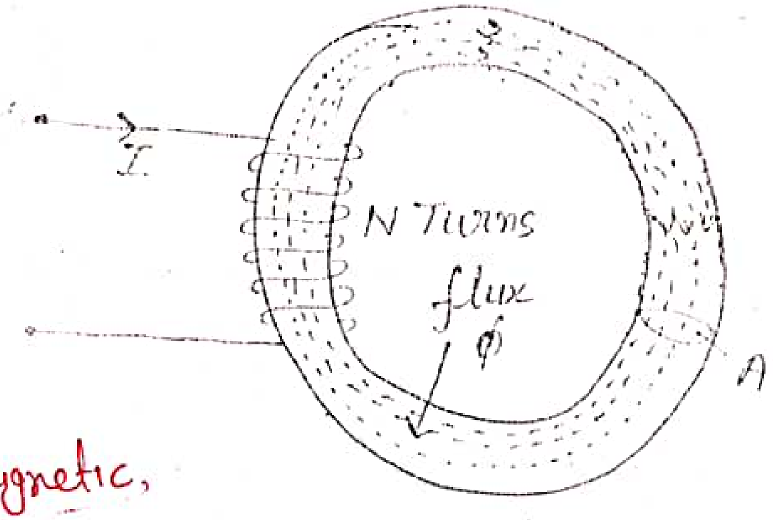
14 M.

Magnetic Circuit:→

The closed path followed by magnetic flux is called a magnetic circuit.

In a magnetic circuit, the magnetic flux leaves the n-pole, passes through the entire circuit and returns to the starting point.

Consider a solenoid or a toroidal iron ring having a magnetic path of l meter, area of cross-section $A\ m^2$ and a coil of N turns carrying I amperes wound anywhere on it as in fig.



So, magnetic field strength inside the solenoid is or magnetising force or magnetic field intensity

$$H = \frac{NI}{l} \ AT/m$$

magnetic flux density

Now $B = \mu_0 \mu_r H = \mu_0 \mu_r H$

$$\therefore B = \frac{\mu_0 \mu_r N I}{l} \ wb/m^2$$

Mohd. Murtaza

Total flux produced

Mohd. Murtaza

$$\phi = B \times A = \frac{\mu_0 \mu_r A N I}{l} \text{ wb}$$

$$\phi = \frac{NI}{l/\mu_0 \mu_r A} = \frac{NI}{\frac{l}{\mu_0 \mu_r A}} = \frac{NI}{S}.$$

The numerator 'NI' which produces magnetisation in the magnetic circuit is known as magnetomotive force (mmf). its unit is ampere-turn.

The denominator $\frac{l}{\mu A}$ or $\frac{l}{\mu_0 \mu_r A}$ is called the reluctance of the circuit.

$$\therefore \text{Flux} = \frac{\text{mmf}}{\text{Reluctance}}.$$

Important Terms:-

In the study of magnetic circuits, we generally come across the following terms:

(i) Magnetomotive force (m.m.f.):- It is a magnetic pressure which sets up or tends to set up magnetic flux in a magnetic circuit and defined as

(Permeability)

when a unit pole placed in a vaccum at a distance of 1 meter from a similar and equal pole repels it with a force of $\frac{1}{4\mu_0}$ Newton $\mu_0 = 4\pi \times 10^{-7}$ H/m (free space)

The work done in moving a unit magnetic pole once around the magnetic circuit is called the magnetomotive force (m.m.f.). It is equal to the product of current and number of turns of the coil i.e.

$$m.m.f. = NI \text{ ampere-turns (AT)}$$

(ii) Reluctance :- The opposition that the magnetic circuit offers to magnetic flux is called reluctance. its unit is AT/wb

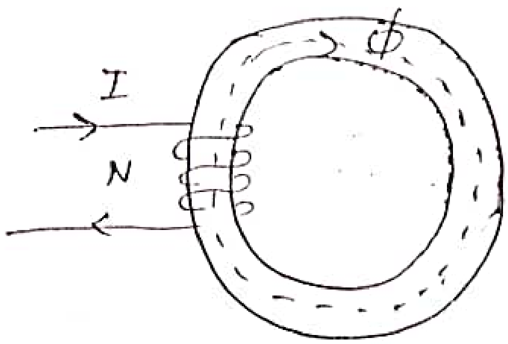
$$\text{Reluctance, } S = \frac{l}{a \mu_0 \mu_r}$$

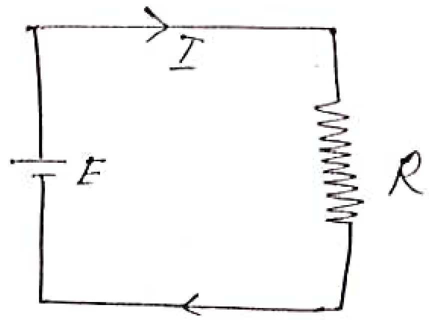
Reluctance in a magnetic material corrosponds to resistance $(R = \rho \frac{l}{a})$ in an electric circuit.

(iii) Flux :- It is equal to the total number of lines of induction existing in a magnetic circuit. it is measured in webers.

(iv) Permeance :-> It is the reciprocal ~~to~~ of reluctance and is a measure of the ease with which magnetic flux can pass through the material.

Comparison between Magnetic & Electric Circuits :→

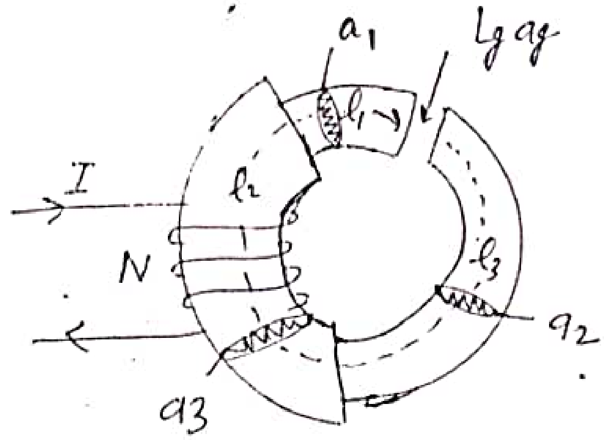




Magnetic circuit	Electric Circuit
1. The closed path for magnetic flux is called a magnetic circuit	1 The closed path for electric current is called an electric circuit.
2. Magnetic flux, $\phi = \frac{\text{m.m.f.}}{\text{reluctance}}$	2. Current $I = \frac{\text{emf}}{\text{resistance}}$
3. m.m.f (ampere-turns)	3. e.m.f. (volts)
4. Reluctance $S = \frac{l}{a \mu_0 \mu_r}$	4 Resistance $R = \rho \frac{l}{a}$
5. Magnetic flux density $B = \frac{\phi}{a}$ wb/m²	5. Current density $J = \frac{I}{a}$ A/m²
mmf drop $= \phi S$	6. Voltage drop $= IR$
Magnetic Intensity $H = \frac{NI}{l}$	7. Electric Intensity $E = V/d$

Mohd. Murtaza

Series Magnetic circuits →



In a Series magnetic ciruit. the same flux ϕ flows through each part of the ciruil. It can just be compared to a series electric circuit which carries the same current throught.

Consider a composite magnetic circuit consisting of three different magnetic materials of different relative permeabilities along with an air gap as shown in fig. Each part of this cirut will offer reluctance to the magnetic flux ϕ. The reluctance offered by each part will depend upon dimensions and μ_r of that part. Since the different parts of the circuit are in series, the total reluctance is equal to the sum of the reluctances of Individual parts i.e.

Mohd. Murtaza

otal reluctance $= \dfrac{l_1}{a_1 \mu_0 \mu_{r1}} + \dfrac{l_2}{a_2 \mu_0 \mu_{r2}} + \dfrac{l_3}{a_3 \mu_0 \mu_{r3}} + \dfrac{l_g}{a_g \mu_0}$ (6)

* For air $\mu_r = 1$

Total mmf = Flux × Total reluctance

$$= \phi \times \left[\frac{l_1}{a_1 \mu_0 \mu_{r1}} + \frac{l_2}{a_2 \mu_0 \mu_{r2}} + \frac{l_3}{a_3 \mu_0 \mu_{r3}} + \frac{l_g}{a_g \mu_0} \right]$$

$$= \frac{\phi}{a_1 \mu_0 \mu_{r1}} \times l_1 + \frac{\phi}{a_2 \mu_0 \mu_{r2}} \times l_2 + \frac{\phi}{a_3 \mu_0 \mu_{r3}} \times l_3 + \frac{\phi}{a_g \mu_0} \times l_g$$

$$= \frac{B_1}{\mu_0 \mu_{r1}} \times l_1 + \frac{B_2}{\mu_0 \mu_{r2}} \times l_2 + \frac{B_3}{\mu_0 \mu_{r3}} \times l_3 + \frac{B_g}{\mu_0} \times l_g$$

$$= H_1 l_1 + H_2 l_2 + H_3 l_3 + H_g l_g \quad (\because H = B/\mu_0 \mu_r)$$

Procedure for Numerical

(i) Find H for each part < H for air $H = B/\mu_0$; H for material $H = \dfrac{B}{\mu_0 \mu_r}$

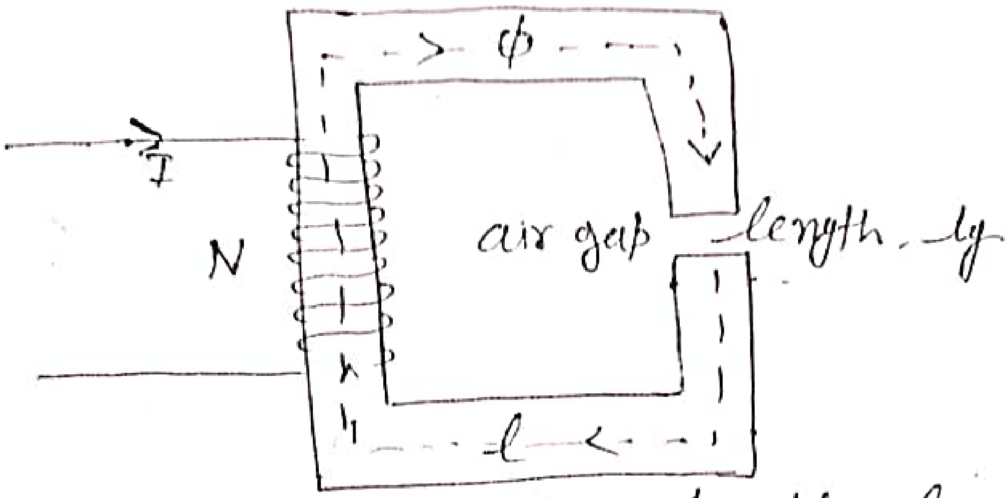
(ii) Find mean lenght of each part $= l$

(iii) Find AT for each part $AT = H \times l$

(iv) Find Total AT by adding each part

Mohd. Murtaza

Air-gaps in Magnetic circuits



Mean iron length $= l$

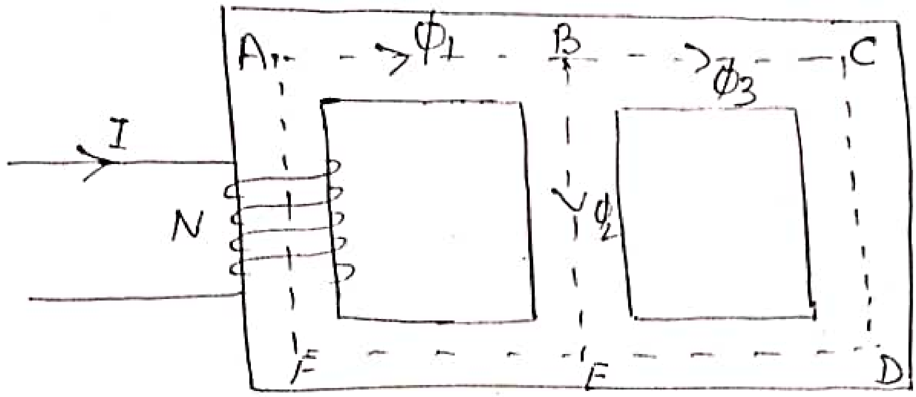
Reluctance of air gap $= \dfrac{l_g}{a\mu_0}$

Reluctance of iron part $= \dfrac{l_i}{a\mu_0\mu_r}$

Mohd. Murtaza

Parallel Magnetic Circuits

Mohd. Murtaza



$\phi_1 < \begin{matrix}\phi_2 \\ \phi_3\end{matrix}$

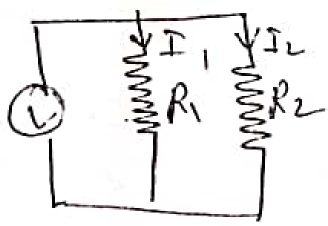
A magnetic circuit which has more than one path for flux is called a parallel magnetic circuit

flux ϕ_2 passes along the Path BE
flux ϕ_3 passes " " " BCDE

$$\phi_1 = \phi_2 + \phi_3$$

Magnetic Path BE and BCDE are parallel. The AT required for this parallel circuit is equal to AT required for any one of the paths.

Let S_1 = reluctance of the path EFAB



S_2 = reluctance of the path BE

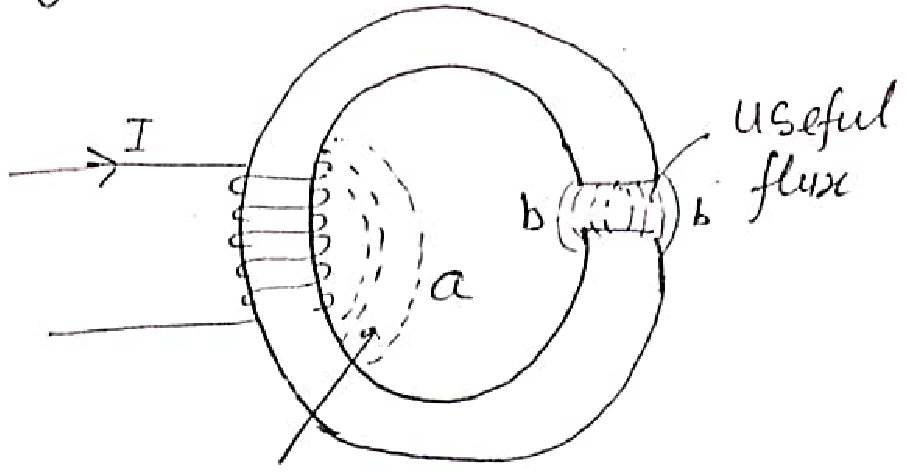
$V = I_1 R_1 = I_2 R_2$

S_3 = reluctance of the path BCDE

Total mmf required = mmf of the path EFAB + MMf of the Path BE or BCDE

$$NI = \phi_1 S_1 + \phi_2 S_2$$

Magnetic Leakage:-



ϕ_i = total flux produced or flux in the iron ring

ϕ_g = useful flux across the air gap

$\therefore$ Leakage flux $\phi_{Leak} = \phi_i - \phi_g$

Leakage ~~flux~~ Coefficient $\lambda = \frac{\text{Total flux}}{\text{Useful flux}} = \frac{\phi_i}{\phi_g}$

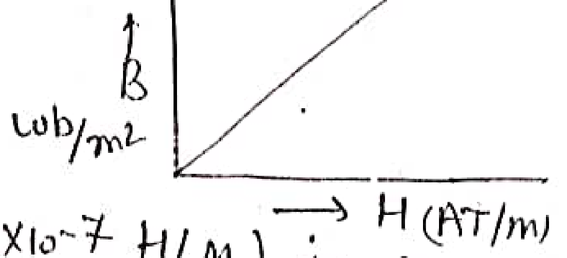
Mohd. Murtaza

Magnetisation curve or B-H curve :→

The B-H curve (or magnetisation curve) indicates the manner in which the flux density (B) varies with the magnetising force (H)

(i) For non-magnetic materials :→ for non magnetic materials (e.g. air, copper, rubber, wood etc) the relation between B & H is given by

$B = \mu_0 H$



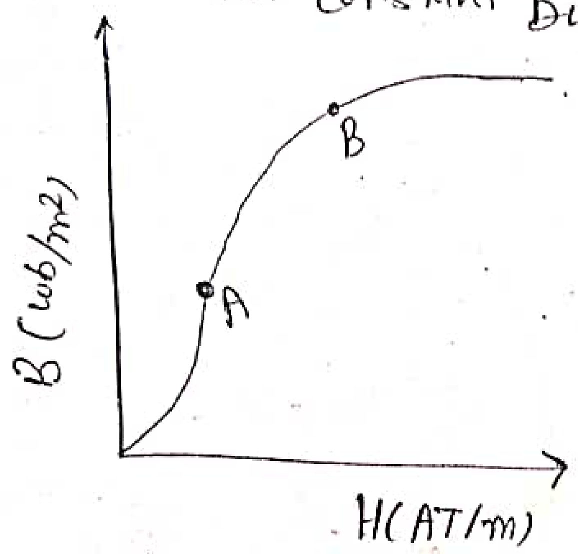
Since $\mu_0 = (4\pi \times 10^{-7}\ H/M)$ is constant

$B = H$

(ii) for magnetic materials :→ for magnetic materials (e.g. iron, steel etc). the relation between B and H is given by

$B = \mu_0 \mu_r H$

μ_r is not constant but varies with the flux density



Mohd. Murtaza

$\therefore$ Total AT required $= H_i \times l_i$

$= 850 \times 0.942 = 800.7$ AT

$\therefore$ Magnetising current, $I = 800.7/500 = 1.6$ A

(*ii*) With air-gap of 1 mm

Flux density in air-gap, $B_g = 1$ Wb/m^2 (same as in steel)

Magnetising force required, $*H_g = \dfrac{B}{\mu_0} = \dfrac{1}{4\pi \times 10^{-7}} = 7.96 \times 10^5$ AT/m

AT required for air gap $= H_g \times l_g = (7.96 \times 10^5) \times (1 \times 10^{-3}) = 796$ AT

Total AT required $= 800.7 + 796 = 1596.7$ AT

$\therefore$ Magnetising current, $I = 1596.7/500 = 3.19$ A

10·12. Magnetic Hysteresis

When a magnetic material is subjected to a cycle of magnetisation (*i.e.* it is magnetised first in one direction and then in the other), it is found that magnetic flux density B in the material lags behind the applied magnetising force H. This phenomenon is known as hysteresis.

The phenomenon of lagging of magnetic flux density (B) behind the magnetising force (H) in a magnetic material subjected to cycles of magnetisation is known as ****magnetic hysteresis.**

magnetising force $H = \frac{NI}{l}$

flux density $B = \mu_0 \mu_r H$

$\phi = B \times A$

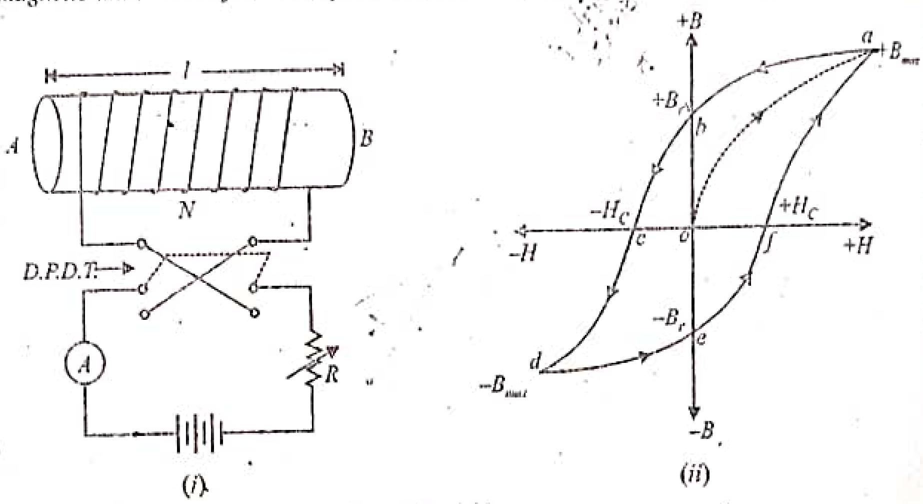


Fig. 10.20

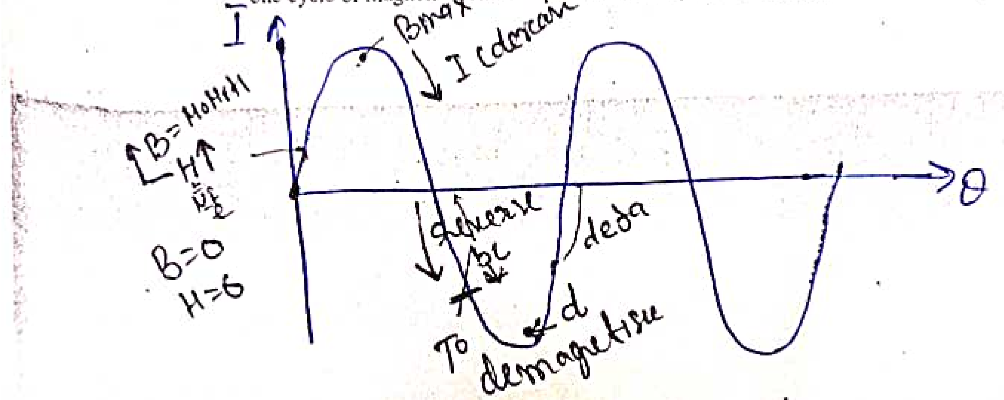
Hysteresis Loop. Consider an unmagnetised iron bar AB wound with N turns as shown in Fig. 10.20 (*i*). The magnetising force H (= NI/l) produced by this solenoid can be changed by varying the current through the coil. We shall see that when the iron piece is subjected to† one cycle of magnetisation, the resultant B-H curve traces a loop *abcdefa* called *hysteresis loop* [See Fig. 10.20 (*ii*)].

(*i*) When current in the solenoid is zero, $H = 0$ and hence B in the iron is zero. As H is increased (by increasing solenoid current), the magnetic flux density (B) also increases until the point of maximum magnetic flux density ($+B_{max}$) is reached. The

* We do not use B-H curve to find AT for air gap. It is because μ_r for air (in fact for all non-magnetic materials) is constant, being equal to 1, and AT can be calculated directly.

** Hysteresis is derived from the Greek word *hysterein* meaning to lag behind. (B lag behind H)

† If we start with unmagnetised iron piece, then magnetise it in one direction and then in the other direction and finally demagnetise it (*i.e.* obtain the original condition we started with), the piece is said to go through one cycle of magnetisation. Compare with one cycle of alternating current or voltage.



Mohd. Murtaza

material is saturated and beyond this point, the magnetic flux density will not increase regardless of any increase in current or magnetising force. Note that *B-H* curve of iron follows the path *oa*.

(*ii*) If now *H* is gradually reduced (by reducing solenoid current), it is found that magnetic flux density *B* does not decrease along *oa* but follows the path *ab*. At point *b*, the magnetising force *H* is zero but magnetic flux density in the material has a finite value $+B_r$ (= *ob*) called **residual flux density**. In other words, *B* lags behind *H*. The greater the lag, the greater is the residual magnetism (*i.e.* ordinate *ob*) retained by the iron piece. The power of retaining residual magnetism is called **retentivity** of the material.

(*iii*) To demagnetise the iron piece (*i.e.* to remove the residual magnetism *ob*), the magnetising force *H* is reversed by reversing the current through the coil. When *H* is gradually increased in the reverse direction, the *B-H* curve follows the path *bc* so that when *H* = *oc*, the residual magnetism is zero. The value of *H* (= *oc*) required to wipe out residual magnetism is known as **coercive force** (H_c).

(*iv*) If *H* is further increased in the negative direction, the material again saturates (point *d*) in the negative direction. Reducing *H* to zero and then increasing it in the positive direction completes the curve *defa*. Thus when an iron piece is subjected to one cycle of magnetisation, the *B-H* curve traces a closed loop *abcdefa* called **hysteresis loop**.

It is clear from the hysteresis loop (*i.e.* *B-H* curve of iron for one cycle of magnetisation) that lags behind *H*. The two never attain zero value simultaneously.

Note. For one cycle of magnetisation, one hysteresis loop is traced. If a magnetic material is cated within a coil through which alternating current (50 Hz) flows, 50 loops will be formed every cond.

0·13. Hysteresis Loss

When a magnetic material is subjected to a cycle of magnetisation (*i.e.* it is magnetised first one direction and then in the other), an energy loss takes place due to the *molecular friction the material. That is, the domains (or molecular magnets) of the material resist being turned rst in one direction and then the other. Energy is thus expended in the material in overcoming is opposition. This loss is in the form of heat and is called *hysteresis loss*. Hysteresis loss is iven by **Steinmetz formula** as :

Hysteresis power loss, $P_h = \eta \, B_{max}^{1.6} f \, V$ watts

here B_{max} = Maximum flux density in the material

f = Frequency of magnetic reversals

V = Volume of material in m^3

η = Steinmetz hysteresis coefficient

In order to reduce this loss, magnetic circuits should be made of such materials which have w value of Steinmetz hysteresis coefficient *e.g.* silicon steel.

0·14. Importance of Hysteresis Loop

The shape and size of the hysteresis loop **largely depends upon the nature of the material. he choice of a magnetic material for a particular application often depends upon the shape and ze of the hysteresis loop. A few cases are discussed below by way of illustration :

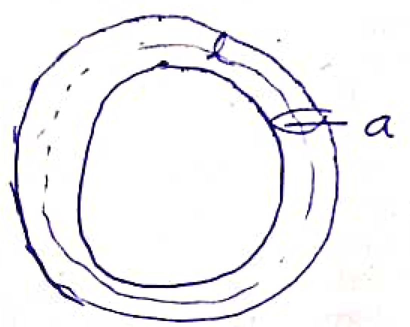
The opposition offered by the magnetic domains (or molecular magnets) to the turning effect of magnetising force is sometimes referred to as the molecular friction.

It also depends upon (*i*) the maximum value of flux density established and (*ii*) the initial magnetic state of the material.

Mohd. Murtaza

A Coil is wound uniformly with 300 turns over a Steel ring of relative permeability 900 having a mean Circumference of 40cm and a cross-sectional area of 5 cm². if the coil has a resistance of 100 Ω and is Connected to 250V dc supply. Calculate (i) the coil mmf (ii) the field Strength (iii) total flux (iv) reluctance of the ring (v) permeance of the ring

Given data



$N = 300$

$\mu_r = 900$

$l = 40\,cm$

$a = 5\,cm^2$

$R = 100\,\Omega$

$V = 250\,V$

Calculate ✓ mmf $= NI$

✓ Field Strength $H = \frac{NI}{l}$

$\boxed{\text{Flux Density } B = \mu_0 \mu_r H}$

✓ Total flux $\phi = B \times a$

✓ reluctance $S = \frac{mmf}{flux}$

✓ Permeance $\frac{1}{S}$

Mohd. Murtaza

Coil current $I = \frac{V}{R} = \frac{250}{100} = 2.5A$

mmf of Coil $= NI = 300 \times 2.5 = 750AT$

Field Strength $H = \frac{NI}{l} = \frac{750}{0.4} = 1875 AT/m$

flux density $B = \mu_0 \mu_r H = (4\pi \times 10^{-7}) \times 900 \times 1875$

$= 2.212 wb/m^2$

Total flux $\phi = B \times a = 2.12 \times (5 \times 10^{-4}) = 10.6 \times 10^{-4}$ wb

Reluctance of ring $S = \frac{mmf}{flux} = \frac{750}{10.6 \times 10^{-4}} = 70.75 \times 10^{4}$ AT/wb

Permeance of ring $= \frac{1}{S} = \frac{1}{70.75 \times 10^{4}} = 1.4 \times 10^{-6}$ wb/AT

19 Aug
30 Sep

Mohd. Murtaza