Unit - I

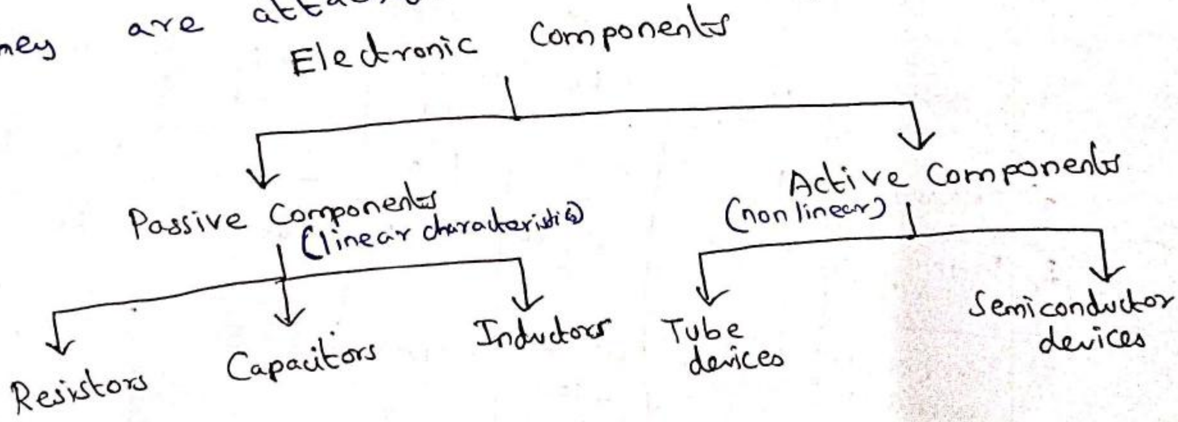
Basic Electronics

1.1 Passive and Active Components:

→ Electronic components may be broadly classified as active and passive components.

→ Passive components are the components which are to be connected with devices to perform particular mathematical and logical functions. These components cannot generate their own signal and require external power to get energized.

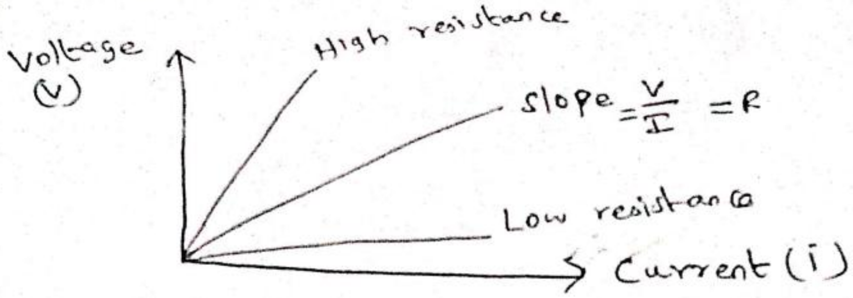
→ Active components are the discrete electronic devices which can generate internal signals for the circuit operation in which they are attached.



1.2 Resistors - Types, features and specification:

→ Resistance ⇒ opposition to current

→ Resistor obeys straight line when voltage is plotted against current.



→ Specifications for resistor include ohms (Ω), kiloohms (kΩ) (or) megaohms (MΩ), accuracy (or) tolerance and power rating.

→ Other consideration include temperature coefficient, noise performance, stability and ambient temperature range.

a) Characteristics of common types of resistor.

	Property	Resistor type					
		Carbon film	Metal film	Metal oxide	Ceramic wirewound	Vitreous wirewound	Metal Clad
1)	Resistance range (Ω)	10 to 10M	1 to 1M	10 to 10M	0.47 to 22k	0.1 to 22k	0.05 to 10k
2)	Tolerance (%)	± 5	± 1	± 2	± 5	± 5	± 5
3)	Power rating (W)	0.25 to 2	0.125 to 0.5	0.25 to 0.5	4 to 17	2 to 4	10 to 300
4)	Temperature coefficient (ppm/°C)	−250	+50 to +100	+250	+250	+75	+50
5)	Stability	Fair	Excellent	Excellent	Good	Good	Good
6)	Noise performance	Fair	Excellent	Excellent	N.A	N.A	N.A
7)	Ambient temperature	−45 to +125	−45 to +125	−45 to +125	−45 to +125	−45 to +125	−55 to +200
8)	Typical applications	General purpose	Amplifiers, test equipment		Power supplies, loads		Very high power applications

→ Resistors are of different types like high-power metal clad, ceramic wire wound, carbon and metal film type.

→ values marked in resistor is not its exact resistance. Some minor variation is inevitable due to production tolerance.

→ eg 100Ω resistor within a tolerance of ± 10%. will have range 90Ω to 110Ω. For ± 1% tolerance, 100Ω resistor will have range 99Ω to 101Ω.

→ E6 series of resistors have ± 20% tolerance have 6 basic values. (1, 1.5, 2.2, 3.3, 4.7, 6.8)

→ E12 series of resistors have ± 10%. tolerance have 12 basic values (1, 1.2, 1.5, 1.8, 2.2, 2.7, 3.3, 3.9, 4.7, 5.6, 6.8, 8.2)

→ E24 series of resistors have ± 5% tolerance have 24 basic values.

Pblm A resistor has a marked value of 220Ω. Determine the tolerance of the resistor if it has a measured value of 207Ω.

gn marked value = 220Ω, measured value = 207Ω

T.F tolerance

soln

$$\text{tolerance} = \frac{\text{error}}{\text{marked value}} = \frac{\text{marked value} - \text{measured value}}{\text{marked value}}$$

$$= \frac{220 - 207}{220} \times 100\%$$

Tolerance = 5.9%

Pblm

A 9V power supply is to be tested with 39 Ω load resistor. If resistor has a tolerance of 10%, find

a) the nominal current taken from the supply

b) the maximum and minimum values of supply current at either end of tolerance range for resistor.

Gn Voltage = 9V, Resistor = 39 Ω, tolerance = 10%

T.F a) I , b) I_{max} , I_{min}

Soln

a) $I = \frac{V}{R} = \frac{9}{39} = 231 \times 10^{-3}$ A = 231 mA

b) $I_{max} = \frac{V}{R_{low}}$, $I_{min} = \frac{V}{R_{high}}$

$R_{low} = R_{actual} - R_{tolerance}$

$= 39 - (10\% \times 39)$

$= 39 - \left(\frac{10}{100} \times 39\right) = 39 - 3.9$

$R_{low} = 35.1\ \Omega$

$I_{max} = \frac{9}{35.1} = 256.4$ mA

$R_{high} = R_{actual} + R_{tolerance}$

$= 39 + (10\% \times 39)$

$= 39 + \left(\frac{10}{100} \times 39\right) = 39 + 3.9$

$R_{low} = 42.9\ \Omega$

$I_{min} = \frac{9}{42.9} = 209.8$ mA.

1.5

Pblm A current of 100 mA ($\pm$ 20%) is to be drawn from 28V dc supply. What value and type of resistor should be used in this application?

Gn $I = 100 mA$ ($\pm$ 20%)

$V = 28V$

T.F R

Soln $R = \frac{V}{I} = \frac{28}{100 \times 10^{-3}} = 280\Omega$

→ resistor value can be 270Ω

→ current can be 120 mA to 80 mA

$\therefore$ Power $= I^2 R = 280 \times (120 \times 10^{-3})^2$ (or) $280 \times (80 \times 10^{-3})^2$

Power $=$ 4.03 W (or) 1.792 W

This would be a vitreous enamel coated wire wound resistor

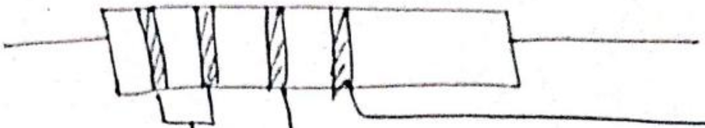
b) Resistor markings:

→ Carbon and metal oxide resistors are normally marked with colour codes which indicate value and tolerance.

→ 2 methods of colour code:
- 4 coloured bands
- 5 coloured bands

P.T.O

(i) Four band resistor colour code:

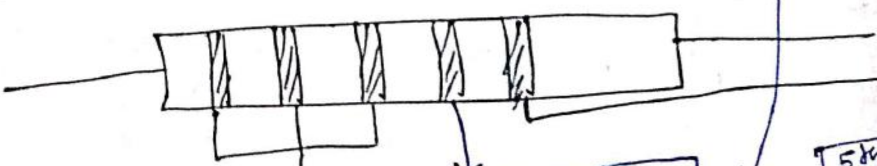


1st and 2nd colour bands	
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Grey	8
White	9

3rd coloured band	Multiply by
Silver	0.01
Gold	0.1
Black	1
Brown	10
Red	100
Orange	1000
Yellow	10000
Green	100000
Blue	1000000

4th coloured band (tolerance)	
Red	± 2%
Gold	± 5%
Silver	± 10%
None	± 20%

(ii) Five band resistor colour code:



1st, 2nd, 3rd colour bands	
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Grey	8
White	9

Same

4th coloured band	Multiply by
Silver	0.01
Gold	0.1
Black	1
Brown	10
Red	100
Orange	1000
Yellow	10000
Green	100000
Blue	1000000

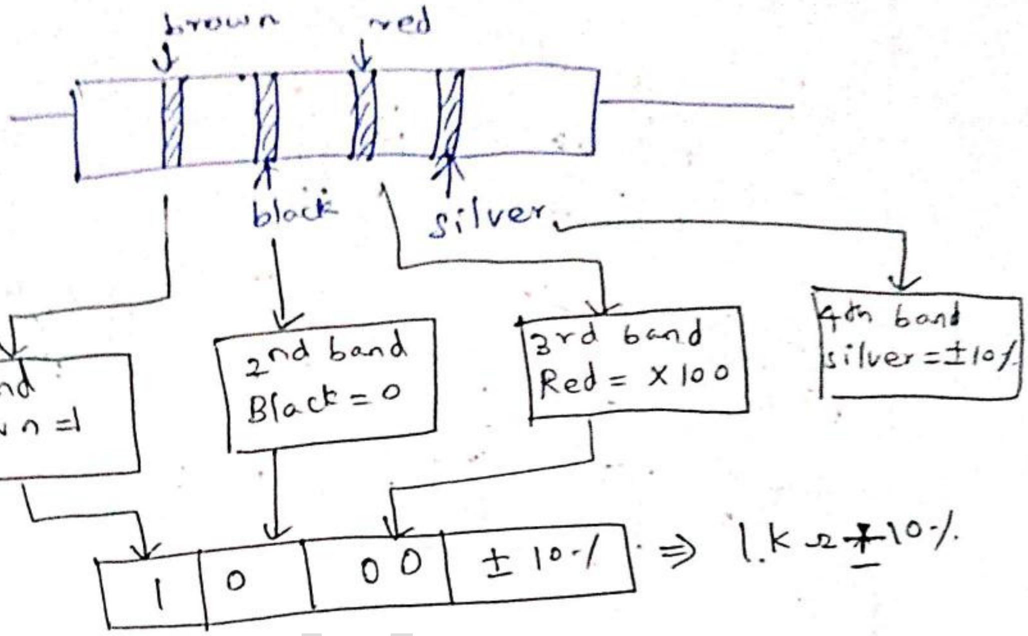
Same

5th (tolerance) coloured band	
Red	± 2%
Gold	± 5%
Silver	± 10%
None	± 20%

Same

Pblm: A resistor is marked with following coloured stripes: brown, black, red, silver. What is its value and tolerance.

Soln



H-w Pblm: A resistor is marked with following coloured stripes: red, violet, orange, gold. What is its value and tolerance

Soln

2	7	000	± 5%

27 kΩ ± 5%

H-w Pblm: A resistor is marked with following coloured stripes: green, blue, black, gold. What is its value and tolerance

Soln

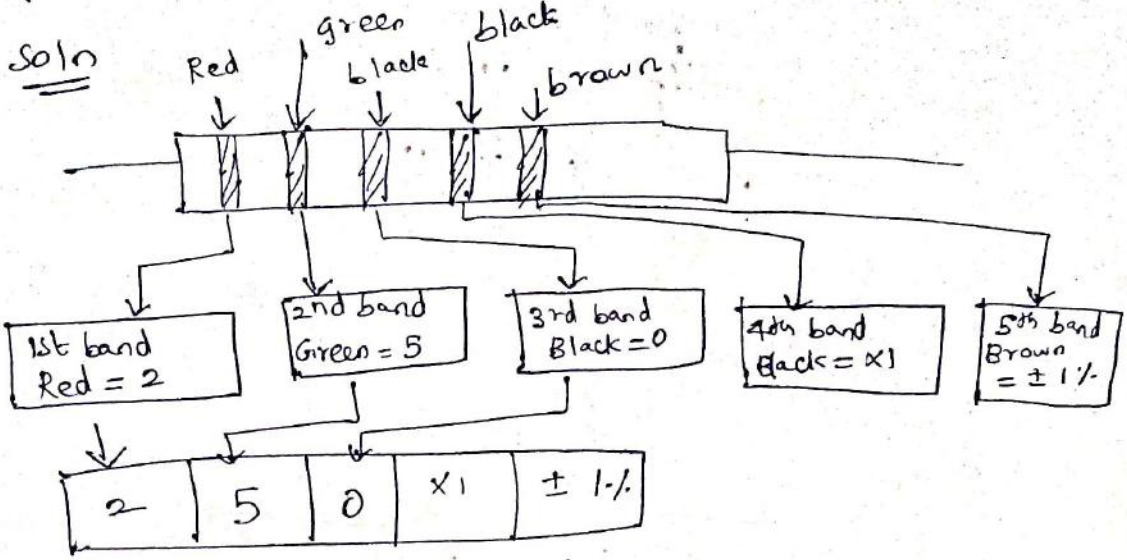
x 1

5	6.		± 5%

∴ 56 Ω ± 5%

Pblm A resistor is marked with following coloured stripes: red, green, black, black, brown. What is its value and tolerance.

Soln



$= 250\Omega \pm 1\%$

Pblm A 2.2 kΩ of ±2% tolerance is required. What four band colour code does this correspond to?

Soln Red (2), Red (2), Red (2) zeros, red (2%) tolerance

2	2	×100	±2%

gn ($2.2\,k\Omega = 2.2 \times 10^3 = 2200$)

Thus all 4 bands should be red.

c) **BS 1852 coding:**

→ BS 1852 coding involves marking the position of decimal point with a letter to indicate multiplier concerned.

BS1852 resistor multiplier markings	
Letter	Multiplier
R	1
K	1,000
M	1,000,000

BS1852 resistor tolerance markings	
Letter	Multiplier
F	± 1%
G	± 2%
J	± 5%
K	± 10%
M	± 20%

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Pblm A resistor is marked coded with legend 4R7K what is its value and tolerance?

Soln

4 R 7 K

↓

4 . 7 Ω ± 10%

Pblm A resistor is marked with legend 330RG. what is its value and tolerance?

Soln

3 3 0 R – G

↓ ↓ ↓ ↓ ↓ ↓

3 3 0 . 0 ±2%

330Ω ± 2%

Pblm A resistor is marked coded with legend R22 M. What is the value and tolerance

Soln

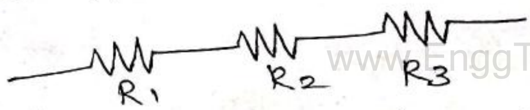
R 22 M
↓ ↓↓ ↓
0. 2 2 Ω ± 20%

Ans : 0.22 Ω ± 20%

d) Series and Parallel combinations of resistors

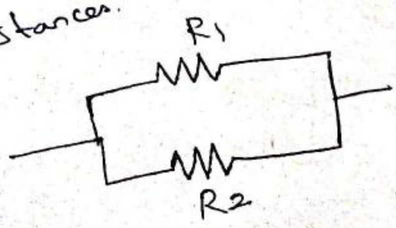
→ Equivalent resistance for series circuit is equal to sum of individual resistances.

$\Rightarrow R = R_1 + R_2$

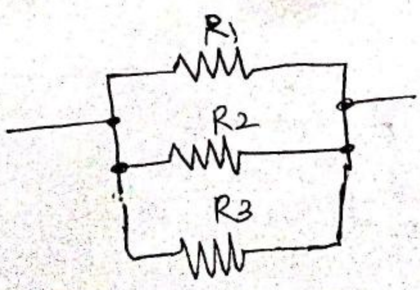


$\Rightarrow R = R_1 + R_2 + R_3$

→ For parallel resistors, reciprocal of effective resistance of each circuit is equal to the sum of the reciprocals of the individual resistances.



$\Rightarrow \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$



$\Rightarrow \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

Pblm Resistors of 22 Ω, 47 Ω and 33 Ω are connected in a) series and b) parallel. Determine the effective resistance in each case

gn $R_1 = 22\,\Omega$, $R_2 = 47\,\Omega$, $R_3 = 33\,\Omega$

Soln

a) For series,

$$R = R_1 + R_2 + R_3 = 22 + 47 + 33$$

$$\boxed{R = 102\,\Omega}$$

b) For parallel,

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

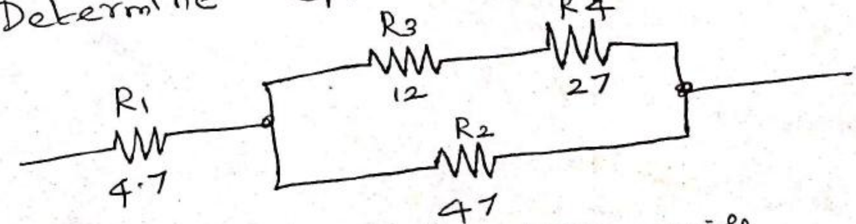
$$\frac{1}{R} = \frac{1}{22} + \frac{1}{47} + \frac{1}{33}$$

$$= 0.045 + 0.021 + 0.03$$

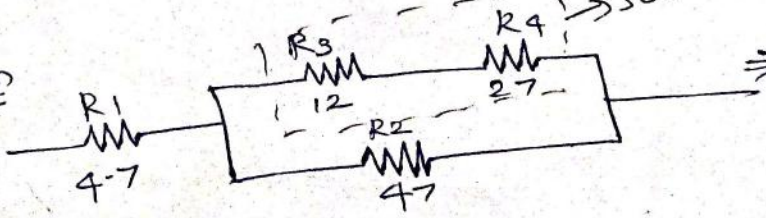
$$\frac{1}{R} = 0.096$$

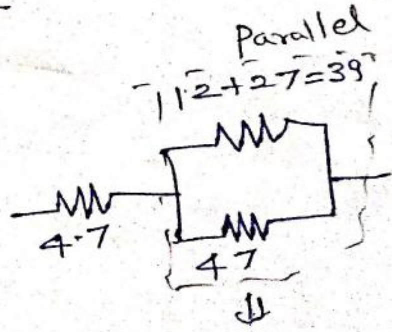
$$\boxed{R = 10.42\,\Omega}$$

Pblm Determine effective resistance of the circuit

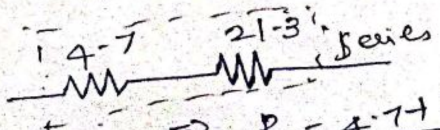


Soln





$$\frac{39 \times 47}{39 + 47} = 21.3\,\Omega$$



$$R = 4.7 + 21.3$$

$$\boxed{R = 26\,\Omega}$$

Pblm A resistance of 50 Ω rated at 2W is required. What parallel combination of preferred value resistors will satisfy this requirement, what power rating should each resistor have?

Soln:

When 2 resistors of same value are connected in parallel, resulting resistance will be half that of a single resistor.

∴ If $R_1 = R_2 = 100\,\Omega$,

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} \Rightarrow \frac{1}{R} = \frac{1}{100} + \frac{1}{100}$$

$$\frac{1}{R} = 0.01 + 0.01$$

$$\frac{1}{R} = 0.02, \quad R = \frac{1}{0.02} = 50\,\Omega$$

∴ Since resistors are same, applied power will be shared equally. Hence, each resistor should have power rating of 1W.

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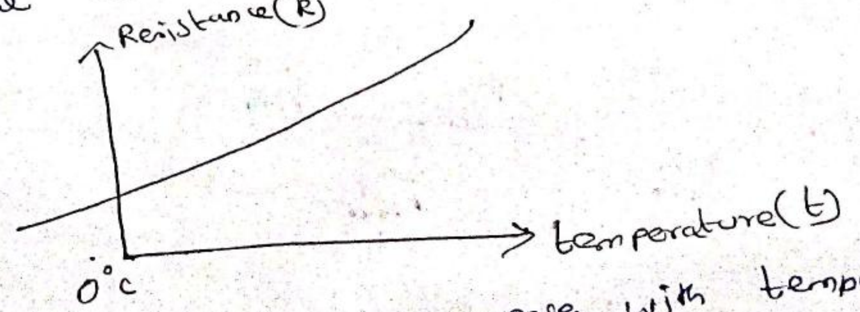
e) Resistance and temperature:

→ Variation of resistance with temperature of a metal conductor (eg. copper)



→ since resistance increases with temperature this characteristics is said to exhibit a positive temperature coefficient (PTC).

→ The resistance of Carbon conductor falls with temperature and it is therefore said to exhibit a negative temperature coefficient (NTC)

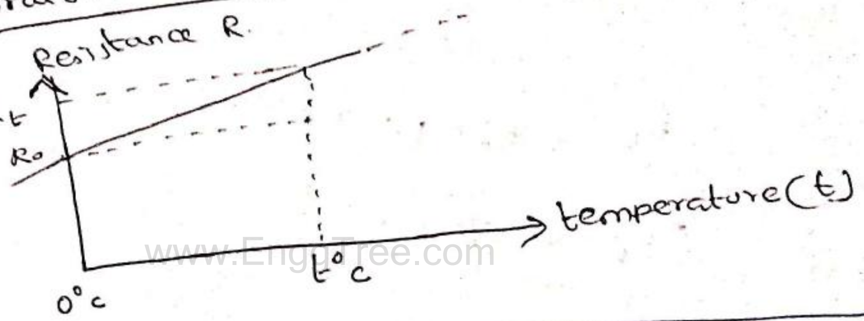
→ $R_t = R_o(1+\alpha t)$

where R_t → Resistance of conductor at a temperature (t)

R_o → Resistance at 0°c.

α → temperature coefficient

→ straight line approximation



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Pblm A resistor has temperature coefficient of 0.001/°c. If resistor has a resistance of 1.5 kΩ at 0°c, determine its resistance at 80°c.

gn $\alpha = 0.001/°c$, $R_o = 1.5\,k\Omega$, $t = 80°c$

T.f R_t

Soln $R_t = R_o(1+\alpha t) = (1.5\times10^3)(1+0.001\times80)$

$R_t = (1.5\times10^3)(1.0.8) = 1.62\,k\Omega$

Pblm A resistor has temperature coefficient of 0.0005/°c. If resistor has a resistance of 680 Ω at 20°c, what will its resistance be at 80°c?

gn $\alpha = 0.0005/°c$ $R_{t_1} = 680\,\Omega$, $t_1 = 20°c$

T.F R_{t_2} at 80°c

Soln $R_{t_2} = R_{80°} = R_0(1+\alpha t_2) = R_0(1+0.0005\times80)$

gn $R_{t_1} = R_0(1+\alpha t_1) \Rightarrow 680 = R_0(1+0.0005\times20)$

$$R_0 = \frac{680}{1+(0.0005\times20)} = \frac{680}{1+0.01} = 673.3\,\Omega$$

$\therefore R_{t2} = R_0(1+0.045) = 673.3\times1.045$

$R_{t2} = 704\,\Omega$

Pblm A resistor has a resistance of 40 Ω at 0°c and 44 Ω at 100°c. Determine resistor's temperature coefficient.

gn $R_0 = 40\,\Omega$, $R_t = 44\,\Omega$, $t = 100°c$

T.F α

Soln $R_t = R_0(1+\alpha t) \Rightarrow 44 = 40(1+(\alpha)100)$

$$\frac{44}{40} = 1+\alpha(100)$$

$$1.1 = 1+100\alpha$$

$$1.1-1 = 100\alpha$$

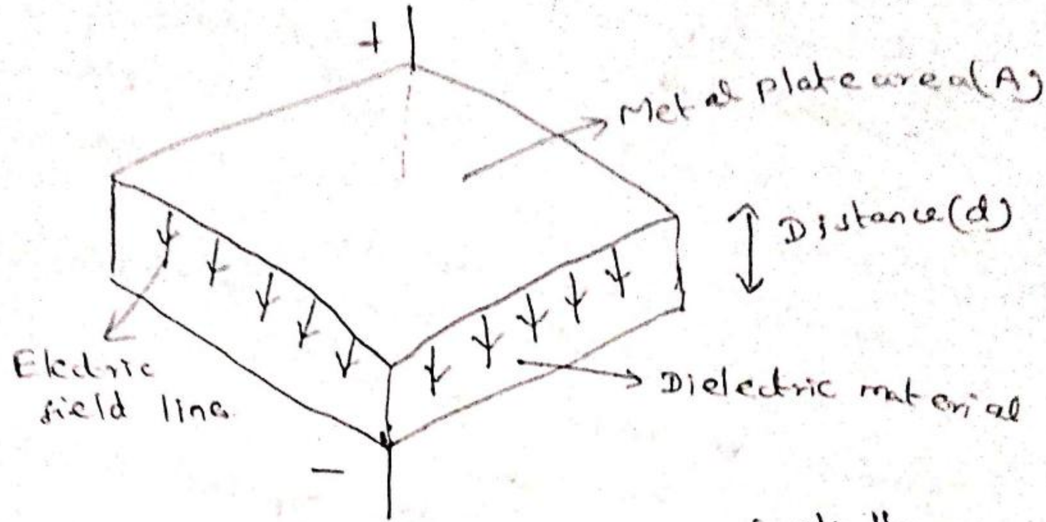
$$\alpha = \frac{0.1}{100}$$

$\alpha = 0.001\,/°c$

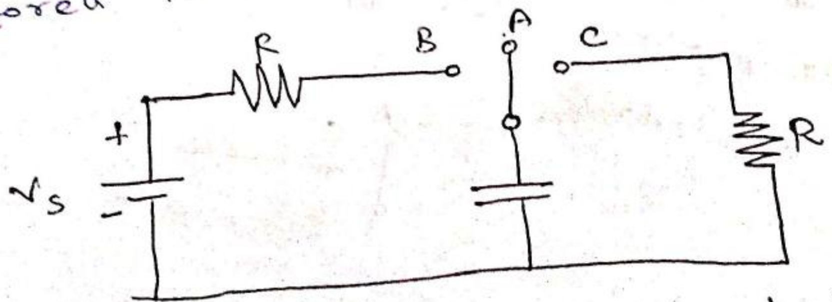
1.3 Capacitors - Types, features and specifications

→ Capacitor is a device for storing electric charge.

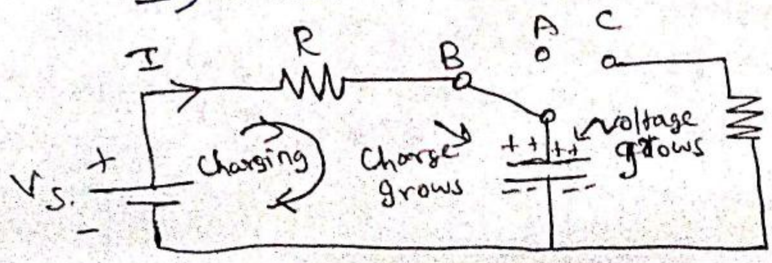
→ Capacitor can consist a 2 parallel metal plates with an insulating dielectric material



→ Consider the capacitor initially uncharged, if the switch is left open (position A), no charge will appear on the plate and in this condition, there will be no electric field in the space between the plates nor will there be any charge stored in the capacitor.



→ When switch is moved to position B,



electrons will be attracted from the positive plate to positive terminal of the battery.

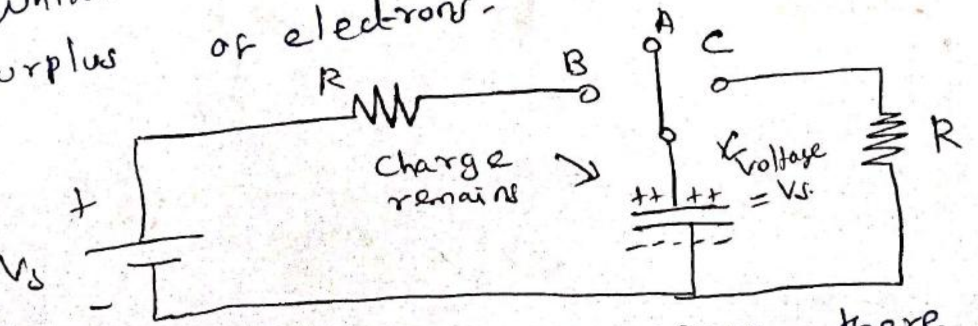
→ At the same time, a similar number of electrons will move from negative terminal of battery to the negative plate.

→ This sudden movement of electrons will manifest itself in a momentary surge of current. (i.e) conventional current will flow from positive terminal of the battery towards the positive terminal of the capacitor.

→ Eventually, enough electrons will have moved to make the emf between plates the same as that of battery.

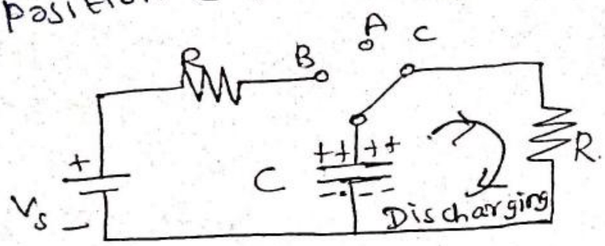
→ In this state, capacitor is said to be fully charged and an electric field will be present in space between two plates.

→ If, at some later time, the switch is moved back to position A, the positive plate will be left with a deficiency of electrons whilst the negative plate will be left with a surplus of electrons.



→ Furthermore, since there is no path for current to flow between the 2 plates, the capacitor will remain charged and a potential difference will be maintained between the plates.

→ Now assume that the switch is moved to position C.



→ The excess electrons on negative plate will flow through resistor to positive plate until a neutral state once again exists (i.e) until there is no excess charge on either plate

→ In this state the capacitor is said to be fully discharged and the electric field between plates will rapidly collapse.

→ The movement of electrons during the discharging of capacitor will again result in momentary surge of current (i.e) current will flow from positive terminal of capacitor and into the resistor.

a) Capacitance:

→ unit of capacitance is farad (F).

→ Capacitor is said to have capacitance of 1 Farad if a current of 1A flows in it when a voltage changing at a rate of 1V/s is applied to it.

→ Current flowing in a capacitor will thus be proportional to product of capacitance and rate of change of applied voltage and rate of change of voltage.

$i = C \times$ rate of change of voltage

$i = C \times \frac{dv}{dt}$

$$i = C \frac{dv}{dt}$$

where $dv \Rightarrow$ small change in voltage
$dt \rightarrow$ small change in time

pblm Pg.No: 33

A voltage is changing at a uniform rate from 10 V to 50 V in a period of 0.1 s. If this voltage is applied to capacitor of 22 μF, determine the current that will flow

gn $dV = (50-10) V = 40 V$

$dt = 0.1 s$

$C = 22 \mu F$

T.F i

soln $i = C \frac{dv}{dt} = 22 \times 10^{-6} \times \frac{40}{0.1}$

$i = 8.8 \times 10^{-3} A$

$$i = 8.8 mA$$

b) Charge, Capacitance and Voltage:

→ Charge Q is proportional to capacitance of capacitor (C) applied voltage (V) and

$Q = CV$

Q (coulombs) $= C$ (farad) $\times$ Voltage (volts) pblm A 10 μF capacitor is charged to a potential of 250V. Determine charge stored.

gn $C = 10\times10^{-6}$ F, $V = 250$

T.F Q

soln $Q = CV$

$= (10\times10^{-6}) \times 250$

$Q = 2.5\times10^{-3}$ C

$Q = 2.5$ mC

c) Energy storage:

→ Energy stored in capacitor is proportional to product of capacitance & square of potential difference.

$$W = \frac{1}{2}CV^2$$

W → Energy (Joules), C ⇒ Capacitance (farad)

V → voltage (volt).

pblm A capacitor of 47 μF is required to store 4 J of energy. Determine potential difference that must be applied to the capacitor

gn $C = 47\times10^{-6}$ F, $W = 4$ J

T.F V

soln $W = \frac{1}{2}CV^2$

$4 = \frac{1}{2}\times 47\times10^{-6}\times V^2$

$V^2 = \frac{4\times2}{47\times10^{-6}}$, $V = \sqrt{\frac{8}{47\times10^{-6}}}$

$V = 412$ V

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d) Capacitance and physical dimensions :

→ Capacitance depends upon size of the plates (ie) Area and seperation between plates (d)

$$C = \frac{\varepsilon_0 \varepsilon_r A}{d}$$, $\varepsilon_0 \Rightarrow$ permittivity of free space

$\varepsilon_r \Rightarrow$ relative permittivity

Pblm: A capacitor of 1 nF is required. If a dielectric material of thickness 0.1 mm and relative permittivity 5.4 is available, determine required plate area.

gn $C = 1 \times 10^{-9}$ F, $d \Rightarrow$ thickness $= 0.1 \times 10^{-3}$ m

$\varepsilon_r = 5.4$

T-f A

soln $C = \frac{\varepsilon_0 \varepsilon_r A}{d} \Rightarrow 1 \times 10^{-9} = \frac{8.854 \times 10^{-12} \times 5.4 \times A}{0.1 \times 10^{-3}}$

$$A = \frac{1 \times 10^{-9} \times 0.1 \times 10^{-3}}{8.854 \times 10^{-12} \times 5.4}$$

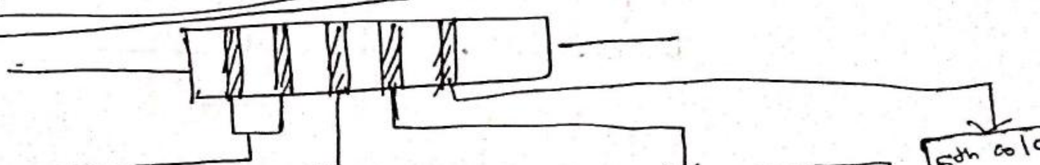
$$\boxed{A = 0.00209 \text{ m}^2}$$

[1.21]

e) Capacitor Specifications:

Property	Capacitor type				
	Ceramic	Electrolytic	Polyester	Mica	Polystyrene
Capacitor range (F)	2.2p to 100n	100n to 10m	10n to 2.2M	0.47 to 22k	10p to 22n
Tolerance (%)	±10 & ±20	-10 to +50	± 10	± 1	± 5
voltage rating (V)	50V to 200V	6.3V to 400V	100V to 400V	350V	100V
Temperature coefficent (ppm/°c)	+100 to -4700	+1000	+100 to +200	+50	+250
stability	Fair	Poor	Good	Excellent	Good
Ambient temperature range (°c)	-85 to +85	-40 to +80	-40 to +100	-40 to +125	-40 to +100
Applications	high frequency & low cost	smoothing & decoupling	General purpose	Tuned circuits & oscillators	General purpose

f) Capacitor markings:



1st and 2nd colour bands	
Black	0
Brown	1
Red	2
orange	3
Yellow	4
Green	5
Blue	6
violet	7
Grey	8
White	9

3rd coloured band	Multiply by
Black	1
Brown	10
Red	100
Orange	1000
Yellow	10000
Green	100000

4th coloured band (tolerance)	
Red	± 2%
Green	± 5%
white	± 10%
Black	± 20%

5th coloured band (voltage)	
Brown	100V DC
Red	200V DC
Yellow	400V DC

Pblm

A monolithic ceramic capacitor is marked with legend '103k'. What is its value.

Soln

From tabulation,

ceramic capacitor varies from pico to nano

∴ 10 3 k

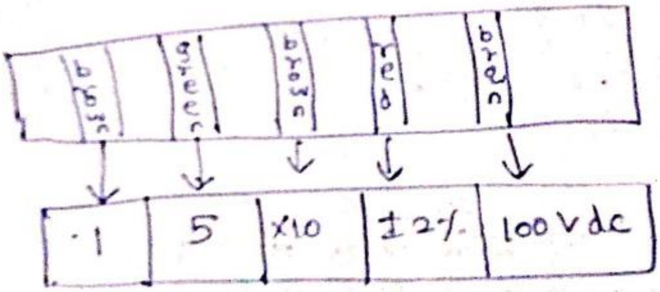
1 → 1, 0 → 0, 3 → 3 digits → 000, k → tolerance ± 10%

∴ Value = 10,000 pF ± 10%

Pblm

A tubular capacitor is marked with coloured stripes, brown, green, brown, red, brown. What is its value, tolerance and working voltage?

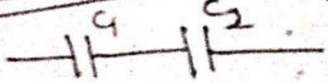
Soln



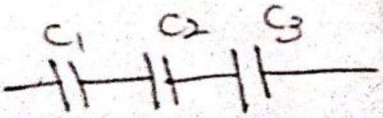
∴ 150 pF ± 2% 100 V dc.

9) **Series and parallel combination of capacitors:**

a) Series



$$\Rightarrow \frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$$



$$\Rightarrow \frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

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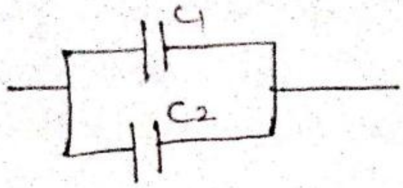
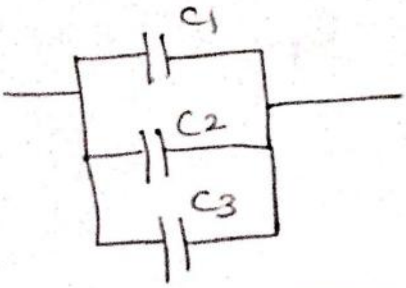
b) Parallel

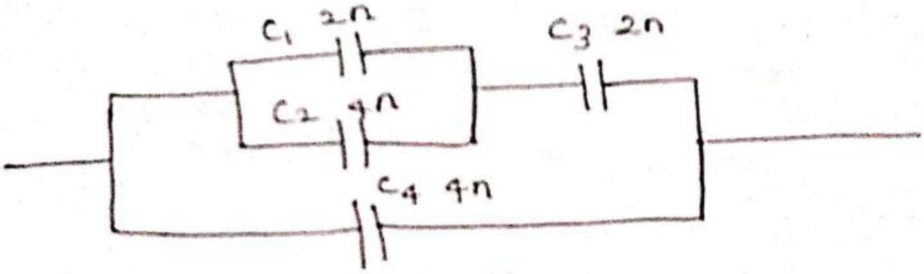


$\Rightarrow C = C_1 + C_2$

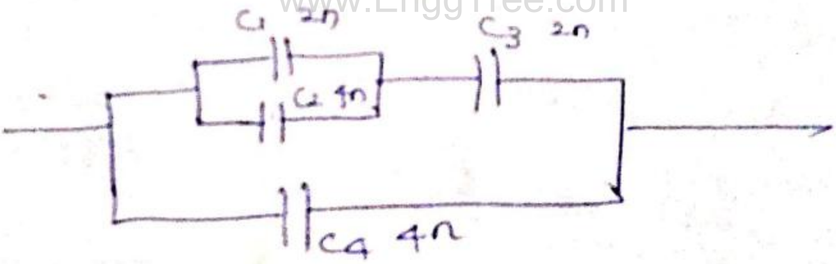


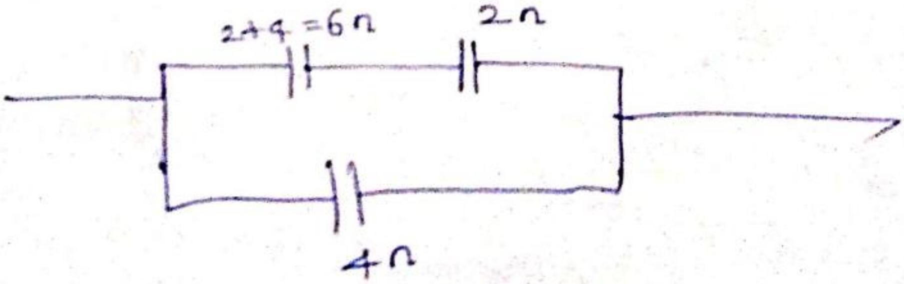
$\Rightarrow C = C_1 + C_2 + C_3$

Pblm Determine the effective capacitance of circuit



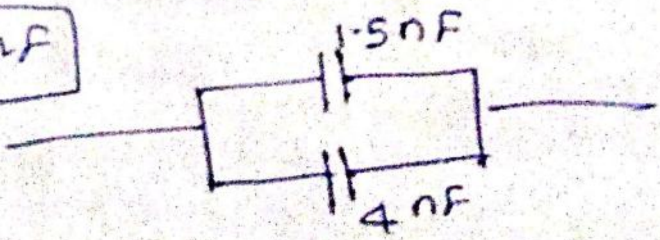
Soln





$$\frac{1}{C} = \frac{1}{6n} + \frac{1}{2n} \Rightarrow \frac{1}{C} = \frac{1}{6\times10^{-9}} + \frac{1}{2\times10^{-9}}$$

$C = 1.5\ nF$



$\Rightarrow C = 1.5 + 4$

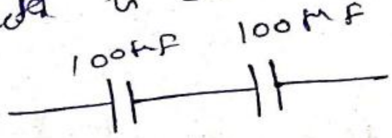
$C = 5.5\ nF$

Pblm

A capacitance of 50 μF (rated at 100 V) is required. What series combination of preferred value capacitors will satisfy this requirement? What voltage rating should each capacitor have?

Soln

Consider 2 ⇒ 100 μF Capacitors can be connected in series



$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$$

$$\frac{1}{C} = \frac{1}{100\times10^{-6}} + \frac{1}{100\times10^{-6}}$$

$$\boxed{C = 50\ \mu F}$$

each capacitor can have 50V rating.

1.4 Inductors: Types, features and specification:

a) Inductance:

→ Inductance is the property of coil which gives rise to the opposition to a change in the value of current flowing in it.

→ Any change in the current applied to a inductor will result in an induced voltage appearing across it.

→ unit of inductance is henry (H)

→ voltage $e = -L \times \frac{di}{dt}$

Pblm A current increases at a uniform rate from 2A to 6A in a period of 250 ms. If this current is applied to an inductor of 600mH, determine voltage induced.

gn

$$di = 6A - 2A = 4\ A$$

$$dt = 250 \times 10^{-3}\ s$$

$$L = 600 \times 10^{-3}\ H$$

T.f e

soln

$$e = -L \frac{di}{dt} = -600 \times 10^{-3} \times \left(\frac{4}{250 \times 10^{-3}}\right)$$

$$= -60 \times \frac{4}{25}$$

$$\boxed{e = -9.6\ V}$$

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b) **Energy Storage:**

→ Energy stored in an inductor is proportional to product of inductance and square of current flowing in it.

$$W = \frac{1}{2} L I^2$$

where W → energy (Joules)

L → Inductance (Henry)

I → Current (Amps)

Pblm An inductor of 20 mH is required to store 2.5 J of energy. Determine current that must be applied.

Gn $L = 20\times10^{-3}$ H

$W = 2.5$ J

T.F I

Soln $W = \frac{1}{2} L I^2$

$2.5 = \frac{1}{2} \times 20\times10^{-3} \times I^2$

$I^2 = \frac{(2.5\times2)}{(20\times10^{-3})}$

$I = \sqrt{250}$

$\boxed{I = 15.81 \text{ A}}$

c) Inductance and Physical dimensions :

→ Inductance depends upon the physical dimensions (ie) length, number of turns, Area, permeability

$$L = \frac{\mu_0 \mu_r n^2 A}{l}$$

where L → Inductance (H), μ_0 → Permeability of free space,

μ_r → relative permeability of core, l → mean length (m)

A → Area of cross section

Pblm An inductor of 100 mH is required. If a closed magnetic core of length 20 cm, cross-sectional area 15 cm^2 and relative permeability 500 is available, determine the number of turns required.

Gn $L = 100\times10^{-3}$ H, $l = 20\times10^{-2}$ m, $A = 15\times10^{-4}$ m^2

$\mu_r = 500$

T.F n

Soln

$$L = \frac{\mu_0 \mu_r n^2 A}{l}$$

$$100 \times 10^{-3} = \frac{4\pi \times 10^{-7} \times 500 \times n^2 \times 15 \times 10^{-4}}{20 \times 10^{-2}}$$

$$n^2 = \frac{100 \times 10^{-3} \times 20 \times 10^{-2}}{4\pi \times 10^{-7} \times 500 \times 15 \times 10^{-4}}$$

$$n = \sqrt{21,215}$$

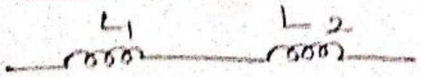
$$\boxed{n = 146}$$

d) Inductor Specifications:

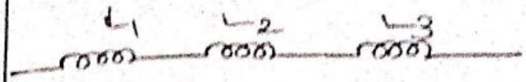
Property	Inductor type			
	Air cored	Ferrite cored	Ferrite pot cored	Iron cored
core material	Air	ferrite rod	Ferrite pot	Laminated steel
Inductance range	50nH to 100µ	10µ to 1m	1m to 100 m	20 m to 20
D.C. resistance (Ω)	0.05 to 5	0.1 to 10	5 to 100	10 to 200
tolerance	± 5	± 10	± 10	± 20
Q factor	60	80	40	20
Frequency range	1M to 500 M	100k to 100M	1k to 10M	50 to 10k
applications	Tuned circuits & filters	Filters and HF transformers	LF & MF filters and transformers	Smoothing chokes and filters

e) Series and Parallel combinations of inductors:

Series

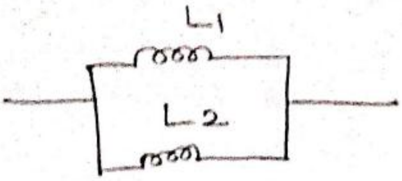


$\Rightarrow L = L_1 + L_2$



$\Rightarrow L = L_1 + L_2 + L_3$

Parallel

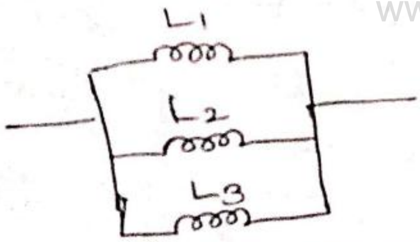


$$\Rightarrow \frac{1}{L} = \frac{1}{L_1} + \frac{1}{L_2}$$

$$\frac{1}{L} = \frac{L_2 + L_1}{L_1 L_2}$$

$$\frac{L_1 L_2}{L_2 + L_1} = L$$

$$L = \frac{L_1 L_2}{L_1 + L_2}$$

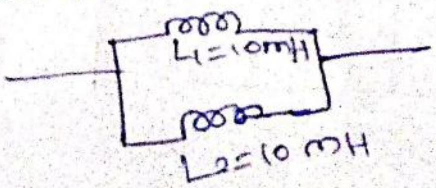


$$\Rightarrow \frac{1}{L} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3}$$

Pblm An inductance of 5mH, rated at 2A is required. What parallel combination of preferred value inductors will satisfy this requirement?

Soln consider 2 ⇒ 10 mH inductors connected parallely

$$L = \frac{L_1 \times L_2}{L_1 + L_2} = \frac{10 \times 10^{-3} \times 10 \times 10^{-3}}{(10+10) \times 10^{-3}}$$



$L = 5\ mH$

→ Equal value of inductors have equal current (i.e) 1 A ∴ 1A + 1A = 2A

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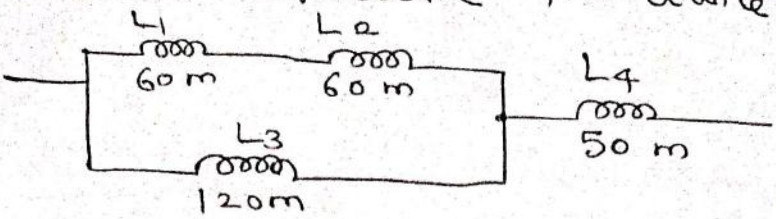
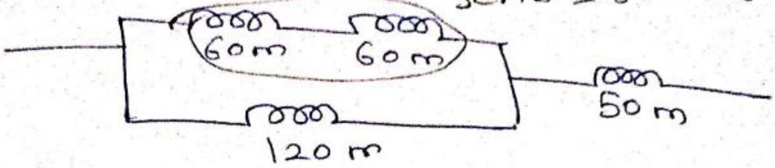
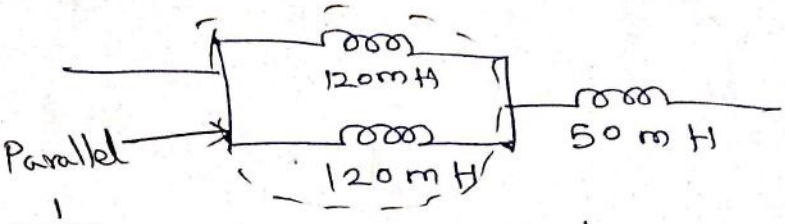
Pblm Determine effective inductance



Soln

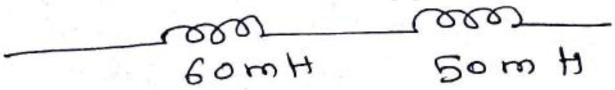
series = 60m + 60m = 120mH





$$\frac{1}{L} = \frac{1}{120\times10^{-3}} + \frac{1}{120\times10^{-3}}$$

$$\boxed{L = 60\ mH}$$



$L = 60\ mH + 50\ mH$

$$\boxed{L = 110\ mH}$$

-5 Energy Band diagram of Conductors, Semiconductor

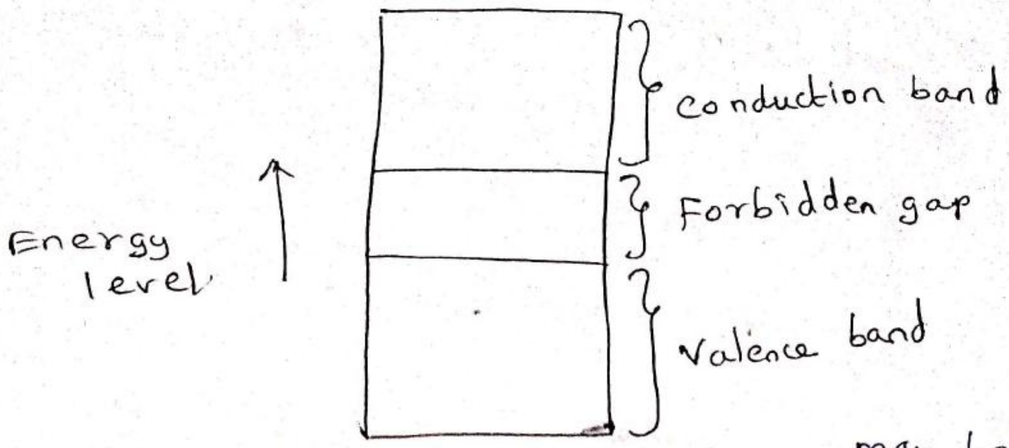
Insulator:

a) **Energy bands:**

→ There are two distinct energy bands in which electrons may exist: the valence band and the conduction band

→ Seperating these 2 bands is an <u>energy gap</u>, termed the <u>forbidden gap</u>, in which electrons cannot normally exist.

<u>Energy band diagram</u>



→ Conduction band electrons may be easily moved by the application of relatively small amount of energy

→ Much larger amounts of energy must be applied to move an electron in valence band of energy levels.

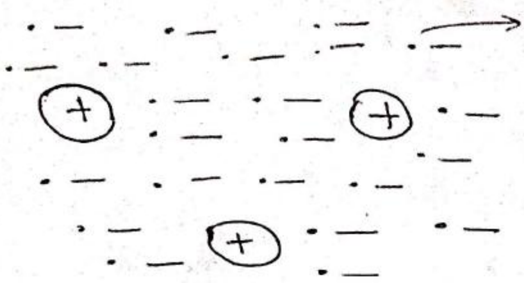
→ Electrons in the valence band are usually in orbit around a nucleus.

→ <u>Energy band diagram</u> is simply a graphic representation of the energy levels associated with electrons.

<u>Bonding forces between Atoms</u>:-

→ Materials like conductor, Semiconductor (or) insulator depends largely upon what happens to outer shell electrons when atoms bond themselves together to form a solid.

→ In the case of copper, the easily detached valence electrons are given up by the atoms.



In metallic bonding, a mass of free electrons (or) electron gas drift around in space between atoms.

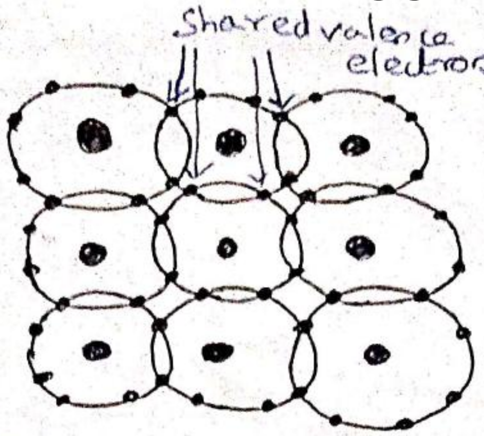
→ The electrons are easily moved under the influence of an applied voltage to create current flow.

→ The bonding force that holds atoms together in a conductor is called <u>metallic bonding</u>

→ Semiconductor atoms normally have 4 outer-shell electrons and 4 holes, and they are so close together that the outer-shell electrons behave as if they are orbiting in valence shells of 2 atoms.

→ In this way, each valence-shell electron fills one of the holes in the valence shell of an adjacent atom. This produce a bonding force referred to as <u>covalent bonding</u>.

→ As shown in fig (next page), it would appear that there are no holes and no free electrons drifting about in the semiconductor material.



Covalent bonding in semiconductors produces very few free electrons (or) holes for current flow

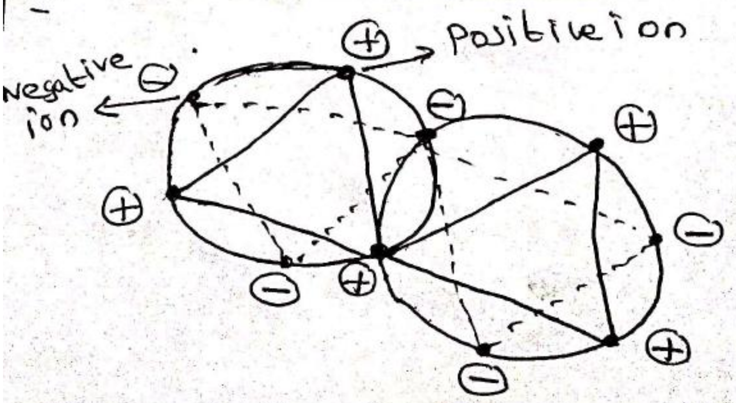
→ In fact, some of the electrons are so weakly attached to their atoms that they can be made to break away to create a current flow when a voltage is applied.

→ In some insulating materials, the atoms bond together in a similar way to semiconductor atoms (covalent bonding).

→ But the valence-shell electrons are so strongly attached to the atoms in an insulator that no charge carriers are available for current flow.

→ In other types of insulating materials, some atoms give up outer-shell electrons, which are accepted into the orbit of nearby atoms

→ Because the atoms are ionized, this is termed ionic bonding.



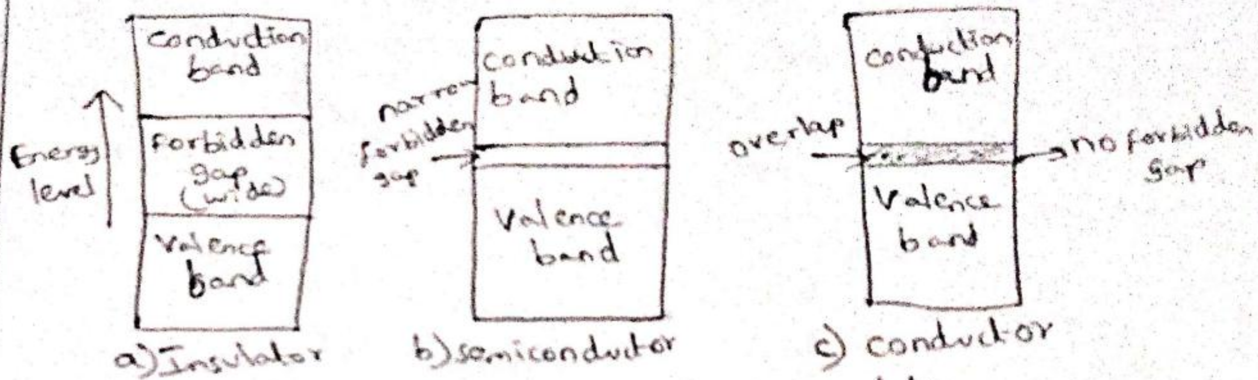
Ionic bonding occurs in some insulating materials

There are no holes (or) free electrons to facilitate current flow.

→ Here again, all of the electrons are

very strongly attached to atoms, and the possibility of current flow is virtually zero.

c) Energy bands in Different Materials-



Energy band diagrams for Insulators, semiconductors and conductors

→ Energy band diagrams show that insulators have a wide forbidden gap, semiconductors have narrow forbidden gap and conductors have no forbidden gap at all.

→ In the case of insulators, they are practically no electrons in the conduction band, and the valence band is filled

→ Moreover, the forbidden gap is so wide that it would require the application of relatively large amounts of energy to cause an electron to cross from valence band to the conduction band.

→ Therefore, when a voltage is applied to an insulator, conduction cannot normally take place either by electron motion (or) hole transfe

→ For semiconductors at a temperature of absolute zero (−273°C), valence band is usually full and there may be no electrons in the conduction band.

→ Forbidden gap in semiconductor is very much narrower than that in an insulator, and the application of small amounts of energy can raise electrons from valence band to the conduction band

→ Sufficient thermal energy for this purpose is available when semiconductor is at normal room temperature.

→ If a voltage is applied to the semiconductor, conduction can occur by both electron movement in conduction band and by hole transfer in the valence band.

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→ In the case of a conductor, there is no forbidden gap, and the valence and conduction energy bands overlap.

→ For this reason, very large numbers of electrons are available for conduction, even at extremely low temperatures.

→ Typical resistance values for $1 cm^3$ cube sample are for conductor $10^{-6}\,\Omega$, for semiconductor $10\,\Omega$, for insulator $10^{14}\,\Omega$.

1.6 Intrinsic and Extrinsic Semiconductor-types

→ Pure semiconductor material is called as intrinsic semiconductor material

→ Before intrinsic material can be used in the manufacture of a device, impurity atoms must be added to improve its conductivity

→ The process of adding atoms is called doping

→ Two type of doping < donor doping / acceptor doping

→ Donor doping generate free electrons in the conduction band (ie) electrons that are not tied to an atom.

→ Acceptor doping produces valence band holes (or) a shortage of valence electrons in the material.

→ After doping, semiconductor material is called as extrinsic semiconductor material.

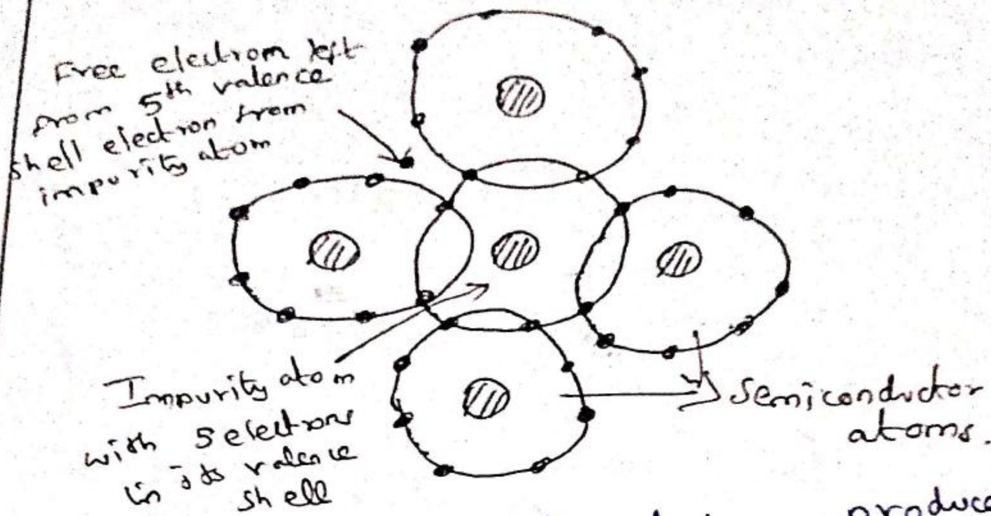
(i) n-type material:

→ In donor doping, impurity atoms that have 5 electrons and 3 hole in their valence shells are added to the undoped material (Fig: next page)

→ The impurity atoms form covalent bonds with silicon (or) germanium atoms

→ Because the semiconductor atoms have only 4 electrons and 4 hole in their valence shells, there is one extra valence shell electron for each impurity atom added.

Donor doping



→ Each additional electron produced in this way enters the conduction band as a free electron.

→ Because free electrons have negative charges, donor-doped semiconductor is called as n-type material

→ Free electrons in conduction band are easily moved around under the influence of an electric field.

→ Consequently, conduction takes place largely by electron motion in donor-doped semiconductor material.

→ Doped material remains electrically neutral (neither positively charged nor negatively charged) because total number of electrons (including free electrons) is still equal to

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total number of protons in in atomic nuclei.

→ The term donor doping comes from the fact that an electron is donated to the conduction band by each impurity atom.

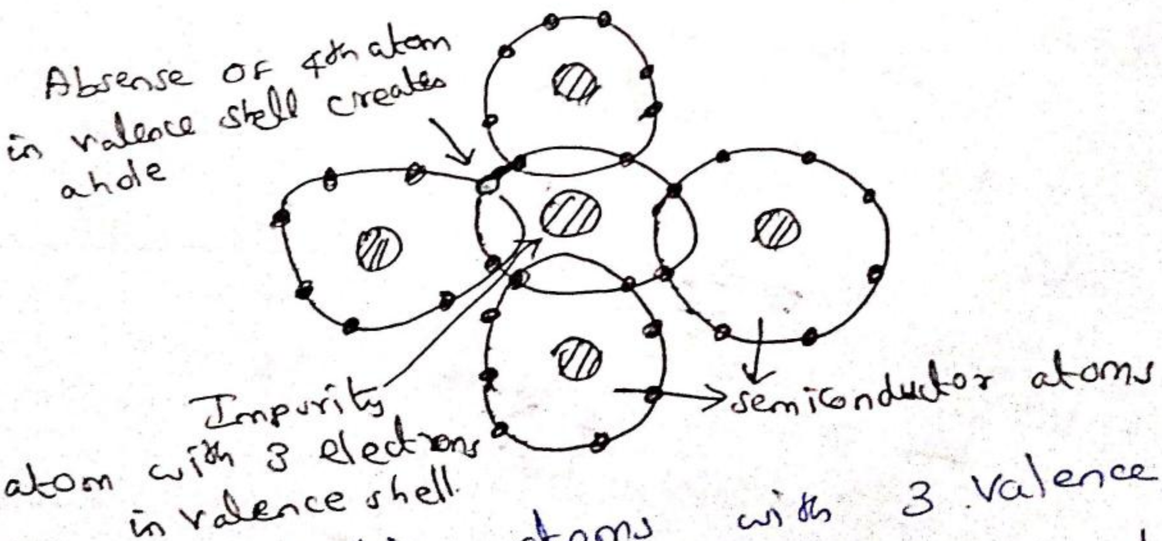
→ Typical donor materials are antimony, phosphorus and arsenic.

→ since these atoms each have 5 valence electrons, they are referred to as pentavalent atoms.

(ii) P-type material:

→ Impurity atoms used for acceptor doping have outer shells containing 3 electrons and 5 holes.

Acceptor doping



→ Suitable atoms with 3 valence electrons (trivalent atoms) are boron, aluminium and gallium.

→ These atoms form covalent bonds with semiconductor atoms, but bonds lack one electron for complete outer shell of eight.

→ Impurity atom illustrated has only 3 valence electrons; so a hole exists in its bond with surrounding atoms.

→ It is seen that in acceptor doping, holes are introduced into valence band so that conduction may occur by the process of hole transfer.

→ Since holes can be said to have positive charge, acceptor doped semiconductor material is referred to as p-type material

→ Like n-type, p-type material remains electrically neutral, because total number of orbital electrons in each impurity atom is equal to total number of protons in its atomic nucleus.

→ The term acceptor doping comes from the fact that holes can accept a free electron.

1.7 PN junction diode:

→ The term diode refers to a two-electrode (or) two-terminal device

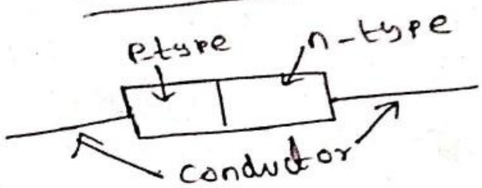
→ A diode is a one-way device, offering a low resistance when forward-biased and behaving almost as an open switch when reverse biased.

→ Pn-junction permits substantial current flow when forward biased, and blocks current when reverse biased.

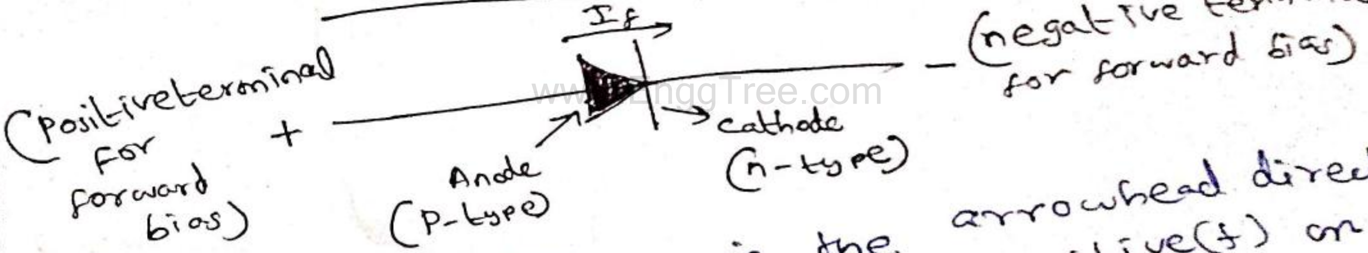
→ Thus, it can be used as a switch = **ON** when forward-biased and **OFF** when reverse-biased

→ A pn-junction provided with copper wire connecting leads becomes an electronic device known as **diode**

Pn-junction diode



circuit symbol (or) graphic symbol



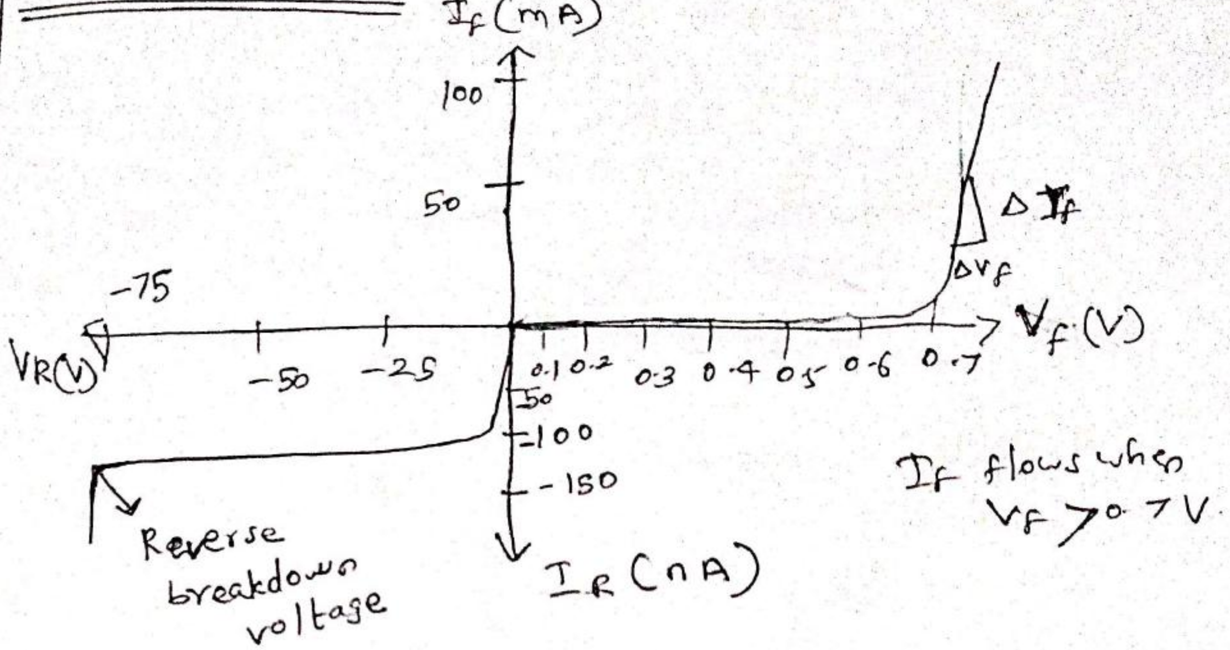
→ current flows in the arrowhead direction when diode is forward biased : positive(+) on anode and negative(−) on cathode

→ circuit symbol is an arrowhead and bar

→ p-side of the diode is always the positive terminal for forward bias and is termed the **anode**, called the **cathode**

→ n-side of the diode is the negative terminal when device is forward biased.

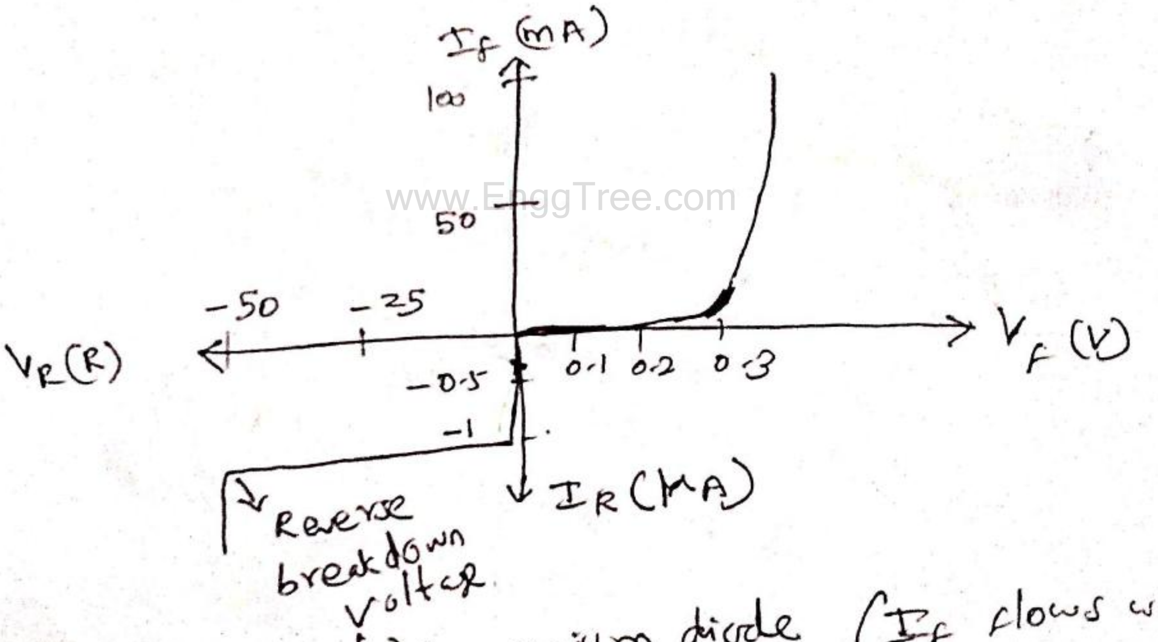
ii) Characteristics:



a) Silicon diode

f → forward

R → reverse



b) Germanium diode (I_f flows when $V_f > 0.3V$)

→ In silicon diode, forward current (I_f) remains very low ($\leq$ 100 μA) until diode forward bias voltage V_f reaches ~ 0.7V. At $V_f > 0.7V$, I_f increases linearly.

→ I_R (reverse current) is very much smaller than forward current.

→ I_R is largely a minority charge carrier reverse saturation current.

→ I_R is quite negligible when compared to I_F and reverse biased diode may be treated as an open switch.

→ dynamic resistance of diode $(r_d) = \frac{\Delta V_F}{\Delta I_F}$ = reciprocal of slope of forward characteristic

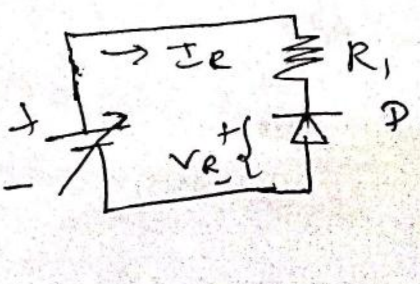
1·8 Zener diode :

→ A diode can be operated in reverse breakdown if current is limited by means of series connected resistor.

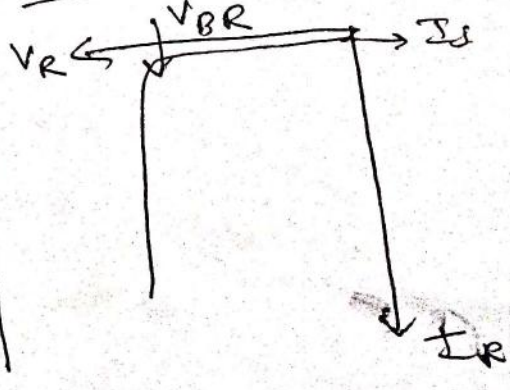
→ Zener diodes are designed for operation in reverse breakdown.

→ when a junction diode is reverse biased, there is normally only a very small reverse saturation current (I_S) on reverse characteristic.

Diode resistor circuit



Diode reverse characteristic



→ When the reverse voltage is sufficiently increased, the junction breaksdown and a large reverse current flows.

→ If the reverse current is limited by means of a suitable series connected resistor (R_1), the power dissipation in the diode can be kept to a level that will not destroy the device.

→ In this case, diode may be operated continuously in reverse breakdown.

→ The reverse current returns to its normal level when voltage is reduced below reverse breakdown level.

→ Diodes designed for operation in reverse breakdown are found to have a breakdown voltage that remains extremely stable over a wide range of current levels.

→ This property gives the breakdown diode many useful applications as a voltage reference source.

→ There are 2 mechanisms that cause breakdown in a reverse biased pn-junction.

→ With a very narrow depletion region, electric field strength (volts/width) produced by a reverse bias voltage can be very high.

→ The high-intensity electric field causes electrons to break away from their atoms, thus converting depletion region from an insulating material into a conductor. This is ionization by electric field, also called as zener breakdown and it usually occurs with reverse bias voltages less than 5V.

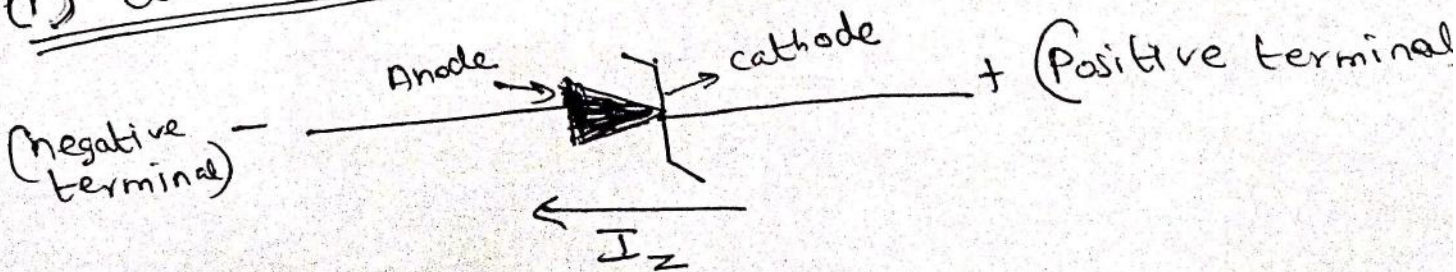
→ In cases where depletion region is too wide for zener breakdown, the electrons in the reverse saturation current can be given sufficient energy to cause other electrons to break free when they strike atoms within the depletion region. This is termed as ionization by collision.

→ The electron released in this way collide with other atoms to produce more free electrons in an avalanche effect.

→ Avalanche breakdown is normally produced by reverse voltage levels above 5V.

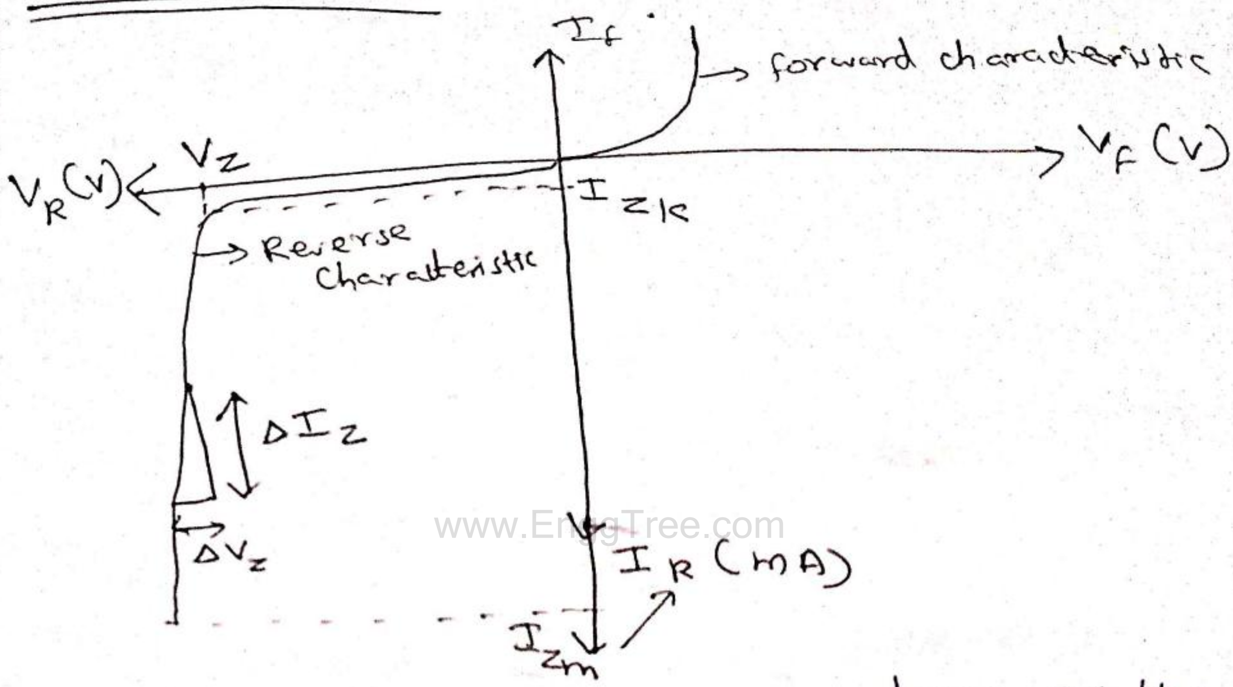
→ Although zener and avalanche are 2 different types of breakdown, the name zener diode is commonly applied to all breakdown diodes.

(i) Circuit symbol:



→ for operation in reverse bias, voltage drop (V_Z) is positive (+) on cathode and negative (−) on anode.

(ii) Characteristics



I_{ZK} → Reverse current near knee of the characteristic (ie) minimum reverse current to sustain breakdown

V_Z → Zener breakdown voltage

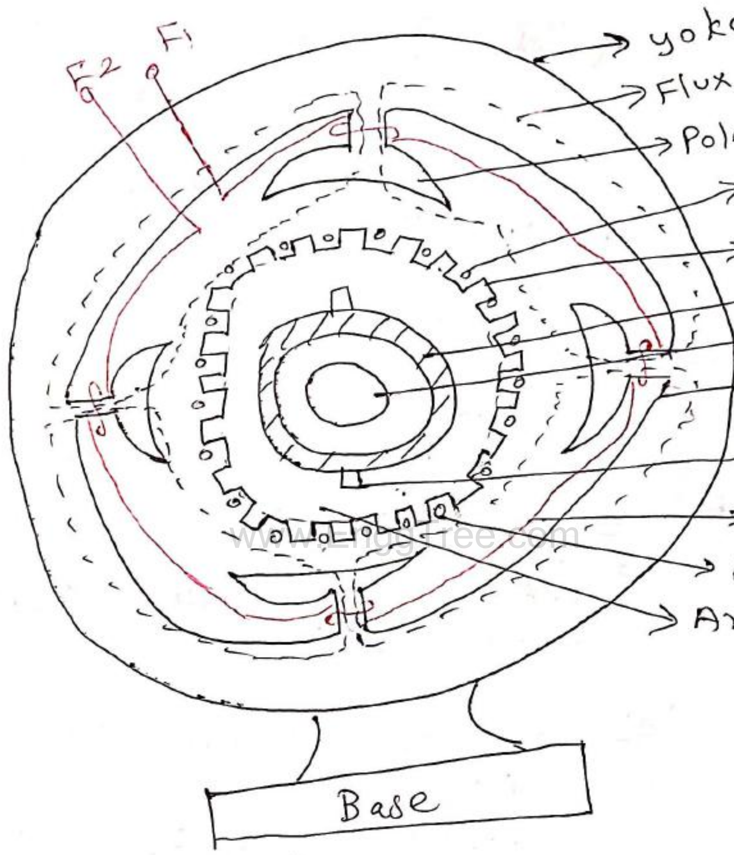
I_{ZM} → Maximum zener current, limited by maximum power dissipation

→ Dynamic impedance (Z_Z) $= \dfrac{\Delta V_Z}{\Delta I_Z}$

ELECTRICAL MACHINES

2.1 Construction, Principle of Operation, Basic Equations and Applications - DC Generator

① Construction:



(i) Yoke:

a) Functions:

→ It is the outermost cover of DC machine

→ It provides mechanical support to pole

b) Choice of material: → cast iron

(ii) Pole

a) Function:

→ Pole core carries field winding to produce flux

b) Choice of material:

→ cast iron (or) cast steel

(iii) Field Winding (or) Exciting Winding:

a) Function:

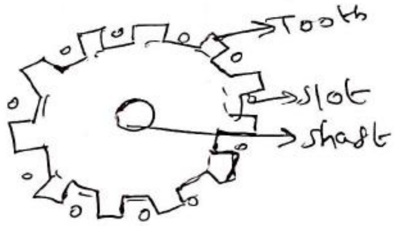
→ Field winding is used to carry current to produce flux.

b) Choice of material:

→ copper

(IV) Armature:

→ It has 2 parts
1. Armature core
2. Armature winding



① Armature core:

a) function: Armature core acts as house for armature winding

b) Choice of material: cast iron (or) cast steel

② Armature Winding:

a) function:

→ Generation of emf in case of generator

→ To carry current in case of motor

b) choice of material: Copper

(v) Commutator:

a) Function: To collect current from armature

b) choice of material: copper

(vi) Brush:

a) function: To collect current from commutator

b) choice of material: carbon

② Principle of Operation

→ Generators work on the principle of dynamically induced emf. This principle is the Faraday's law of electromagnetic induction.

→ It states that "whenever flux linking with conductor changes, an electro motive force is set up in that conductor" This emf is called dynamically induced emf

→ In practical generator, conductors are rotated to cut the magnetic flux, keeping flux stationary.

→ To have rotation of conductors, conductors placed on armature are which are rotated with the help of prime mover like diesel engines, steam engines, turbines etc

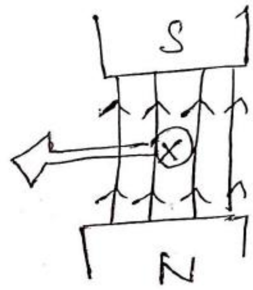
→ flux is produced by current carrying winding called field winding.

→ Direction of induced emf can be obtained by using Fleming's right hand rule.

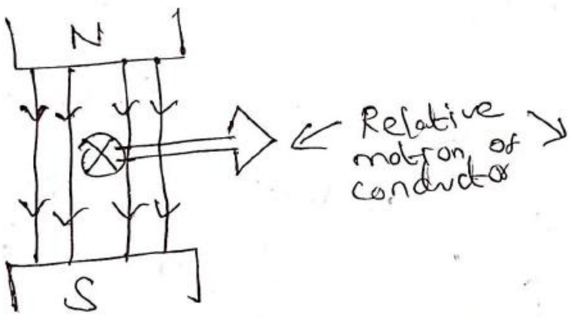
Direction of emf

a) current coming out

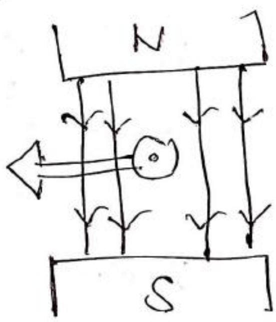
b) current going in



c) current going in



d) current coming out

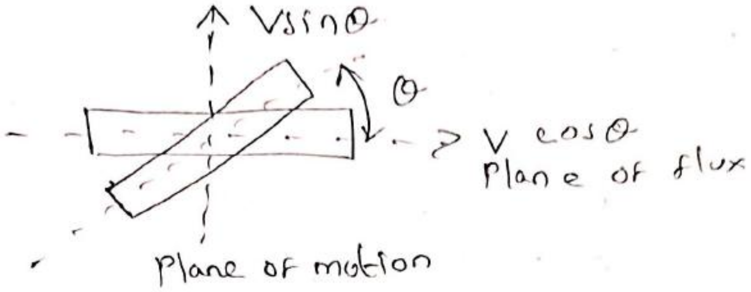


→ Magnitude of induced emf $E = B \times l \times v$

where B → flux density
l → length of conductor
v → Relative velocity component

→ If angle between plane of rotation & plane of flux is 'θ', then induced emf

$E = B l v \sin\theta$



→ Induced emf is purely sinusoidal (i.e) alternating

→ commutator is a device in dc generator to convert alternating emf to unidirectional emf

→ without commutator, generator is called as an alternator

(3) Basic Equations :

→ EMF $E = \frac{\phi Z N}{60} \frac{P}{A}$

where ϕ → flux (wb)

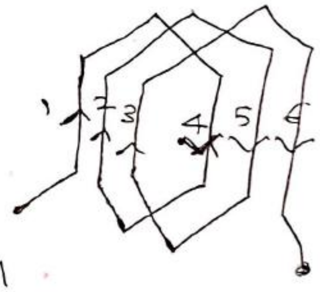
Z → No. of conductors

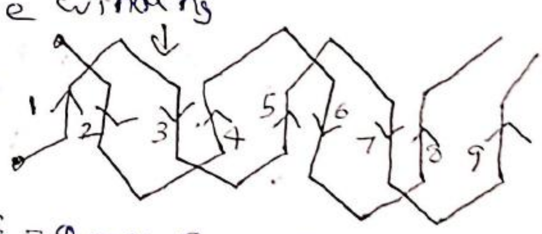
N → speed (rpm)

P → No. of poles

A = P for Lap winding

A = 2 for wave winding





→ for lap winding, A = P, $E = \frac{\phi Z N}{60} \frac{P}{P} = \frac{\phi Z N}{60}$

→ for wave winding, A = 2, $E = \frac{\phi Z N}{60} \frac{P}{2} = \frac{\phi Z N P}{120}$

④ Applications :

→ DC generators are used in
ⓐ labs for testing
ⓑ Battery charging
ⓒ DC locomotive
ⓓ Power supply

2.2 Construction, Principle of operation, Basic Equations and Applications - DC Motors

① Construction

Same as 2.1 (i) in page No : 2.1-2.3

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② Principle of Operation:

→ Principle: Faraday's law of electro magnetic induction

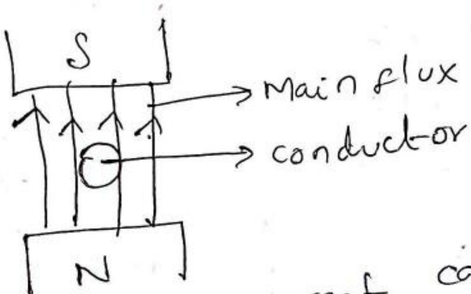
"When a current carrying conductor is placed in a magnetic field, it experiences a mechanical force".

→ In dc motor, field winding produces magnetic field and armature conductors play a role of current carrying conductors and hence force is produced

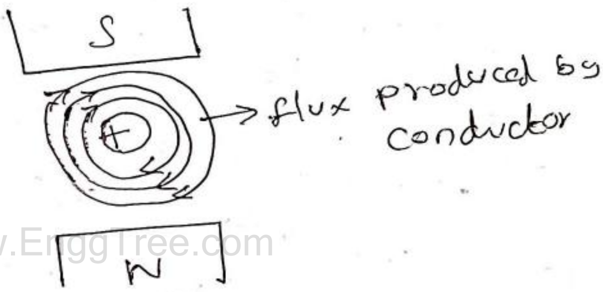
→ Individual force experienced by conductors acts as turning force called torque

→ Torque = force × radius

→ consider a single conductor placed in magnetic field.



→ Flux produced by current carrying conductor



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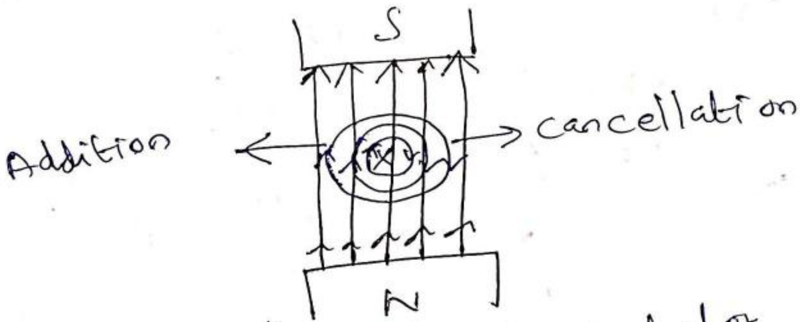
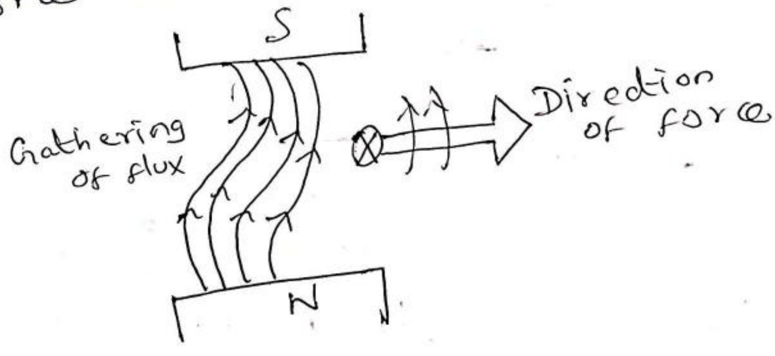
→ Interaction of 2 fluxes



→ Force experienced by conductor



→ It is clear that on one side, there is gathering of 2 fluxes and in other side, there is cancellation of 2 fluxes.

→ This gives a mechanical force on conductor.

→ Force $F = BIl$ (Newton)

where B → flux density
i → magnitude of current
l → length of conductor

→ Direction of force is obtained by Fleming's left hand rule.

→ After a motoring action, there is generating action (ie) induced emf produced by Faraday's law and it is in opposite to supply voltage by Lenz's law

→ As this emf opposes supply voltage, it is called back emf (E_b)

→ $E_b = \frac{\phi Z N}{60} \frac{P}{A}$ (volts)

(3) Basic Equations

→ Torque $T = 0.159\, \phi I_a \frac{PZ}{A}$ (N-m)

where ϕ → flux
I_a → Armature current
P → No. of poles
Z → No. of conductors
A → $A = P$ for Lap winding, $A = 2$ for wave winding

4) Applications:

	Types of motor	Applications
1)	Shunt motor	Lathe machines Blowers Drilling machine
2)	Series motor	Cranes Hoists Conveyors Elevators
3)	Compound motor	Punches Elevators Rolling mills Printing press

2.3 Construction, Principle of operation, Basic Equations and Applications - Single phase Transformer

1) Construction.

→ Transformer is a static device by means of which an electrical power is alternating current transformed from one circuit to another with the desired change in voltage and current, without any change in frequency.

→ There are 2 basic parts of transformer

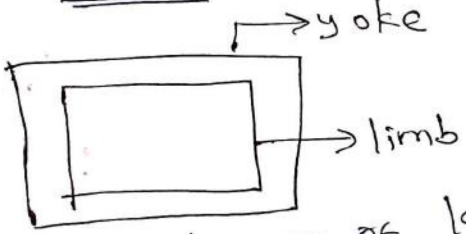
(i) Magnetic core
(ii) windings (or) Coils.

→ Core of transformer is either square (or) rectangular in size

→ It is further divided into 2 parts

(i) Vertical portion on which coils are wound is called <u>limb</u>

(ii) Top and bottom horizontal portion is called <u>yoke</u>

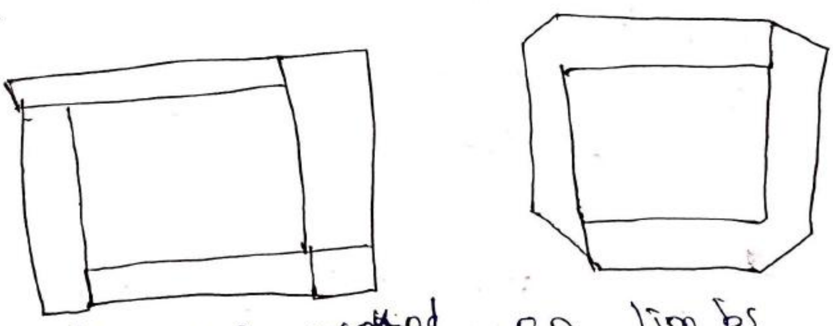


→ core is made up of laminations

→ Because of laminated type of construction, eddy current losses get minimised.

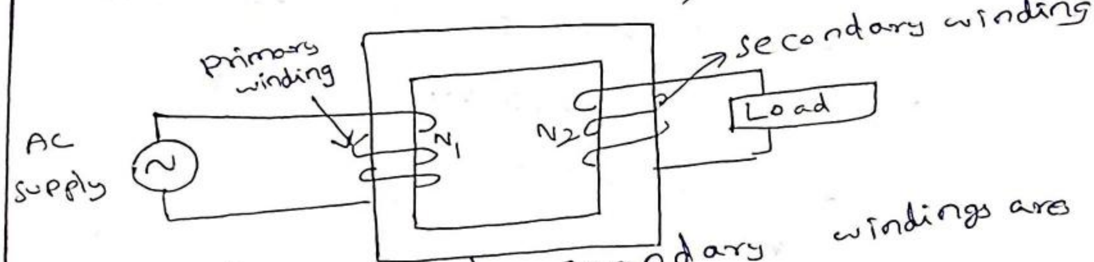
→ laminations are insulated by varnish.

→ laminations are overlapped ~~by~~ to avoid air gap at joints. For this, 'L' shaped (or) 'I' shaped laminations are used.



→ coils are wound on limbs

→ In basic transformer,



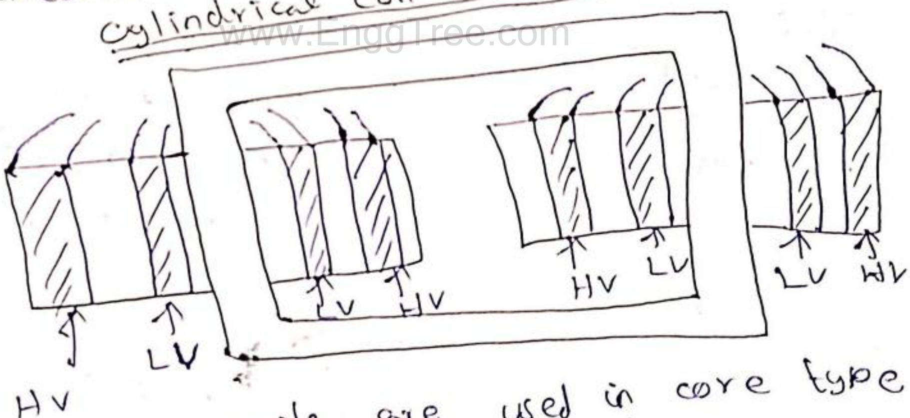
primary and secondary windings are wound on different limbs.

→ To have high mutual inductance and to reduce leakage flux, windings should be very close to each other.

→ common arrangement is cylindrical concentric coils

LV → Low voltage
HV → High voltage

cylindrical concentric coils



→ These coils are used in core type transformer and these are mechanically strong

→ Insulation is given by paper, cloth (or) mica

→ LV winding is placed near the core for ease of insulating it from the core.

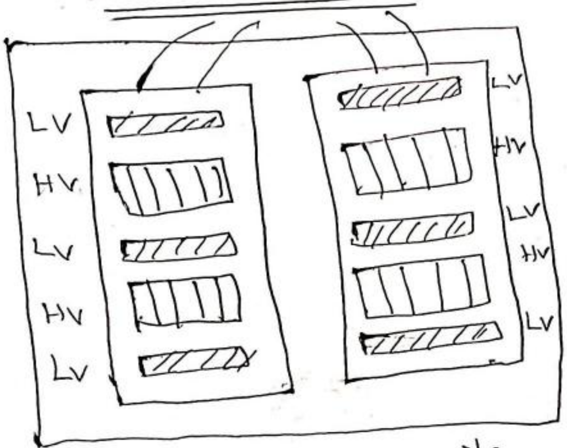
→ HV coil is placed after LV coil

→ The other type of coils used for

shell type of transformer is sandwich coils

→ Each HV portion lies between two LV portion, sandwiching the HV portion.

→ Sandwich coils



→ Top and bottom coils are low voltage coils.

→ All portions are insulated from each other by paper.

Types of Transformer
- (i) core type
- (ii) Shell type
- (iii) Berry type

(i) core type transformer :

→ It has a single magnetic circuit

→ core is rectangular having 2 limbs

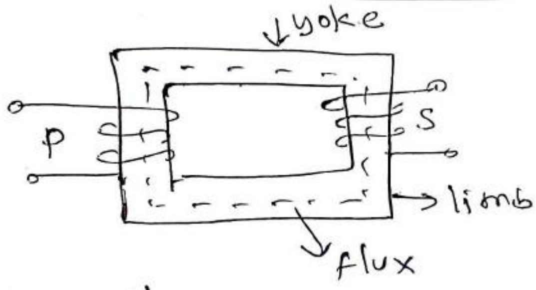
→ winding encircles the core

→ coils are of cylindrical type and so coils are wound in helical layers insulated each other by paper (or) mica

→ Both coils are placed on both the limbs

→ low voltage coil is placed inside near the core while high voltage coil surrounds low voltage coil.

Schematic representation



(ii) Shell type transformer:

→ It has double magnetic circuit

→ core has 3 limbs

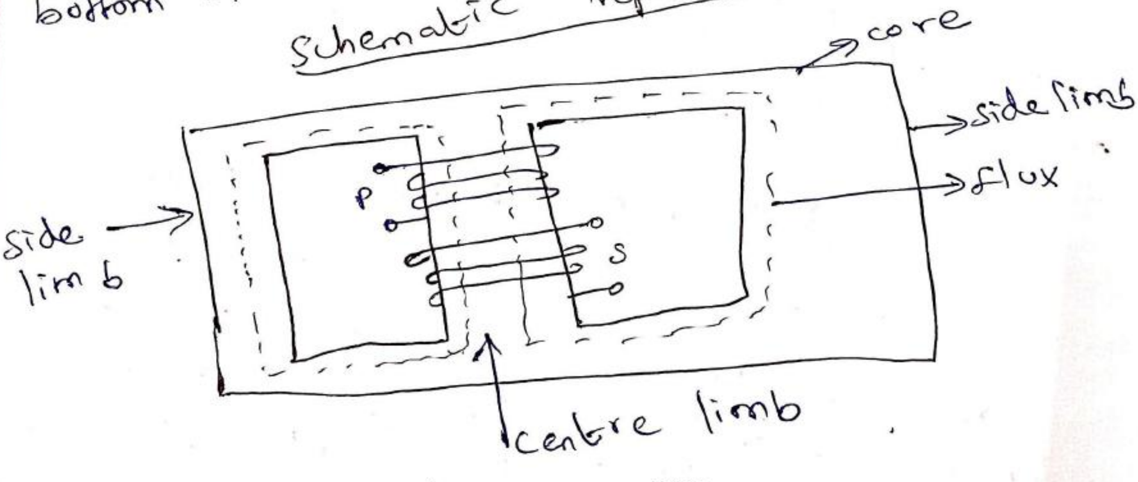
→ Both windings are placed on central limb

→ core encircles most part of the windings

→ core is laminated.

→ Each HV coil is in between 2 LV coils and LV coils are nearest to top and bottom of the yokes.

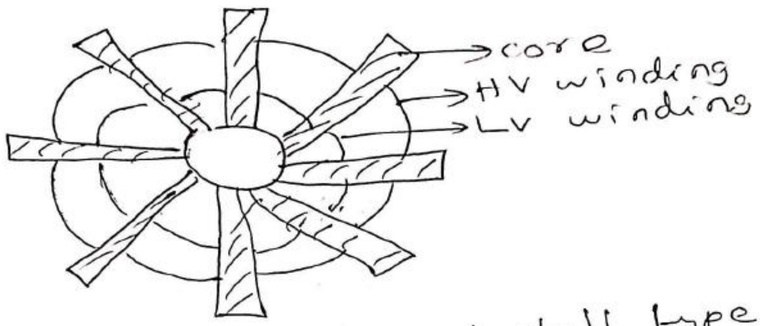
Schematic representation



(iii) Berry type transformer:

→ This has distributed magnetic circuit.

→ Its core construction is like spokes of the wheel



(b) Comparision of core and shell type transformer

Sl.No	Core type	Shell type
1.	winding encircles the core	core encircles most part of the winding
2.	It has single magnetic circuit	It has double magnetic circuit
3.	core has 2 limbs	core has 3 limbs
4.	cylindrical coils are used	sandwich coils are used.
5.	preferred for low voltage transformers	preferred for high voltage transformers

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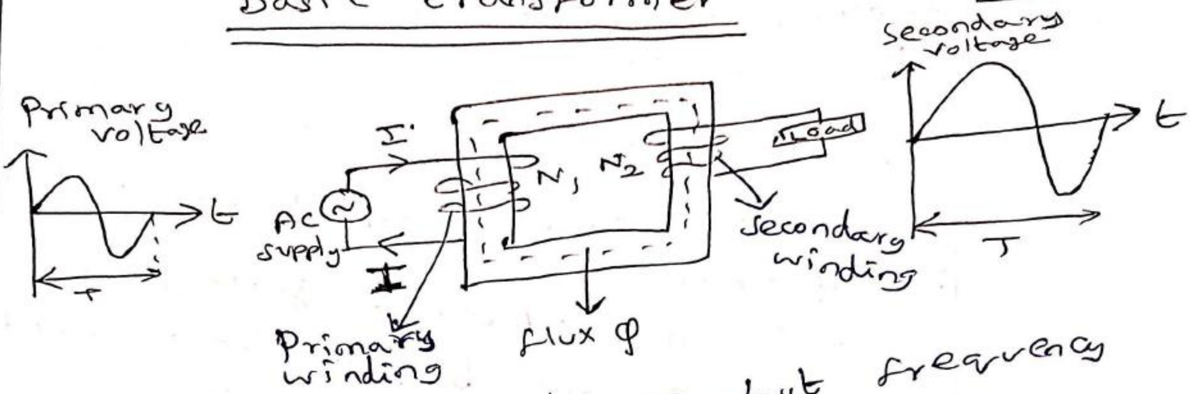
(2) Principle of Operation:

→ **Principle : Mutual Induction**

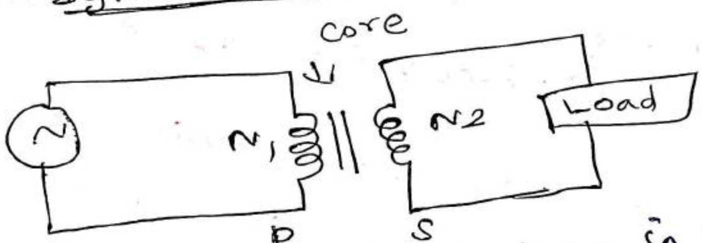
"When two coils are inductively coupled and if current in one coil is changed uniformly, then an emf gets induced in other coil. This emf can drive a current, when a closed path is provided to it".

Basic transformer



→ Voltage level changes but frequency (ie) time period remains same.

Symbolic representation



→ When primary winding is excited by voltage, it circulates an alternating current.

→ This current produces an alternating flux (φ) and this flux links with secondary winding.

→ As flux is alternating, according to faraday's law of electromagnetic induction mutually induced emf gets developed in secondary winding.

→ If now load is connected to secondary winding, emf drives a current through it.

→ Though there is no electrical contact between 2 windings, an electrical energy gets transferred from primary to secondary.

Can dc supply be used for transformer?

→ Dc supply cannot be used for transformers

→ If dc supply is given, current will not change due to constant supply and transformer will not work.

→ Total impedance of winding is very low. So this winding will draw very high current if dc supply is given to it.

→ This may cause burning of windings and may cause permanent damage to transformer.

→ Thus dc supply should not be connected to transformers.

(3) Basic equations:

→ Emf equation $E = 4.44 f \phi_m N$ (volts)

where f → frequency, ϕ_m → maximum flux

N → number of turns.

→ Transformation ratio $k = \frac{V_2}{V_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2}$

→ voltage regulation in % $(R) = \frac{E_2 - V_2}{V_2} \times 100$

→ Efficiency in % $(\eta) = \frac{\text{Output power}}{\text{Input power}} \times 100\%$

→ Condition for maximum efficiency ⇒ Copper loss = Iron loss

④ **Applications:**

→ Transformers are used in

a) transmission and distribution for step up (or) step down voltage

b) substations to regulate voltage

c) Battery charging

d) Lighting systems

e) Renewable energy systems

2.4 Construction, Principle of Operation, Basic Equations and Applications for single phase Induction Motor:

① **Construction:**

→ 2 parts
- → Stationary part called Stator
- → Rotating part called Rotor

→ Stator has laminated construction made up of stampings to carry stator windings.

→ Single phase ac supply is given to stator.

→ Lamination is used to minimize iron loss

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→ Silicon steel is used to minimize hysteresis loss

→ Synchronous speed $N_s = \frac{120 f}{P}$

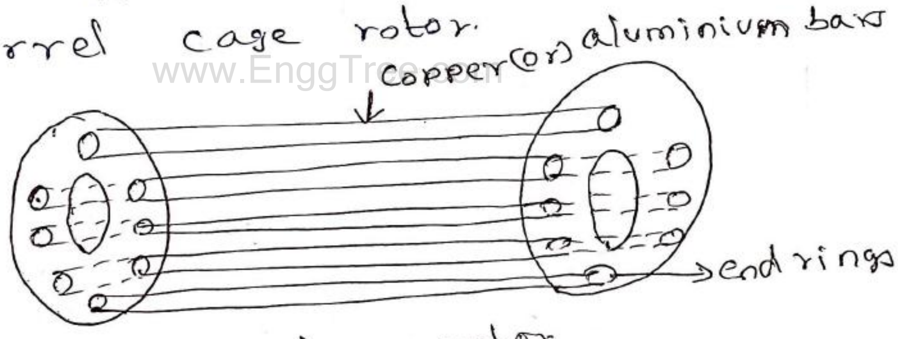
→ Induction motor never rotates with N_s

→ Motor is of squirrel cage type

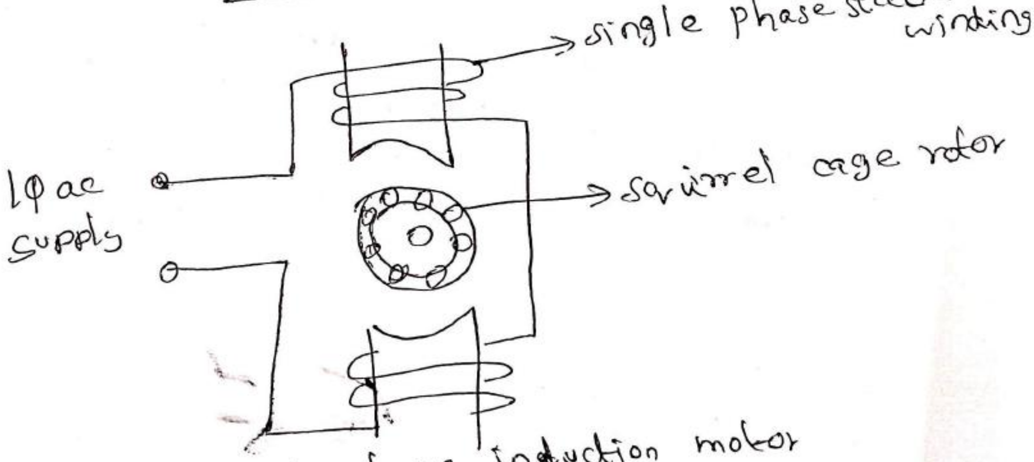
→ copper (or) aluminium bars are placed in slots.

→ Bars are permanently shorted with the help of end rings.

→ entire structure looks like cage called squirrel cage rotor.



Squirrel cage rotor



Single phase induction motor

② Principle of Operation:

a) Working principle:

→ In single phase induction motor, single phase ac supply is given to stator & so it produces alternating flux called main flux

→ This flux links with rotor conductors and so emf gets induced. This emf produces rotor current.

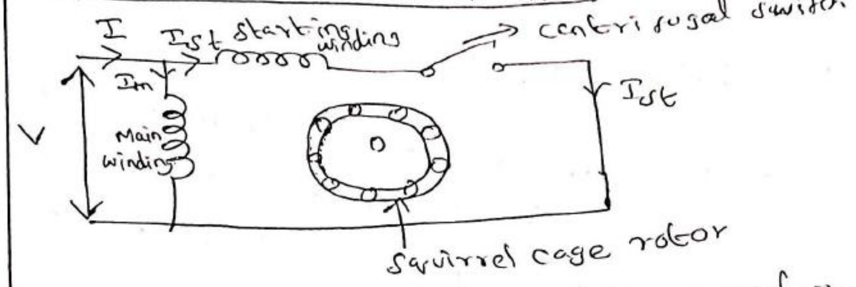
→ Rotor current produce flux called rotor flux. This rotor flux is produced due to induced emf according to Induction principle

→ Comparison between DC motor and induction motor: DC motor has 2 fluxes due to seperate supply in armature and field winding. While Induction motor has supply only to stator. DC motor is self starting motor and Induction motor is not self starting.

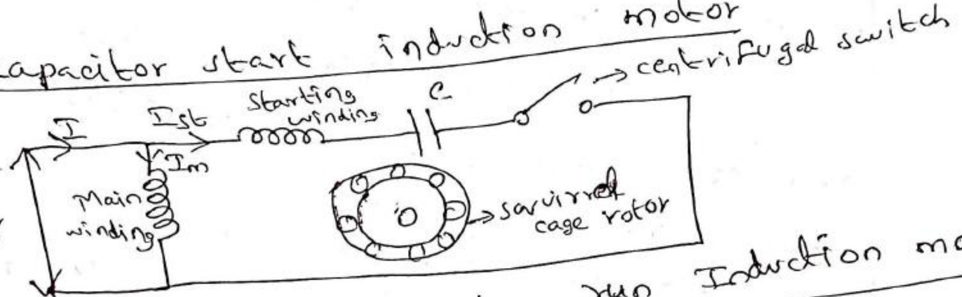
b) Starting methods of single phase Induction motor:

(i) Split phase Induction motor
(ii) Capacitor start Induction motor
(iii) Capacitor start Capacitor run Induction motor
(iv) Shaded pole Induction motor.

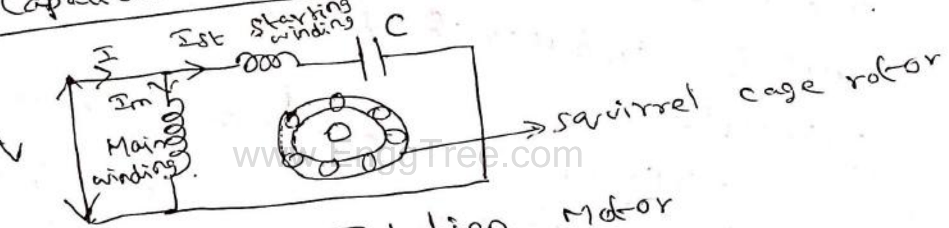
(i) split phase induction motor



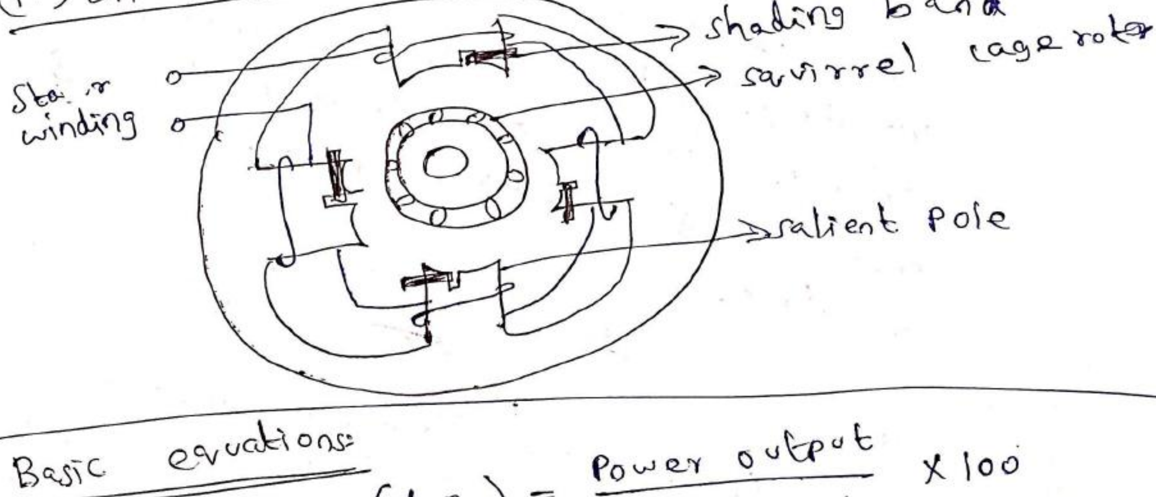
(ii) capacitor start induction motor



(iii) Capacitor start capacitor run Induction motor



(iv) Shaded Pole Induction Motor



(3) Basic equations:

→ Efficiency (% η) = $\frac{\text{Power output}}{\text{Power input}} \times 100$

(4) Applications :-

→ fans, Blowers, Grinder, compressor, toy motors, record players, hair dryer, washing machine

2.5 Construction, principle of operation, Basic Equations and Applications for Three phase Induction motor:

2-21

① Construction:

→ Two main parts

(i) Part (ie) 3φ windings, which is stationary called stator

(ii) Part which rotates and is connected to mechanical load through shaft called rotor

(i) Stator:

→ laminated construction made up of stampings to carry stator winding.

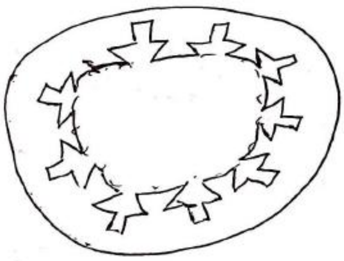
→ lamination is used to reduce iron loss

→ stampings made up of silicon to reduce hysteresis loss

→ slots on periphery carries 3φ winding called stator winding in star (or) Delta

→ 3φ winding produce rmf when excited.

→ ducts are provided for cooling



(ii) Rotor

→ laminated construction

→ cylindrical with slots in periphery

Types of Rotor

a) Squirrel cage rotor
b) Slip ring (or) wound rotor

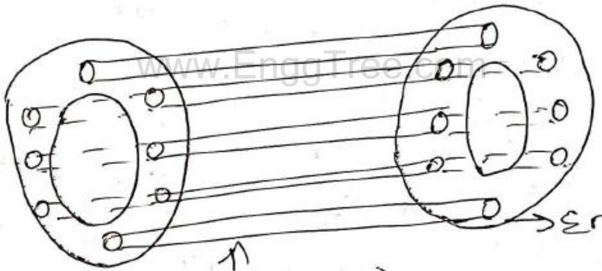
a) Squirrel cage rotor:

→ rotor has copper (or) aluminium bars called rotor conductor

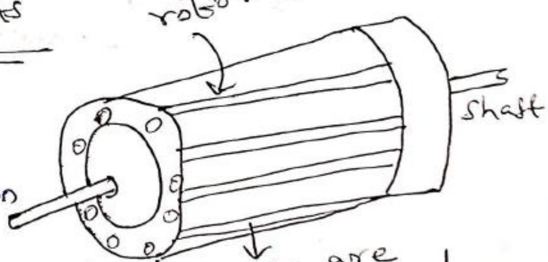
→ Bars are placed in slots and permanently shorted with copper ring called end ring

→ Entire structure looks like cage called squirrel cage rotor

→ Since rotor is shorted, rotor resistance is very very small. so it is short circuited rotor



→ Slots are skewed in nature.



→ Advantages for skewed slots

→ Magnetic hum (ie) noise gets reduced due to skewing

→ It makes motor operation smooth.

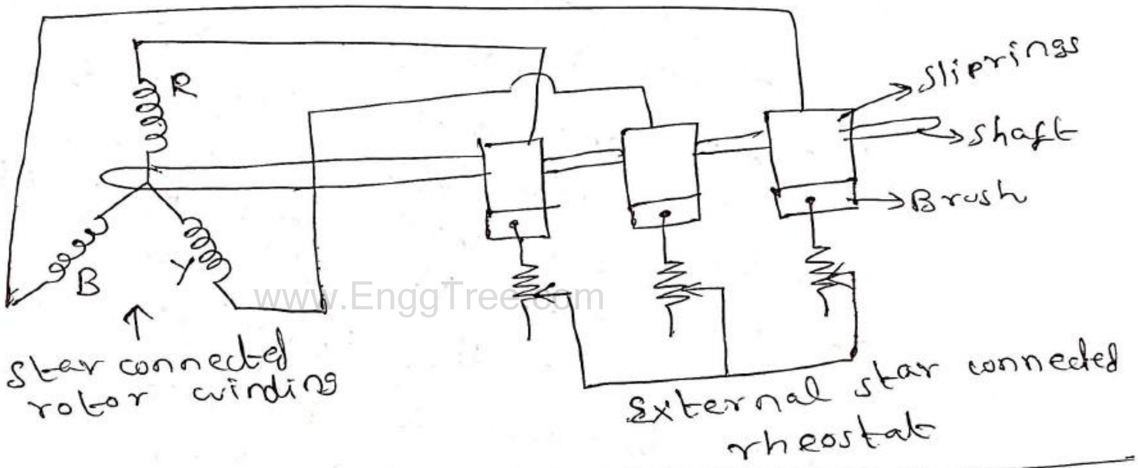
→ Tendency of magnetic locking gets reduced due to skewing.

b) Slip ring (or) wound rotor

→ Rotor carries 3φ λ (or) Δ connected distributed winding, wound for same number of poles like stator.

→ 3 ends of 3φ winding is connected to slip ring

→ external resistance can be connected with the help of slipring and brushes.



② principle of operation

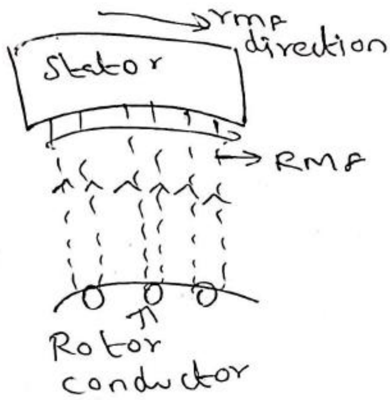
→ Principle : Electromagnetic Induction

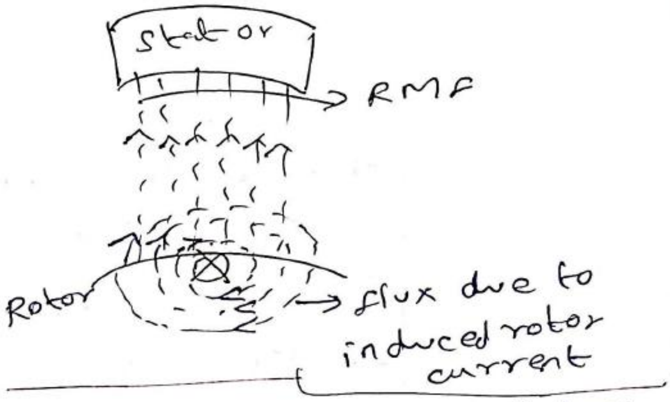
→ 3φ supply is given to 3φ stationary winding and it produces rmf (ie) rotating magnetic field

→ Speed of rmf = $N_s = \frac{120f}{P}$

where f → frequency, P → pole

→ rmf produce an effect of rotating poles around rotor.





→ Initially rotor is stationary and stator rmf is rotating

→ Due to this rmf, rotor conductors cuts the flux and emf is induced in rotor.

→ On the left side of the rotor conductor, flux will add each other and at right side, it will cancel each other.

→ Due to the interaction of these 2 fluxes, torque is produced and it tries to catch the speed of rmf.

→ But induction motor never rotates at synchronous speed.

→ Reason for why induction motor never rotates at synchronous speed.

→ If induction motor rotates in synchronous speed (N_s), $N_s - N_s = 0$. So induced emf is also zero. So torque on motor becomes zero. So motor will stop. But due to inertia of motor, this does not happen in practise. So rotor continues to rotate with Speed less than synchronous speed.

→ Speed at which induction motor rotate is called subsynchronous speed and so it is called as asynchronous motor $(N < N_S)$

→ Slip speed $= N_S - N$
= Synchronous speed − Rotor speed

③ Basic Equations:

→ $\text{Slip } S = \frac{N_S - N}{N_S} = \frac{\text{Slip speed}}{\text{Synchronous speed}}$

→ $\text{Torque} = \frac{k S E_2^2 R_2}{R_2^2 + (S X_2)^2}$

→ $\text{Slip} = \frac{R_2}{X_2}$ at maximum torque

④ Applications:

→ Pumps
→ compressors
→ fans
→ conveyor belts
→ lathes
→ Milling machines
→ Hoists

2-6 Construction, principle of operation, Basic Equations and Applications for Three phase Alternator

(1) Construction

→ In alternator, stationary winding is called 'stator', while rotating winding is called Rotor

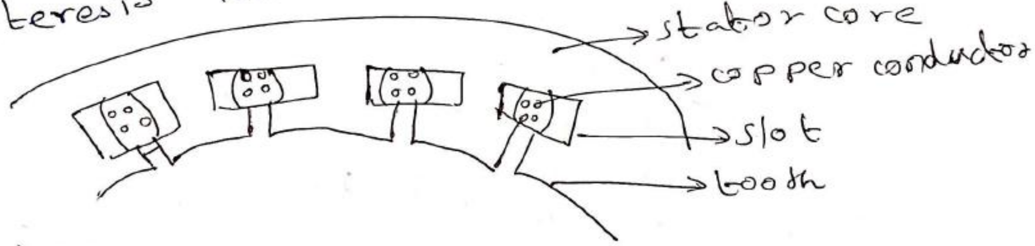
(i) Stator:

→ Stator is a stationary armature

→ This has core and slots to hold armature winding.

→ Stator core uses laminated construction to reduce eddy current losses.

→ Core is made of steel to reduce hysteresis loss



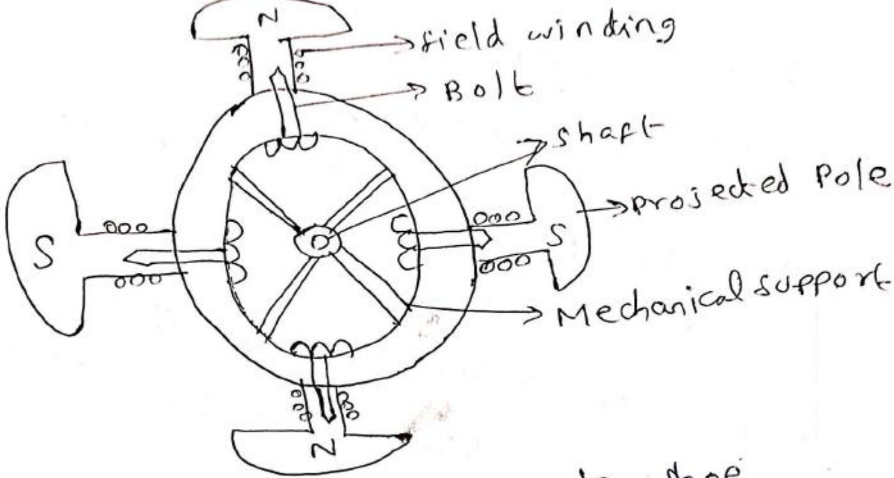
(ii) Rotor:

↳ 2 types
(a) Salient pole type
(b) Smooth cylindrical type

a) Salient Pole type:

→ This is also called as 'Projected pole' type as all poles are projected out from rotor.

→ Poles are built up of thick steel laminations and poles are bolted to rotor



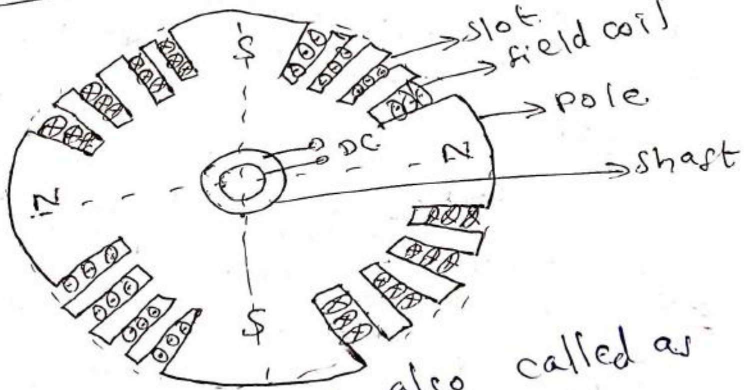
→ field winding is on pole shoe

→ This type of rotor is preferred for low speed alternators (125 to 500 rpm).

→ These rotors have large diameters and small axial length. Mechanical strength is less.

→ Prime movers are water turbines and IC engines.

b) Smooth cylindrical type :



→ This type is also called as non-salient type (or) non-projected pole type of rotor.

→ Rotor has smooth solid steel cylinder, having number of slots to accomodate field coil.

→ unslotted portions of the cylinder acts as poles

→ Poles are not projecting out and surface of rotor is smooth which maintains uniform air gap between stator and rotor.

→ rotors have small diameters and large axial length and so mechanically very strong.

→ so this generator is preferred for high speed alternator (1500 to 3000 rpm)

→ such high speed alternators are called as "turboalternators"

→ primemovers are generally steam turbines, electric motors

c) Difference between salient pole and cylindrical type of rotor:

Sl.No	Salient pole type	Smooth cylindrical type
①	Poles are projecting	Poles are not projecting
②	Airgap is non uniform	Uniform air gap
③	High diameter and small axial length	Small diameter and large axial length
④	Preferred for low speed alternator	Preferred for high speed alternator
⑤	Primemovers are water turbines, IC engines	Primemovers are steam turbines, electric motor

(2) Principle of Operation:

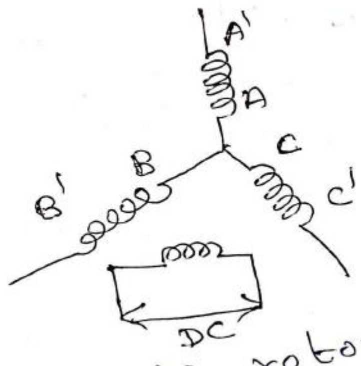
→ Rotor winding is supplied by dc source and alternate North(N) and South(S) poles are developed on rotor

→ When rotor is rotated in anticlockwise direction by primemover, armature conductors are cut by magnetic flux of rotor poles.

→ Emf is induced in armature conductors due to electromagnetic induction.

→ Induced emf is alternating, since north and south pole of rotor alternately pass the armature conductors.

→ $N_S = \frac{120f}{P}$ where N_S → Synchronous speed
f → frequency
P → poles



→ When rotor is rotated, 3φ voltage is induced in armature winding

(3) Basic Equations:

→ EMF equation $E = 4.44 f \phi T_{ph} k_c k_d$

where f → frequency, φ → flux, T_{ph} → Turns,
k_c → coil span (or) pitch factor
k_d → breadth factor (or) winding factor

$$\% \text{ Regulation} = \frac{E_{ph} - V_{ph}}{V_{ph}} \times 100$$

(4) Applications:

→ Battery charging
→ In hydroelectric plants
→ In wind power plants
→ In Diesel-electric trains

2.7 Construction, Principle of Operation, Basic equations and Applications of stepper Motors:

→ Stepper motor convert train of input pulses into precisely defined increment in shaft position.

→ Each input pulse actuate one step movement of shaft.

→ Angle through which shaft moves from each pulse is called step angle (degree).

→ It is suitable for controlling position called Position control system.

(1) Construction

→ Stator has 3φ winding which is star connected.

→ Stator core is made of silicon steel stampings fixed on stator frame.

→ Stator windings are supplied through a ... voltage source

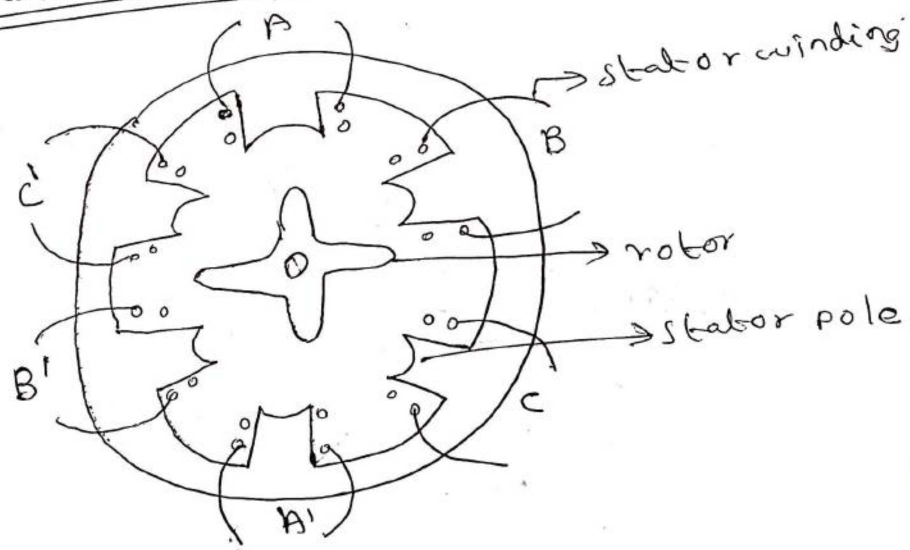
One by one to different phases.
∴ According to rotor teeth alignment with stator teeth stepper motor operates.

④ Applications

↳ Quartz watches
↳ Camera shutter operation
↳ Floppy disk drive
↳ Dot matrix
↳ Robotics
↳ X ray machines
↳ Ultrasound scanners.

Types :
→ Variable Reluctance (VR) stepper Motor
→ Permanent Magnet (PM) stepper motor
→ Hybrid stepper motor.

a) Variable Reluctance stepper motor



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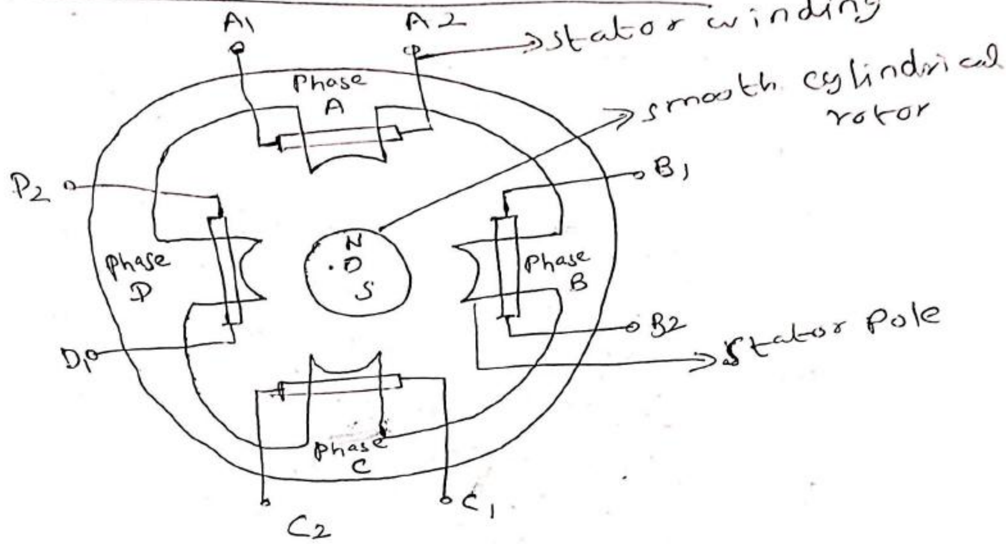
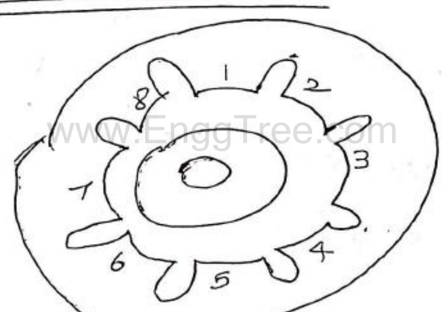
b) Permanent Magnet stepper Motor :



c) Hybrid stepper Motor :



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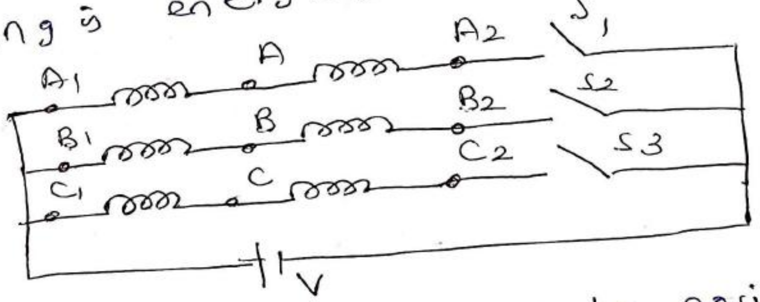
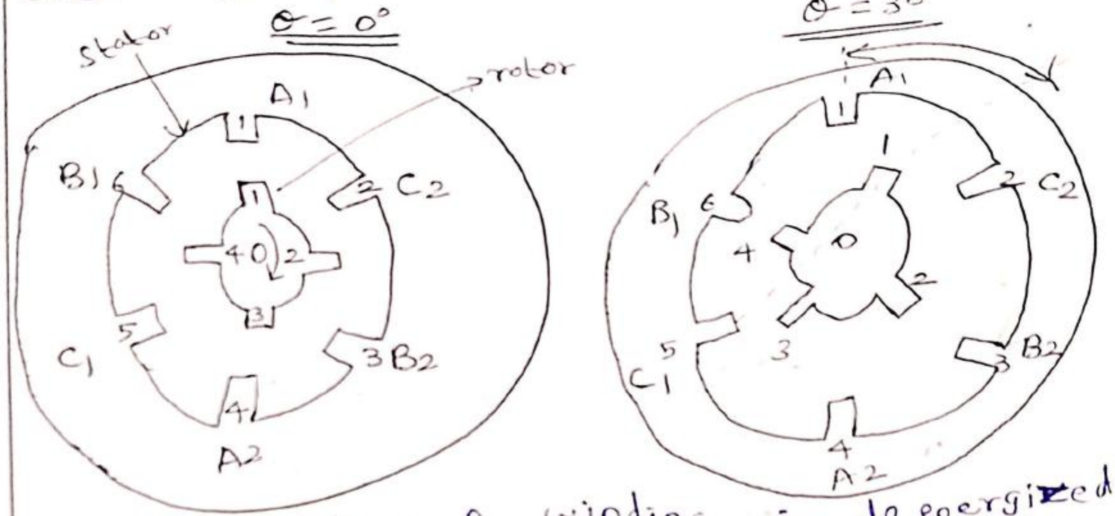
(2) Principle of operation :

→ when we close switch S_1, phase A winding is energised.



→ Now rotor moves to position on which rotor teeth align themselves with stator teeth of phase A (i.e) Rotor teeth 1 & 3 align themselves with stator teeth 1 & 4 Hence $\theta = 0^\circ$



→ Next phase A winding is deenergized by opening switch S_1 and phase B winding is energized by closing switch S_2 (i.e) Rotor teeth 2 and 4 align with stator teeth 3 and 6. Hence $\theta = 30^\circ$.

Phase A	Phase B	Phase C	θ	Rotor teeth	Stator teeth
+	0	0	0°	1 & 3	1 & 4
0	+	0	30°	2 & 4	3 & 6
0	0	+	60°	1 & 3	2 & 5
+	0	0	90°	2 & 4	1 & 4

③ Basic Equations

→ Rotor poles $N_r = N_s \pm \frac{N_s}{q}$

$q \rightarrow$ No. of phases

eg $N_r = 6 \pm \frac{6}{3}$ (If stator pole = 6 & phase = 3)

$= 6 \pm 2 = 8$ (or) 4

→ Step angle (α) $= \frac{360^\circ}{qN_r}$

2.8 Construction, principle of Operation, Basic Equations and Applications of BLDC Motor: (Brushless DC Motor):

(1) Construction:

→ BLDC motor is a motor that uses electronic control to vary its speed which does not have brushes.

→ The controller provides pulse of current to motor windings which control speed and torque of synchronous motor.

→ Stator has 3φ winding which is star connected.

→ Stator core is made of silicon steel stampings fixed on stator frame.

→ Stator windings are supplied through ~~volta~~ variable voltage source.

→ Rotor in a BLDC motor is salient pole permanent magnet type.

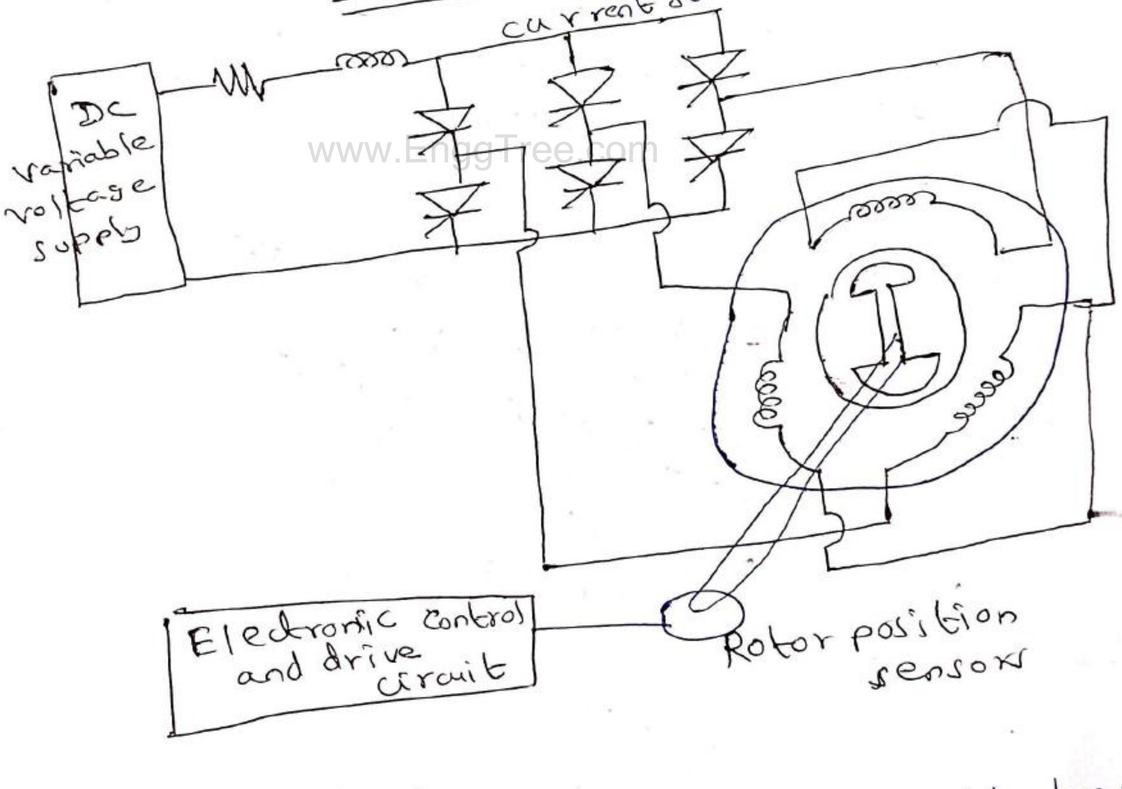
→ Position sensors placed on rotor shaft provide signals to control gate drive circuit which cause SCRs in the inverter circuit to be triggered in proper sequence.

→ Then it should be in synchronism with rotor's mechanical position.

→ Stator and rotor fields get locked to each other and remain in synchronism at every rotor speed.

→ Rotor position sensors are hall effect sensors and optical sensor consisting of LEDs and photo transistors.

BLDC Motor



(2) Principle of Operation

→ BLDC motor drive circuit has inverter bridge, electronic controller, hall effect sensor and BLDC motor

→ Hall effect sensors are used for position and speed feedback

→ Electronic controller can be a microcontroller (or) microprocessor (or) DSP processor (or) any other processor.

→ The electronic controller receives feedback signals, process them and send control signals to inverter driver circuit.

→ When DC supply is given, switching makes to generate an ac voltage waveform.

→ Due to force of interaction between electromagnet stator and permanent magnet rotor, rotor continues to rotate.

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③ **Applications:**

→ computer hard drives
→ DVD / CD players
→ Electric vehicles
→ Industrial robots
→ washing machines
→ compressors
→ dryers.
→ pumps
→ fans
→ Blowers.

Unit - III

Measurements and Instrumentation

3.1 Functional elements of an instrument:

→ An instrument may be defined as device to maintain relation between physical variables and ways to communicate to a human observer

→ Measurement systems contain three main functional elements

(i) Primary sensing element
(ii) Variable conversion element
(iii) Data presentation element

(i) Primary sensing element:

→ In electrical measurement systems, A transducer is defined as a device which converts physical quantity into an electrical quantity.

→ physical quantity to be measured is sensed and detected by an element which gives output.

→ This output is then converted into an electrical signal by transducer.

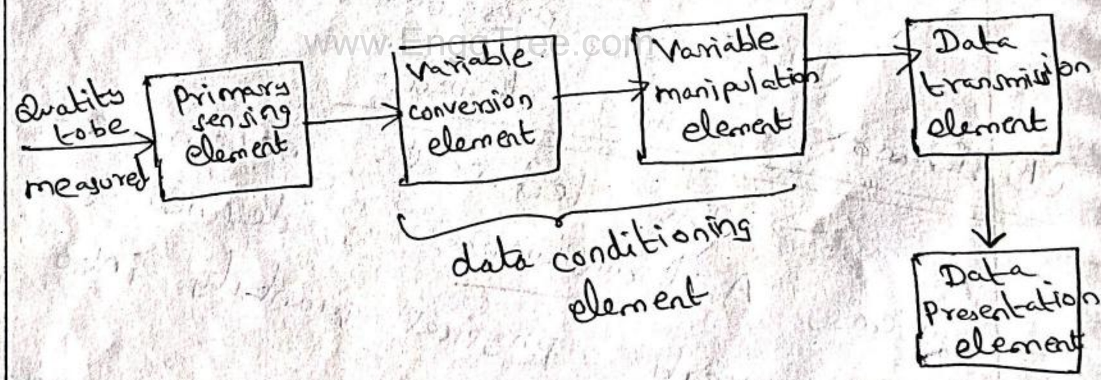
→ The first stage of measurement

system is called detector transducer stage.

(ii) Variable conversion element:

→ If the next stage of the system accepts only in digital form, A/D (Analog to Digital) converter is used to convert analog signal to digital signal

Functional elements of an instrumentation system



→ Variable manipulation element is used to change the signal into numerial value of the signal

→ Fundamental problem is to prevent the signal contaminated by unwanted noise signals

→ Process like modulation, sampling, filtering etc are performed to bring the signal to desired form called Signal conditioning

→ The element which helps to transmit data from one to another is called Data Transmission element

(iii) Data presentation element:

→ The information about measured quantity should be conveyed to monitoring and control purposes.

→ This is done by Data presentation element

3.2 Standard and Calibration:

(1) Standard:

→ Standard is a physical representation of a unit of measurement.

→ eg: Unit of mass is kg (kilogram)

→ There are different types of

standards

(i) international standards
(ii) primary standards
(iii) secondary standards
(iv) working standards.

(i) International standards:

→ International standards are defined on the basis of international agreement

→ These are maintained at the international Bureau of weights and measures

(ii) Primary standards:

→ Primary standards are absolute standards of high accuracy that can be used as ultimate reference standars.

→ These standards are maintained by national standards laboratories.

(iii) Secondary standards:

→ Secondary standards are the basic reference standards used in industrial measurement laboratories.

(iv) working standards:

→ working standards are used to

check and calibrate general laboratory instruments for their accuracy and performance.

② Calibration:

→ The calibration of all instruments is important since it affords the opportunity to check instrument against a known standard and to find errors and accuracy.

→ Calibration involves a comparision of the particular instrument with either

a) primary standard

b) secondary standard with higher accuracy than instrument to be calibrated

c) instrument of known accuracy

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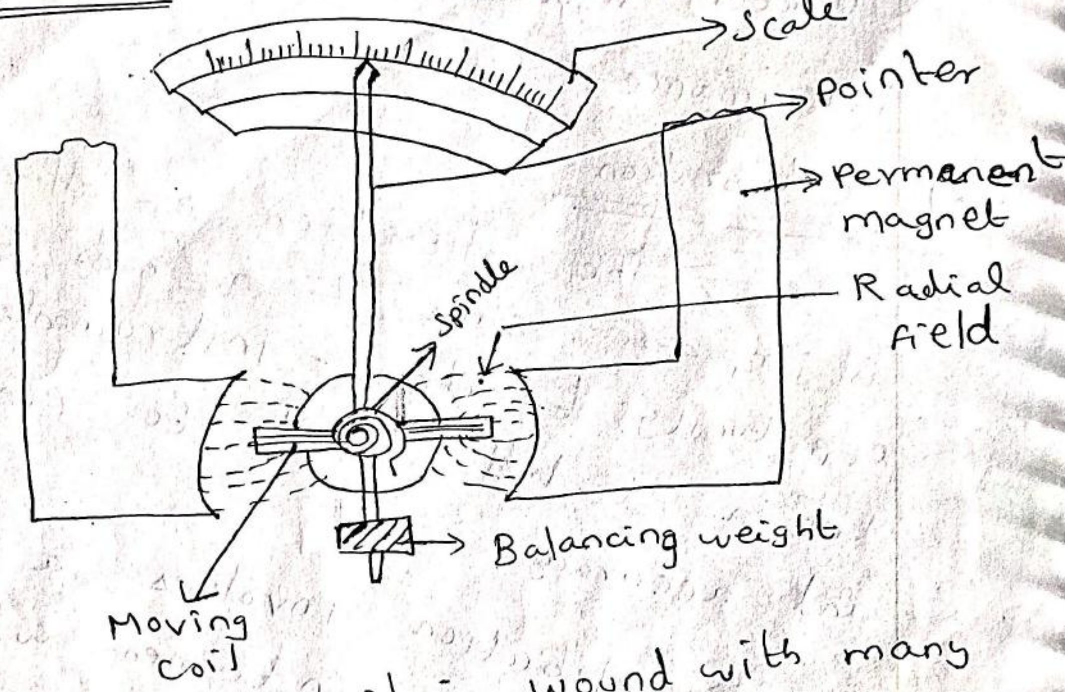
3.3 Operating principle - types - Moving coil and Moving iron meters:

① Moving Coil Instrument:

→ permanent magnet moving coil (PMMC) instrument is the most accurate type for DC measurements.

(i) Construction:



→ Moving coil is wound with many turns of silk covered copper wire

→ Coil is mounted on rectangular aluminium former

→ Coils moves freely in the field of permanent magnet.

→ Damping torque is produced by movement of aluminium former moving in magnetic field of permanent magnet

→ pointer is carried by spindle and moves over a graduated scale

→ Weight of instrument is counter

balanced by weights and rigidly connected to it.

→ Mirror is placed below pointer to get accurate reading

(ii) Operation:

→ It works on the principle of motor.

→ When current carrying coil is placed in magnetic field produced by permanent magnet, coil experiences a force and moves.

→ As the coil is moving and magnet is permanent, instrument is called Permanent Magnet Moving Coil Instrument.

→ This principle is called D'Arsonval Principle

→ pointer deflection is proportional to the current passing through coil.

② Moving Iron Meters:

→ Moving iron instruments are used to measure current and voltage to an accuracy for AC measurements.

(ii) Principle of operation:

→ Soft iron plate of high permeability forms moving element of the system.

→ This iron plate is situated, that it can move in magnetic field produced by stationary coil.

→ coil is given supply by current (or) voltage under measurement.

→ when coil is excited, it becomes an electromagnet and iron plate moves as to increase flux.

→ iron plate tries to occupy a position of minimum reluctance.

→ Thus the force is produced.

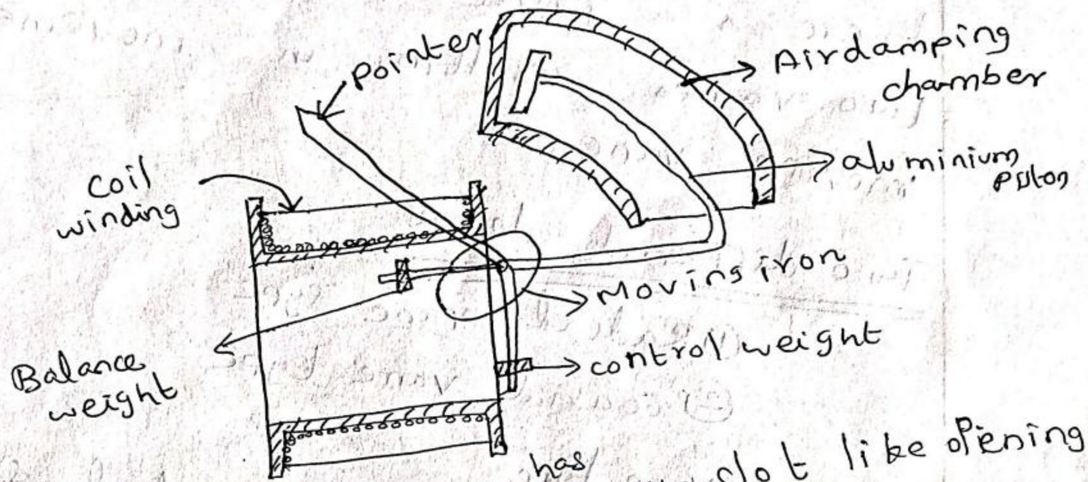
(iii) Types:

→ Moving iron instruments are of two types

a) Attraction type

b) Repulsion type < ① Coaxial vane design, ② Radial vane design

a) Moving iron Attraction type instruments:



→ coil is flat and has narrow slot like opening

→ moving iron is a flat disc.

→ when current flows through coil, a magnetic field is produced and moving iron is attracted.

→ Controlling torque is provided by spring

→ Damping is provided by aluminium piston which moves in fixed chamber closed at one end.

b) Moving iron repulsion type instruments:

→ In repulsion type, there are two vanes inside the coil one fixed and other movable.

→ When current flows through the coil, there is a force of repulsion between two vanes resulting in movement of moving vane.

Two different designs

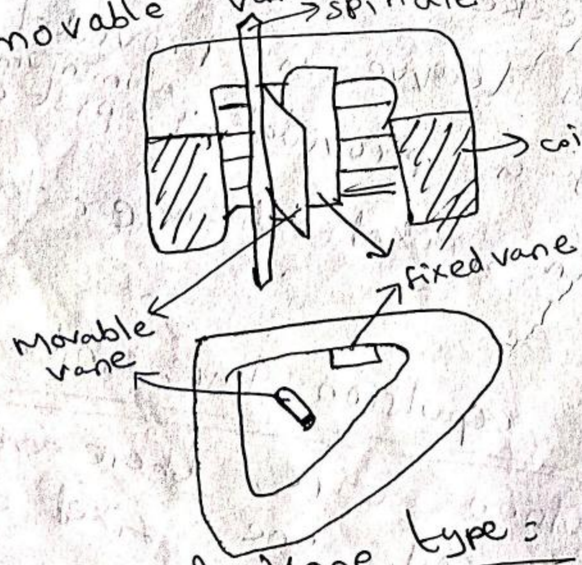
① Radial vane Type
② Coaxial vane type

① Radial vane type:

→ Here vanes are radial strips of iron.

→ strips are placed within coil

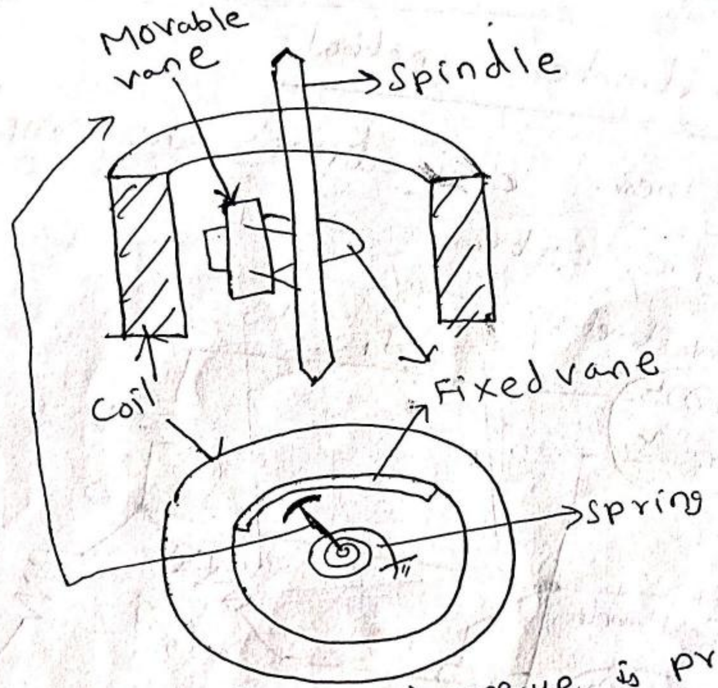
→ fixed vane is attached to coil and movable vane is attached to spindle.



② Coaxial Vane type:

→ Here, fixed and moving vanes

are sections of coaxial cylinders.



→ controlling torque is provided by springs

→ Damping torque is produced by air friction.

→ iron vanes are magnetised by current in coil and there is a force of attraction in attraction type instrument and there is a force of repulsion in repulsion type instrument

→ Moving iron instruments are independent on current direction and so it can be used on both ac and dc.

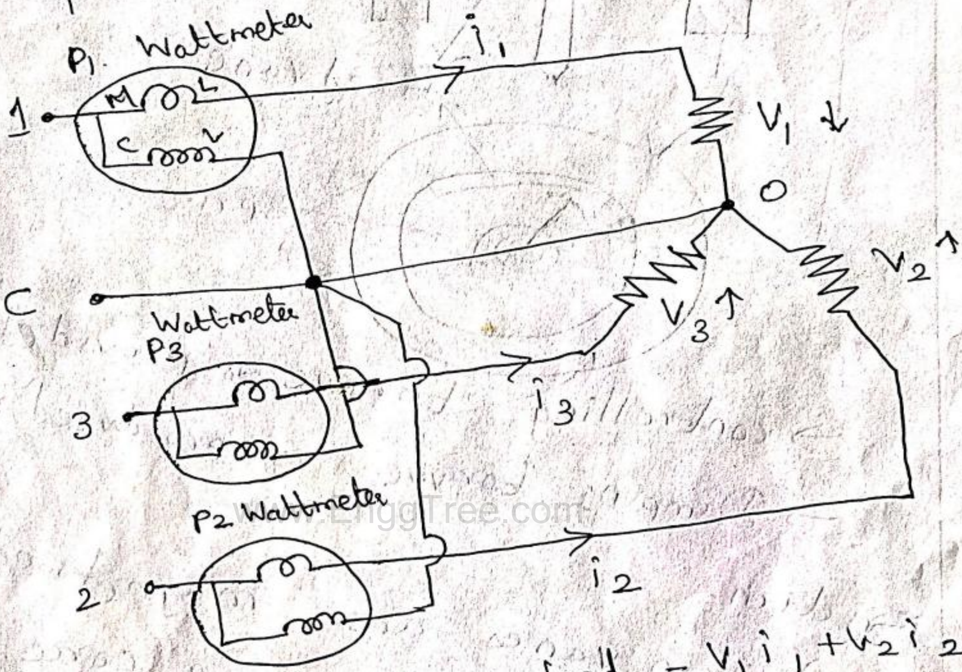
(ii) Driving Torque (or) Deflecting torque of MI Instrument

refer: Pg. No: 3-25

3.4 Measurement of three phase power:

(i) Three wattmeter method:

→ These connections are employed for 3φ 4 wire system.



→ Instantaneous power of load $= V_1 i_1 + V_2 i_2 + V_3 i_3$

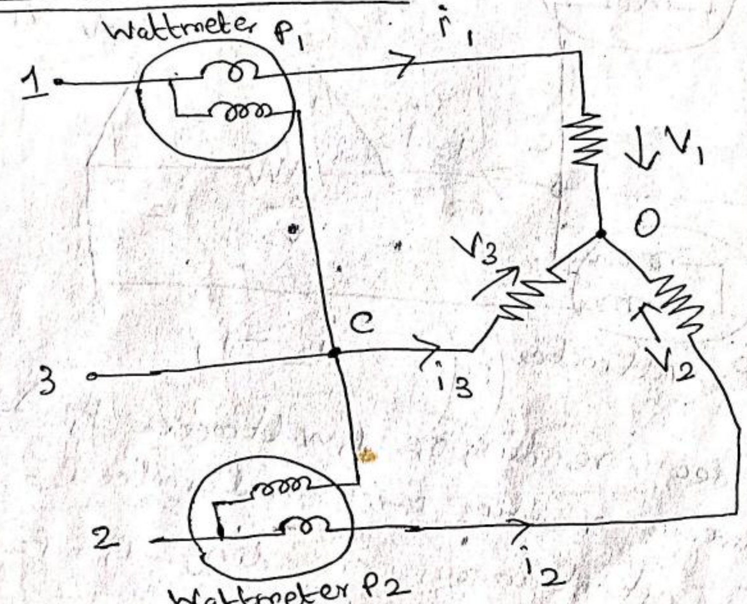
→ Hence these 3 wattmeters measure power of the load.

(ii) Two wattmeter method:

→ In 3φ, 3 wire system, we require 3 elements. But if we make common points of the pressure coils coincide with one of the lines, we require only 2 elements.

→ Let us consider 2 wattmeters connected to measure power in 3φ circuit

a) Star (Wye) Connection:



Instantaneous reading of P_1 Wattmeter $(P_1) = i_1(V_1 - V_3)$

Instantaneous reading of P_2 Wattmeter $(P_2) = i_2(V_2 - V_3)$

Sum of instantaneous readings of 2 wattmeters $= P_1 + P_2$

$$= i_1(V_1 - V_3) + i_2(V_2 - V_3)$$

$$= i_1V_1 - i_1V_3 + i_2V_2 - i_2V_3$$

$$= V_1i_1 + V_2i_2 - V_3(i_1 + i_2) \quad \text{--- (1)}$$

→ Sum of the two wattmeter reading is equal to the power consumed by the load.

→ From KCL, $i_1 + i_2 + i_3 = 0$, $i_3 = -(i_1 + i_2)$

∴ Sum of instantaneous power $= V_1i_1 + V_2i_2 + V_3i_3$

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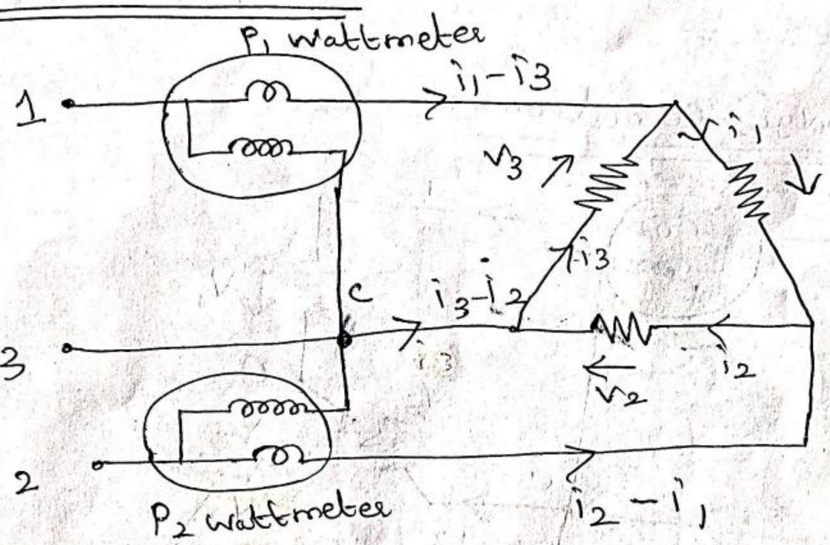
b) Delta connection:



→ instantaneous reading of P_1 wattmeter $P_1 = -V_3(i_1 - i_3)$

→ instantaneous reading of P_2 wattmeter $P_2 = V_2(i_2 - i_1)$

→ sum of instantaneous reading $P_1 + P_2$

$$= -V_3(i_1 - i_3) + V_2(i_2 - i_1)$$

$$= -V_3 i_1 + V_3 i_3 + V_2 i_2 - V_2 i_1$$

$$= V_2 i_2 + V_3 i_3 + i_1(-V_3 - V_2)$$

→ By KVL, $V_1 + V_2 + V_3 = 0$

$$\therefore V_1 = -V_3 - V_2$$

∴ Sum of instantaneous reading $= V_2 i_2 + V_3 i_3 + V_1 i_1$

→ Therefore sum of two wattmeter is equal to power consumed by the load.

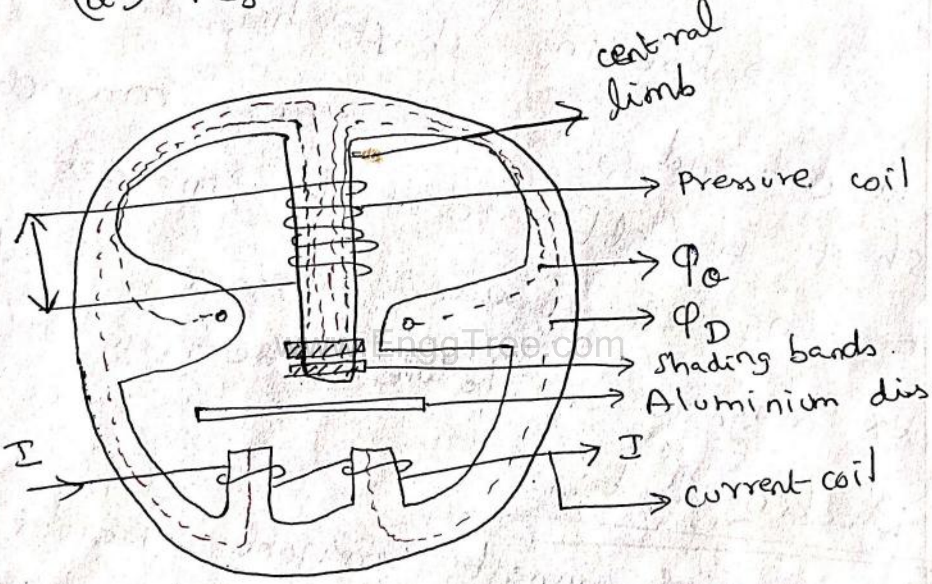
(iii) Power factor derivation at page No: 3.27

3.5 Energy Meter:

(i) Construction:

→ There are 4 main parts of the operating mechanism

(a) driving system
(b) moving system
(c) braking system
(d) registering system



a) driving system:

→ It has 2 electromagnets
→ core is made of silicon steel laminations.
→ coil of one electromagnet is excited by load current called current coil.
→ coil of second electromagnet is connected across voltage called pressure coil

→ copper shading bands are provided on central limb.

→ Function of these bands are to bring flux by magnets.

b) Moving System:

→ It has aluminium disc mounted on shaft. which lies between electromagnets

→ Rotating shaft has small magnet at each end, where upper magnet of shaft is attracted to magnet in upper bearing & lower magnet is attracted to magnet in lower bearing.

c) Braking System:

→ permanent magnet positioned near edge of aluminium disc forms braking system.

→ Aluminium disc moves in the field of this magnet & provides a braking torque

d) Registering (counting) Mechanism:

→ Function of this mechanism is to

record continously a number which is proportional to revolution made by moving system.

(ii) Operation of single phase Energy Meter:

→ Supply voltage is applied across pressure coil

→ pressure coil produces flux φ_2

→ current coil produces flux φ_1

→ Both fluxes φ_1 & φ_2 induce emf in disc which produce eddy current in disc

→ Interaction between fluxes φ_1 & φ_2 and eddy current produce driving torque & disc starts rotating.

→ Speed of disc is controlled by braking magnet

→ Spindle is connected to recording mechanism through gears which records the energy supplied.

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3.6 Instrument Transformer - CT and PT

→ Transformers used in conjunction with measuring instruments for measurement purposes are called Instrument Transformers.

→ Transformer used for measurement of current is called current transformer (or) simply CT

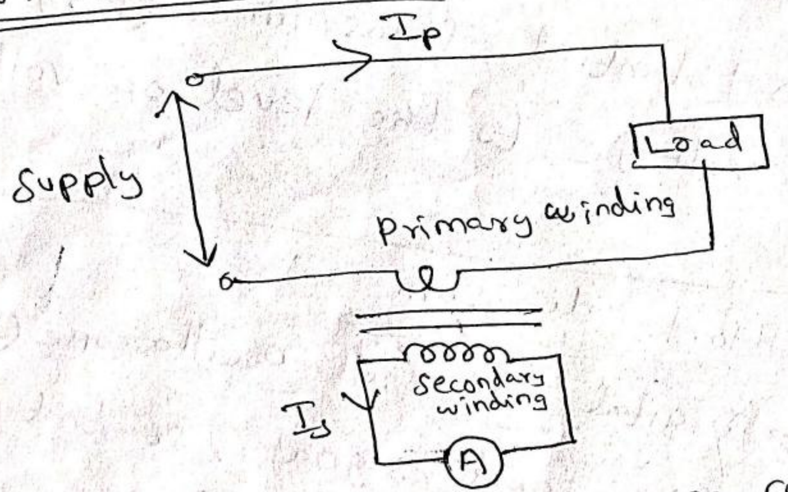
→ Transformer used for voltage measurements are called Voltage transformer (or) Potential Transformer (or) simply PT.

(i) Use of Instrument Transformers:

→ In power systems, currents and voltages handled are very large and therefore direct measurements are not possible as these currents and voltages are far too large for any meter of reasonable size and cost.

→ The solution lies in stepping down these currents and voltages with the help of instrument transformers so that they can be metered with instruments of moderate sizes.

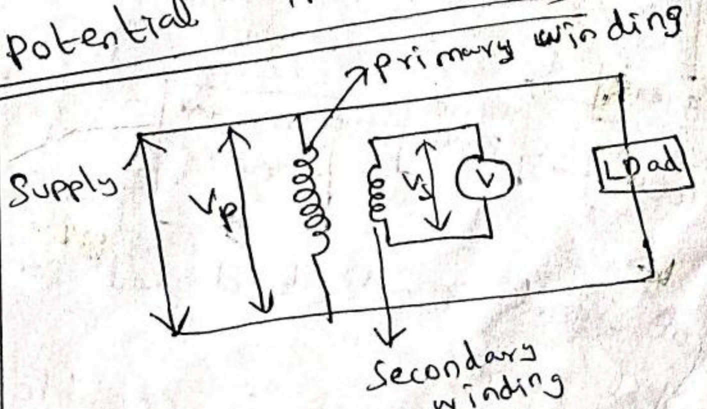
(i) Current Transformer:



→ primary winding is so connected that the current being measured passes through it and secondary winding is connected to ammeter.

→ Current transformer steps down the current to the ammeter level.

(ii) Potential Transformer:



→ Primary winding is connected to voltage being measured & secondary winding to a voltmeter.

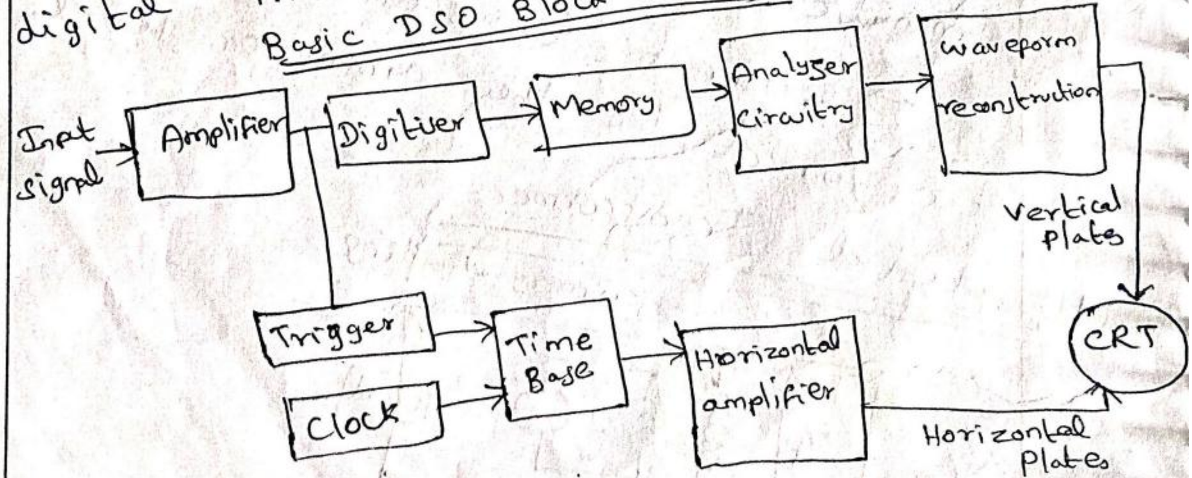
→ Potential Transformer (PT) steps down voltage to the level of voltmeter.

3.7 DSO - Block diagram:

→ Digital Storage Oscilloscope (DSO) digitises the input signal, so that all subsequent signals are digital.

→ A conventional Cathode Ray Tube CRT is used and storage occurs in electronic digital memory.

Basic DSO Block diagram



→ Input signal is digitised and stored in memory in digital form.

→ In this state, it is capable of

being analysed to produce a variety of different information.

→ To view the display on CRT, data from memory is reconstructed in analog form.

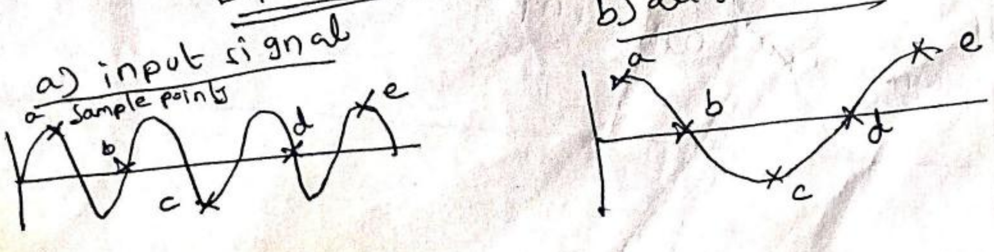
→ Digitising occurs by taking sample of input waveform at periodic intervals.

→ In order to ensure that no information is lost, sampling theory states that the sampling rate must be atleast twice as fast as the highest frequency in the input signal

→ If this is not done, then aliasing will result. Aliasing means measurement error in signal occurring due to an incorrectly set sampling rate.

→ This requirement for high sampling rate means that Analog to digital converter digitiser must have a fast conversion rate.

Effect of low sampling frequency



→ digitized analog signal is amplified by amplifier if it has any weak signal.

→ After amplification, digitized signal is stored in memory.

→ Analyzer circuit proces digital signal after the digital signal waveform is reconstructed to analog form.

→ Then signal is applied to vertical plates of CRT.

→ CRT has two inputs - vertical and horizontal input.

→ vertical input signal is 'Y' axis and horizontal input signal is 'X' axis.

→ The time base circuit is triggered by trigger and clock input signal to generate ramp signal.

→ Ramp signal is amplified by horizontal amplifier

→ On CRT screen, we will get waveform of input signal versus time.

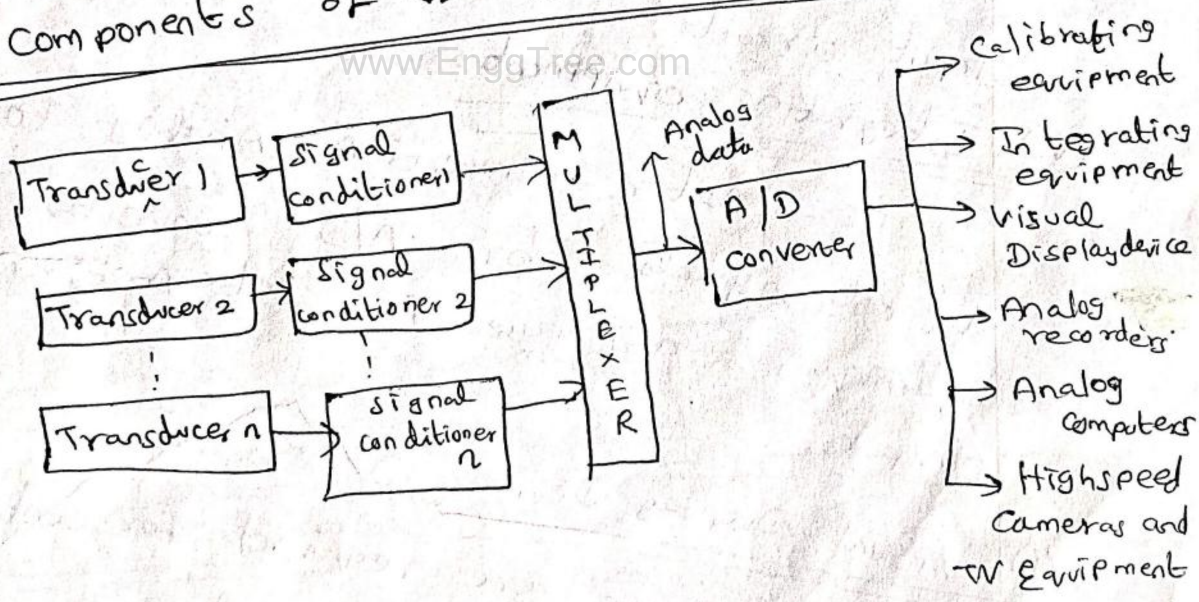
3.8 Data Acquisition

→ Data Acquisition systems are used to measure and record analog signals in basically two different ways:

(i) Signals which originate from direct measurement of electrical quantities. These signals may be dc (or) ac voltages, frequency etc.

(ii) Signals which originate from use of transducers.

(1) Components of an Analog Data-Acquisition System:



(i) Transducers:

→ Transducer is used as an input to the quantity data acquisition system for being measured.

(ii) Signal conditioning equipment:

→ It transform output of transducer to desired magnitude.

→ It may include devices for amplifying, refining etc.

(iii) Multiplexer:

→ It process the multiple analog inputs to one measuring input.

(iv) Calibrating Equipment:

→ It has millivolt calibration of all input circuits

(v) Integrating equipment:

→ After converting Analog to digital signals by A/D converter, digital integration (or) summation techniques are used for purposes.

(vi) Visual Display Devices:

→ These are required for continuous monitoring of input signals.

(vii) Analog Recorders:

→ These include strip chart

recorders, magnetic tape recorders and cathode ray Oscilloscope (CRO) with photographic equipment.

(viii) **Analog Computers:**

→ Output voltage of analog computer can be either recorded in analog form (or) converted to digital form for recording and for further computations

(ix) **High speed cameras and TV Equipment:**

→ High speed cameras are used to obtain complete visual record for further analysis.

→ TV equipment is used to enable operator to make visual observations.

Continuation of Pg. No: 3.11

(iii) **Driving Torque (or) Deflecting torque of MI instrument**

→ Let T_d be deflecting torque

→ Mechanical work done $= T_d \, d\theta$

→ emf $e = \frac{d}{dt}(LI) = I\frac{dL}{dt} + L\frac{dI}{dt}$

→ electrical energy supplied $e(I\,dt) = (I^2 dt) \frac{I\,dL}{dt} + I\,dt\left(\frac{L\,dI}{dt}\right)$

→ $eIdt = I^2 dL + ILdI$

→ Stored energy changes from

$\frac{1}{2} I^2 L$ to $\frac{1}{2}(I+dI)^2(L+dL)$

→ Change in stored energy

$= \frac{1}{2}(I+dI)^2(L+dL) - \frac{1}{2}I^2L$

$= \frac{1}{2}(I^2+dI^2+2IdI)(L+dL) - \frac{1}{2}I^2L$

→ Neglecting higher order terms,

Change in stored energy $= ILdI + \frac{1}{2}I^2dL$

→ From the principle of conservation of energy,

Electrical energy supplied = Increase in stored energy + mechanical work done

$I^2dL + ILdI = \frac{1}{2}I^2dL + ILdI + T_d d\theta$

$= \frac{1}{2}I^2dL + ILdI - ILdI$

$T_d d\theta = I^2dL - \frac{1}{2}I^2dL + 0$

$T_d d\theta = \frac{1}{2}I^2dL$

$T_d = \frac{1}{2}I^2\frac{dL}{d\theta}$

where T_d → Deflecting torque

I → current, L → Inductance

→ Controlling torque $T_C = k\theta$

where k → control spring constant

θ → deflection

→ At equilibrium $T_C = T_d$

$$\therefore k\theta = \frac{1}{2} I^2 \frac{dL}{d\theta}$$

$$\text{Deflection } \theta = \frac{1}{2} \frac{I^2}{K} \frac{dL}{d\theta}$$

Continuation of pg. No. 3.13

(iii) Power factor derivation by Two wattmeter method:

$$W_1 = E_L I_L \cos(30° - \varphi)$$

$$W_2 = E_L I_L \cos(30° + \varphi)$$

$$W_1 + W_2 = E_L I_L \cos(30° - \varphi) + E_L I_L \cos(30° + \varphi)$$

$$= E_L I_L (\cos 30° \cos\varphi + \sin 30° \sin\varphi) + E_L I_L (\cos 30° \cos\varphi - \sin 30° \sin\varphi)$$

$$= E_L I_L \left[\cos 30° \cos\varphi + \sin 30° \sin\varphi + \cos 30° \cos\varphi - \sin 30° \sin\varphi\right]$$

$$= E_L I_L (\cos 30° \cos\varphi + \cos 30° \cos\varphi)$$

$$W_1 + W_2 = E_L I_L \, 2 \cos 30° \cos\varphi = E_L I_L \cos\varphi \times 1.732$$

$$= E_L I_L \cos\varphi \sqrt{3} \quad \text{—(1)}$$

|||ly for $W_1 - W_2 = E_L I_L \begin{pmatrix} \cos 30° \cos\varphi + \sin 30° \sin\varphi \\ - \cos 30° \cos\varphi + \sin 30° \sin\varphi \end{pmatrix}$

$$W_1 - W_2 = E_L I_L \, 2 \sin 30° \sin\varphi = E_L I_L \sin\varphi \, (1) \quad \text{—(2)}$$

$$\frac{②}{①} \Rightarrow \frac{W_1 - W_2}{W_1 + W_2} = \frac{E_L I_L \sin\phi}{\sqrt{3}\, E_L I_L \cos\phi}$$

$$\frac{W_1 - W_2}{W_1 + W_2} = \frac{\tan\phi}{\sqrt{3}}$$

$$\tan\phi = \sqrt{3}\left(\frac{W_1 - W_2}{W_1 + W_2}\right)$$

$$\therefore \phi = \tan^{-1}\left[\sqrt{3}\left(\frac{W_1 - W_2}{W_1 + W_2}\right)\right]$$

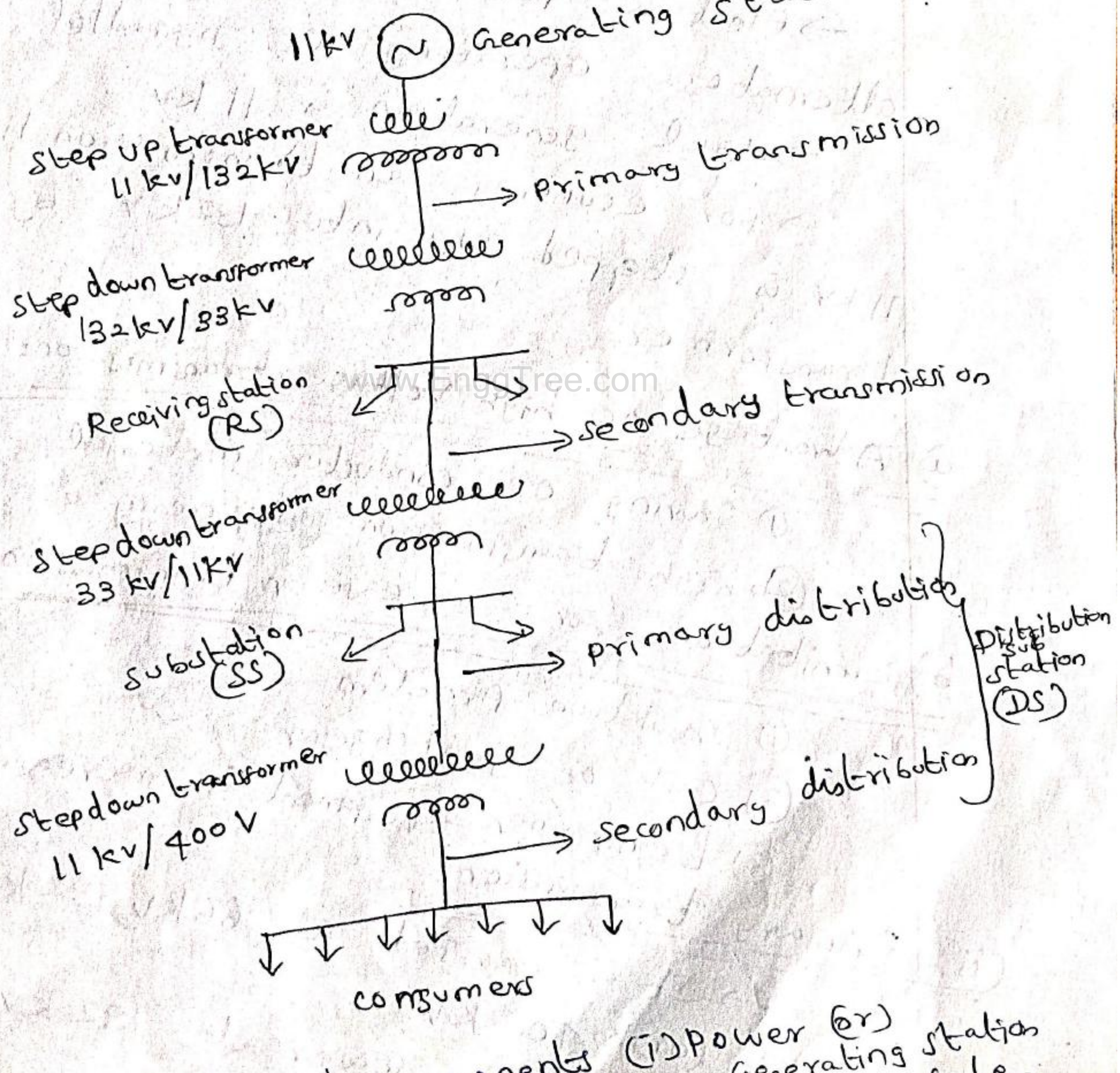
$$\cos\phi = \text{power factor} = \cos \tan^{-1}\left(\frac{\sqrt{3}\,(W_1 - W_2)}{W_1 + W_2}\right)$$

Unit IV

Basics of Power systems

4.1 Power System Structure - Generation, Transmission and Distribution, Various Voltage levels:

Structure of Electric Power system



→ 3 Principal components

(i) Power (or) Generating station

(ii) Transmission system

(iii) Distribution system

→ Transmission and distribution systems are further subdivided into

a) Primary transmission and secondary transmission.

b) primary distribution and Secondary distribution

(i) Generating station (GS):

→ Electric power is produced by 3φ alternators operating in parallel.

→ Usual generation is 11 kV

→ for economy in transmission line, 11 kV is stepped up into 132 kV by 3φ transformer.

a) Advantages of high voltage transmission:

① Saving of conductor material

② high transmission efficiency

b) Limitation for increase in transmission voltage

① Insulation problem

② cost of switchgear

③ transformer equipment is increased

(ii) Primary transmission:

→ It is carried at 66 kV, 132 kV, 220 kV (or) 400 kV

→ Electric power at 132 kV is

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transmitted by 3φ, 3 wire overhead system

(iii) Secondary transmission:

→ primary transmission line ends at receiving station (RS)

→ Here voltage is reduced to 33 kV by step up transformer.

→ Power is transmitted at 33 kV by 3φ, 3 wire overhead system to various substation (SS).

(iv) Primary Distribution:

→ secondary transmission ends at substation (SS)

→ Here voltage is reduced from 33 kV to 11 kV using 3φ, 3 wire system.

(v) secondary distribution:

→ 11 kV is stepped down to 400 V, 3φ, 4 wire for secondary distribution, in distribution substation (DS).

→ Voltage between any 2 phases is 400 V and between any phase and neutral is 230 V

→ Secondary distribution has feeders, distribution and service mains.

4.2 Earthing

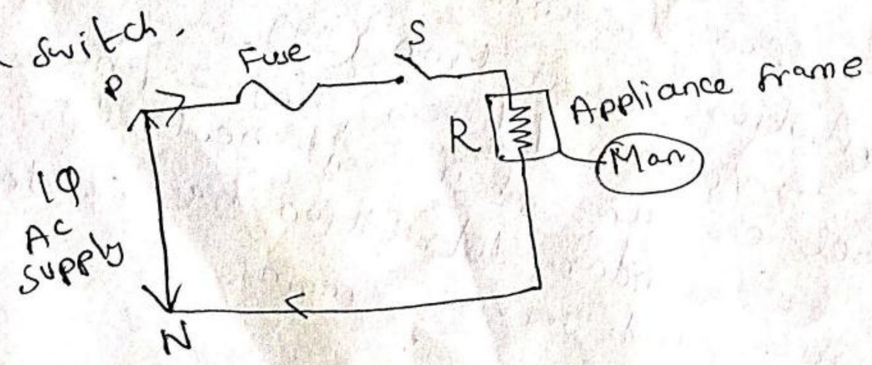
→ The process of connecting metallic bodies of all electrical apparatus and equipment to huge mass of earth by a wire of negligible resistance is called earthing.

→ It ensures that whenever a live conductor comes in contact with outer body, the charge is released to earth immediately.

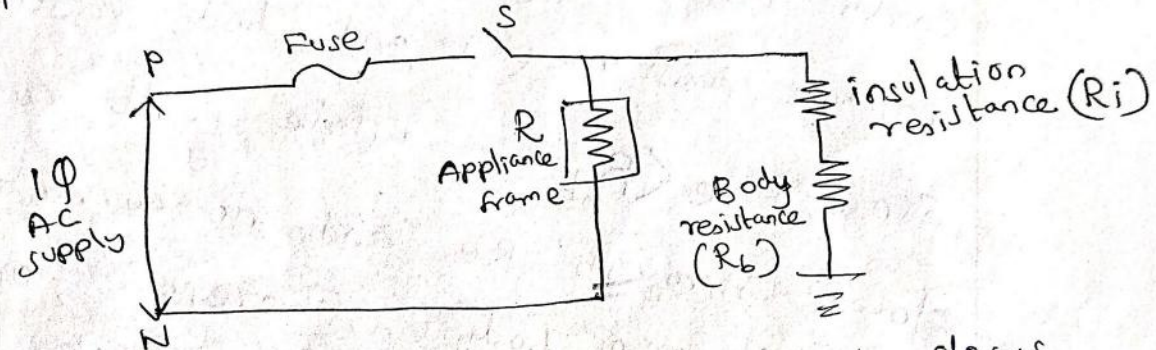
(i) Purpose of Earthing:

→ Basic purpose of earthing is to protect human body operator from electric shock

→ consider an electrical circuit where an electrical appliance of resistance R is connected to supply through a fuse and a switch.

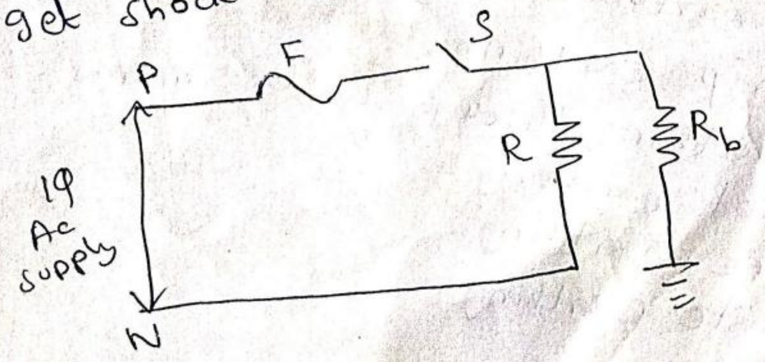


→ when an operator touches the metallic body of apparatus, having perfect insulation, equivalent circuit where two parallel paths are formed.



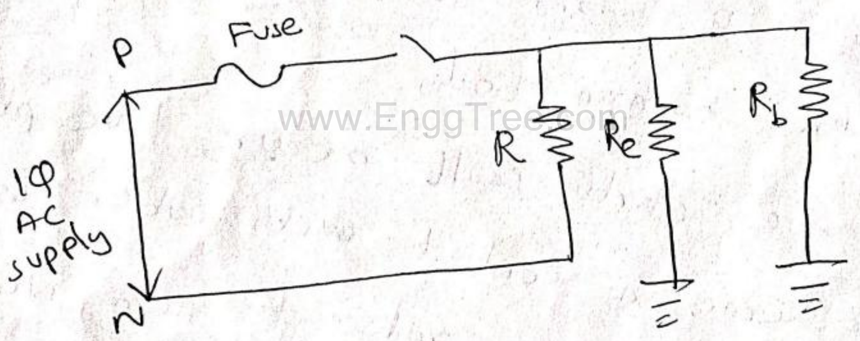
→ since Ri > R, whole current flows through 'R' and so no current flows through human body.

→ when earth fault occurs, live phase wire comes in contact with outer body and insulation resistance reduces to zero, Now R is in parallel with R_b and heavy current flows through human body and operator get shock.



→ If metallic body (or) outer frame is properly earthed, then under earth fault condition, circuit will be such that earth resistance (R_e) is in parallel with appliance resistance (R) and body resistance (R_b).

Since $Re < R_b$, whole fault current flows through Re and no current flows through human body. Therefore, operator is protected from electric shock.



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4.3 Methods of Earthing:

→ There are various methods to achieve earthing. They are

(i) Strip earthing
(ii) Earthing through water mains
(iii) Rod earthing
(iv) Pipe earthing
(v) Plate earthing

(i) Strip earthing:

→ This system of earthing employs the use of 5 SWG (Standard Wire Gauge) copper wire buried in horizontal trenches.

→ This type of earthing is used where earth bed has rocky soil.

(ii) Earthing through water mains:

→ Here, a stranded copper lead is used that is rounded on pipe with the help of steel binding wire and earthing clip.

→ Copper lead is soldered to make it solid.

→ Before making connection to water main, it should be ensured that G.I. (Galvanised Iron) pipe is used throughout.

(iii) Rod earthing:

→ It is the cheapest method of earthing and is employed in sandy areas.

→ Here copper rod is hammered directly into ground.

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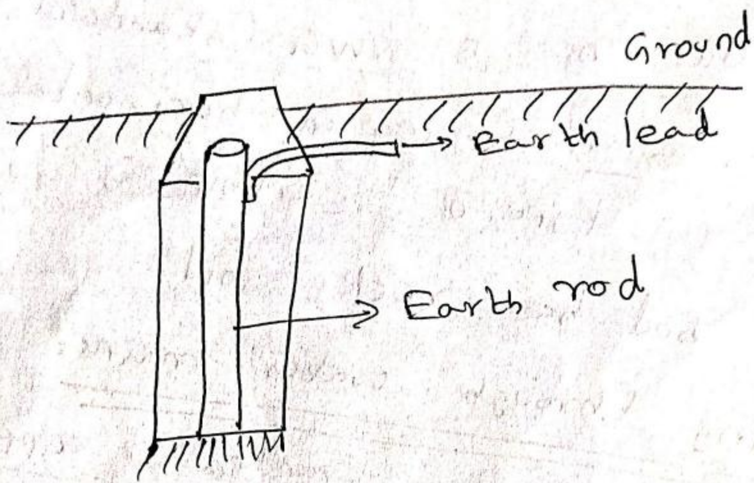
→ Earth lead is joined to this rod with the help of nuts and bolts.



(iv) Pipe Earthing :

→ Galvanised Iron (G.I) pipe earthing is the best form of ground connection.

→ Iron is the cheapest material and remains serviceable even if put in salty mass of earth.

→ Pipe is used as earth electrode.

→ Earthing lead should be soldered and connected to the pipe.

→ Layers of charcoal and salt are provided around G.I. pipe to keep surroundings moist enough.

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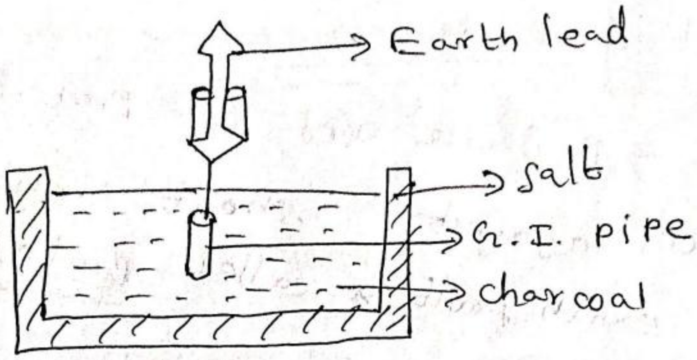


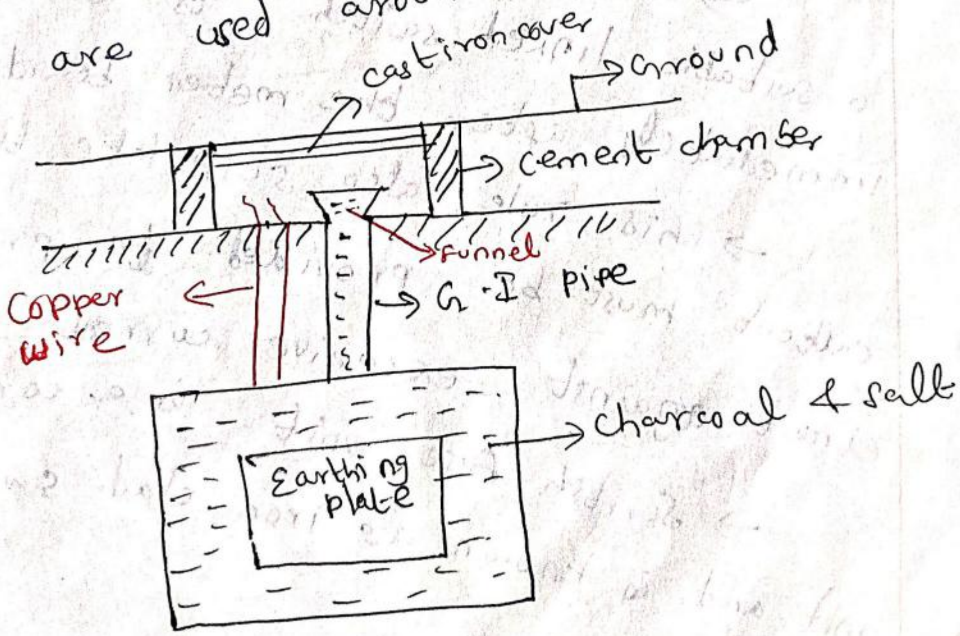
(V) Plate earthing:

→ Here copper (or) G.I plate is used as earth electrode instead of G.I pipe.

→ Plate is buried inside ground

→ G.I. wire is used for G.I. plate and copper wire for copper plate earthing.

→ Alternate layers of charcoal and salt are used around plate.



4.4 Protective devices:

→ A device used to protect equipment, devices against short circuit, over current and earth fault is called protective devices

(i) Types of Protective Devices:

(a) Fuse
(b) Miniature Circuit Breaker (MCB)
(c) Moulded case circuit Breaker (MCCB)
(d) Earth Leakage Circuit Breaker (ELCB)
(e) Earthing (or) Grounding.

4.5 Switch Fuse Unit:

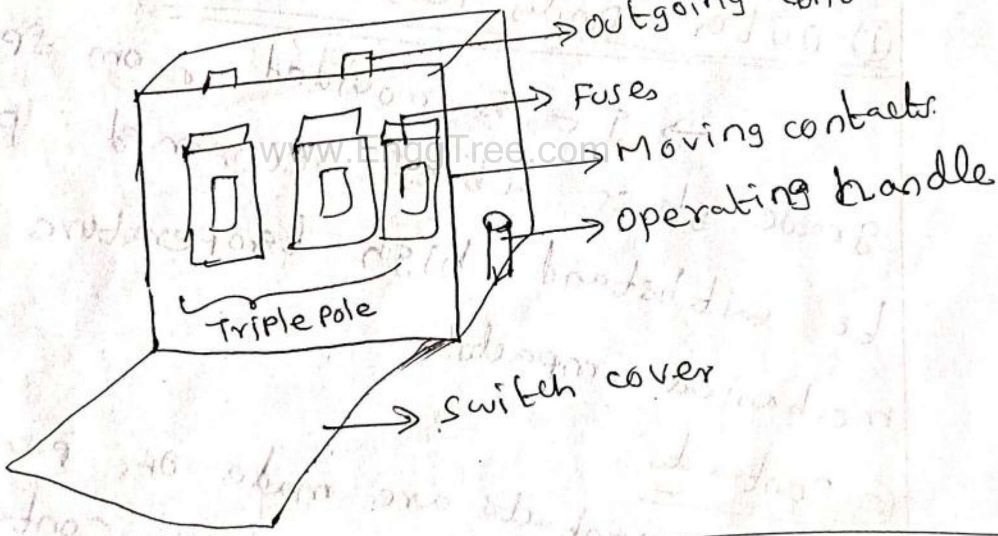
→ As per Indian electricity rule 50, a suitable linked switch is to be provided immediately after the meter board.

→ This rule also stipulate that suitable cutout must be provided to protect the circuit against excessive current.

→ Switch fuse unit is a combined unit and is known as iron clad switch, being made of iron.

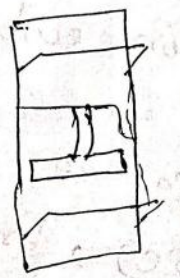
→ It may be double pole for 1φ, 2 wire circuits (or) triple pole for controlling 3φ, 3 wire circuits (or) triple pole with neutral link for controlling 3φ, 4 wire circuits.

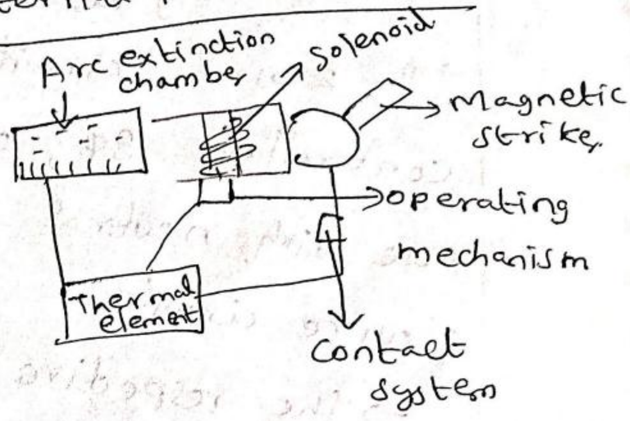
→ The respective switches are known as Double Pole Iron Clad (DPIC), triple pole Iron clad (TPIC) and Triple pole with neutral link iron clad (TPNIC)



4.6 Miniature circuit Breaker (MCB):

→ It is a device that provides definite protection to the wiring installations and sophisticated equipment against overcurrents and short circuit faults.





(i) Construction:

→ MCB has following main parts.

① Outer Body (or) housing:

→ It is moulded from special grade glass fibre reinforced polyester to withstand high temperature and mechanical impacts.

② Contacts:

→ contacts are made of pure silver to give long life, low contact resistance and low heat generation

③ Operating mechanism:

→ These are made of special plastic to eliminate wear and tear, rust & corrosion.

→ These components are very light weight and have low inertia and so reliability & ruggedness is maintained.

④ Arc extinguising chamber:
→ arc produced is cleared by providing special arc chute chamber.

⑤ Fixing arrangement:
→ MCB mounting clip get connected easily with screw driver.

⑥ Mechanical interlocking of multiple MCBs:
→ levers of all 3 (or) 4 multiple MCBs are connected internally.

(ii) Working:
→ MCB may operate under 2 different conditions

(i) Moderate overload condition: Detection of these condition is achieved by use of thermometal that deflects in response to current passing through it.

(ii) Short circuit conditions: When current flowing through MCB reaches a predetermined level, it pushes solenoid plunger that release trip mechanism and seperate the contacts.

(iii) Applications:

→ In sophisticated appliances like computers, air conditioners, compressors etc.

4.7 Moulded Case Circuit Breaker (MCCB)

→ It is a type of electrical protection device that can be used for wide range of voltages, and frequencies of both 50 Hz & 60 Hz.

→ Main distinctions between MCB & MCCB are that MCCB can have current ratings upto 2500 A & its trip settings are normally adjustable.

→ MCCB is much larger than MCB.

(i) Main functions:

→ MCCB has 3 main functions

a) Protection against overload:

→ for current above rated value

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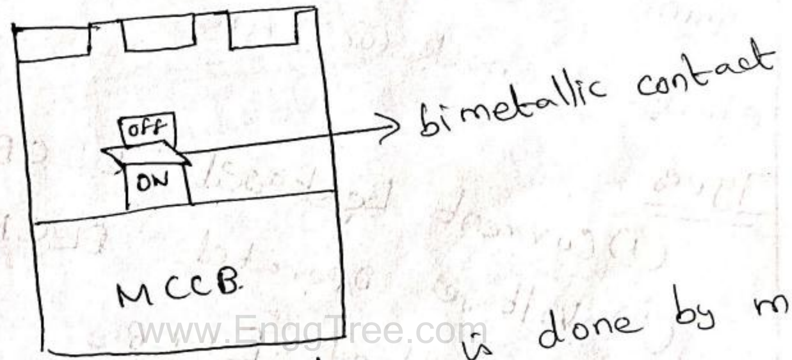
b) Protection against electrical faults:

→ For faults such as short circuit (or) line fault.

c) Switching a circuit on and off:

→ to break circuit during faults.

(ii) Operating Mechanism:



→ overload protection is done by means of thermal mechanism.

→ MCCB has bimetallic contact which expands and contracts in response to change in temperature.

→ If current exceeds trip value, contact will start to heat & expand until circuit is interrupted.

→ Thermal protection against overload is designed to allow short duration overcurrent.

→ Fault protection is done with electromagnetic induction.

→ Fault current should be interrupted

immediately.

→ when fault occurs, extremely high current induce magnetic field trips a contac and current is interrupted.

4.8 Earth leakage Circuit Breaker (ELCB):

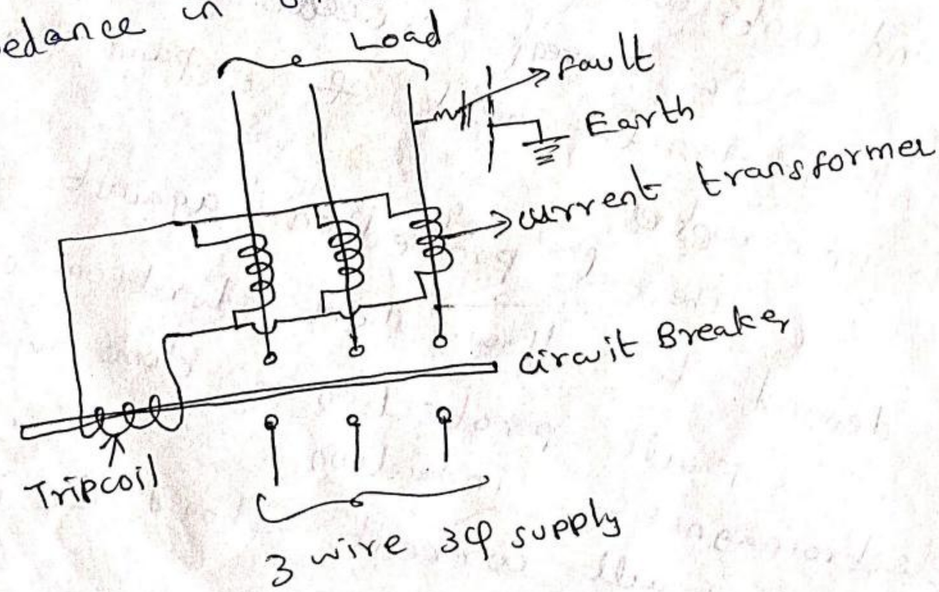
→ It is a device that provides protection against earth leakage which may cause electric shock (or) fire.

Types:

(i) Current operated ELCB
(ii) Voltage operated ELCB

(i) Current Operated ELCB:

→ It is operated when product of operating current in amps & earth loop impedance in ohms does not exceed 40.

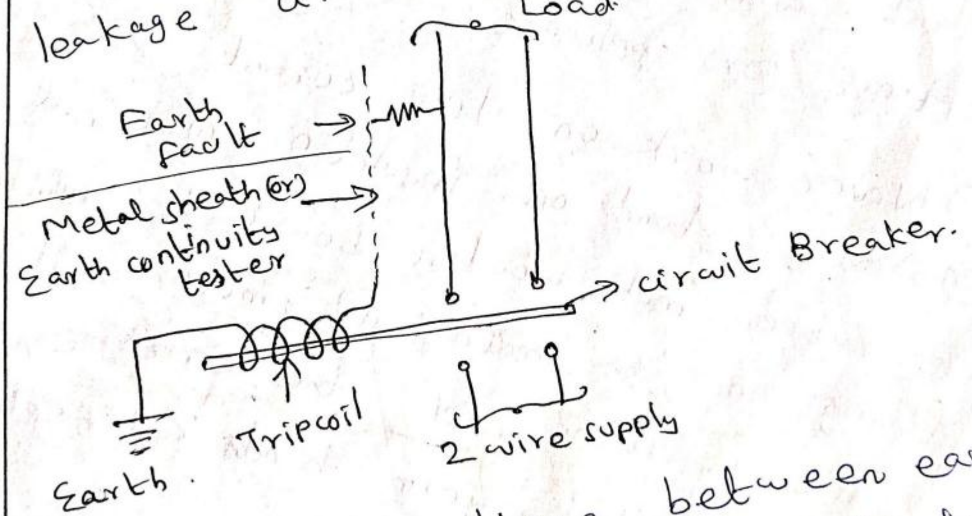


→ In normal conditions, when there is no earth leakage, the algebraic sum of currents in 3 coils of current transformers (CTs) is zero & no current flows through trip coil

→ In case of any leakage, currents are unbalanced & trip coil is energized & thus circuit breaker is tripped.

(ii) Voltage - Operated ELCB:

→ It is suitable for use when earth loop impedance exceeds values applicable to fuses (or) to current operated earth leakage circuit breaker.



→ when voltage between earth continuity conductor (ECC) and earth electrode rises to a sufficient value, tripcoil will carry required current to trip circuit breaker.

→ With such a circuit breaker, the earthing lead between trip coil & earth electrode must be insulated.

→ In addition, earth electrode must be placed outside the resistance area of any other parallel paths which may exist.

4.9 Safety Precautions and first aid:

(1) Precautions against Electric Shock:

→ The following precautions should be taken as preventive measures from electric shock while dealing with electrical equipment fittings (or) appliances

1. Never work on live circuit.
2. Always stand on insulating material such as rubber mat, wooden board etc while switching on the main switch, motor switch etc
3. While switching 'ON' the circuit, equipment etc, ensure that your hands and feet are dry
4. Avoid working at all those places where

your head is liable to touch the live circuits/parts

⑤ while working with electrical equipments, never come in contact with metallic casing, earth conductor, etc

⑥ while working on high voltage circuit, avoid your direct contact with concrete flooring

⑦ Never touch the person directly, while rescuing him from electric shock.

⑧ consider all conductors as live, till you are not sure.

(ii) <u>First aid:</u>

<u>① If you receive an electric shock,</u>

★ let go off the electric source as soon as you can

★ If the shock feels minor, see a doctor as soon as you can, even if you don't have any noticeable symptoms, remember some internal injuries are hard to detect at first

★ cover any burns with sterile gauze bandages

★ Don't use adhesive

② If someone else has been shocked,

* Don't touch them
* Unplug (or) turn off power at control pan[el]
* If you can't turn off the power, use a piece of wood (or) broom handle, dry rope (or) dry clothing to seperate victim from power source
* Donot try to move victim touching a high voltage wire, call for emergency help.
* keep the victim lying down. Donot move the victim if there is suspicion of neck (or) spine injuries.
* If victim is not breathing, apply resuscitation. If victim has no pulse, begin cardio pulmonary resuscitation. (CPR).

Then cover the victim with blanket to maintain body heat and get medical attention.

2m Transmission losses:

These losses are due to energy dissipation in conductors, corona losses, leakage current losses, lengthy distribution lines, low power factor

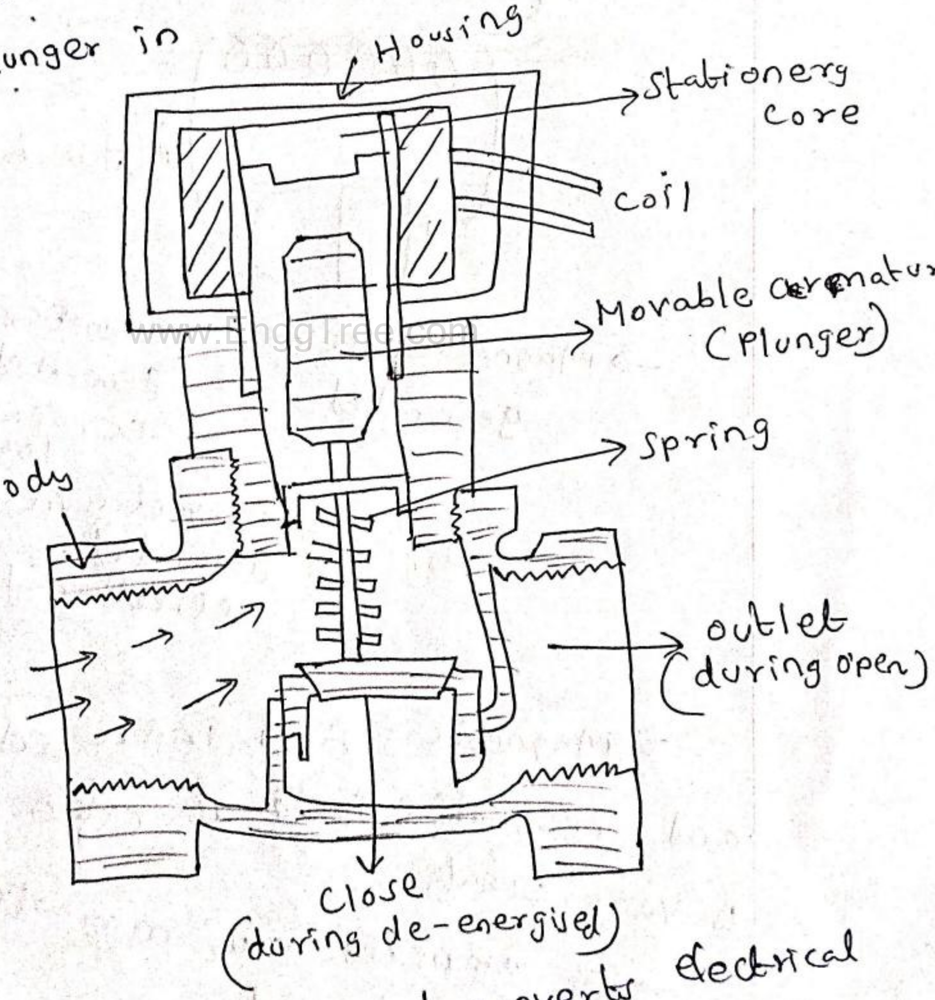
Unit - V

Sensors and Transducers

5.1 Solenoids:

→ A solenoid is a device comprise of a coil of wire, the housing and a moveable armature.

→ when an electric current is given, a magnetic field forms around. the coil draws the plunger in



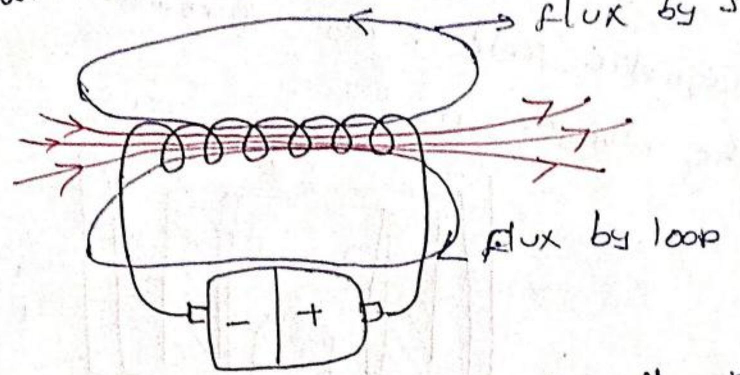
→ Simply, a solenoid converts electrical energy into mechanical work.

→ consider a solenoid whose length is

large compared to its radius.

→ Here wire is wound in the form of helix with a very little gap between turns.

→ Also wires are enameled and so insulated from each other. As a result, each turn can be taken as a closed circular loop.



→ Magnetic field generated = magnetic field generated by circular loop + magnetic field generated by solenoid

= Magnetic field generated by circular loop + sum of force generated by each turn.

→ Magnetic field inside solenoid is uniform and magnetic field at exterior to solenoid is very weak.

→ By ampere's law, magnetic force produced by solenoid,

$$F = \mu_0 n I$$

where μ_0 → permittivity constant
n → number of turns of wire
I → current flows in wire.

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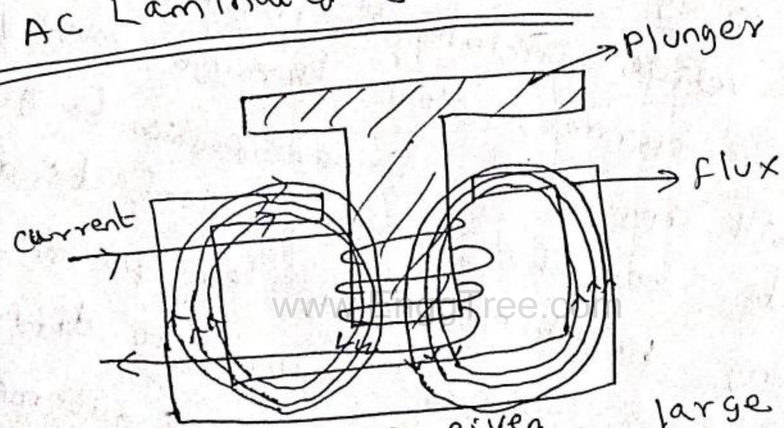
→ Direction of force is given using right hand thumb rule.

(i) Different types of Solenoids:

a) AC Laminated solenoid
b) DC C-frame solenoid
c) DC D-frame solenoid
d) Linear solenoid
e) Rotary solenoid.

a) AC Laminated solenoid:



→ when supply is given, large force is performed in first stroke. This solenoid is famous for this first stroke output

b) DC C-frame solenoid:

→ It uses only a fram formed like letter 'C' which is covered by coil. This can be designed to be used with AC power

(c) DC D-Frame Solenoid:

→ It has a 2 piece frame that covered with coil.

→ It can also be used for AC.

d) Linear solenoid:

→ These are capable of using a pulling or pushing force on a mechanical device.

→ eg: A solenoid in starter device of a vehicle includes a motor. whenever electric current flows through solenoid, then it will move in a linear fashion to get 2 contacts together. when 2 contacts are getting together, they let power to flow from battery supply to different components of automobile and automobile to start.

→ Best application of solenoid is electric lock.

→ When lock is attached to the bolt on a door, it can immediately protect a door sufficient to hold up to a great deal of violence

e) Rotary solenoid:

→ Rotatory solenoid is a good example of mechanical force which can be used to make easy of an automatic control process to make life easier.

→ In a rotary solenoid, a disc is used instead of solenoid being a simple device with a core and coil.

→ The body of solenoid is lined up with the grooves and ball bearings are used to make easier motion.

(ii) Applications of solenoid:

→ Solenoid is used in antennas, electromagnets, valves etc.

→ In medical, locking systems, industrial use and automotive solenoid applications.

→ In door locking system

→ In computer printers, fuel injection gear used on cars.

→ In various industrial settings.

(iii) Advantages:

→ Its response is immediate when electricity is applied.

→ Quick response is one of the most significant factors in the applications of solenoids.

5.2 Electro-Pneumatic Systems:

→ Pneumatic actuators are used across a variety of industrial applications.

→ Pneumatic actuators provide controlled and limited movements (or) positioning of items within an application with a push and pull function.

→ Actuators are generally operated via one of 2 basic motions (ie) linear and rotary actuator motions.

(i) Working of Electric actuator:

→ An electric actuator is a device that creates movement of a load (or) generates an action that requires some form of force to take place using an electric motor.

→ This electric motor creates a rotary (or) linear action that drives the actuator forward to create movement.

→ The electric motor is controlled by an electric drive which allows for the speed at which the motion takes place to be controlled. Thus the linear or rotary speed of the actuator is controlled.

→ A feedback system is put in place to provide feedback on the position of

Give Short notes

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the actuator, which enables the actuator to move the item into position, stop and then move on (or) alternatively return to its resting position.

→ The electric actuators are easily programmed to meet a variety of application requirements.

(ii) **Pneumatic actuator:**

→ Pneumatic actuators are highly reliable, efficient and safe way to control motion within an industrial application.

→ Pneumatic actuators operate using pressurized air (or) gas to convert energy into a rotary (or) linear motion.

→ As a result of this, pneumatic actuator are often selected for use in the repeated opening and closing of valves (or) other industrial applications.

Give short notes

→ Pneumatic actuators excel for use in areas with flammable (or) ignitable materials in which an electric actuator may cause a spark to ignite.

→ Pneumatic actuators rely heavily on some form of pressurized air (or) gas, which enters a chamber and builds up in pressure.

→ when it has built up enough pressure, this results in a controlled kinetic movement of a device, such as a piston (or) a valve.

→ The resulting movement can be directed through linear (or) rotary motions.

(iii) Different types of Pneumatic Actuator:

a) Rotary Actuators
b) Tie Rod Cylinders
c) Grippers
d) Rodless Actuators
e) Vacuum Generators.

(iv) Electro - Pneumatic Actuator:

Give short notes

→ Manufacturing environments demand precise movement and control.

→ By implementing actuators into manufacturing process, precise control of movement can be easily achieved.

→ Electro pneumatic actuators are considered a cost - effective alternative to electromechanical and electrohydraulic actuators in low - power applications.

→ Electro - pneumatic actuators are widely used to automate a number of areas of industrial applications, from production to assembly and packaging systems

→ Pneumatic components are

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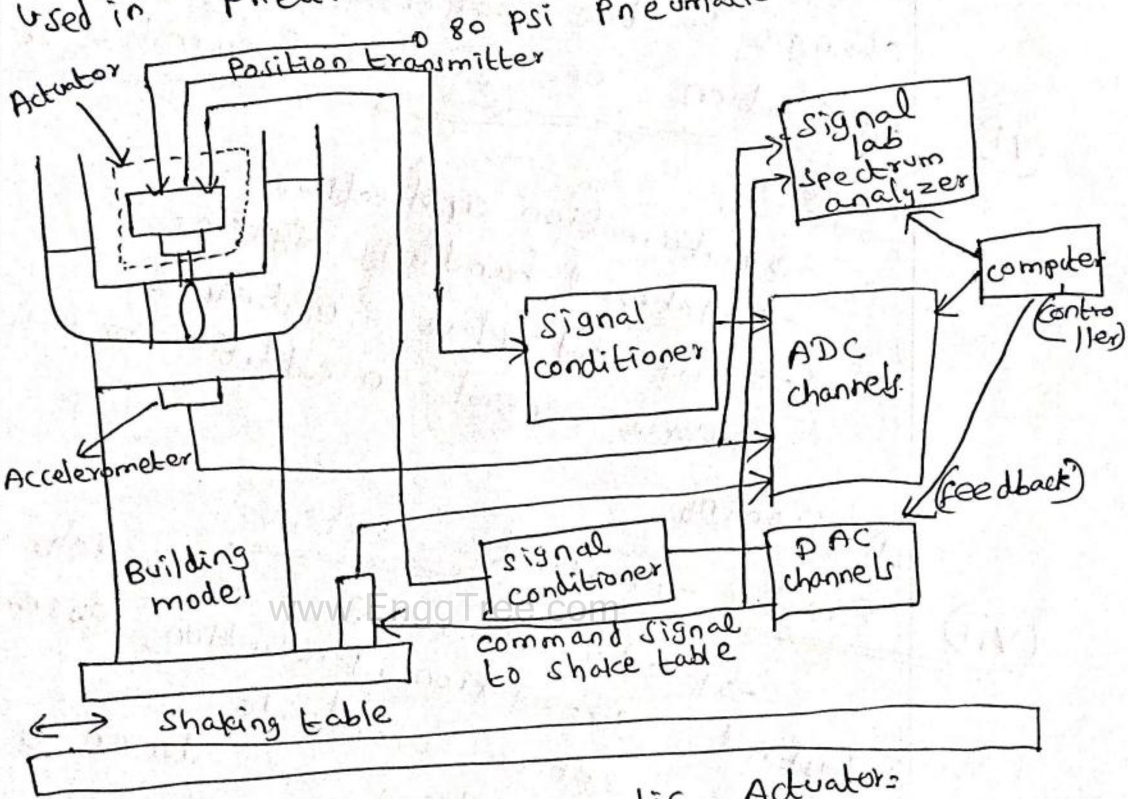
controlled by sensors, switches and industrial computer systems.

→ Use of electric components replaces the manual control which was traditionally used in pneumatic systems.



(V) Benefits of an electro-pneumatic Actuator:

→ Greater reliability - as the moving parts are generally subjected to less wear due to electrical control compared to mechanical control.

→ Electrical control system can be easily changed and modified including sensors and switches.

Give Short notes

→ Dynamic positioning done by parameter changes by controller with extreme accuracy

→ Best suitable system for high level of control and ability to make timely changes to the positioning system.

(vi) Applications of Electro-Pneumatic actuator Systems

→ Automation application

→ Material handling systems

→ Pick and place materials

→ Force control in addition to accurate positioning.

(vii) Electro-Pneumatic systems:

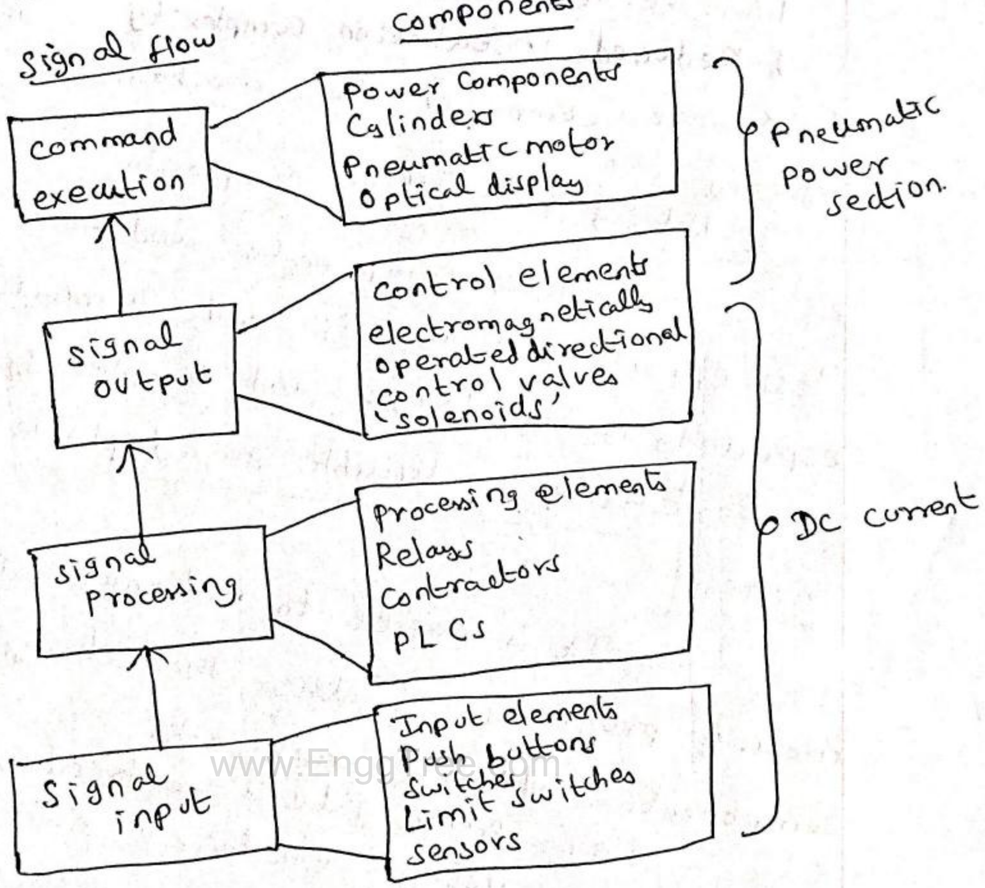
→ Electro-pneumatic is widely used in industrial automation, production, assembly and packaging systems worldwide.

→ These systems are driven by electro-pneumatic control systems.

→ In electro-pneumatic, pneumatic components are controlled using electrical and electronic circuits.

→ Electronic and electromagnetic sensors, electrical switches and industrial computers are used to replace manual control of pneumatic system.

a) Signal flow in electro-pneumatic control system.



1. Signal input: This signal is usually generated from sensor (or) switch.
2. Signal Processing: Signal is processed in the processing station such as OR gate, AND gate (or) time delay valve
3. Signal output: Signal forms a link between signal control section & power section
4. Command execution: It takes place at high power level for a) high speed - fast ejection of product b) apply high force as in power level.

b) Advantages of electro pneumatic systems:

1. Greater reliability

→ Less moving parts subjected to wear compared to mechanical control systems

2. Reduced installation complexity

→ Less components and hoses, leads to less effort in planning and commissioning especially with large and complex systems

3. Easily modifiable & adaptable control system

→ It is easier to change wiring and modify programs rather than changing mechanical components and hose networks.

→ eg: AND gate is replaced with logic and through using electrical switches

4. Easy handling

→ due to less complexity

5. Secure mounting

→ by using fewer hoses coupling system

6. Environmentally-friendly

→ due to less lubrication requirement.

c) components of electro-pneumatic system

① DC power supply
② Switches
③ Relays
④ Solenoid valves
⑤ Sensor

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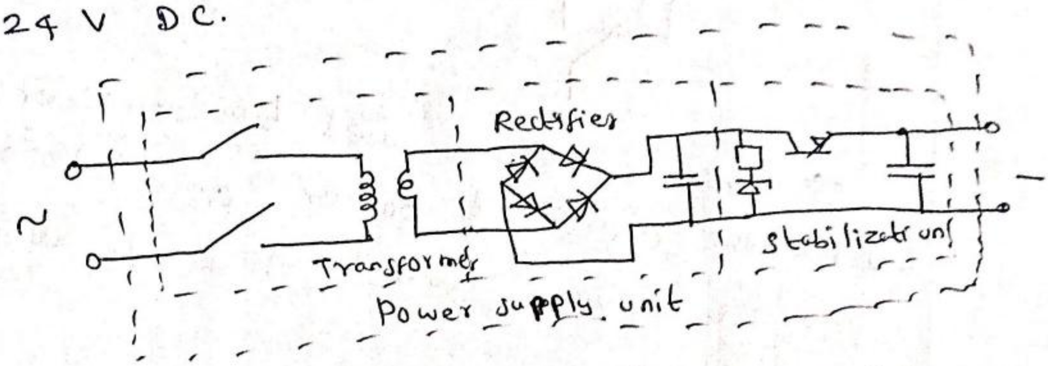
① DC power supply:

→ Power supply converts 230 V AC to 24 V DC.



→ Transformer reduces the main voltage 230V to 24 volt

→ Rectifier converts the AC voltage to DC voltage

→ Stabilizer is used to smooth and maintain constant voltage at the output

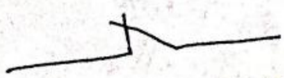
② Switches:

→ switches are installed to connect (or) interrupt the electric current

a) Push button switch (N/O → Normally Open)

→ Normally open (N/O) switch remains open when at rest preventing current flow

b) Push button switch (N/C → Normally closed)



→ This switch remains closed allowing

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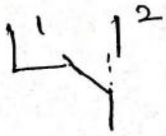
current flow when at rest.

c) Change over switch (two way)



→ This switch is used to transfer (or) switch the electrical power from 1 to 2.

→ It never switch 1 & 2 at the same time

③ Relays

→ It is an electromagnetic switch that uses a small electrical input to control a larger electrical load (or) circuit.

④ Solenoid valves

→ It is an electromechanical device used to control flow of liquids (or) gases.

⑤ Sensor :

→ Sensor detects and measures physical events (or) changes, then converts these into electrical signals.

5.3 Proximity Sensors :

→ Proximity sensors comprises all sensors that execute non-contact detection as compared to limit switches that notice objects though contacting physically.

→ These type of sensors change the data into an electrical signal on the movement (or) occurrence of a target.

→ These sensors are used in mobile phones.

→ Once the target is in small range, then lock screen of the mobile user interface will come into view called sleep mode.

→ The main purpose of this sensor is to notice object without any physical contact with it.

→ A non contact sensor that is used to detect the presence of a target (or) object is called a proximity sensor.

→ This sensor is capable of detecting close-by objects through electromagnetic radiation without any physical contact.

→ For instance, an IR proximity sensor is used in mobile phones to detect a human ear when the operator places the phone on the ear, mobile display will be turned off automatically, so power consumption can be reduced.

(i) Working Principle:

→ A non-contact sensor detects the existence of a target once it enters the field of the sensor.

→ Detection of a target can be done based on kind of sensor by using light, sound, IR (or) electromagnetic fields.

→ These sensors are utilized in recycling plants, phones, anti-aircraft systems and self driving cars.

(ii) Proximity sensor types:

a) Inductive proximity sensor
b) capacitive proximity sensor
c) Ultrasonic proximity sensor
d) Optical proximity sensor
e) Magnetic proximity sensor

a) Inductive proximity sensor:

→ These are contactless sensors used to detect metal objects.

→ This kind of sensor depends on induction law.

→ Once a metallic object approaches it then it drives an oscillator through a coil.

b) Capacitive proximity sensor:

→ These are contactless sensors used to notice both the objects like metallic and non metallic that includes powders, liquids, granular etc.

→ This sensor works by noticing a change in capacitance.

→ It has 2 charging plates; internal plate is connected to an oscillator whereas the external plate is used as detecting surface.

→ Once an object reaches the detecting region, then both plate's capacitance also increases, results in amplitude gain of oscillator.

→ This gain activates the output switch of the sensor.

→ These sensors oscillate only once the target is re...

→ Applications of capacitive proximity sensors include industrial processes, controlling moisture etc.

c) Ultrasonic proximity sensor:

→ These sensor is used in applications of automation as well as manufacturing

→ Main purpose of this sensor is to detect objects and measurement of distance.

→ These sensors are used in processing beverages, food and several packaging applications.

→ Frequency range of these sensors

is higher than audible sound of humans approx. 20 kHz.

→ Basic principle of this sensor is to transmit an ultrasonic signal and gets a signal back.

→ By using time disparity (difference) among these signals, distance toward the target can be decided.

→ These sensors can use sound instead of light.

d) Optical Proximity sensor:

→ Generally these sensors are cost-effective as compared to inductive and capacitive types.

→ These are applicable in automated systems.

→ These are also called as light beam sensors.

→ These sensor has a sensor and a light source.

→ sensor is used to detect the light.

→ light sensor is a photodiode that produces less light when light energy strikes it.

→ Applications of these sensors

mainly include copy machines, light fixtures etc

e) Magnetic Proximity sensor:

→ Magnetic proximity sensor simply detect magnetic target.

→ Once it enters the range of the sensor detection, then it activate the switches.

(iii) Features of proximity sensor:

→ contactless sensing

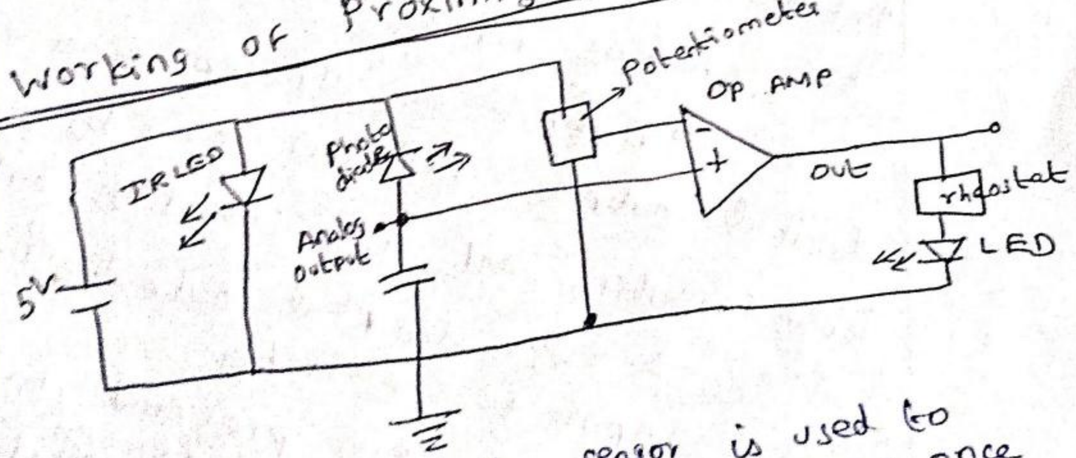
→ used for broad temperature range

→ used in android and IOS based mobiles.

→ Longer service life

→ Response rate speed is high.

(iv) working of Proximity sensor:



→ Infrared proximity sensor is used to notice the existence of a target once it comes to a fixed range

→ The circuit has 2 LED's parallel to each other as photo diode and IR emitting

LED.

→ Both acts like a pair of transmitter and receiver.

→ According to the photodiode properties, interrupted IR waves will reduce resistance of the photo diode and electric signal is generated.

→ This signal gives voltage across resistor which is fed to non inverting (+) end of op-amp

→ The OP-Amp's main function is to evaluate 2 inputs given to it.

→ The photodiode signal can be given to non inverting (+) input and potentiometer's threshold voltage is given to inverting input.

→ Output of opamp gives the digital output high (or) low by comparing both inverting and non inverting input.

→ This digital output cannot be given as input to switches.

→ So these are processed by LED and the light is given to sensors.

(V) Applications:

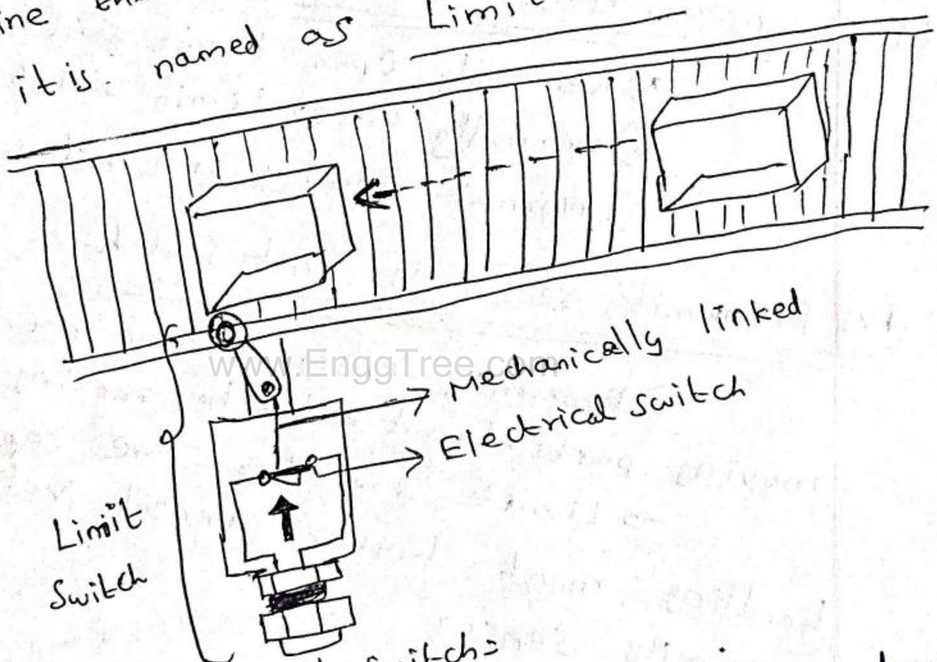
→ Mobile phone, Robots, automation systems, electric vehicles, Detecting positions of obstacle.

5.4 Limit switches:

→ Limit switch is an electromechanical device operated by a physical force applied to it by an object.

→ Limit switches are used to detect the presence (or) absence of an object.

→ These switches were originally used to define the limit of travel of an object and so it is named as 'Limit switch'.



(i) Working of Limit switch:

→ Limit switches are electromechanical device consists of an actuator linked mechanically to an electrical switch.

→ when an object contacts the actuator, switch will operate causing an electrical connection to make (or) break depends on application.

(ii) Limit switch applications

a) Limit switch is used to detect if the fridge door is open (or) closed.

b) On many over head garage doors, there is a limit switch that stops the movement of door when it reaches its fully opened position.

(iii). Configurations of limit switches:

a) Normally Open Limit switch
b) Normally Closed Limit Switch
c) Normally open/closed Limit switch.

(iv) Proximity Sensor Vs limit switch:

→ Proximity sensor has no mechanical moving parts. Limit switch has moving parts

→ Limit switches are capable of handling much higher current values than proximity sensor.

5-10, 5-5 Piezo Electric Transducers, Piezo Electric Crystals:

→ Piezo electric transducer is one which an electric potential appears across crystal if dimensions of crystal are changed by applications of mechanical force.

→ This potential is produced by the displacement of charges.

→ The effect is reversible (ie) conversely if a varying potential is applied to crystal axis, it will change the dimensions of the crystal, thereby deforming it. This effect is called <u>Piezo-electric effect</u>.

→ Elements exhibiting piezo-electric qualities are called as <u>electro-resistive elements</u>

→ common piezo electric materials are Rochelle salts, lithium sulphate, quartz and ceramic.

→ The materials that exhibit piezo electric effect are divided into 2 categories

a) Quartz and Rochelle salt belong to <u>natural group</u>

b) Materials like lithium sulphate belong to the synthetic group

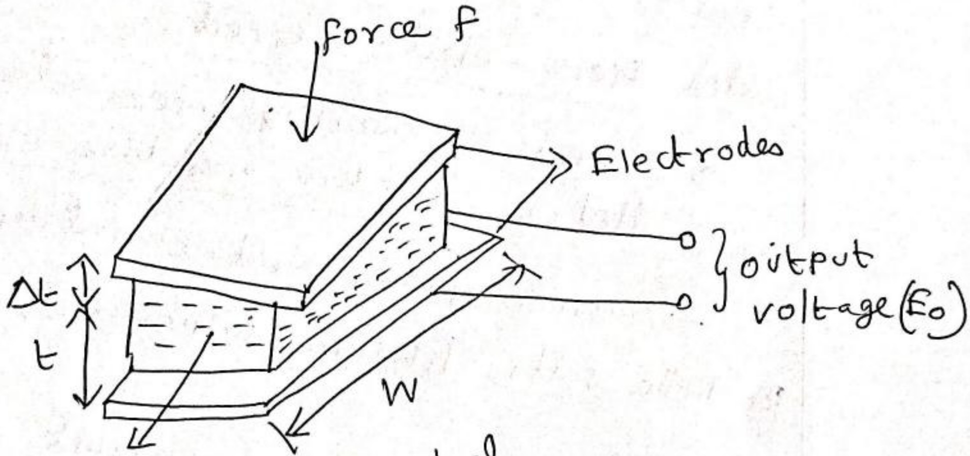
→ piezo electric element used for converting mechanical motion to electrical signals may be charge generator and capacitor.

→ Mechanical deformation generates charge and appears as voltage across electrodes

Voltage E = Q I C

where Q → charge
I → current
C → capacitance.

→ A tensile force produces a voltage of a polarity while a compressive force produces a voltage of opposite polarity



Piezo Electric crystal

→ Magnitude and polarity of induced surface charges are proportional to the magnitude and direction of the applied force F.

Charge $Q = d \times F$ coulomb — ①

where d → charge sensitivity

F → Force (N)

→ force F cause a change in thickness of the crystal

$$F = \frac{AE}{t} \Delta t \text{ Newton} \quad — ②$$

where A → Area of crystal (m^2)

t → thickness of crystal (m)

E → Young's modulus (N/m^2)

from ①,

→ $E = \frac{F}{A}\left(\frac{t}{\Delta t}\right)$ — ③

→ $\text{Stress} = \frac{F}{A}$ — ④

→ $\text{Strain} = \frac{\Delta t}{t}$, $\frac{1}{\text{strain}} = \frac{t}{\Delta t}$ — ⑤

Sub ⑤ & ④ in ③

$\therefore E = \frac{\text{Stress}}{\text{Strain}} = \frac{F}{A}\left(\frac{t}{\Delta t}\right)$

→ sub ② in ①

$Q = d \times AE \frac{\Delta t}{t}$ — ⑥

Capacitance $C = \frac{Q}{E}$

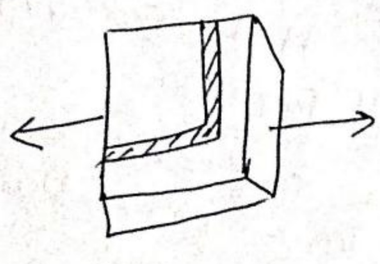
$\therefore$ from ⑥

$C = \frac{Q}{E} = d A \frac{\Delta t}{t}$

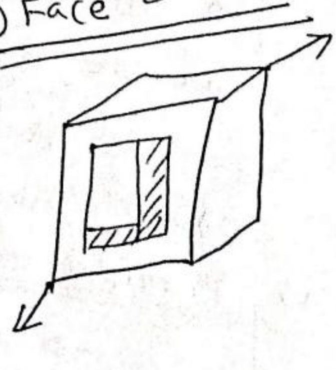
(i) Modes of operation of Piezo electric Crystals:

→ Piezo electric crystals are used in many modes.

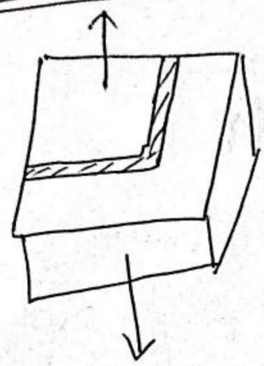
a) Thickness Shear:



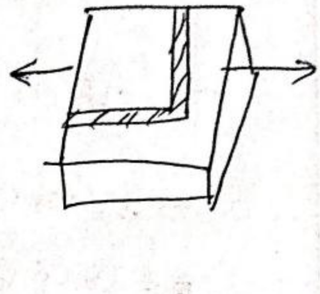
b) Face Shear



c) Thickness expansion



d) Transverse expansion



(ii) Properties of piezo electric crystals:

a) High stability

b) High output insensitivity to temperature and humidity.

c) Ability to be formed into desired shape

d) can withstand high stress and good frequency response

5-6 Hall Effect:

→ Hall effect is a process in which a transverse electric field is developed in a solid material when material is placed in magnetic field carrying an electrical current (e) ⊥r to the current

→ Hall effect was discovered by Edwin Herbert Hall in 1879

(i) Principle of Hall Effect:

→ When a current carrying conductor is introduced to a perpendicular magnetic field, a voltage can be measured at right angle to current path.

→ This effect of obtaining a measurable voltage is called as Hall effect.

(ii) Theory:

→ When a conductive plate is connected to a circuit with battery, current starts to flow.

→ Motion of the charge carriers result in production of magnetic field.

→ When magnet is placed near the plate, magnetic field is distorted.

→ The force which distorts the direction of flow of charge carriers is called as Lorentz force.

→ Due to the distortion in magnetic field, negatively charged electrons will be moved to one side and positively charged holes to the other side.

→ Potential difference called as Hall voltage (V_H) will be generated between both sides of plate

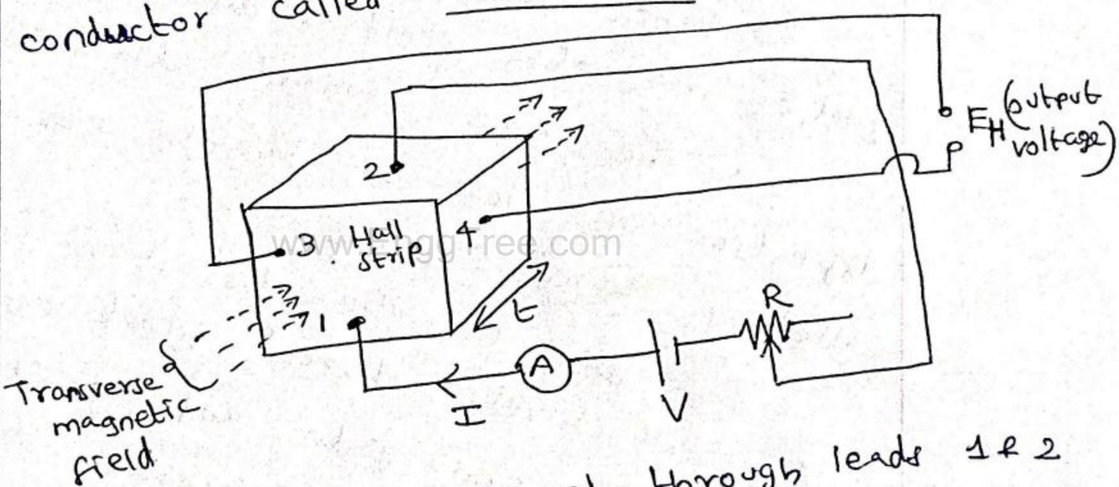
→ Hall voltage $V_H = \frac{IB}{qnd}$

where I → current, B → magnetic flux density, q → charge, d → thickness of sensor, n → no. of charge carriers per unit volume.

(iii) Hall-Effect Transducer:

→ Hall effect transducer is that if a strip of conducting material carries a current in presence of transverse magnetic field, potential difference is produced between opposite edges of conductor.

→ Voltage magnitude depends on current, magnetic field strength and property of conductor called Hall effect.



→ current is passed through leads 1 & 2 and output leads are connected to edges 3 & 4

→ When transverse magnetic field passes through strip, output voltage appears across output leads.

→ E_H = output voltage $= K_H \frac{IB}{t}$

where K_H → Hall effect coefficient
t → thickness of strip

(iv) Applications of Hall effect Transducer:

→ measurement of displacement
→ measurement of voltage
→ measurement of current
→ measurement of power

5.7 Photo sensors:

→ Photo sensors (or) photo electric sensors are used to detect distance, absence or presence of objects using light transmitter and receiver.

→ Photoelectric sensor has an emitter to emit light and receiver to receive light.

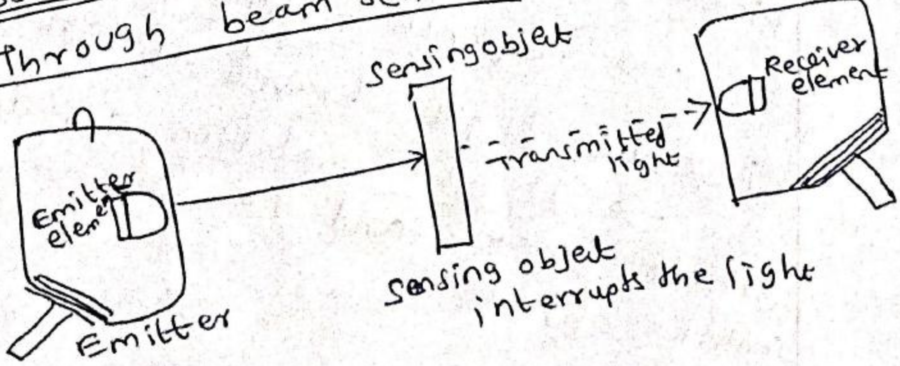
→ When emitted light is interrupted (or) reflected by sensing object, it changes the amount of light at receiver.

→ Receiver detects the change and converts it to an electrical output.

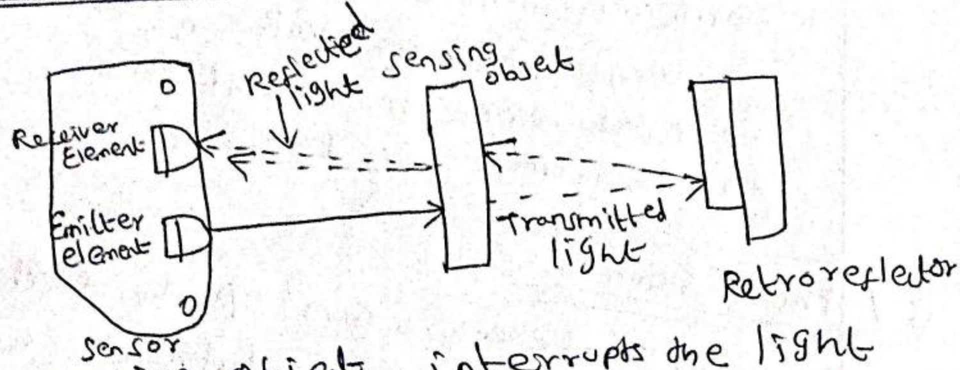
→ Light source is Infrared (or) visible light.

(i) Classification of photoelectric sensors:

a) Through beam sensors:

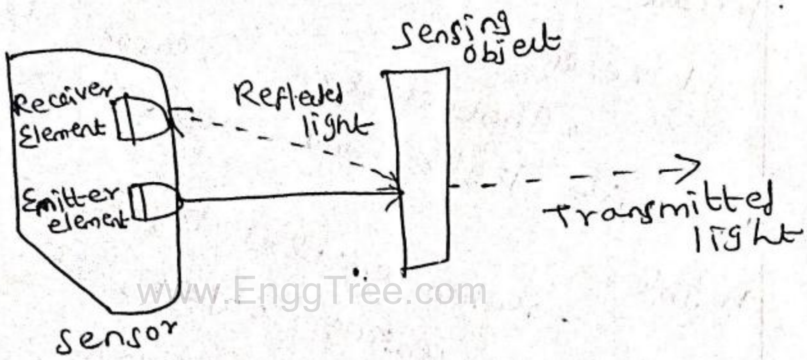


b) Retro reflective sensors



→ sensing object interrupts the light

c) Diffusive - reflective sensors



(ii) Features:

→ Long sensing Distance

eg: Through beam sensor can detect objects more than 10m

→ used to detect objects including glass, plastic, wood and liquid.

→ response time is extremely fast because light travels at high speed.

→ High resolution can detect very small beam and so it can detect very small objects

→ rate at which objects or.

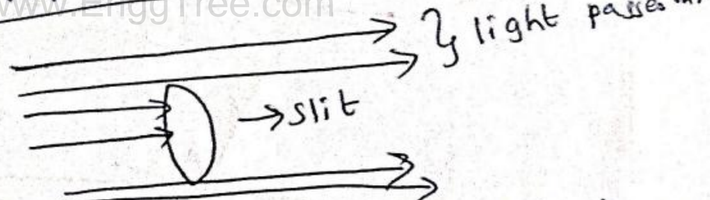
(or) absorbs light depends on wavelength of light and colour of object. This can be used to detect colors

→ positioning the beam on an objects simple makes easy adjustment

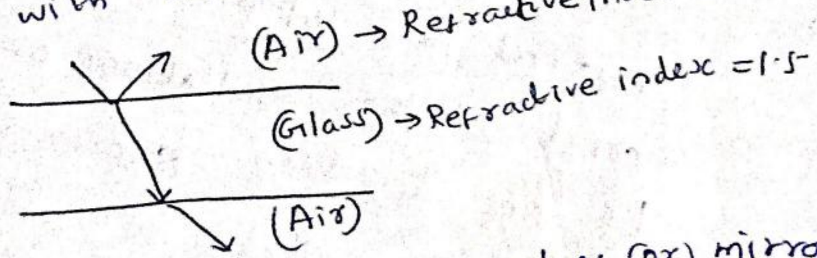
(iii) Operating Principle

a) Properties of Light :

→ When light travels through air (or) water, it always travel in a straight line. Slit on outside of a through-beam light is used to detect objects. This principle is called Rectilinear Propagation



→ when light is deflected when it pass through boundary between 2 media, refraction principle take place through boundary between 2 media with different refractive index.



→ Flat surface such as glass (or) mirror, reflects light at an angle equal to incident angle called regular reflection principle

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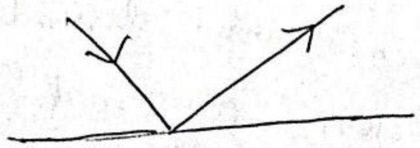
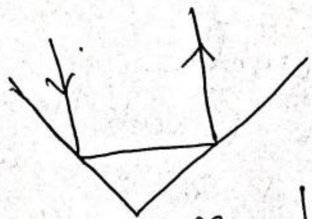
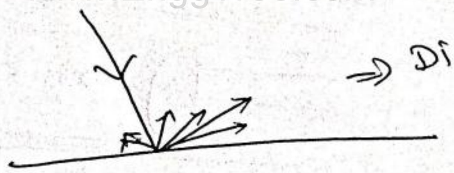


→ Light emitted toward a corner cube repeatedly propagate. regular reflections, and reflected light ultimately moves back toward the emitted light called Retroreflection



→ Matte surfaces like white paper reflects light in all directions. This scattering of light is called diffuse reflection principle



→ Photo electric sensors use LEDs as the light source. Light emitted from LEDs oscillate in vertical and horizontal directions referred as Unpolarized light. Optical filters constrain the oscillation of unpolarized light to one direction known as polarizing filters.

The light oscillates in only one direction is called as polarized light

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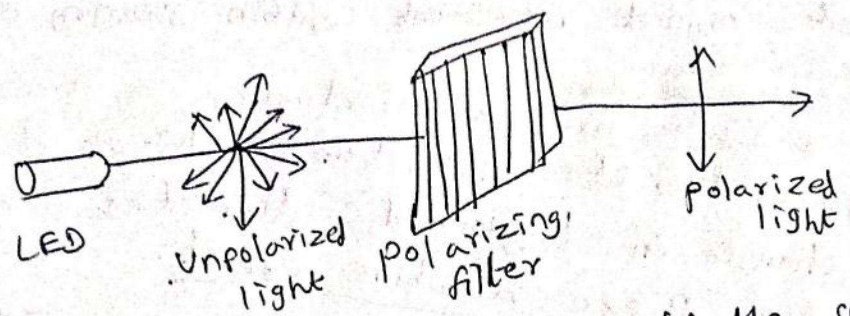
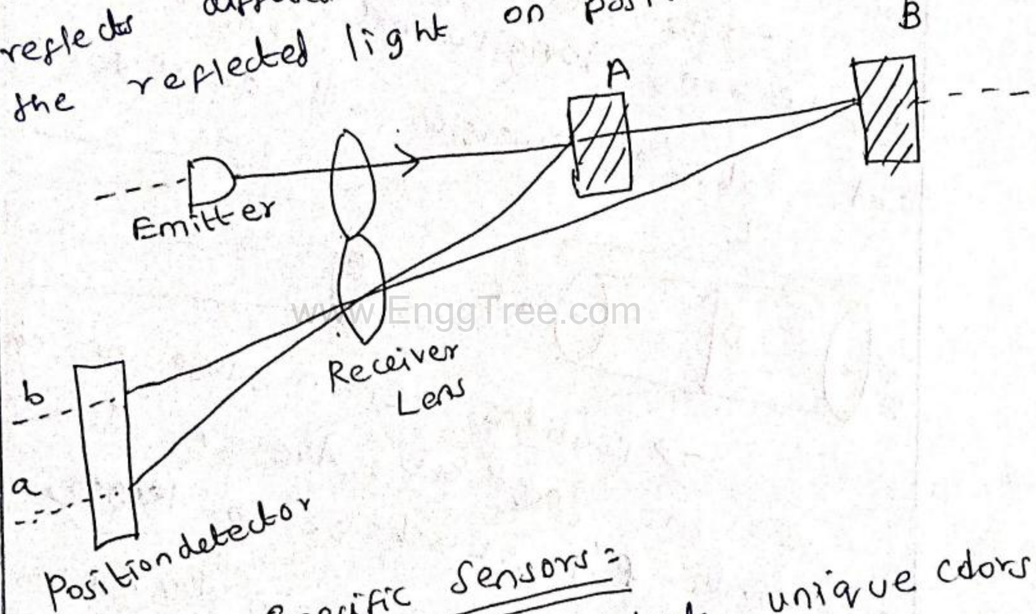
5.33



(iii) → Distance settable sensors generally operate on the principle of triangulation. Light from emitter strikes the sensing object and reflects diffused light. Receiver lens concentrates the reflected light on position detector.



(iv) Application Specific Sensors :-

→ Colour sensors detect unique colors (or) multiple shades of colours depending on manufacturers range of colours.

→ Contrast sensors are used to detect two colours difference.

→ Luminescence sensors are used to detect inks, greases, glues, paints etc.

→ Passive infrared sensors are used to detect object within sensing area.

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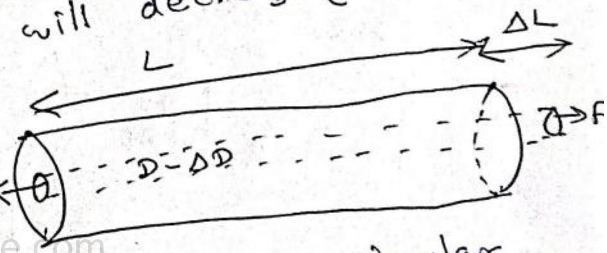
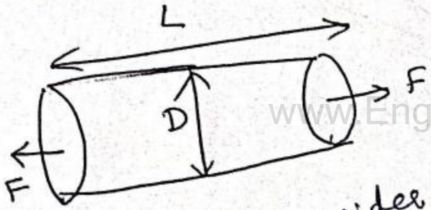
5.8 Strain Gauge

→ If a metal conductor is stretched (or) compressed, its resistance changes due to changes in length and diameter. This property is called piezo resistive effect.

→ Resistance strain gauges (or) piezo resistive gauges are used to measure strain and stress.

→ If strip of elastic material is subjected to tension, longitudinal dimensions will increase (L+ΔL) and lateral dimension will decrease (D − ΔD)





→ Consider strain gauge of circular wire has length = L, Area = A, Diameter → D resistivity 'ρ', Δ → change

→ Gauge factor is defined as the ratio of per unit change in resistance to per unit change in length.

$$\text{Gauge factor}(G_f) = \frac{\Delta R/R}{\Delta L/L}$$

$$\text{Strain}(\varepsilon) = \frac{\Delta L}{L}$$

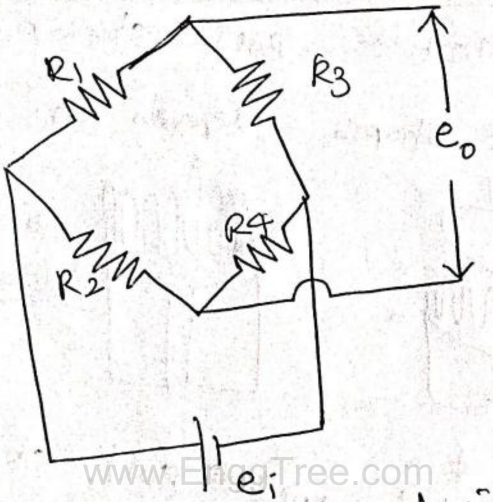
$$\therefore G_f = \frac{\Delta R/R}{\varepsilon}$$

(i) Types of Strain Gauges:

a) Unbonded metal Strain Gauges:

→ It consists of a wire stretched between 2 points in an insulating medium such as air

→ wires can be copper nickel, chrome nickel (or) nickel iron alloys.



→ This gage is used in transducer.

b) Bonded wire strain Gauge:

→ Here, resistive element is cemented to carrier (base) which may be a thin sheet of paper in the form of wire, foil (or) film of the material.

→ wire is covered on top with a thin sheet of material to prevent it from any mechanical damage.

→ This spreading of wire permits a

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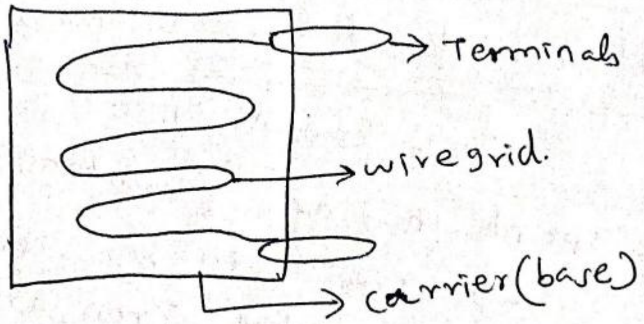
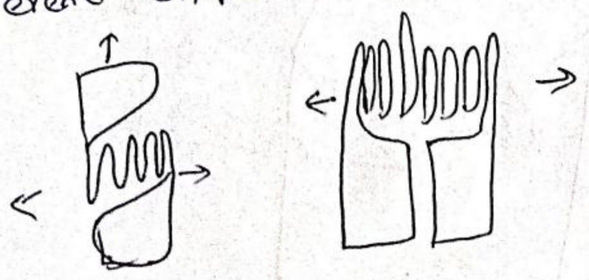
uniform distribution of stress.

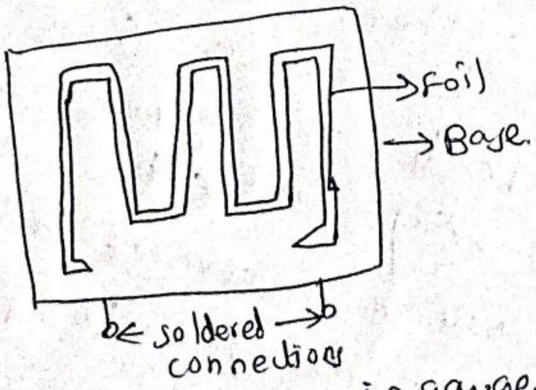


c) Bonded Metal foil Strain gauges:

→ Metal foil strain gauges are used in different shapes depends on application.



→ Bonded metal foil strain gauges is an extension of metal foil gauges with soldered connections.

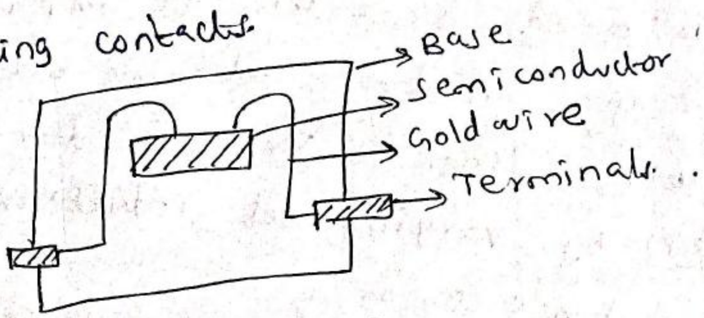


d) Semi conductor strain gauges:

→ Semi conductor materials used are silicon (or) Germanium

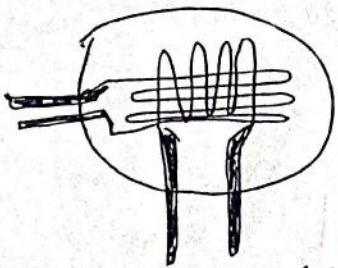
→ These materials are used to create

filament and Gold leads are used for making contacts.



e) Diffused strain Gauge:-

→ Here diaphragm is made of silicon



→ strain can be measured when stress is applied. parallel to the strain axis.

5-9 LVDT: (Linear Variable Differential Transducer)

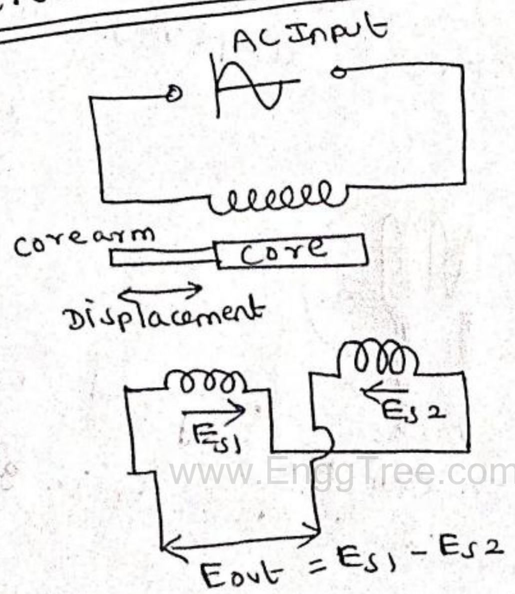
→ Displacement is a vector quantity representing a change in position of a body with respect to reference.

→ It can be linear (or) rotational motion.

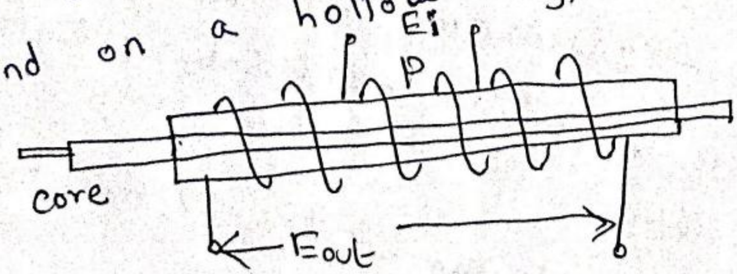
→ In linear displacement, magnitude of measurement may range from few mm to few centimetre.

→ In variable inductance type, Inductance is varied according to displacement by varying mutual inductance between 2 coils using linear variable differential transformer (or) by varying self inductances using variable reluctance sensor.

(1) Construction and working of LVDT =



→ Linear variable differential transformer consists of a single primary winding P, and two secondary windings S_1 and S_2 wound on a hollow cylindrical former.



→ Secondaries have an equal number of turns but they are connected in series opposition so that emf induced in coils oppose each other.

→ primary winding is connected to an ac source whose frequency may range from 50Hz to 20kHz.

→ A movable soft iron core slides inside the hollow former.

→ Position of movable core determines flux linkage between ac excited primary winding and each of 2 secondary windings.

→ With the core in the centre (or) reference position, induced emf in the secondaries are equal and since they oppose each other output voltage will be zero.

→ When an extremely applied force moves the core to the left hand position, more flux links the left hand coil than right hand coil.

→ Emf induced in left hand coil E_{s1} is larger than emf induced in right hand coil E_{s2}.

→ Magnitude of output voltage } $E_{out} = E_{s1} - E_{s2}$
= Difference between 2 secondary voltages

→ When the core is forced to move to right, more flux links the right hand coil than left hand coil and emf induced in right hand coil E_{S2} is larger than emf induced in left hand coil E_{S1}.

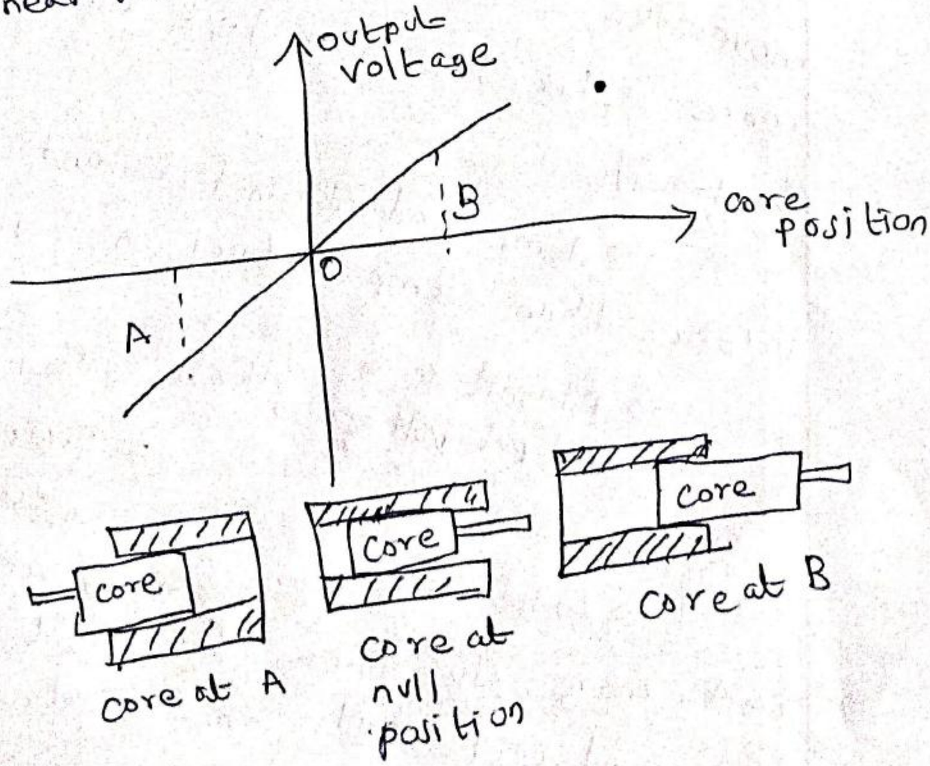
$$E_{out} = E_{S2} - E_{S1}$$

→ Thus LVDT output voltage is a function of core position.

→ The amount of voltage change in any secondary winding is proportional to the amount of movement of core.

→ The amplitude of the output voltage is a function of distance of core moves, while polarity (or) phase indicates the direction of motion.

→ Amount of output voltage of LVDT is a linear function of core displacement.



(ii) Advantages of LVDT

→ Output voltage is linear for displacement

→ Output voltage is continuous, stepless

→ LVDT gives reasonable high output

→ LVDT has high sensibility (ie) 1mm displacement of core produces output voltage of 300 mV.

→ LVDT is mechanically rugged and can withstand mechanical shocks and vibrations

→ LVDT has less friction due to no sliding contacts

→ LVDT consumes less power.

→ LVDT transducer are small, simple, light in weight. They are stable and easy to align and maintain.

(iii) Disadvantages of LVDT:

→ large displacements are necessary for appreciable output

→ Interference can be reduced by shielding

(iv) Applications of LVDT:

→ LVDT can be used as a device to measure force, weight, pressure etc.

→ LVDT can be used in all applications where displacement changes.

5.11 Differential Pressure Transducer:

→ Differential pressure Transducer is a transducer that converts an input mechanical pressure in gases (or) liquids into an electrical output signal.

→ It has pressure sensitive element that can measure, detect (or) monitor pressure and electronic components to convert the information into an electrical output signal.

→ Pressure (P) is defined as the amount of force exerted by a liquid (or) gas applied to a unit of area.

$$P = \frac{F}{A} = \frac{\text{force}}{\text{Area}}$$ units → pascal (or) N/mm^2

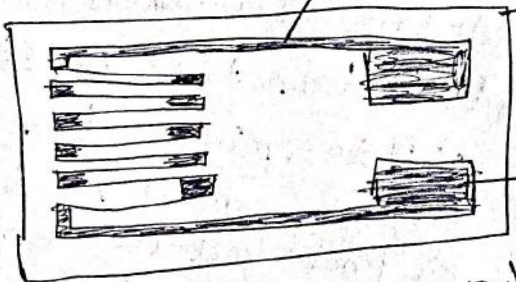
→ Pressure transducer use piezoresistive technology, as the piezo resistive element changes the electrical resistance proportional to strain applied.

(i) Working of Differential Pressure Transducer:

→ Metal foil strain gauge is a transducer whose electrical resistance varies with applied pressure (or) force (or) tension (or) compression.

→ strain gauges are electrical conductors tightly attached to a film in zigzag shape

→



→ when this film is pulled, the conductors, stretches and elongates.

→ when it is pushed, it is contracted and get shorter. This change in shape causes the resistance to change.

→ As per the change in resistance, pressure changes. and so sensor produce electrical signal in millivolts proportional with pressure.

→ Bridge amplifier converts mv to regulated excitation voltage (mv/v)

→ Pressure sensor signal conditioner includes noise filtering, signal amplification and output signal conversion.

<u>Types:</u>
→ Absolute pressure transducer
→ Gauge pressure transducer

<u>Application:</u> → used to measure flow of a liquid (or) gas in pipes (or) ducts.

5.12 Optical Transducers:-

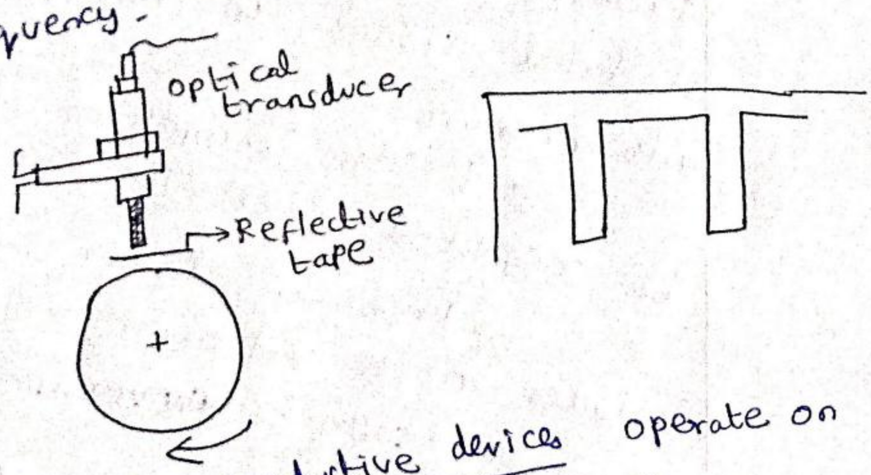
→ Optical transducer converts light into electrical quantity. It is also called as Photoelectric transducers.

→ Optical transducer can be classified as

a) Photo emissive transducers
b) photo conductive transducers
c) Photo voltaic transducers.

→ Photo emissive devices operate on principle that radiation falling on a cathode causes electrons to be emitted from cathode surface.

→ Optical transduction utilizes changes in optical properties such as phase, amplitude and frequency.



→ Photo conductive devices operate on principle that whenever a material is illuminated, its resistance changes.

→ Photo voltaic cells generate

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an output voltage that is proportional to radiation intensity.

→ Radiation that is incident may be X-rays, gamma rays, ultraviolet rays, Infrared rays (or) visible light.

→ Purpose of an optical transducer is to measure physical quantity of light

Classification of Optical transducer:

→ Optical transducers can be classified into 2 groups

① Those which employ an optically related property such as refractive index, colour (or) polarization and converts into electrical signal like current (or) voltage

eg. Photo detector, spectrometer

② Those which incorporate optical fibers (or) waveguide which function in 2 modes

a) when fiber (or) waveguide acts as a sensing element for measuring current

eg current is measured by rotation of plane of polarized light (or) strain is measured by phase modulation.

b) when fiber (or) a waveguide convey optical radiation to transducer and to return modulated signal (amplitude, phase (or) frequency) carrying the measurement information.

5.13 Digital transducers:

→ In modern PC based automation systems, it is required to connect the output of transducers to the computer.

→ For this, output of transducers must be in digital form.

→ If transducer output is in analog form, Analog to Digital converter (ADC) is used to convert analog to digital and then only computers can handle datas.

→ Digital transducers are in form of linear (or) rotary displacement

→ Digital transducers are also called as encoders (or) digitizer as they convert continuous analog signal into binary (or) decimal data.

(i) Classifications:

→ Digital transducers are classified as

a) Tachometer transducers
b) Incremental encoders
c) Absolute encoders

a) Tachometer transducers:

→ It is an encoder with single output for each increment in displacement.

→ Output is in the form of pulses

→ For the motion in only one direction, displacement can be obtained by counting pulses at the output using digital counters.

→ But for the motion in opposite direction, this transducer produces identical pulses. So it produces errors as the pulses for the motion in the particular direction cannot be identified clearly.

→ Hence tachometer transducers are useful for the measurement for the speed where motion is in one direction.

b) Incremental Encoders:

→ It uses minimum 2 (or) 3 output to identify the pulses for the motion in forward (or) backward direction along with reference position.

→ 2 outputs gives the pulses for corresponding motion in different directions and 3 outputs produces single pulse per revolution to provide zero reference.

→ Using up down counter, number of pulses can then be counted.

→ Encoder has advantages of the ability to rotate through many revolutions.

→ But due to result of false pulse, it causes electric error.

→ Also with power failure, data is lost and it cannot be recovered even after power on.

c) Absolute encoders:

→ These are mainly used for the measurement of single revolution

→ These encoders use multiple outputs to be read out in parallel to produce the output in binary format of angular shaft position.

(ii) Linear and rotary encoders:

→ light source and photo sensor working as a detector, both are placed on 2 sides of the sector.

→ Then displacement is applied to the sector, this changes the amount of light falling on photo electric sensor because of opaque and transparent areas on sector.

→ The pattern of illuminated sensor is then carried to the location of sector.

→ These gives clear true digital readout.

→ As there are no mechanical contact, wear and tear and alignment problems are not present.

→ These encoders converts linear (or) angular position of shaft into corresponding digital signal.

→ These encoders are known as special encoders since mechanical action which acts as analog is converted into digital.

→ Basically 2 types of special encoders

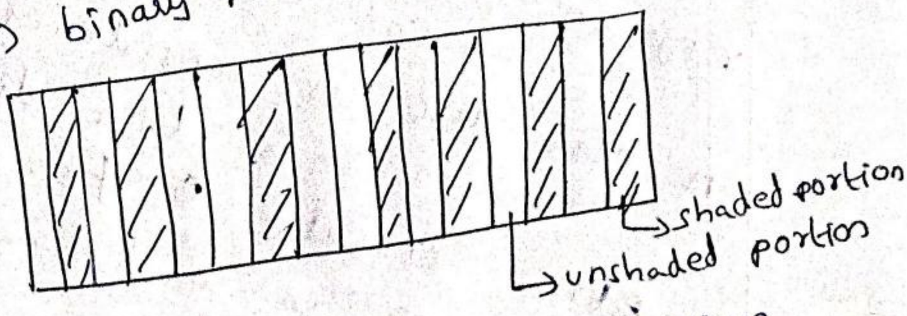
→ The encoder that converts mechanical position along straight line is called Displacement encoder (or) linear velocity transducer (LVT).

→ The encoder that provides the conversion of rotating shaft position into digital signal called shaft encoder (or) rotary encoder (or) Tachometer (or) Angular velocity encoder.

a) Linear encoder:

→ Principle of linear encoder is based on 'ON' (or) 'OFF' switching of multiple tracks.

→ Each slot represents a bit either in BCD (or) binary format.



→ Tracks are either opaque (or) transparent.

→ Opaque parts are the shaded areas while transparent parts are the unshaded areas

→ when conducting material comes in contact with sliding contact, circuit gets completed and encoder gives out digital output which indicates position and hence displacement is determined.

b) Rotary Encoders:

→ It is used for measurement of angular position.

→ Here sensing is done with large number of gear teeth.

→ Sensing and angular displacement can be done either by direct electrical contact (or) by electromagnetic induction mechanism.

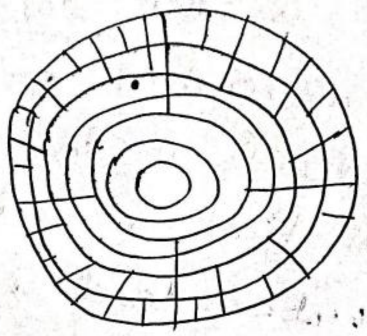
→ To print special coding pattern, glass disc is mounted on disc.

→ pattern is generated by concentric rings on disc.

→ For angular displacement, circumference on flat disc is considered.

→ Disc is then divided into concentric circular tracks.

→ Then each track is again divided into segments.



(iii) Advantages:

→ These are very much suitable for slowly moving systems

→ accuracy can be obtained using sectors

(iv) Disadvantages:

→ wear of contractors

→ maintenance of contractor is required

5.14 Smart sensors:

→ when transducer is miniatorized so as that considered as single device along IC chip, it can be treated as smart sensor.

→ It is equivalent to micro miniaturization of entire system.

→ Smart sensors are defined as sensors that provide standardized output signals in digital form and suited for transmission to control unit.

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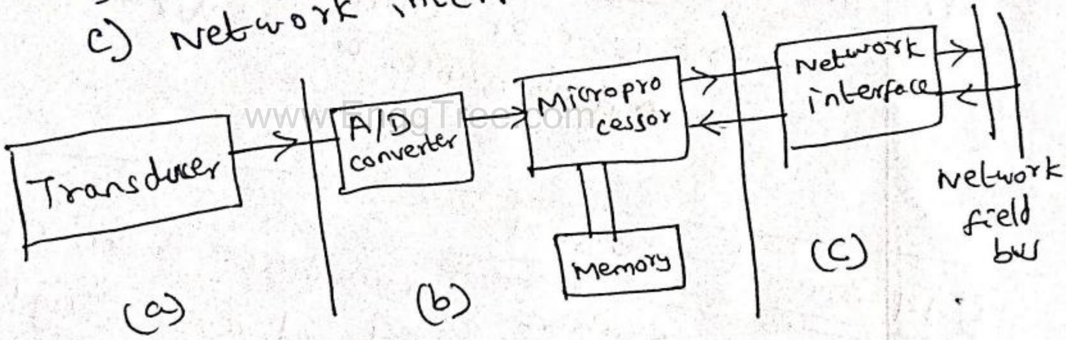
→ A sensor is called soft sensor that handles mathematical operations to deliver output signals in desired dimensions.

→ eg: when tank is getting filled with water, water level is measured and from level values, flow rate of water can be calculated. The calculator is soft sensor.

→ Smart sensor has following elements

a) Transducer
b) processor and memory device
c) Network interface



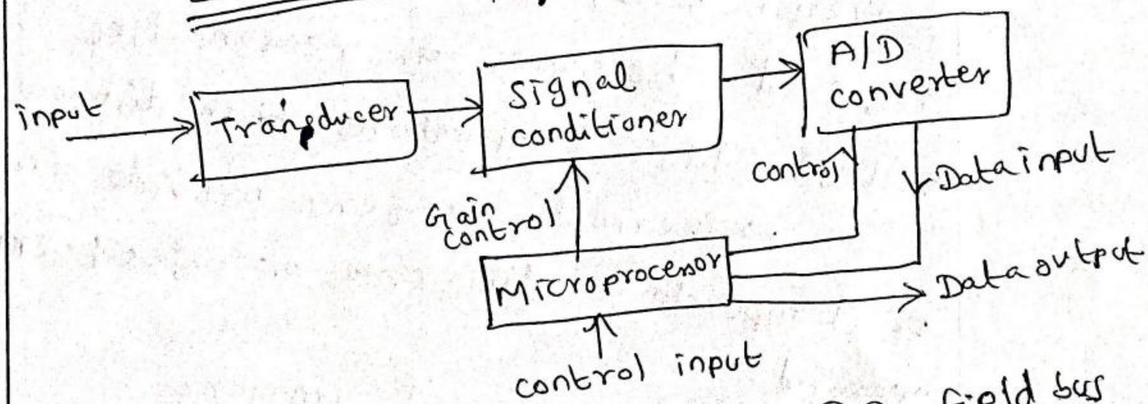
→ Smart sensor is defined as micro-processor based process transmitter that supports 2 way communications, digitize transducer signals to improve system performance.

→ Transducer output is in analog form, after moves to A/D converter, it is changed into digital form and then fed to microprocessor.

→ Network accepts the data from microprocessor.

→ This configuration is implemented in a single chip.

IC chip of smart sensor.



→ The network field bus (or) field bus (or) network bus (or) field instrumentation bus offers quick replaceability if found defective.

5-15 Thermal Imagers:

→ Thermal Imager is a non contact temperature measurement device.

→ Thermal Imager detect Infrared energy emitted, transmitted (or) reflected by materials at temperature above absolute zero & converts energy factor into temperature.

→ Thermogram is the thermal image displayed by camera which is emitting, transmiting or reflecting infrared energy

(i) Use of thermal imager to measure temperature :

→ For moving objects like rollers, conveyor belts, non contact measurements are required because of reasons like high voltage, high temperatures, high distance.

→ Thermal imagers provide image of temperature difference of object being measured.

(ii) parameters of thermal imager:

a) Field of view : It is the angle of vision at which instrument operates - To get an accurate temperature, target being measured should fill the field of view of instrument.

b) Emissivity: It is defined as the ratio of energy radiated by an object at given temperature to energy emitted by perfect radiator at same temperature. The higher the emissivity, it is easier to obtain accurate temperature measurement.

(iii) Working of Thermal imager:

→ 'Heat signature' refers to the objects that emit infrared energy.

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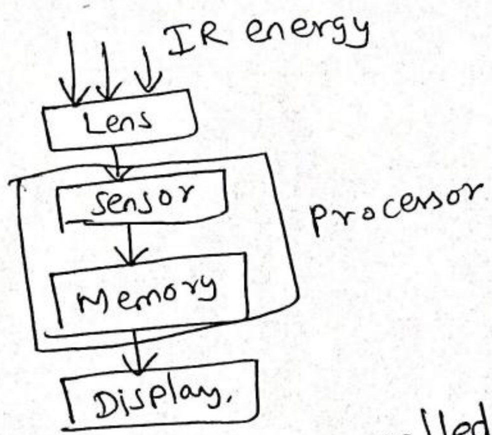

→ Infrared camera called as thermal imager detects infrared energy of objects and converts data into electronic image that shows temperature of the object.

→ If infrared camera focus IR energy into chip, each pixel in sensor produces electronic signal.

→ Processor takes the signal and applies a mathematical calculation to create colour map.

→ Each temperature value is assigned a different colour.

→ resulting matrix is sent to memory and in camera's display, thermal image of that object is displayed.

→ Many IR cameras include visible light camera that captures standard digital image with each trigger. and so intensity of captured image can be varied.

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