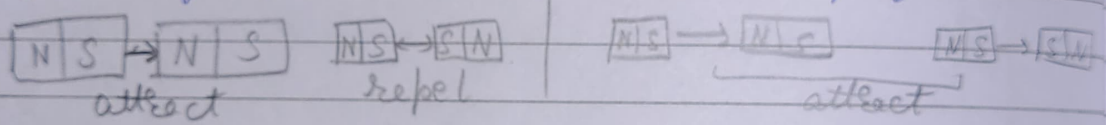
Unit → 3

Electrical Machines

* Magnetic Materials

- Materials which provide a path of magnetic flux.
- Magnetic Materials are those materials which can be magnetized when placed in an external magnetic field and can be attracted by a magnet.

* Magnets	Magnetic Material
It attracts to opp. pole and repel to same poles of a magnets.	It always attract towards magnetic poles of magnets, it never repels.



* Electro - magnetic Induction.

The phenomenon by which emf is induced in a circuit when magnetic flux linking with it changes is called electro - magnetic Induction.

* Faraday's law of Electromagnetic Induction;

1). It states that "whenever a conductor cuts across the magnetic field, an emf is induced in conductor".

2). The magnitude of induced emf in a coil is directly proportional to the rate of change of flux linkages.

Rate of change of flux linkage $= \frac{N(\phi_2 - \phi_1)}{t}$

Date / /
Page No.

N = No. of turns of coil
t = time in second
$(\phi_2 - \phi_1)$ = change of flux in wb.
According to Faraday's Second law.

$$e \propto \frac{N(\phi_2 - \phi_1)}{t}$$

$$e = \frac{N(\phi_2 - \phi_1)}{t}$$

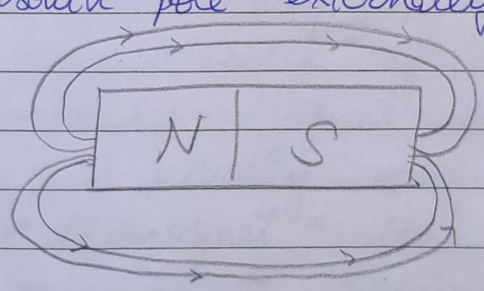
$$e = -N\frac{d\phi}{dt} \text{ volt}$$

emf in opp direction

* Magnetic Field.
The imaginary space around a magnet or a current carrying conductor within which its magnetic effects can be observed.

* Magnetic Flux.
The amount of magnetic lines of force set up in a magnetic circuit is called flux (ϕ).
Symbol ⇒ ϕ
Unit ⇒ weber (wb).

* Lines of Force.
They exit from north pole and enter to south pole externally.



* Magnetic Flux Density (B)

Magnetic flux per unit area of a surface at right angles to magnetic field.

$$\text{Flux Density} = \frac{\text{Magnetic flux}}{\text{Surface Area}}$$

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

Unit = Wb/m^2 or Tesla.

* MMF [Magnetomotive Force].

- Force that drives or tends to drive the flux through a magnetic circuit.

MMF = Flux X Reluctance

- It is equal to product of number of turns and current passing through magnetic circuit.

MMF = no. of turns X current

$= N \cdot I$

Unit = Ampere - Turn (AT) or Amperes

* Reluctance.

- It is the resistance to magnetic flow.
- It is the opposition offered to flow of magnetic lines of force.
- $\text{Reluctance} = \frac{\text{MMF}}{\text{Flux}}$
- Unit = Ampere turn / weber
- Symbol = S
- $\text{Reluctance} = \frac{l}{a\mu} = \frac{l}{a\mu_0\mu_r}$

a = Cross - Sectional area

l = length

μ_0 = Permeability of air

μ_r = Relative Permeability of material.

* Permeance.
- It is ability of material to set up magnetic flux easily.
- Reciprocal of reluctance (S)
- Permeance $= \frac{1}{\text{Reluctance}} = \frac{1}{\frac{l}{a\mu_0\mu_r}} = \frac{a\mu_0\mu_r}{l}$
- Unit = Wb/At

* Magnetic flux intensity.
- The force acting on a unit north pole when placed at a point in magnetic field.
- Symbol = H
- $H = \frac{mmf}{\text{length of magnetic path}}$

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

→ Type of Magnets
- Permanent
- Temporary
- Electromagnet

1) Permanent = Produce Magnetic field due to their internal structure. They don't lose their magnetism easily.
It is made off ferromagnetic material.
It don't stop producing magnetic field even by external influence.

2). Temporary = Magnet made of soft iron; that is usually easy to magnetize.

3). Electromagnet = Magnetic material surrounded by a coil through which an electric current is passed to magnetize the core.

Date / /
Page No.

* Material Display =
When its domains are aligned in same direction.
There are many ways to align them but the most reliable method is to heat the magnet to certain temp.

* Magnetic Dipole Moment =
Max amount of Torque caused by magnetic force on a dipole that arises per unit value of surrounding magnetic field in vacuum.

Magnetic Dipole Moment

- Absent
  - Diamagnetic
- Present
  - Paramagnetic
  - Ferromagnetic
  - Antiferromagnetic
  - Ferrimagnetic.

Ferromagnetic	Paramagnetic	Diamagnetic
• Strongly attracted towards magnetic field.	Feeble attraction towards magnetic field.	Feeble repulsion from magnetic field.
• Field lines are concentrated in material.	More no of field lines pass through material than outside.	less no. of field lines pass through material than outside.
• set along direction of Magnetic field.	Tend to align along Magnetic field direction.	Tend to align ⊥ to magnetic field direction
• Susceptibility (χ) is large and (+)ve.	Susceptibility less than unity but (+)ve.	Susceptibility is small but (-)ve.
• $\mu_r >> 1$	$\mu_r > 1$	$\mu_r < 1$
• (χ) decreases with temp in complex manner.	$\chi \propto \frac{1}{T}$	(χ) is independent of temp.

⇒ Important Terms;

1). **Magnetic Permeability** :- It is ability of material to permit the passage of magnetic lines of force OR The degree or extent to which magnetic field can penetrate a material.

$\mu_r = \frac{\mu}{\mu_0}$

High μ_r = High conductivity
Low μ_r = Low "

Units = $WbA^{-1}m^{-1}$ or TmA^{-1}.

2) **Magnetising Intensity (H)** :-
The degree to which a magnetic field can magnetise a material.

$B = n\mu I$ → Magnetic Induction of field.

$nI = H$

$\boxed{B = \mu H}$

Units = Am^{-1}.

3). **Intensity of Magnetisation ($\vec{I}$)** -
It represents the extend to which a specimen is magnetised; when placed in a magnetising field.
It is magnetic moment per unit volume of material.

4). **Magnetic Susceptibility (χ)** ⇒ It is a dimensionless proportanality constant that indicates the degree of magnetization of a material is to an applied magnetic field.

$\chi = \frac{M}{H}$ → Magnetization
→ field intensity

5) Coercivity = Removal of magnetization.
It is the value of magnetising field when magnetisation in a material become zero after magnetisation.

6). Retentivity = Ability of magnetic field remaining in material, even after removing external source.
Units = weber / m^2

→ Statically Induced emf.
When the coil and magnetic field system both are stationary but magnetic field linking with coil changes, the emf thus induced in coil is called statically Induced emf.

① Self - Induced emf = The emf induced in a coil due to change of flux produced by it linking with its own turns is called self-induced emf.
The magnitude of self-induced emf is directly proportional to the rate of change of current in coil ie $e \propto \frac{dI}{dt}$ or $e = L\frac{dI}{dt}$

L = Constant of proportionality [co-efficient of self - inductance]

②. Mutually - Induced emf = The emf induced in a coil due to change of flux produced by another coil, linking with it is called mutually induced emf.

Date / /
Page No.

⇒ Co-efficient of Coupling

when current flows through one coil, it produces flux (ϕ). It may be reduced while linking with other coil because of leakage flux by a fraction K known as co-efficient of coupling.

<u>Expression</u>;

$$L_1 = \frac{N_1 \phi_1}{I_1} \quad ; \quad M = \frac{N_2 K \phi_{12}}{I_1}$$ → Current flowing through coil I_1

$$L_2 = \frac{N_2 \phi_2}{I_2} \quad ; \quad M = \frac{N_2 K \phi_{21}}{I_2}$$ → Current

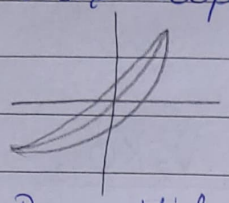
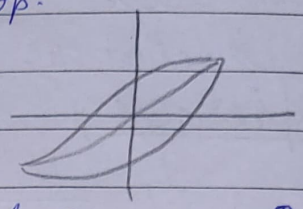
$$M \times M \Rightarrow \frac{N_2 K \phi_{12}}{I_1} \times \frac{N_2 K \phi_{21}}{I_2}$$

$$M^2 = K^2 L_1 L_2$$

$$M = K \sqrt{L_1 L_2}$$

$$\boxed{K = \frac{M}{\sqrt{L_1 L_2}}}$$

Date / /
Page No.

Soft - Magnetic Material	Hard - Magnetic Material
• which have a smaller area enclosed by their hysteresis loop.	larger area taken by their hysteresis loop.
	
• Low R ; High Permeability So, Hysteresis Less, narrow loop.	High R ; Low Permeability High hysteresis loss ; wide loop
• Alloy have low % of Iron. Eg. Pure Iron.	Alloy have high % of Iron. Eg. Steel
• low coersicivity Hysteresis loss ↓ ; Eddy I loss ↓	High coersicivity Hysteresis loss ↑ ; Eddy I loss ↑ for metal and ↓ for ceramic
• Use in transformer core, motor, generator, electro-magnet.	Use in making permanent magnet, speaker, microphone
⇒ Magnetic Circuit	Electric circuit.
• The closed path for magnetic flux.	The closed path for electric current.
• Flux = $\frac{mmf}{reluctance}$	Current = $\frac{emf}{resistance}$
• ϕ in Wb	I in Ampere
• mmf in AT	emf in V
• Reluctance ; $S = \frac{l}{a\mu} = \frac{l}{a\mu_0\mu_r}$ AT/Wb	Resistance ; $R = \frac{\rho l}{a} \Rightarrow \frac{1}{\sigma}\frac{l}{a}$ Ω
• Permeance = $\frac{1}{reluctance}$	Conductance = $\frac{1}{Resistance}$
• $\mu = \frac{1}{S}$	$\sigma = \frac{1}{\rho}$

• Permeability = μ	Conductance = σ
• Reluctivity	Resistivity
• Flux density ; $B = \frac{\phi}{a}$ Wb/m²	Current Density ; $J = \frac{I}{a}$ A/m².
• Magnetic Intensity ; $H = \frac{NI}{l}$	Electrical Intensity ; $E = \frac{V}{d}$

Properties

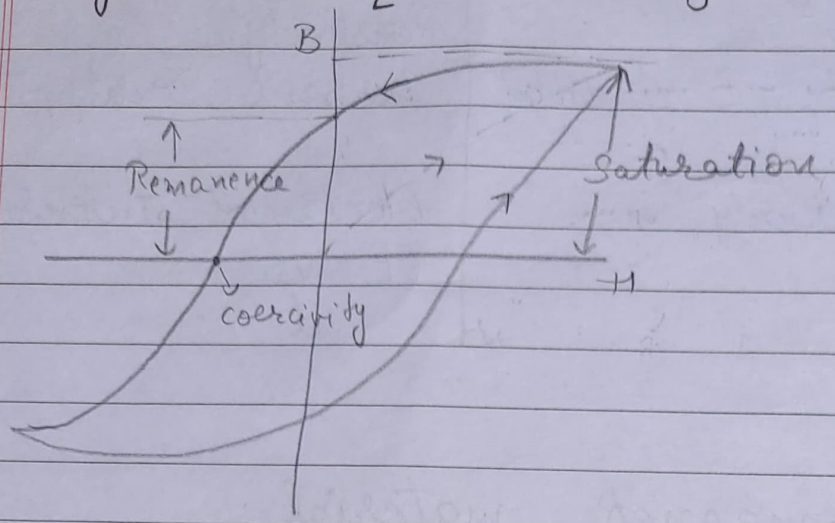
(a) Anti-ferromagnetic material ;

- The adjacent magnetic dipoles are aligned anti-parallel direction and magnitude are same.
- The susceptibility is positive and it is very small.
- The magnetic susceptibility initially increases slightly with temp. and beyond T_N it decreases with temp.
- When $T < T_N$ material behave as a antiferromagnetic material.

(b). Ferrimagnetic material.

- The adjacent magnetic dipoles are aligned anti-parallel direction and magnitudes are diff.
- It has net magnetic moment.
- The susceptibility is (+)ve and it is very large.
- They have high permeability and high resistivity.
- Low eddy current and low hysteresis loss.

→ Hysteresis [B – H curve].



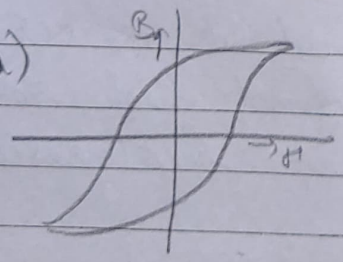
* Importance

(i) Hard steel = This loop has larger area which indicates that this material will have more hysteresis loss. Therefore it is never used for construction of machine parts. It is more suitable for permanent magnets.

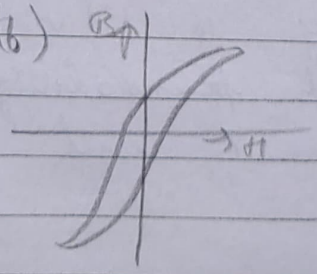
(ii). Silicon Steel = This loop has smallest area which indicates that this material have small hysteresis loss. It is most suitable for construction of electrical machines; eg transformer core, armature of dc machines.

(iii). Wrough iron = Loop shows that this material has fairly good residual magnetism and coercivity. It is best suited for making cores of electromagnets

(a)



(b)



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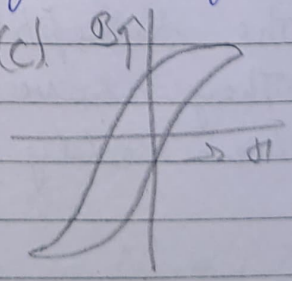
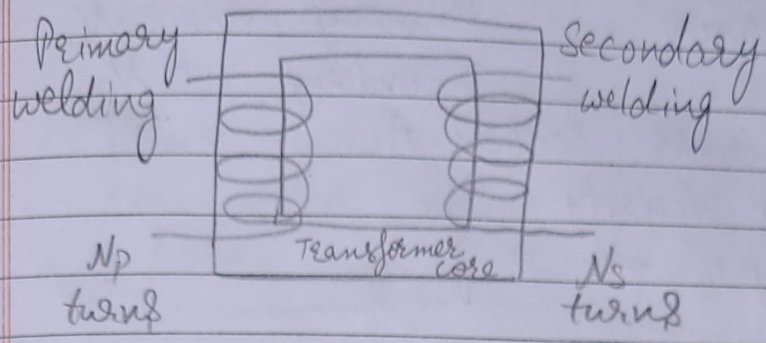


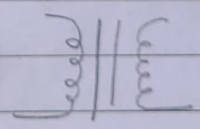
Transformer



A transformer is a static device which can transfer power from one circuit to another at same frequency.

→ Working.

Transformer consist of two coils. If one coil is connected with ac voltage source then it will produce alternating flux in core. Most of flux is linked with second coil hence mutually induced emf will produce in second coil as per faraday's law of electromagnetic induction.

Symbolic Representation => 

→ Voltage Induced in Coil

$$E = N \times \frac{\Delta \phi}{\Delta t}$$

$\Rightarrow E = 4.44 \times f \times N \times \phi_{max}$ → Emf Equation.

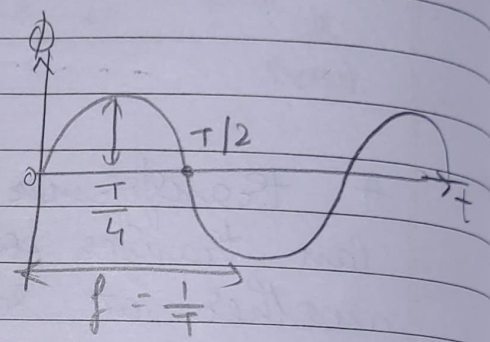
E = Effective induced voltage

f = frequency ; N = Number of turns

ϕ_{max} = Peak value of flux.

→ Emf Equation of Transformer.

No of turns in Primary side = N_1
" " " " Secondary " = N_2
Area of cross-section = A
Max flux density = B_m
Frequency of core = f



$\phi = \phi_m \sin \omega t$
ϕ = Max flux in core

$B_m = \frac{\phi_m}{A} \Rightarrow [\phi_m = B_m A]$

$Emf = \frac{\text{Change in } \phi}{\text{change in time}} = \frac{d\phi}{dt}$

Max ϕ occur at time i.e $= \frac{T}{4}$

$t = \frac{T}{4}$

$f = \frac{1}{T}$

$t = \left(\frac{1}{f}\right)\left(\frac{1}{4}\right) \Rightarrow \frac{1}{4f}$

$Emf = \frac{\phi_m}{\left(\frac{1}{4f}\right)}$

$\boxed{Emf = 4f\,\phi_m \text{ volt}}$

Date / /
Page No.

Rms = ?

Form factor = $\frac{\text{Rms value}}{\text{Average value}}$

Rms value = Form factor X Average Value.

Rms value = 1.11 X 4 f ϕ_m

$\boxed{\text{Rms} = 4.44\, \phi_m f}$ volt #

Voltage Transformation Ratio.

$$\frac{E_2}{E_1} = \frac{N_2}{N_1} = K$$

$\boxed{E_2 = K E_1}$ #

→ Efficiency (η) →

$$\eta = \frac{\text{Output}}{\text{Input}} = \frac{\text{Input} - \text{Loss}}{\text{Input}}$$

$$\rightarrow \frac{\text{Input}}{\text{Input}} - \frac{\text{Loss}}{\text{Input}} \rightarrow \boxed{1 - \frac{\text{Loss}}{\text{Input}}}$$ #

→ Conditions for Max. Efficiency;

Copper loss = Core loss

$W = I^2 R$

Proof;

$$\eta = 1 - \frac{\text{Loss}}{\text{Input}}$$

$$= 1 - \frac{I^2 R + W}{V_1 I_1 \cos\phi}$$

Date / /
Page No.

$$= 1 - \frac{I_1 R}{V_1 \cos\phi} + \frac{W}{V_1 I_1 \cos\phi}$$

Diff w.r.t I_1

$$\frac{d\eta}{dI_1} = \frac{d}{dI_1}(1) - \frac{d}{dI_1}\left(\frac{I_1 R_1}{V_1 \cos\phi}\right) + \frac{d}{dI_1}\left(\frac{W}{V_1 I_1 \cos\phi}\right)$$

$$\frac{d\eta}{dI_1} = 0 - \frac{R}{V_1 \cos\phi} + \frac{W}{V_1 I_1^2 \cos\phi}$$

η will be max ; at $\frac{d\eta}{dI} = 0$

$$\frac{+R}{V_1 \cos\phi} = \frac{+W}{V_1 I_1^2 \cos\phi}$$

Multiply x divide by I_1^2

$$\frac{R_1 I_1^2}{V_1 I_1^2 \cos\phi} = \frac{W}{V_1 I_1^2 \cos\phi}$$

$$\boxed{R_1 I_1^2 = W}$$

Hence Proved

Cu Loss = Core Loss

→ Auto Transformer :-

In these transformer only one winding is used as primary and secondary. Also, primary and secondary are conductively coupled.

Core - Type Transformer	Shell - Type Transformer
• The core has only one magnetic circuit.	It has two magnetic circuits.
• Core has two limbs.	Core has three limbs.
• It has less mechanical protection to coil.	It has better mechanical protection to coil.
• It has better cooling since more surface is exposed to atmosphere.	Cooling is not very effective.
• Natural - cooling is provided.	Natural cooling cannot provide.
• This transformer is easy to repair.	It is not easy to repair.

⇒ Step - up ⇒ They step up voltage from lower value to higher value. $N_1 < N_2$

⇒ step - down ⇒ They step up voltage from higher value to lower value. $N_1 > N_2$

Energy In = Energy out

$P_{in} \times$ time $= P_{out} \times$ time

$$P_{in} = P_{out}$$

$$V_1 \times I_1 = V_2 \times I_2$$

$$\frac{V_1}{V_2} = \frac{I_2}{I_1}$$

Date / /
Page No.

Ideal Transformer.

An ideal transformer is one which has no ohmic resistance and no magnetic leakage flux.

$$E_2 I_2 \cos\phi = E_1 I_1 \cos\phi$$

$$E_2 I_2 = E_1 I_1$$

$$\frac{E_2}{E_1} = \frac{I_1}{I_2}$$

$E_1 = V_1$; $E_2 = V_2$

$$\frac{V_2}{V_1} = \frac{E_2}{E_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2} = K$$

Transformation Ratio (K) = Ratio of secondary turns to primary turns.

→ Properties of Ideal Transformer;

- It has no winding resistance
- No leakage flux
- No leakage Inductance
- No iron losses
- 100 % efficiency.

→ Advantages. (Auto Transformer).

- less copper is reqd.
- less cost
- less weight & small size
- only one winding used for primary & secondary

Date / /
Page No.

Eddy Current Loss.

In transformer, we supply A.C in primary, this A.C produces alternating magnetizing flux in core and as this flux links with secondary winding, there will be induced voltage in secondary; resulting current to flow through the load connected with it. Some of alternating fluxes of transformer, may also link with other conducting parts; there would be locally induced emf.
Due to these emf's there would be current that will not contribute in output of transformer and dissipated as heat.

→ Method to Minimize it;

- By using less thickness of laminations
- By using less value of Magnetic flux density.

Hysteresis Loss.

It is the loss in form of heat when magnetization of material is made to alternate with respect to time.
It occurs in electrical machines due to repeated magnetization and demagnetization of core.

→ Methods to minimize it.

- By using good magnetic material.
- By using less value of Magnetic flux density.

Date / /
Page No.

Three - Phase Transformer.

- It is used to generate and transmit large amount of power.
- These are required to step-up or step-down voltages in various stages of a power system network.
- These can be constructed by following ways :-

(a) Three separate single phase transformers are suitable connected.

(b). A single three-phase transformer in which cores and windings for all three phases are combined in single structure.

Advantages

* Three Single Phase Transformer
- Continuity of supply
- less installation of cost
- Easy transportation
- Stand by function
- Unbalanced load supply

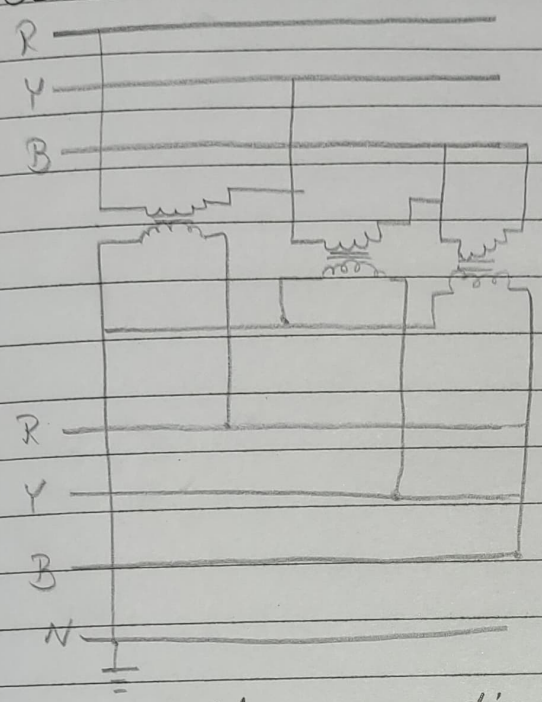
* Three Phase Transformer.
- Saving in iron material
- Small size
- less transformer oil
- Economical
- Higher efficiency.

Date / /
Page No.

Three - Phase Transformer connections.

Varieties of Connections;
Star Star, Star Delta, Delta Star, Delta Delta

Delta - Star Connection.



It is used to ~~set~~ step-up the voltage level

Star - Delta Connection.

It is used to step-down voltage to lower value in transmission.

Voltage - Tranformer's Regulation.

- Voltage Regulation $= \frac{E_{no\ load} - V_{full\ load}}{V_{full\ load}}$
- % Voltage Regulation $= \frac{E_2 - V_2}{E_2} \times 100$
- In a transformer, the value of primary voltage is always greater than induced emf in primary windings. $V_1 > E_1$
- In a transformer, the value of secondary terminal voltage at no load is always greater than secondary terminal voltage at full load. $E_2 > V_2$