EE100

Basic Electrical Engineering

Module – 03: Magnetic Circuits

Magnetic field; Toroidal core: Flux density, Flux linkage

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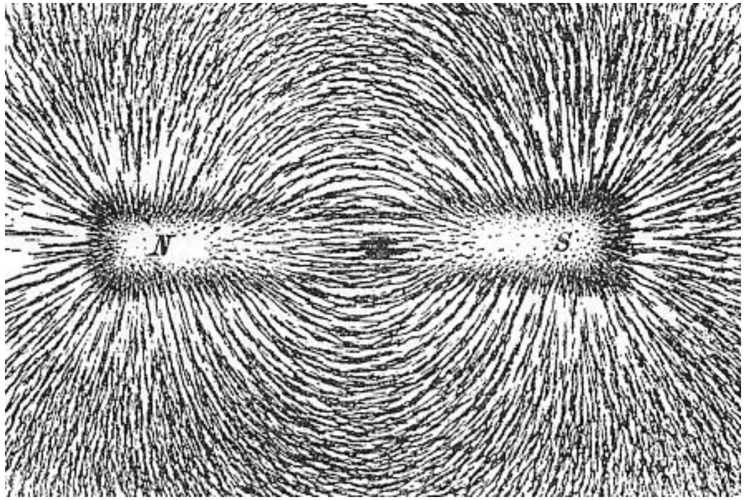
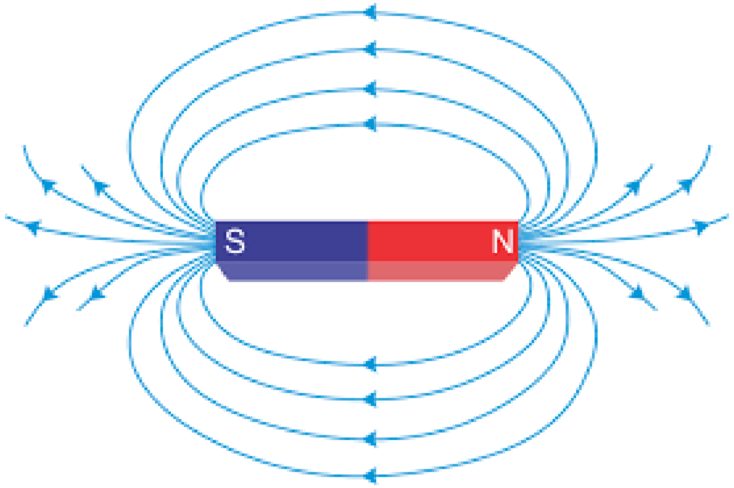
Electromagnetic System

Magnetic Field

- The space around the poles of a magnet is called the magnetic field
- It is represented by magnetic lines of force



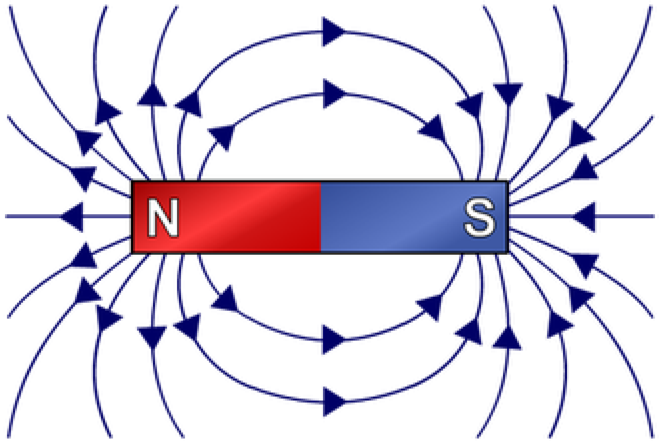


Magnetic Force

- The force exerted on one magnet by another one, either of attraction or of repulsion is called the magnetic force.
- According to Coulomb's first law unlike poles attract each other and like poles repel each other.

Magnetic Flux (ϕ)

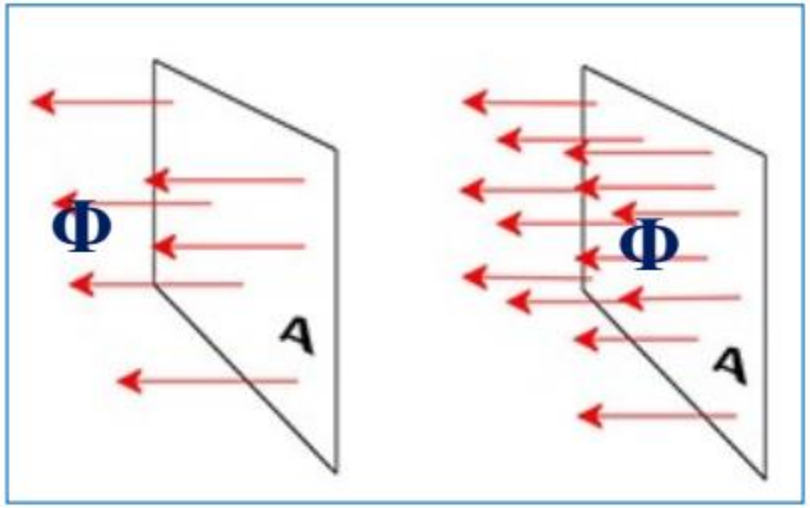
- The number of magnetic lines of forces set up in a magnetic circuit is called Magnetic Flux.
- It is analogous to electric current I in an electric circuit.
- Properties of magnetic flux
  - unit is Weber (Wb)
  - Always form a closed loop.
  - Always start from the North pole and ends in the South pole.
  - Never intersect each other.

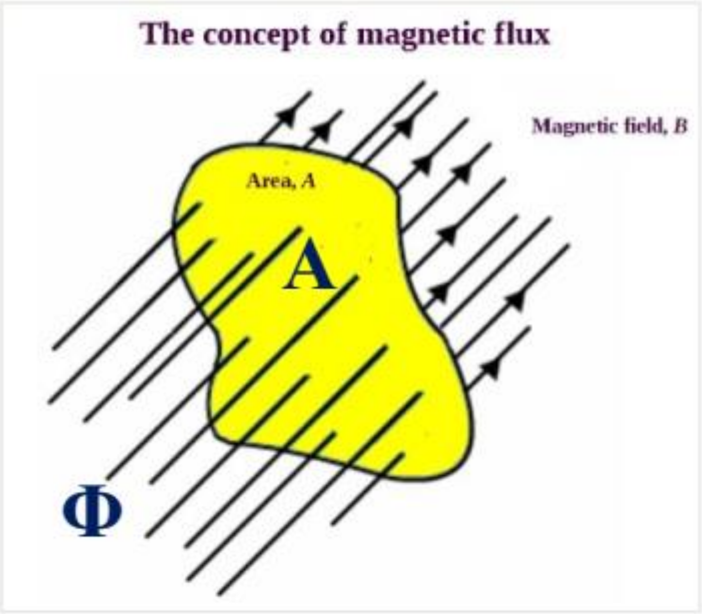


Magnetic flux density (B)

- It is the amount of magnetic field (flux) passing through a defined area that is perpendicular to the direction of flux.
- Unit of magnetic flux density is Tesla (T) or Wb/m^2.

$$\text{Magnetic flux density} = \frac{\text{magnetic flux}}{\text{area}}$$





$$B = \frac{\phi}{A}$$

$$\boxed{\phi = BA}$$

Magnetic flux density (B)

A magnetic pole face has a rectangular section having dimensions (200 mm x 100 mm). If the total flux emerging from the pole is 150μWb, calculate the flux density.

Flux $\Phi = 150\ \mu\text{Wb} = 150 \times 10^{-6}\ \text{Wb}$

Cross sectional area $A = 200 \times 100 = 20000\ \text{mm}^2$

$= 20000 \times 10^{-6}\ \text{m}^2$

$$\text{Flux density } B = \frac{\Phi}{A} = \frac{150 \times 10^{-6}}{20000 \times 10^{-6}}$$

$$= \mathbf{0.0075\ T\ or\ 7.5\ mT}$$

The maximum working flux density of a lifting electromagnet is 1.8 T and the effective area of a pole face is circular in cross-section. If the total magnetic flux produced is 353 mWb, determine the radius of the pole face.

Flux density $B = 1.8$ T; flux $\Phi = 353\ \text{mWb} = 353 \times 10^{-3}\ \text{Wb}$

$$\text{Since } B = \frac{\Phi}{A}, \text{ cross-sectional area } A = \frac{\Phi}{B} = \frac{353 \times 10^{-3}}{1.8}\ \text{m}^2$$

$$= 0.1961\ \text{m}^2$$

The pole face is circular, hence area $= \pi r^2$, where r is the radius.

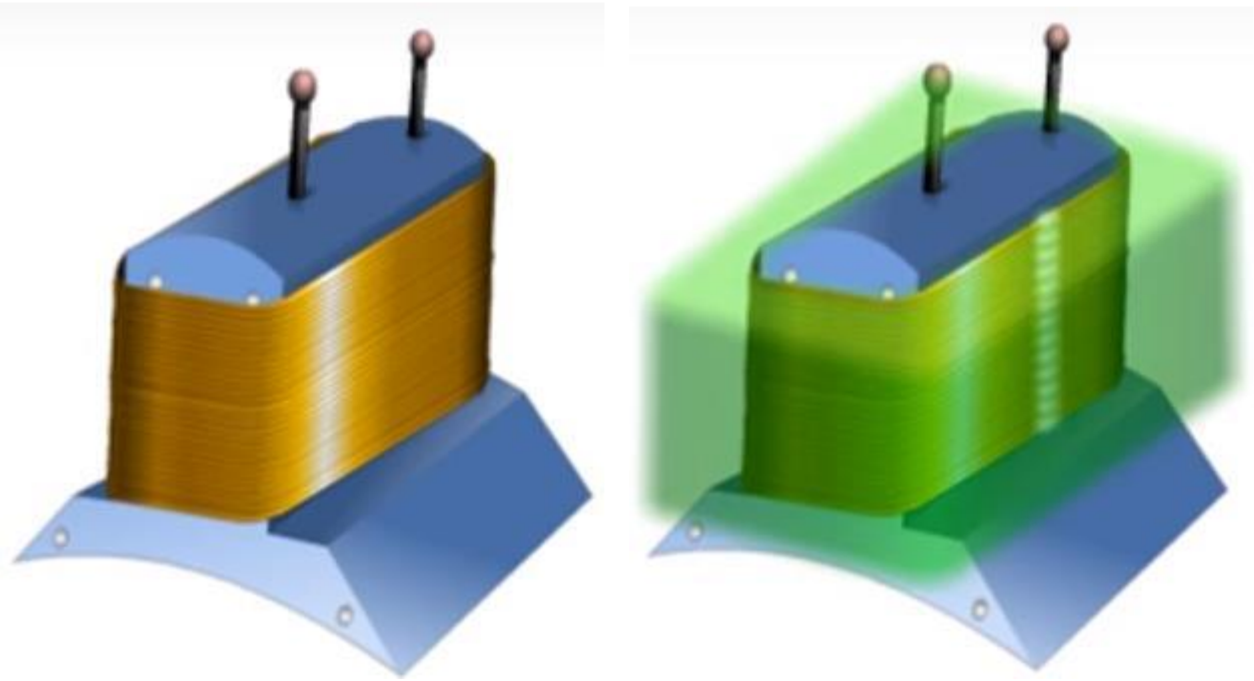
Hence $\pi r^2 = 0.1961$

$$\text{from which } r^2 = \frac{0.1961}{\pi} \text{ and radius } r = \sqrt{\left(\frac{0.1961}{\pi}\right)} = 0.250\ \text{m}$$

i.e. **the radius of the pole face is 250 mm**

Electromagnetic System

Electromagnet



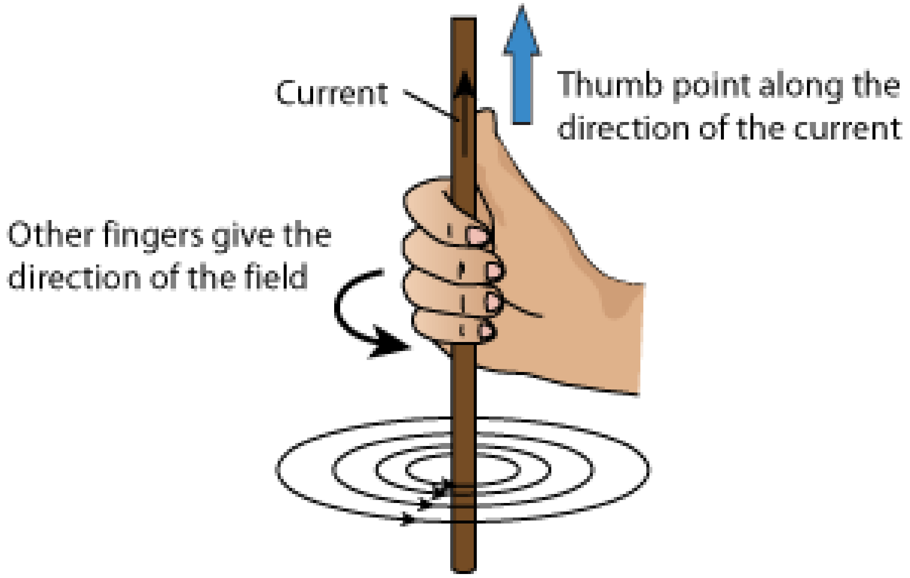
- An electromagnet is a type of magnet in which the magnetic field is produced by an electric current.
- Electromagnets usually consist of wire wound into a coil.
- The main advantage of an electromagnet over a permanent magnet is that the magnetic field can be quickly changed by controlling the amount of electric current in the winding. However, unlike a permanent magnet that needs no power, an electromagnet requires a continuous supply of current to maintain the magnetic field.

Electromagnetic System

- A current carrying conductor creates a magnetic field around it.
- The nature of magnetic field around a straight current carrying conductor is like concentric circles having their centre at the axis of the conductor.
- The direction of these circular magnetic lines is dependent upon the direction of current.
- The density of the induced magnetic field is directly proportional to the magnitude of the current.
- Direction of the circular magnetic field lines can be given by Maxwell's right hand grip rule

Maxwell's Right Hand Grip Rule

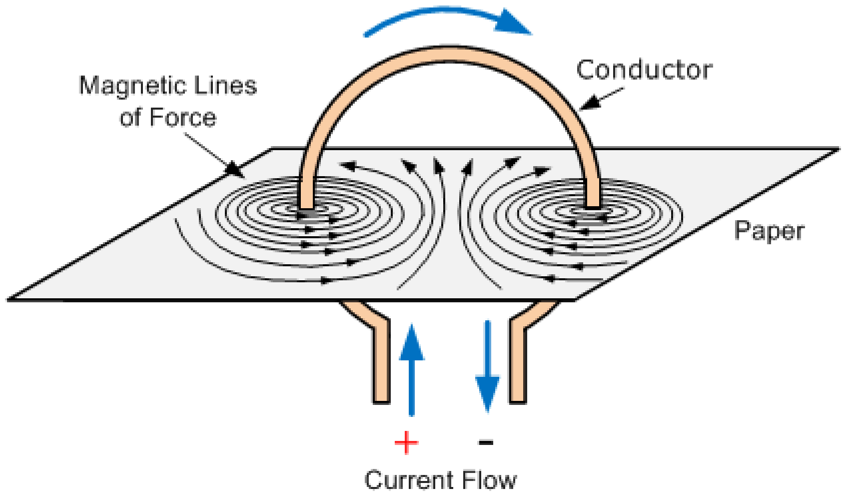
Assume that the current carrying conductor is held in the right hand so that the fingers wrap around the conductor and the thumb is stretched. If the thumb is along the direction of current, wrapped fingers will show the direction of circular magnetic field lines.

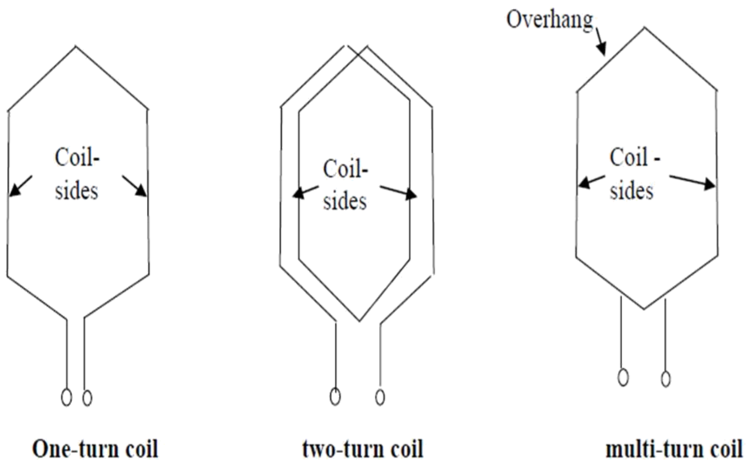


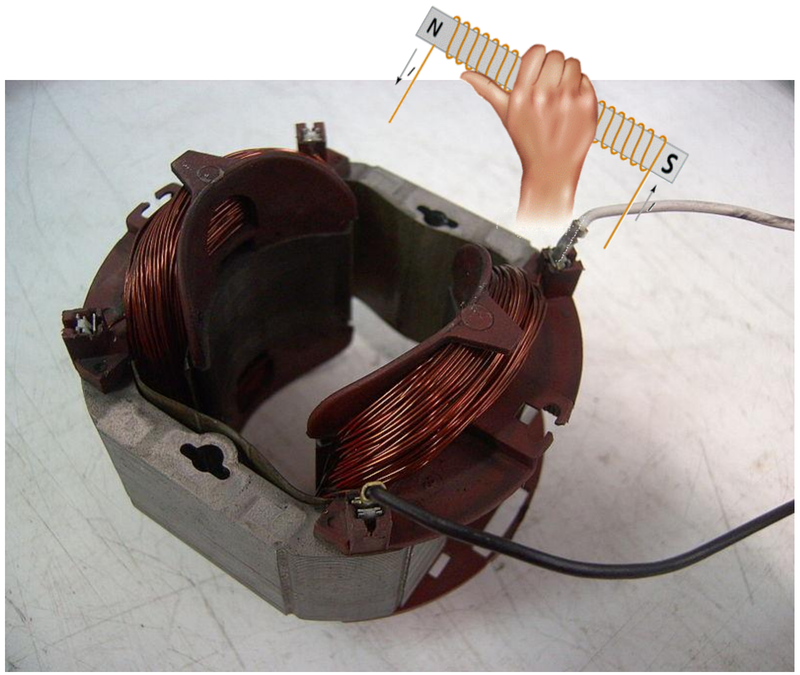
Electromagnetic System

Coil

- The current carrying wire wound spirally in the form of helix about an axis is known as solenoid or coil
- It acts just like a bar magnet having north and south poles







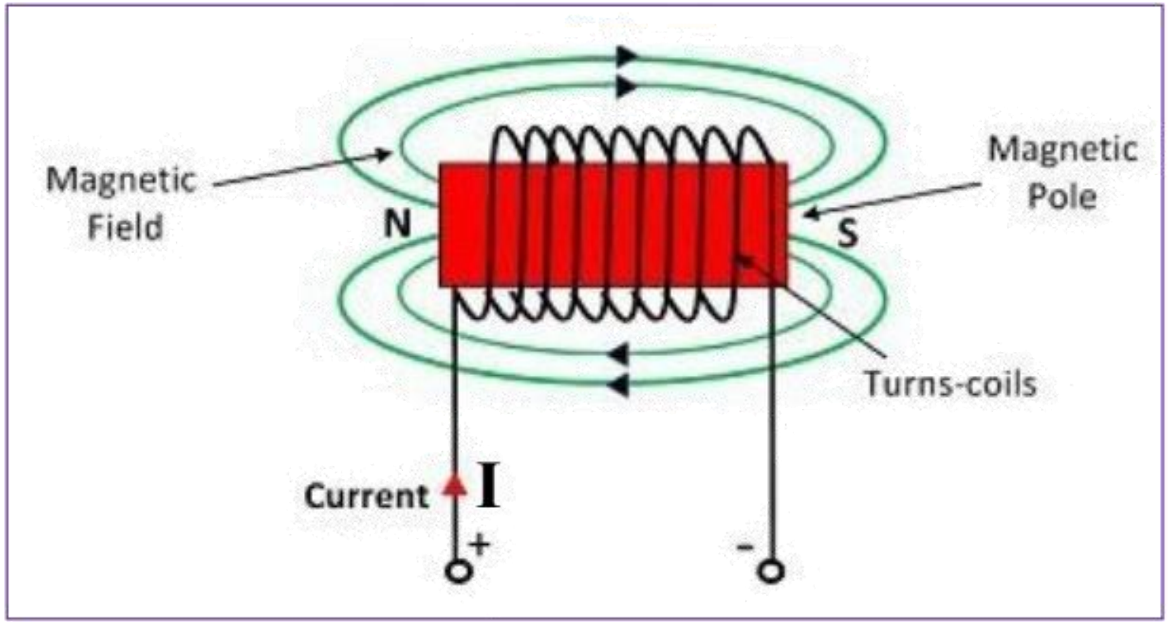
Magnetomotive force (MMF, Fm)

- It is the cause of the existence of magnetic flux in a magnetic circuit.
- Unit of MMF is Ampere-Turns (AT).

$$\boxed{F_m = N \times I \text{ (AT).}}$$

N: Number of turns

I: Current through the conductor (A)

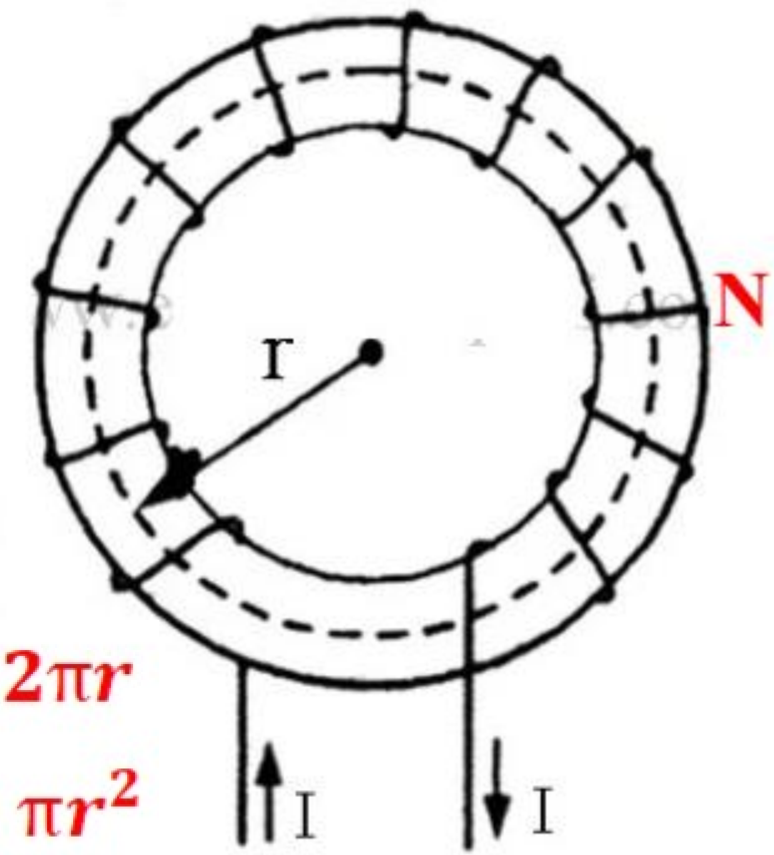


Magnetic field strength (magnetizing force) (H)

- It is defined as magnetomotive force per unit length.
- Unit of magnetic field strength is Ampere-Turns/m (AT/m).

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

l: Mean length of flux path in meters



$l = 2\pi r$

$A = \pi r^2$

Magnetic field strength (magnetizing force) (H)

A magnetizing force of 8000 A/m is applied to a circular magnetic circuit of mean diameter 30 cm by passing a current through a coil wound on the circuit. If the coil is uniformly wound around the circuit and has 750 turns, find the current in the coil.

$H = 8000$ A/m; $l = \pi d = \pi \times 30 \times 10^{-2}$ m; $N = 750$ turns

Since $H = \dfrac{NI}{l}$ then, $I = \dfrac{Hl}{N} = \dfrac{8000 \times \pi \times 30 \times 10^{-2}}{750}$

Thus, **current $I = 10.05$ A**

A current of 5 A is passed through a 1000-turn coil wound on a circular magnetic circuit of radius 120 mm. Calculate (a) the magnetomotive force, and (b) the magnetic field strength.

(a) **Magnetomotive force, m.m.f.** = NI = (1000)(5) = **5000 A**

(b) Length of magnetic field, $l = 2\pi r = 2\pi(0.120)$ m

Hence, **magnetic field strength, H** $= \dfrac{NI}{l} = \dfrac{(1000)(5)}{2\pi(0.120)} = \mathbf{6631\ A/m}$

Permeability of free space (μ_0):

- For air or any non-magnetic medium, the ratio of magnetising flux density (B) to magnetising force (H) is constant.
- This is constant is called permeability of free space (μ_0).

$$\text{Permeability}, \mu_0 = \frac{B}{H} = 4\pi x 10^{-7} \frac{\text{Wb}}{\text{AT}-\text{m}}$$

- **Absolute permeability of other than free space medium : $\mu = \mu_0 \mu_r$** where, μ_r is relative permeability

$$\mu_r = \frac{\textit{Flux density in material}}{\textit{Flux density in vacuum}}$$

Permeability of free space (μ_0):

Determine the magnetic field strength and mmf required to produce a flux density of 0.25 T in an air-gap of length 12 mm.

For air: $B = \mu_0 H$ (since $\mu_r = 1$)

$$\textbf{Magnetic field strength } H = \frac{B}{\mu_0} = \frac{0.25}{4\pi \times 10^{-7}} = \mathbf{198\ 940\ A/m}$$

$$\textbf{mmf} = Hl = 198\ 940 \times 12 \times 10^{-3} = \mathbf{2387\ A}$$

Reluctance (S)

Magnetic resistance of a magnetic circuit to the presence of magnetic flux is called as *reluctance* (AT/wb)

$$Reluctance\ (S) = \frac{MMF}{Flux}$$

$$= \frac{NI}{\Phi}$$

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

$$= \frac{l}{\mu A}$$

$$= \frac{l}{\mu_o \mu_r A}$$

Reluctance (S)

Determine the reluctance of a piece of metal of length 150 mm and cross sectional area 1800 mm^2 , if the relative permeability of the metal is 4000.

$$\textbf{Reluctance } S = \frac{l}{\mu_0 \mu_r A} = \frac{150 \times 10^{-3}}{(4\pi \times 10^{-7})(4000)(1800 \times 10^{-6})}$$

$$= \mathbf{16\ 580/H}$$

A mild steel ring has a radius of 50 mm and a cross-sectional area of 400 mm^2. A current of 0.5 A flows in a coil wound uniformly around the ring and the flux produced is 0.1 mWb. If the relative permeability at this value of current is 200, find (a) the reluctance of the mild steel and (b) the number of turns on the coil.

$l = 2\pi r = 2 \times \pi \times 50 \times 10^{-3}$ m; $A = 400 \times 10^{-6}$ m^2; $I = 0.5$ A;
$\Phi = 0.1 \times 10^{-3}$ Wb; $\mu_r = 200$

(a) **Reluctance** $\boldsymbol{S} = \dfrac{l}{\mu_0 \mu_r A} = \dfrac{2 \times \pi \times 50 \times 10^{-3}}{(4\pi \times 10^{-7})(200)(400 \times 10^{-6})}$

$= \mathbf{3.125 \times 10^6/H}$

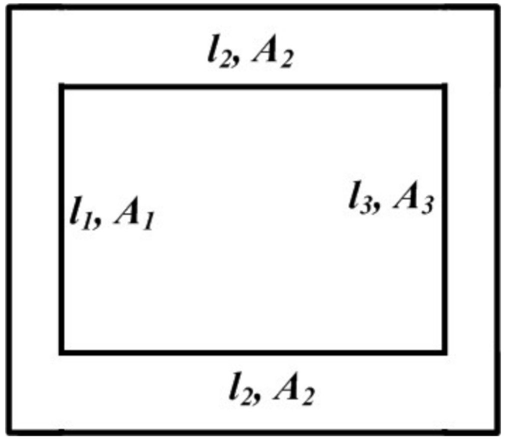
(b) $S = \dfrac{\text{mmf}}{\Phi}$ i.e. $\text{mmf} = S\Phi$

so that $NI = S\Phi$ and

hence $N = \dfrac{S\Phi}{I} = \dfrac{3.125 \times 10^6 \times 0.1 \times 10^{-3}}{0.5} = \mathbf{625\ turns}$

Composite series magnetic circuits

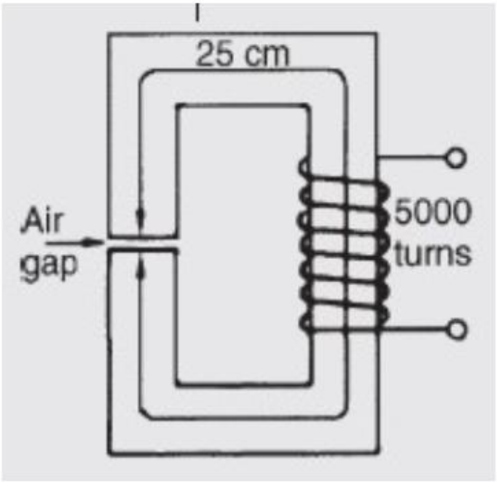
For a series magnetic circuit having n parts, the **total reluctance *S*** is given by:



$$S_{Total} = S_1 + S_2 + \ldots + S_n$$

$$S_{Total} = \frac{l_1}{\mu_1 A_1} + \frac{l_2}{\mu_2 A_2} + \ldots + \frac{l_n}{\mu_n A_n}$$

Magnetic circuit with air-gap



Electromagnetic System

A closed magnetic circuit of cast steel contains a 6 cm long path of cross sectional area 1 cm^2 and a 2 cm path of cross-sectional area 0.5 cm^2. A coil of 200 turns is wound around the 6 cm length of the circuit and a current of 0.4 A flows. Determine the flux density in the 2 cm path, if the relative permeability of the cast steel is 750.

For the 6 cm long path:

$$\text{Reluctance } S_1 = \frac{l_1}{\mu_0 \mu_r A_1} = \frac{6 \times 10^{-2}}{(4\pi \times 10^{-7})(750)(1 \times 10^{-4})}$$

$$= 6.366 \times 10^5/\text{H}$$

For the 2 cm long path:

$$\text{Reluctance } S_2 = \frac{l_2}{\mu_0 \mu_r A_2} = \frac{2 \times 10^{-2}}{(4\pi \times 10^{-7})(750)(0.5 \times 10^{-4})}$$

$$= 4.244 \times 10^5/\text{H}$$

$$\text{Total circuit reluctance } S = S_1 + S_2 = (6.366 + 4.244) \times 10^5$$

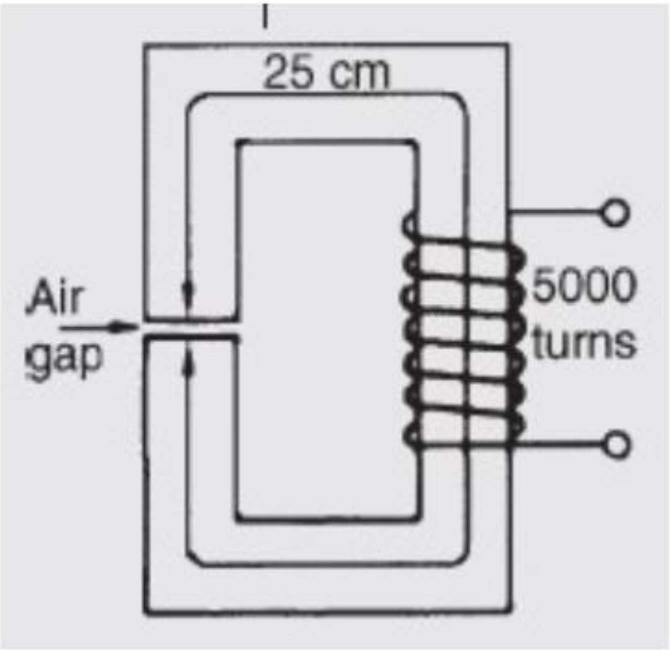
$$= 10.61 \times 10^5/\text{H}$$

$$S = \frac{\text{mmf}}{\Phi}, \text{ i.e. } \Phi = \frac{\text{mmf}}{S} = \frac{NI}{S} = \frac{200 \times 0.4}{10.61 \times 10^5} = 7.54 \times 10^{-5} \text{ Wb}$$

$$\text{Flux density in the 2 cm path, } B = \frac{\Phi}{A} = \frac{7.54 \times 10^{-5}}{0.5 \times 10^{-4}} = \mathbf{1.51\ T}$$

Electromagnetic System

A cast steel core with uniform cross-sectional area 2 cm^2 and mean length of 25 cm is shown in figure. Relative permeability of the stee1 is 48000. The air gap is 1 mm wide and the coil has 5000 turns. Determine the current in the coil to produce a flux density of 0.80 T in the air gap.



Thank You !