEABILITY :→

The ratio of the flux density produced in a material to the flux density produced in a vaccum (or in a non-magnetic core) by the same field strength is termed as the relative permeability and is denoted by the symbol μ_r.

For air, $\mu_r = 1$

Nickel-iron alloys, $\mu_r = 100\,000$.

For non-magnetic material, $B = \mu_0 H$. ($\because \mu_r = 1$)

For ferro-magnetic materials. $B = \mu_0 \mu_r H$.
$= \mu H$

where μ is known as absolute permeability

$\therefore \mu = \mu_0 \mu_r$.

μ_r is not constant for a ferromagnetic material and μ_r decreases with increase in H.

$\mu = \frac{B}{H}$, $\therefore$ μ = Slope of B/H curve. μ is large for low value of B & vice-versa. $\therefore$ $S = \frac{l}{\mu A}$ is for small values of B & vice-versa.

RELUCTANCE:→

Let us consider a ferromagnetic ring having a cross-sectional area of A m^2 and a mean circumference of l meters, wound with N turns carrying a current of I amps, then total flux (ϕ) = flux density × Area.

$$\therefore \quad \phi = B \times A.$$

$$\& \quad F = Hl.$$

$$\frac{\phi}{F} = \frac{BA}{Hl} = \mu_0 \mu_r \frac{A}{l}.$$

$$\Rightarrow \quad \phi = \frac{F}{\left(\frac{l}{\mu_0 \mu_r A}\right)}$$

$$\Rightarrow \frac{F}{\phi} = \frac{l}{\mu_0 \mu_r A} = S.$$

where S is known as the reluctance of the magnetic circuit.

$$S = \frac{l}{\mu_0 \mu_r A}$$

The above expression is similar to $R = \rho \cdot \frac{l}{A} = \frac{l}{\sigma A}$ in electric circuit. From this $\mu_0 \mu_r$ corresponds to reciprocal of ρ:

$$S = \frac{F}{\phi} \text{ AT/wb or A/wb.}$$

$$= 1 \text{ / henry} \quad (\because \text{AT/wb} = \frac{1}{\text{henry}}).$$

MAGNETOMOTIVE FORCE :→

It drives or tends to drive magnetic flux through a magnetic circuit. MMF is equal to the workdone in joules in carrying a unit magnetic pole once through the entire magnetic circuit. MMF between two points is measured by the workdone in joules on carrying a unit magnetic pole from one point to another.

RELUCTANCE :→

It is the property of a material which opposes the creation of magnetic flux on it. It may also be defined as the opposition offered to the passage of magnetic flux through a material

PERMEANCE :→ It is the reciprocal of reluctance.

ANALOGY BETWEEN ELECTRIC CIRCUIT & MAGNETIC CIRCUIT :→

ELECTRIC CIRCUIT		MAGNETIC CIRCUIT.	
Quantity	Unit	Quantity	unit.
EMF	volt.	1) MMF	A or AT.
Electric field strength	volts/meter	2) Magnetic field strength.	AT/m or A/m.
Current $= \frac{EMF}{R}$	A	3) Magnetic flux $= \frac{MMF}{S}$.	wb.
Current density	A/m^2	4) Magnetic flux density	wb/m^2 or T.
Resistance, $R = \rho \cdot \frac{l}{A}$ ~~Reluctance~~ $= \frac{l}{\sigma A}$	Ω	5) Reluctance, $S = \frac{l}{\mu A}$	AT/wb or A/wb.
Conductance, $G = \frac{1}{R}$	$\mho$	6) Permeance, $\frac{1}{S}$	wb/AT or wb/A.
Resistivity or specific resistance		7) Reluctivity or specific reluctance.	
Conductivity		8) Permeability.	
		9) Total mmf $= \phi S_1 + \phi S_2 + \phi S_3 + \cdots$	

Difference Between Electric Circuit & Magnetic Circuit:

1. Strictly speaking flux does not actually flow in the sense in which electric current flows.

2. Temperature remaining Constant, Resistance is independent of electric current. But in magnetic circuit reluctance depends upon the magnetic flux.

$$S = \frac{l}{\mu A}$$. (Here μ depends upon the flux density B).

~~...~~, μ is large for small B and vice-versa.

$\therefore$ If B is small, μ is large & 'S' is small.

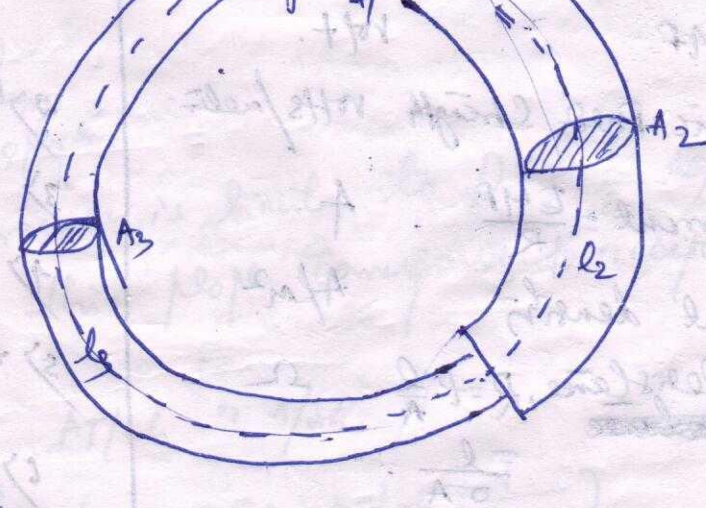
and if B is large, μ is small & 'S' is large.

3. Flow of current in an electric circuit involves Continuous expenditure of energy but in a magnetic circuit, energy is needed only for creating the magnetic flux initially but not for maintaining it.

Composite Series Magnetic Circuits:→

Total Reluctance (S)

$$= \frac{l_1}{\mu_0 \mu_{r_1} A_1} + \frac{l_2}{\mu_0 \mu_{r_2} A_2} + \frac{l_3}{\mu_0 \mu_{r_3} A_3} + \frac{l_g}{\mu_0 A_g}.$$



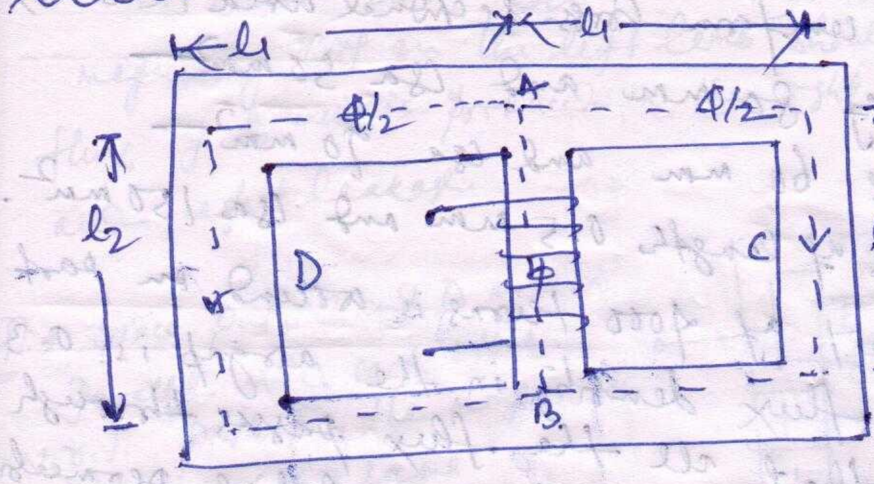
$$\therefore \phi = \frac{F}{S}.$$

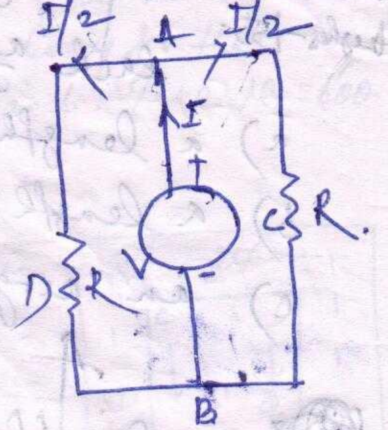
$$F = F_1 + F_2 + F_3 + F_g.$$

$$= H_1 l_1 + H_2 l_2 + H_3 l_3 + H_g l_g.$$

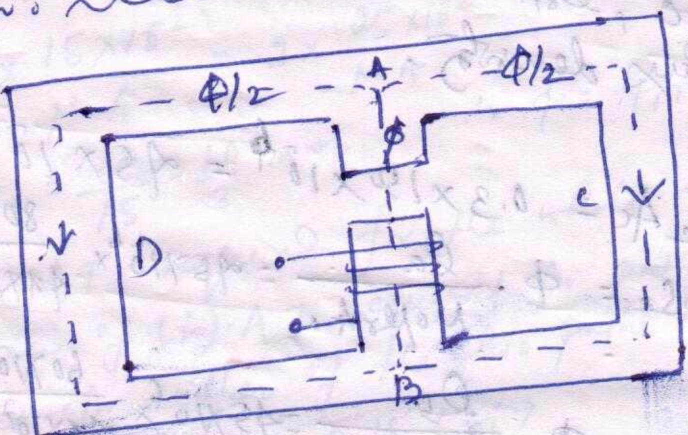
Find H for each portion by using the relation $H = \frac{B}{\mu_0 \mu_r}$.

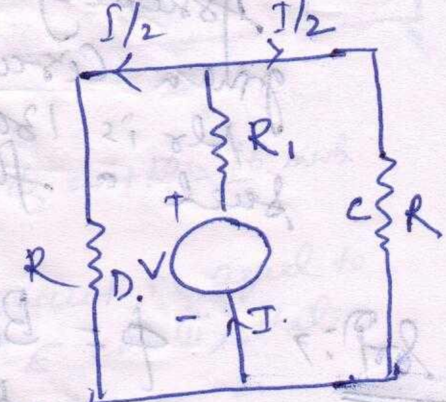
PARALLEL MAGNETIC CIRCUITS:→





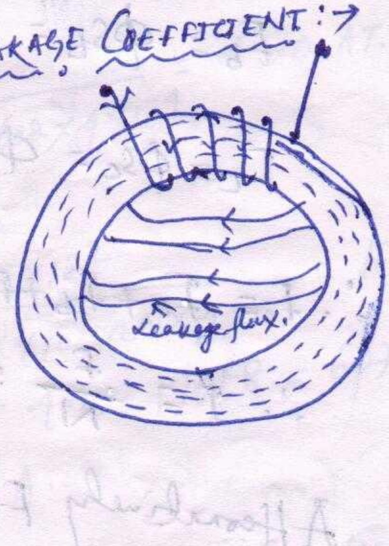
SERIES-PARALLEL MAGNETIC CIRCUITS





LEAKAGE FLUX AND HOPKINSON'S LEAKAGE COEFFICIENT:→

$$\text{Leakage Coefficient}, \lambda = \frac{\text{Total flux}}{\text{Useful flux}} = \frac{\Phi_t}{\Phi}$$



The value of λ for modern electric machines varies between 1.1 & 1.25.

Problems

Hughes-155: A magnetic circuit comprises three parts in series, each of uniform cross-sectional area (C.S.A.). They are:

a) a length of 80 mm and csa 50 mm^2

b) a length of 60 mm and csa 90 mm^2

c) an airgap of length 0.5 mm and csa 150 mm^2.

A coil of 4000 turns is wound on part b), and the flux density in the airgap is 0.3T. Assuming that all the flux passes through the given circuit, and that the relative permeability μ_r is 1300, estimate the coil current to produce such a flux density.

Sol: $\to$

$$\Phi = B_c A_c = 0.3 \times 150 \times 10^{-6} = 45 \times 10^{-6}\ \text{wb}.$$

$$F_a = \Phi S_a = \Phi \cdot \frac{l_a}{\mu_0 \mu_r A_a} = 45\times10^{-6} \times \frac{80\times10^{-3}}{4\pi\times10^{-7}\times1300\times50\times10^{-6}} = 44.1\ \text{AT}.$$

$$F_b = \Phi S_b = \Phi \cdot \frac{l_b}{\mu_0 \mu_r A_b} = 45\times10^{-6} \times \frac{60\times10^{-3}}{4\pi\times10^{-7}\times1300\times90\times10^{-6}} = 18.4\ \text{AT}.$$

$$F_c = \Phi S_c = \Phi \cdot \frac{l_c}{\mu_0 A_c} = 45\times10^{-6} \times \frac{0.5\times10^{-3}}{4\pi\times10^{-7}\times150\times10^{-6}} = 1193\ \text{AT}.$$

$$\therefore F = F_a + F_b + F_c = 44.1 + 18.4 + 119.3 = 181.8\ \text{AT} = NI$$

$$\therefore I = \frac{F}{N} = \frac{181.8}{4000} = 45.4\times10^{-3}\ \text{A} = 45.4\ \text{mA}.$$

Alternatively F_a, F_b & F_c can be calculated as follows.

$$F_a = H_a l_a = \frac{B_a}{\mu_0\mu_r} \times l_a = \frac{\frac{45\times10^{-6}}{(50\times10^{-6})}}{4\pi\times10^{-7}\times1300} \times 80\times10^{-3}$$

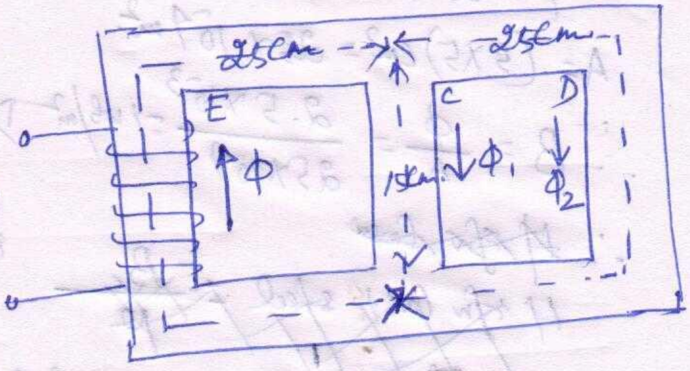
$$= 45\times10^{-6} \times \frac{80\times10^{-3}}{4\pi\times10^{-7}\times1300\times50\times10^{-6}}$$

$$= 44.1\ \text{AT}.$$

Similarly, $F_b = H_b \cdot l_b = \frac{B_b}{\mu_0\mu_r} \times l_b$

$$F_c = H_c \cdot l_c = \frac{B_c}{\mu_0} \times l_c.$$

Ex-983. is shown below. Determine the current that the 500 turn magnetising coil on the left limb should carry so that a flux of 2 mwb is produced in the right limb. Take $\mu_r = 600$ and neglect leakage.



Soln: → Since path C and D are in parallel with each other w.r.t. path E, the mmf across the two is the same.

$\therefore \phi_1 S_1 = \phi_2 S_2$

$\Rightarrow \phi_1 \times \frac{15\times10^{-2}}{\mu A} = 2 \times \frac{25\times10^{-2}}{\mu A}$ $\qquad \therefore \phi = \phi_1 + \phi_2 = 2 + \frac{10}{3} = \frac{16}{3}$ mwb.

$\Rightarrow \phi_1 = \frac{50}{15} = \frac{10}{3}$ mwb.

Total AT required for the whole circuit is equal to the sum of (i) AT required for path E and (ii) that required for either of the two paths C or D.

i) MMF required for path E: →

$F_E = \phi_E \times S_E = \frac{16}{3}\times10^{-3} \times \frac{25\times10^{-2}}{4\pi\times10^{-7}\times600\times4\times10^{-4}} = 4420$ AT.

ii) MMF required for path D: →

$F_D = \phi_D \times S_D = 2\times10^{-3} \times \frac{25\times10^{-2}}{4\pi\times10^{-7}\times600\times4\times10^{-4}} = 1658$ AT.

$\therefore$ Total MMF required $= F_D + F_E = 4420 + 1658 = 6078 = NI$

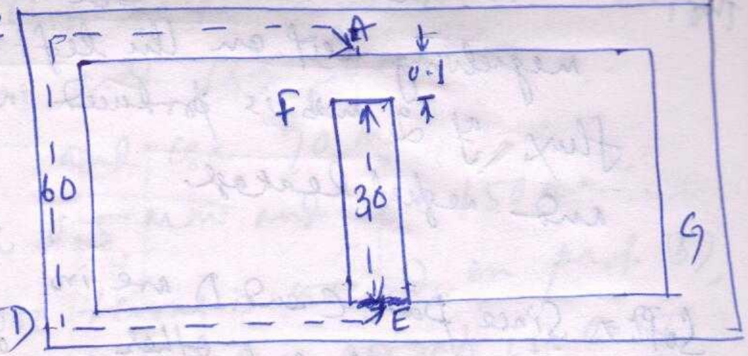
$\therefore I = \frac{6078}{500} = 12.16$ A.

Eg 6.20 Example-982. A cast steel D.C. electromagnet having a cross-section (5cm × 5cm) has a coil of 1000 turns on its central limb. Determine the current that the coil should carry to produce a flux of 2.5 mwb in the airgap. Neglect leakage. Dimensions are given in cm. The magnetisation curve for cast steel is as under:

Flux density (wb/m²):	0.2	0.5	0.7	1.0	1.2
Ampere turns/metre:	300	540	650	900	1150

Sol^n: Total mmf required

$= F_{ag} + F_{EF} + F_{ACD}$.



$\phi = 2.5$ mwb.

$A = (5 \times 5)\ cm^2 = 25 \times 10^{-4}\ m^2$

$\therefore B = \frac{\phi}{A} = \frac{2.5 \times 10^{-3}}{25 \times 10^{-4}} = 1\ wb/m^2$

$\therefore$ ~~H for Cast~~

~~H for Cast steel = B/μ = 1 / ... =1 ...~~

From the magnetisation curve table, for a flux density (B) of $1\ wb/m^2$, H for cast steel in the central limb is $900\ AT/m$.

$\therefore \mu = \frac{B}{H} = \frac{1}{900}$.

$\therefore F_{EF} = \phi_{EF} \times S_{EF} = 2.5 \times 10^{-3} \times \frac{30 \times 10^{-2}}{(\frac{1}{900}) \times \frac{25 \times 10^{-4}}{10}} = \frac{30 \times 10^{-1}}{10} \times 900 = 270\ AT$.

$F_{ACD} = \phi_{ACD} \times S_{ACD} = (\frac{2.5}{2}) \times 10^{-3} \times \frac{60 \times 10^{-2}}{*\frac{0.5}{540} \times 25 \times 10^{-4}} = \frac{1.25 \times 60 \times 10^{-1}}{1.5 \times 25} \times 540$

$= \frac{0.05 \times 60 \times 540}{0.5 \times 10}$

$= 324\ AT$.

[* For path ACDE, $\phi = \frac{2.5}{2} = 1.25$ mwb

$\therefore B = \frac{1.25 \times 10^{-3}}{25 \times 10^{-4}} = 0.5\ wb/m^2$.

$\therefore$ for the path ACDE, H from the magnetisation curve table is $540\ AT/m$

$\therefore \mu = \frac{B}{H} = \frac{0.5}{540}$

$F_{ag} = \phi_{ag} \times S_{ag} = 10^{-3} \times 2.5 \times \frac{0.1 \times 10^{-2}}{4\pi \times 10^{-7} \times \frac{25 \times 10^{-4}}{10}} = \frac{0.1 \times 10^{6}}{4\pi \times 10} = 795.77\ AT$

$\therefore F_{Total} = 270 + 324 + 795.77 = 1389.77\ AT = N I$

$\therefore I = \frac{1389.77}{1000} = 1.389\ A$.

Alternatively F_{EF}, F_{ACD} & F_{ag} can be found as follows:

$F_{EF} = H_{EF} \times l_{EF} = 900 \times 30 \times 10^{-2} = 270\ AT$.

$F_{ACD} = H_{ACD} \times l_{ACD} = 540 \times 60 \times 10^{-2} = 324\ AT$.

& $F_{ag} = H_{ag} \times l_{ag} = \frac{B}{\mu_0} \times l_{ag} = \frac{1}{4\pi \times 10^{-7}} \times 0.1 \times 10^{-2} = \frac{0.1 \times 10^{5}}{4\pi} = 795.77\ AT$.

References:-

1. Electrical and Electronics Technology
   E. Hughes, Pearson.
2. Principles and Applications of Electrical Engineering.

   Giorgio Rizzoni, McGraw Hill

3. A textbook of Electrical Technology.
   B. L. Theraja.
   A. K. Theraja.

   S. Chand.