# Magnetism and Electromagnetism

## Definition of Terms:-

**Flux:- The magnetic flux is equal to the total number of lines of induction existing in the magnetic circuit & corresponds to current in electric circuit. Its symbol is 'Ø' & unit is weber (wb).**

### Magnetic Induction or Flux Density (B):-

**The flux density is the number of flux per unit area, the area being taken at right angles to the direction of the flux. Its unit is wb/m$^2$. [B=Ø/A]**

### Absolute & Relative Permeabilities of a Medium:-

**The phenomena of magnetism & electromagnetism are dependent upon a certain property of the medium called permeability. Each medium is supposed to posses two permeabilities.**
**1) Absolute Permeability ($\mu$) & (2) Relative Permeability ($\mu_r$)**

**For measuring relative permeability vacuum or free space is chosen as the reference medium & its absolute permeability is $\mu_0 = 4\pi \times 10^{-7}$ H/m. So the relative permeability of vacuum with respect to itself is 1.**

**For free space,**

**Absolute Permeability is $\mu_0 = 4\pi \times 10^{-7}$ H/m**

**Relative Permeability $\mu_r$ =1.**

**A medium other than vacuum whose relative permeability as compared to vacuum is $\mu_r$ , then its absolute permeability is $\mu = \mu_0 \mu_r$ H/m.**

### Relative Permeability ($\mu_r$):-

**The relative permeability or permeability of a material is the ratio of the flux (or the number of lines of induction) existing in the material to the flux which would exist in space occupied by the material if it were replaced by vacuum, the mmf (magneto motive force) acting on the space remaining unchanged.**

**Field Intensity or Field strength or Magnetising Force or Magnetic Intensity or Intensity of Magnetic Field (H):-**

**Field strength at any point within a magnetic field is numerically equal to the force experienced by a N-pole of one weber placed at that point. Hence unit of H is newton / wb or AT/m.**

**Force experience between the two pole of strength of $m_1$ & $m_2$ is**

**$F = K\, m_1\, m_2 / \mu r^2 = m_1\, m_2 / 4\pi r^2\, \mu_0\, \mu_r$ in a medium**

**$= m_1\, m_2 / 4\pi r^2\, \mu_0$ in air**

**Field intensity at a point 'A' at distance 'r' metre from a pole of 'm' wb (assume a pole of 1 wb placed at point 'A') is given by**

**$F = m \times 1 / 4\pi r^2\, \mu_0$ therefore $H = m / 4\pi r^2\, \mu_0$ AT/m**

**[ Note:- When a bar of magnetic material say iron placed in a uniform field of strength H N/wb & a flux density B wb/m$^2$ is developed in the bar then the absolute permeability of the material is defined as**

**$\mu = B/H$ H/m or $B = \mu H = \mu_0 \mu_r H$ wb/m$^2$**

**If H is established in air or vacuum then flux density developed in air is**

**$B_0 = \mu_0 H$**

**Therefore Relative Permeability $\mu_r = B$ (material) / $B_0$ (Vacuum) ]**

## Some Definition Related to Magnetic Circuit:-

**Magneto Motive Force (mmf):-**

**mmf tends to drive the flux through the magnetic circuit & corresponds to emf in electric circuit. It is directly proportional to the amp-turns of the circuit. Its unit is AT.**

**Amp-Turns (AT):-**

**The amp-turns acting on a magnetic circuit are given by the product of the turns linked with the circuit & the ampere in these turns. If any amp-turns act in opposition they must be subtracted.**

**e.g 10A in 150 turns gives 1500AT**

**15A in 100 turns gives 1500 AT (same result).**

**Reluctance (S):-**

**Reluctance is resistance to the passage of magnetic flux & corresponds to resistance in the electric circuit. Reluctance is the ratio of magnetic potential difference to flux. Its unit is AT/wb.**

**Permeance:-**

**It is reciprocal of reluctance similar to conductance (1/R) in electric circuit. Its unit is wb/AT.**

**Reluctivity:-**

**It is specific reluctance & corresponds to resistivity which is specific resistance.**

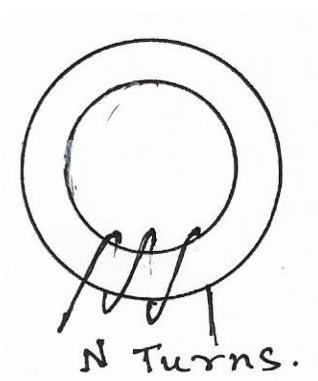
**[ Note:- The reluctance of any portion of a magnetic circuit is proportional to its length, inversely proportional to its cross section & inversely proportional to the permeability of the material.**

**Reluctance is given by $\ell/\mu A = \ell/\mu_0 \mu_r A$ ]**

## Magnetic Circuit

**It may be defined as the path which followed by magnetic flux.**

**Consider a solenoid or an iron ring having a magnetic path of '$\ell$' m, area of cross section A $m^2$ & a coil of N turns carrying current 'I' amp wound anywhere on it.**




**The field strength inside a solenoid is given by $H = NI/\ell$ AT/m**

**Now $B = \mu_0 \mu_r H = \mu_0 \mu_r NI/\ell$ wb/$m^2$**

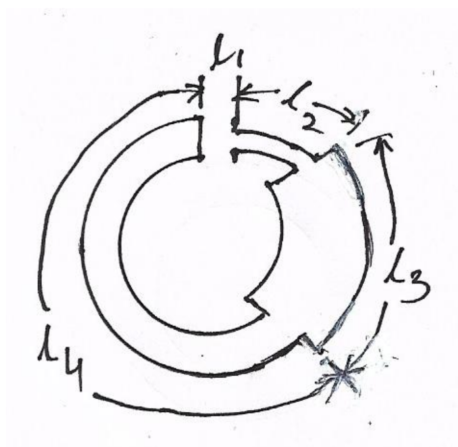
**Total flux produced $\varnothing = B \times A = = \mu_0 \mu_r NIA / \ell$ wb $= NI / (\ell / \mu_0 \mu_r A)$**

**Numerator is the mmf analogous to emf in electric circuit. The denominator is reluctance of the magnetic circuit & analogous to resistance of electric circuit.**

**Therefore Flux = mmf / reluctance**

**Sometimes it is called the ohms law of magnetic circuit.**

**[Note:- For composite magnetic circuit as shown in fig. consisting of a number of different magnetic material of different permeability's & length & say one air gap ($\mu_r$ =1), the total reluctance is the sum of individual reluctances as they are joined in series.**




**Total Reluctance = $(\ell_1 / \mu_0 A_1) + (\ell_2 / \mu_0 \mu_{r2} A_2) + (\ell_3 / \mu_0 \mu_{r3} A_3) + (\ell_4 / \mu_0 \mu_{r4} A_4)$ ]**

**<u>How to find AT</u>**

**$H = NI / \ell$ or $NI = H \times \ell$**

***Calculation of total AT for composite circuit:-***

1) **Find H for each portion of the circuit**

   **For air, $H = B / \mu_0$ otherwise $H = B / \mu_0 \mu_r$**

2) **Find AT for each path separately using $AT = H \times \ell$**

3) **Add these AT's to get the total AT**

## Comparison between magnetic circuit & electrical circuit

| Similarities | |
|---|---|
| **Electrical Circuit** | **Magnetic Circuit** |
| 1. Current | 1. Flux |
| 2. E.m.f | 2. M.m.f |
| 3. Resistance | 3. Reluctance |
| 4. Resistivity | 4. Reluctivity |
| 5. Conductivity | 5. Permeability |
| 6. Current Density | 6. Flux Density |
| 7. Conductance | 7. Permeance |
| **Dissimilarities** | |
| 1. Current actually flow in electric circuit | 1. Flux is not actually flow in magnetic circuit |
| 2. Current cannot flow if circuit is open | 2. Flux can pass through the circuit if there is reasonable air gap in the circuit. |
| 3. Energy is consumed so long as the current flows in the electric circuit | 3. Energy is consumed only to establish the magnetic flux but not regard to maintain it. |
| 4. There are a lot of good insulators of electric current. | 4. There is no good insulator of magnetic flux. |
| 5. Resistance of electric circuit is generally remains constant but varies with temperature. | 5. In magnetic circuit reluctance is not constant & varies with the flux density largely. |

**Prob.-1.**

**A circular ring of magnetic material has a mean length of 1.0 m & a cross-sectional area of 0.001 $m^2$ . A saw-cut of 6 mm width is made in the ring. Calculate the magnetizing current required to produce a flux of 1.0 mwb in the air gap if the ring is wound uniformly with a coil of 200 turns. Take relative permeability of the ring material=500.**

Ans.- $\varnothing$ = 1 mwb = $1 \times 10^{-3}$ wb

$A = 0.001\ m^2$ therefore $B = (1 \times 10^{-3}) / 0.001 = 1\ wb/m^2$

For Air gap,

$H = B/\mu_0 = 1/(4\pi \times 10^{-7})$

$\ell = 6 \times 10^{-3}$ m

$AT = 6 \times 10^{-3} / 4\pi \times 10^{-7} = 4774.64$

For material,

$H = B / \mu_0\ \mu_r = 1 / 4\pi \times 10^{-7} \times 500$

$\ell = 1$ m therefore $AT = H \times \ell = 1591.54$

Total AT = 4774.64 + 1591.54 = 6366.18

Exciting current = 6366.18 / 200 = 31.83 A

Prob.-2.

An iron ring with a mean circumference of 140 cm & cross-section 12 $cm^2$ is wound with 500 turns of wire. When the exciting current is 2A, the flux is found to be 1.2 mwb. What is the relative permeability of the iron.

Ans:-

$H = B / \mu_0\ \mu_r$

$B = (1.2 \times 10^{-3}) / (12 \times 10^{-4}) = 1$ wb $wb/m^2$

$AT = H \times \ell$

Or, $500 \times 2 = (1 \times 140 \times 10^{-2}) / 4\pi \times 10^{-7}\ \mu_r$

Therefore $\mu_r = 1114.08$

**Prob.-3.**

**An iron ring of mean length 50 cm has an air gap of 1 mm & a winding of 200 turns. If the permeability of the iron is 300 when a current of 1A flows through the coil find the flux density.**

**Ans:-**

**For air gap,**

**$H = B/\mu_0$ , $\ell = 0.001$ m**

**Therefore $AT = B \times 0.001/\mu_0$**

**For iron,**

**$H = B/\mu_0\mu_r$ , $\ell = 0.5$ m**

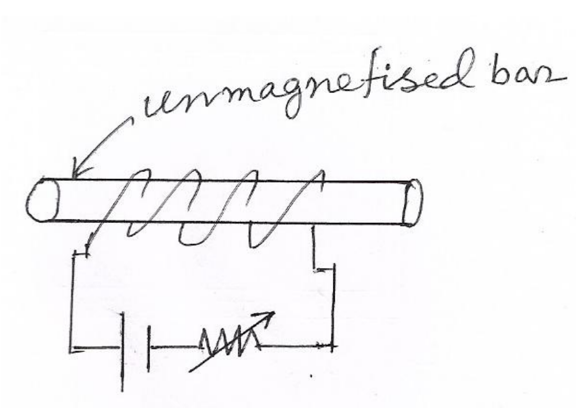
**Therefore $AT = B \times 0.5/\mu_0\mu_r$**

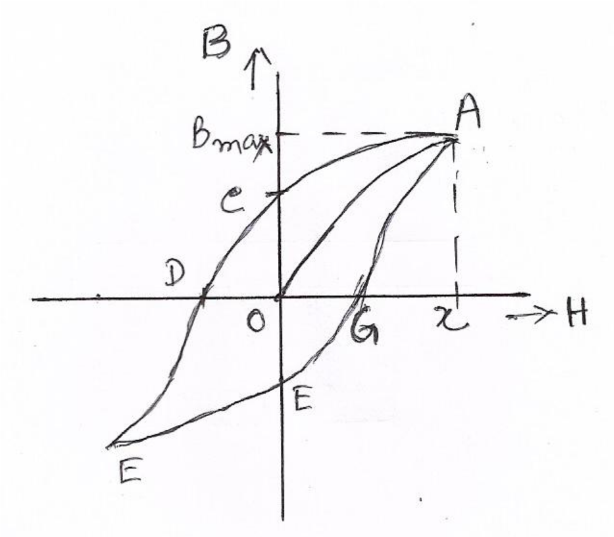
**Therefore $[B \times 0.001/\mu_0] + [B \times 0.5/\mu_0\mu_r]$ = total AT = 200 x1**

**$\mu_0 = 4\pi \times 10^{-7}$ H/m , $\mu_r = 300$ find B**

**Answer is B= 94.2 mwb/m2**

## Idea of Magnetic Hysteresis






**H= NI / ℓ**

**H can be increased or decreased by increasing or decreasing 'I'.**

**Let H be increased from 'o' to a certain maximum value & corresponding 'B be noted. If plotted curve OA is obtained. Materials becomes magnetically saturated for H=ox & at that time $B_{max}$ established through it. If H is now decreased, B will not decreased along OA. When H=0, B=OC not zero. This value B=OC measures the retentivity of the material & is called residual flux density ( $B_r$ ). When H is reversed then $B_r$ =0 at a point 'D' i.e at H=OD. This value of H is called coercive force.**

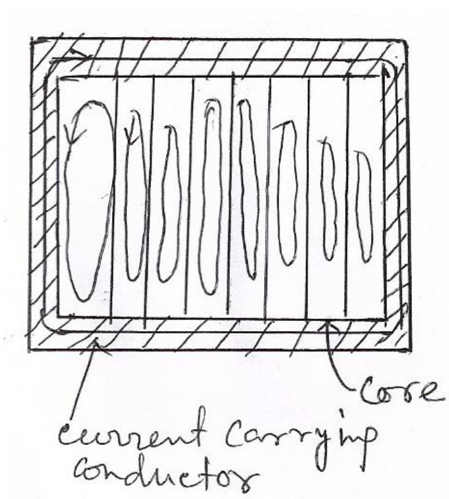
**From the curve it is clear B always lag behind H. The two never attain zero simultaneously. This lagging of B behind H is given the name 'hysteresis' ( means to lag behind). The closed loop ACDEFGA which is obtained through one complete cycle of magnetization is called as 'hysteresis loop'.**

**[ Note:- (1) Hysteresis loop measures the energy dissipated due to hysteresis which appears in the form of heat & so raises the temperature of that portion of magnetic circuit which is subjected to magnetic reversals.**

**(2) Shape of hysteresis loop depends on the nature of magnetic material. Hysteresis loss will be large if loop is large.**

**(3) A material is said to be cyclically magnetized when each increasing or decreasing value of H, B has the same value in successive cycles.]**

<u>Idea of Eddy Current Loss</u>




**Say a current carrying conductor is wound on a solid core of a magnetic material. Then as per faradays laws of electromagnetic induction a voltage is induced in the solid core. As the core is solid so a current is flowing in the solid core. This current is called eddy current as because this is induced due to the processes of induction. The direction of the current will be such that it will oppose the very cause to which it is due. This current will creates $i^2r$ loss in the core & heats up the core & the loss due to this current is called eddy current loss.**

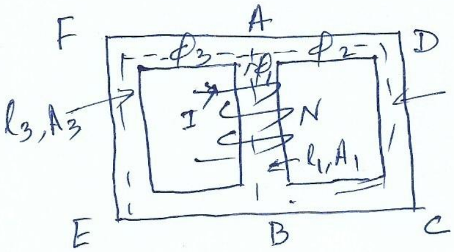
**To reduce it if we laminate the core with thin layer then this current will induce in each lamination & as the laminations are very thin so the resistance offered to the current in each lamination is high & effect of current flow in the core is reduced. If we increase the silicon content of steel laminations then it will**

**reduces the hysteresis loss & also increases the electrical resistivity which in turn reduces the eddy current loss.**

# Parallel magnetic ckt.

A magnetic ckt. which contains two or more than two path for magnetic flux is called parallel magnetic ckt. Its behaviour can be compared to parallel electric ckt.

Consider a ckt. as shown below.




Here flux $\phi_1$ is set up in central limb which is divided in to two paths. i.e. path ADCB carries flux $\phi_2$ & path AFEB carries flux $\phi_3$.

$$\therefore \quad \phi_1 = \phi_2 + \phi_3 .$$

Here the magnetic paths ~~AB~~ ADCB & AFEB are in parallel.

Reluctance of path BA $= \dfrac{l_1}{A_1 \mu_0 \mu_{r_1}}$ ~~(say)~~ $= S_1$ (say)

" " " ADCB $= \dfrac{l_2}{A_2 \mu_0 \mu_{r_2}} = S_2$ (say).

" " " AFEB $= \dfrac{l_3}{A_3 \mu_0 \mu_{r_3}} = S_3$ (say).

$\therefore$ The total mmf required.

= mmf required for path BA + mmf required for path ADCB or path AFEB.

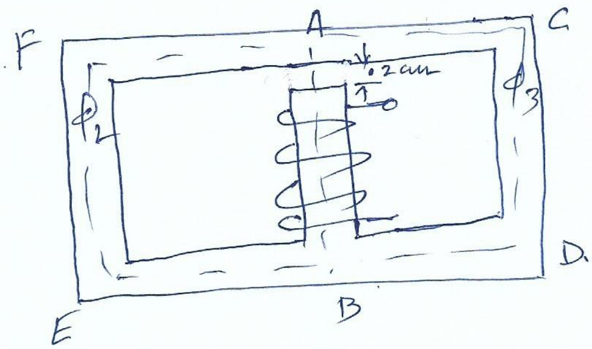
$$\therefore \text{ Total AT} = \phi_1 S_1 + \phi_2 S_2 = \phi_1 S_1 + \phi_3 S_3 .$$

(11)

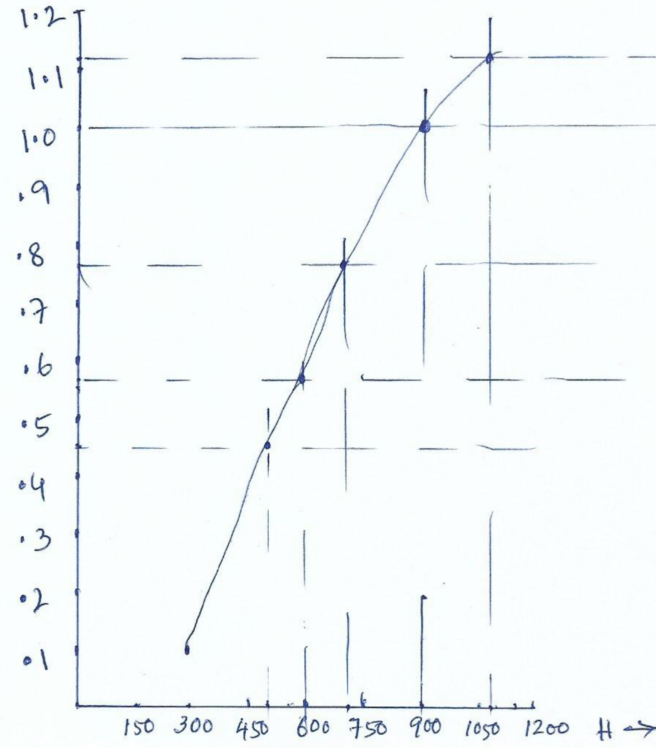
Prob:

A 710 turns coil is wound on the central limb of the cast steel symmetrical frame of uniform cross section 16 cm² is as shown. Calculate the current required to produce a flux of 1.8 mWb in an air gap of 0.2 cm length. Given $L_{AFEB} = L_{ACDB} = 25\,cm$ & $L_{AB} = 12.5\,cm$. The magnetization details is as follows.

| | | | | | | |
|---|---|---|---|---|---|---|
| H → | 300 | 500 | 600 | 700 | 900 | 1092 |
| B → | 0.1 | 0.45 | 0.562 | 0.775 | 1 | 1.125 |




Ans:- 2.92 A



Flux density in air gap & central limb.

$= B_{cl} = \frac{\phi}{A} = \frac{1.8 \times 10^{-3}}{16 \times 10^{-4}} = \frac{1.8}{1.6} = 1.125 \text{ wb/m}^2$

Flux in side limb $= \frac{\phi}{2} = \frac{1.8 \times 10^{-3}}{2} = 0.9 \times 10^{-3}$ wb.

Flux density for side limbs

$= B_{sl} = \frac{0.9 \times 10^{-3}}{16 \times 10^{-4}} = \frac{0.9}{1.6} = 0.5625 \text{ wb/m}^2$

H for air gap $= \cancel{1.8 \times 10^{-3}}$ ~~1092 AT/m~~.

$= \frac{1.125}{4\pi \times 10^{-7}} = \frac{1.125 \times 10^{7}}{4 \times 3.14}$

$= \frac{1125 \times 10^{4}}{4 \times 3.14} = 895700.637$ AT/m

H for central limb = 1092 AT/m (From graph)
i.e. for 1.125 wb/m2 H is 1092 AT/m.

∴ H. for side limb = 600 AT/m (From graph)
i.e. for 0.5625 wb/m2 H is 600 AT/m.

AT for Air gap $= 895700.637 \times 0.2 \times 10^{-2}$
$= 895700.637 \times 2 \times 10^{-3}$
$= 1791.4$ AT.

AT for Central limb $= 1092 \times (12.5 - 0.2) \times 10^{-2}$
$= 134.316$ AT.

AT for Side limb $= 600 \times 25 \times 10^{-2} = 150$ AT.

∴ Total AT $= 1791.4 + 134.316 + 150$
$= 2075.716$ AT.

∴ current in the coil $I = \frac{2075.716}{710} = 2.92$ A.