Unit 2 - Electrical Machines

DC Machines

Classification: Depending on whether torque or emf is generated DC machines are classified as DC motors or DC generators.

DC motor ⇒ unidirectional torque is generated

DC generator ⇒ unidirectional current is generated.

1 DC GENERATOR

A DC generator is a DC machine which generates electrical energy from mechanical energy. The emf that is induced is called dynamically induced emf.

Principle: A. Faraday's Laws of Electromagnetic Induction

(i) Whenever the flux linking with a conductor changes, an emf is induced.

(ii) The induced emf is directly proportional to the rate of change of flux $\quad E \propto \frac{d\phi}{dt}$

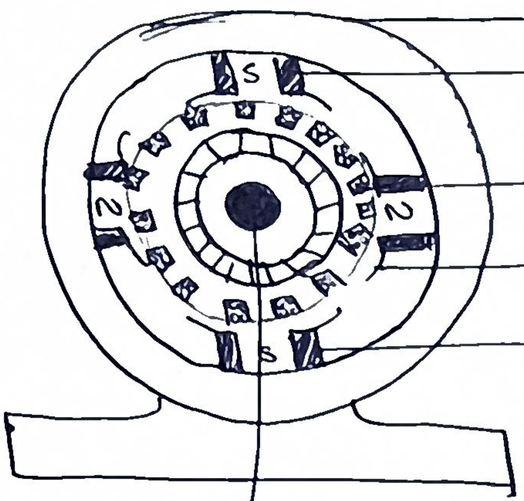
B. Lenz's Law: The emf induced is in a direction that opposes the cause producing it (rate of change of flux).

i.e $\quad E = -\frac{d\phi}{dt}$

C. Fleming's Right Hand Rule: is used to find the direction of induced emf.

Thumb → direction of mag. force F
Index → direction of field B
Middle → direction of current

Construction



① Magnetic Frame | yoke ⇒ outer frame

→ supports pole core and pole shoes

→ protects inner parts of generator

② Pole core and Pole shoes :→ field | exciting coils wound around pole core

→ ensures uniform distribution of flux

③ Field coils | exciting coils → enamelled Cu wire to produce a magnetic field

④ Armature → rotating component of generator

⑤ Commutators → wedge shaped segments that rotate along the armature

→ provides a connection between rotating armature & stationary external ckt

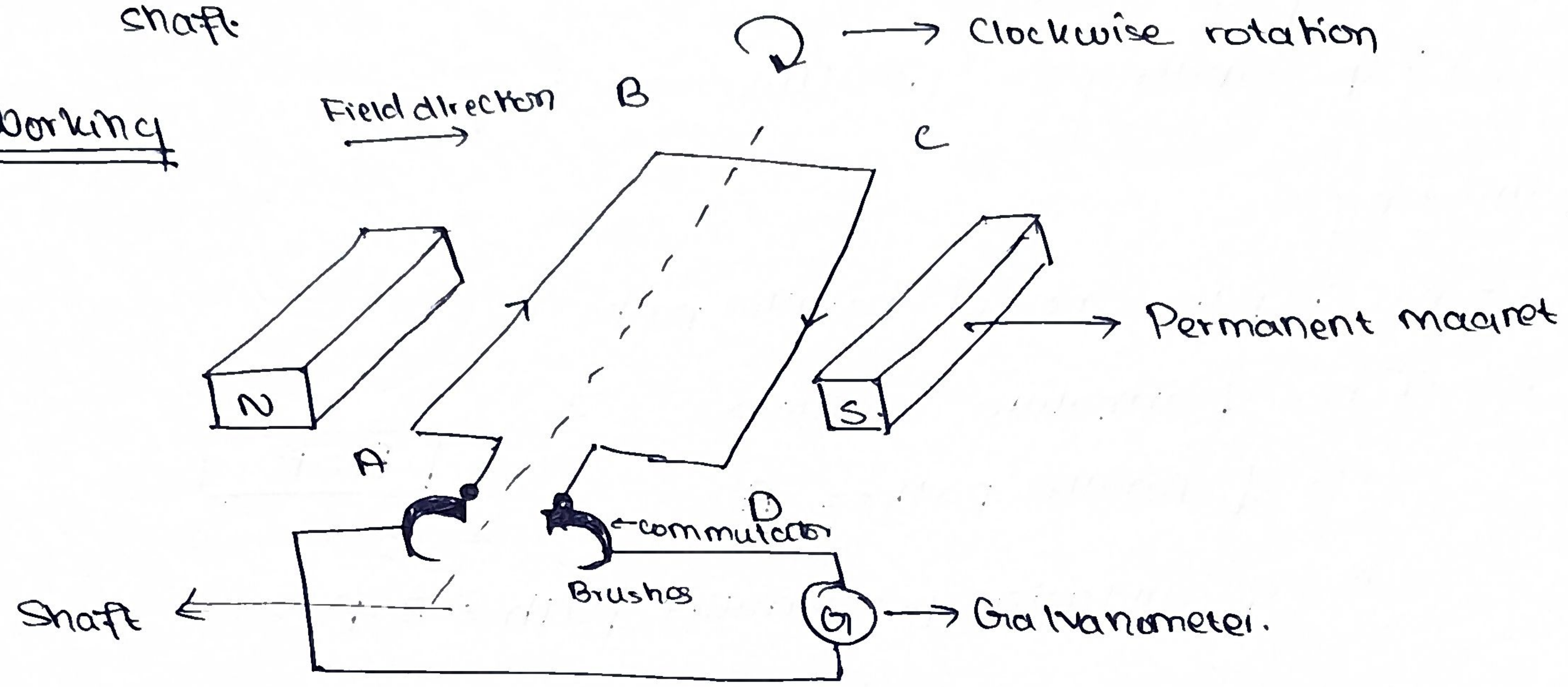
→ helps make current unidirectional

⑥ Brushes → carbon | graphite components attached to armature

→ taps electrical power generated in armature,

7. Shaft → transfer of mechanical power to the machine
→ rotating parts like armature are attached to the shaft.

Working



→ The coil ABCD, placed between 2 permanent magnets is rotated in the clockwise direction.

→ The rotation of the coil produces an induced emf.

→ The direction can be found using Fleming's Right Hand Rule.

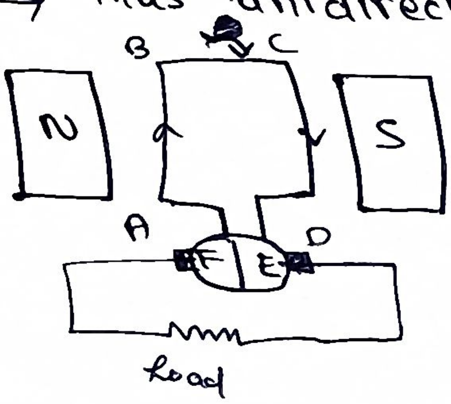
→ emf induced is maximum when field & plane of coil are parallel
is minimum when field & plane of coil are ⊥r

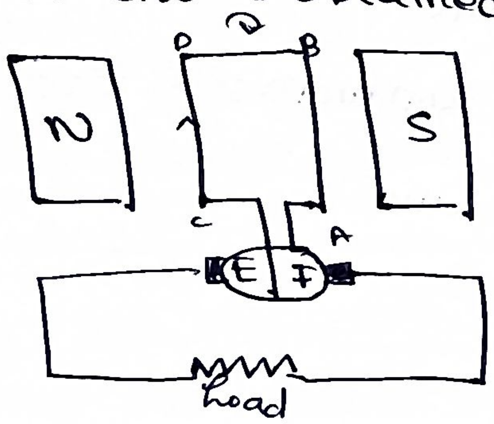
Working with a split ring commutator

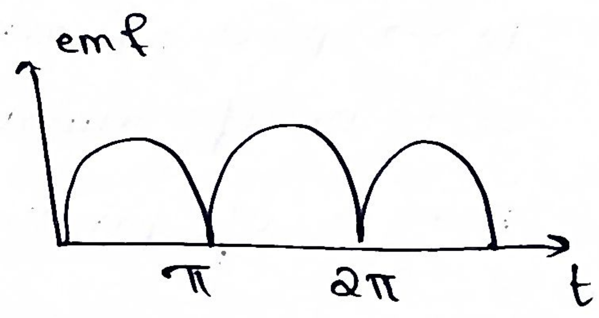
→ Direction of current in every armature conductor would change after every half rotation.

→ With a split ring commutator, connections of the armature connections also get reversed when the current reversal occurs

→ Thus unidirectional current is obtained







* Types of Armature windings

Based on the way in which armature conductors are connected, they are classified as:

(i) Lap winding (ii) Wave winding

Lap Winding

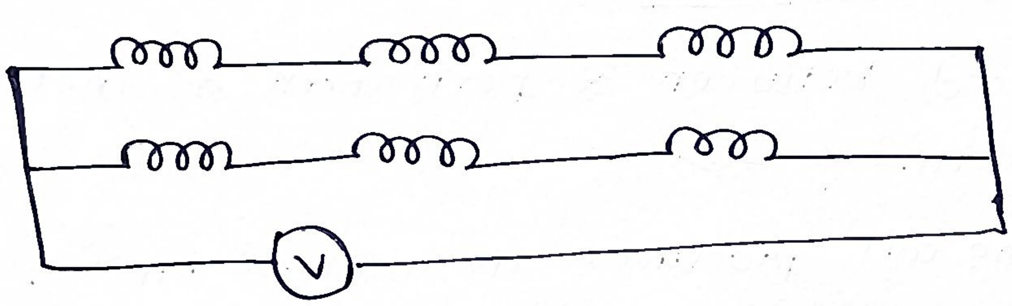
→ no. of poles = no. of parallel paths

→ if no. of armature conductors = Z

no. of parallel paths = A $\boxed{A = P}$

no. of conductors per parallel path = Z/P

For eq.



here $Z = 6$ no. of conductors per path = $Z/P = 3$

$A = 2$

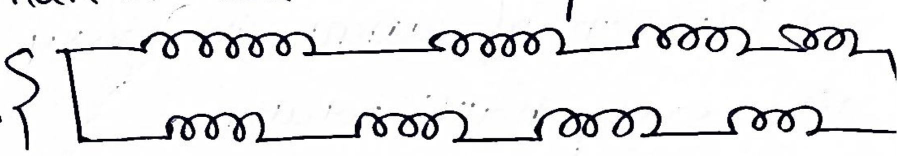
Wave winding

→ no. of parallel paths (A) is always 2

$\boxed{A = 2}$

Note: induced emf is lesser in lap than in wave winding

2.



*EMF Equation

Let ϕ → Flux / pole

P → Total no. of poles

N → speed of armature

Z → no. of armature conductors

A → no. of parallel paths

Flux cut by one conductor = (flux/pole) * no. of poles

$= P\phi$

No. of revolutions per second = $N/60$

Time taken per revolution = $dt = 60/N$

$$E_g = \frac{d\phi}{dt} = \frac{P\phi}{\frac{60}{N}} = \frac{N\phi P}{60}$$

$$\boxed{E_g = \frac{N\phi P}{60}}$$

No. of conductors per path = Z/A

∴ Emf per path $\boxed{E_g = \frac{ZN\phi P}{60A}}$

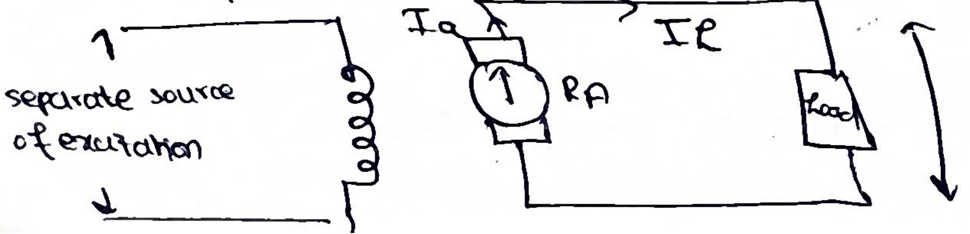
$A = P$, for lap
$A = 2$, for wave

Do eq. 3.1, slides 25, 26

Types of DC Generator

- DC Generator
  - separately excited
  - self excited
    - shunt generator
    - series generator
    - compound generator
      - long shunt
      - short shunt

① Separately Excited DC Generator → power for exciting field windings is from a separate DC source

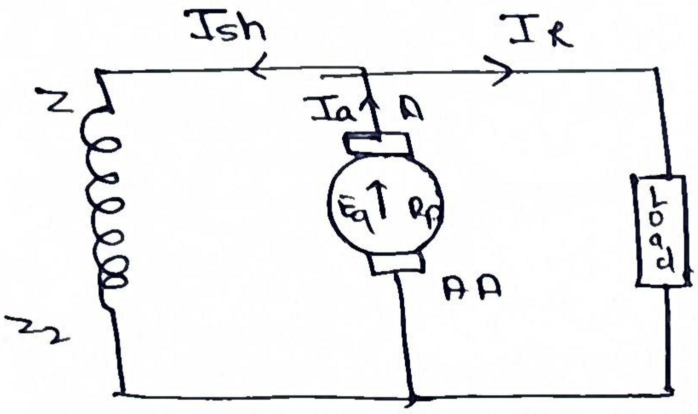


Armature current : $I_a = I_L$

EMF eqn : $E_g = V + I_a R_a$

(2) Self-excited DC Generators

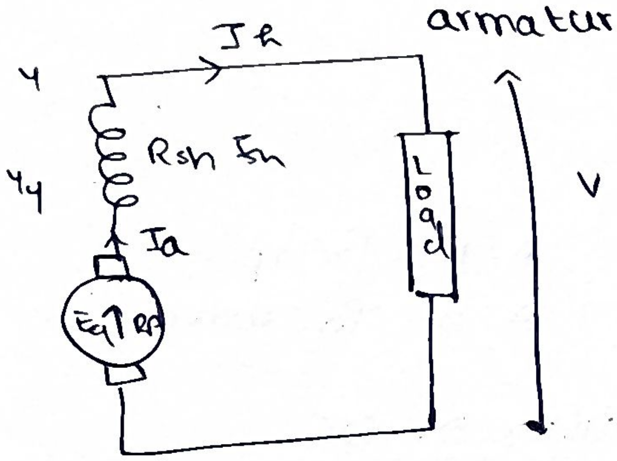
2.1 DC Shunt Generator : Field winding is in parallel to the armature winding



Armature current : $I_a = I_{sh} + I_L$

Emf equation : $E_g = V + I_a R_a$

2.2 DC Series Generator : Field winding is in series ~~parallel~~ to the armature winding



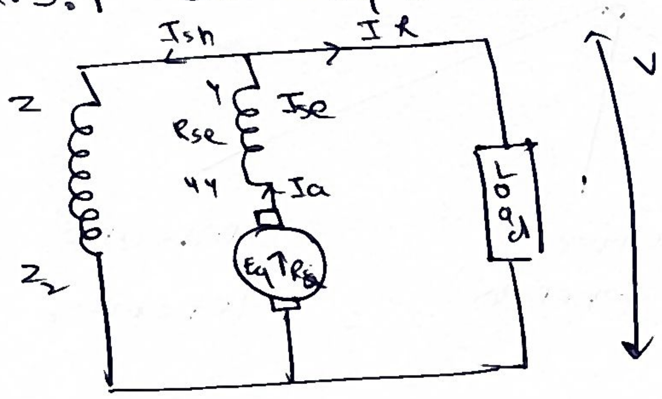
Armature current : $I_a = I_L = I_{sh}$

Emf equation : $E_g = V + I_a R_a + I_{sh} R_{sh}$

$= V + I_a (R_a + R_{sh})$

2.3 DC Compound Generator : has 2 windings which are either connected in series or parallel to the armature

2.3.1 DC Long shunt

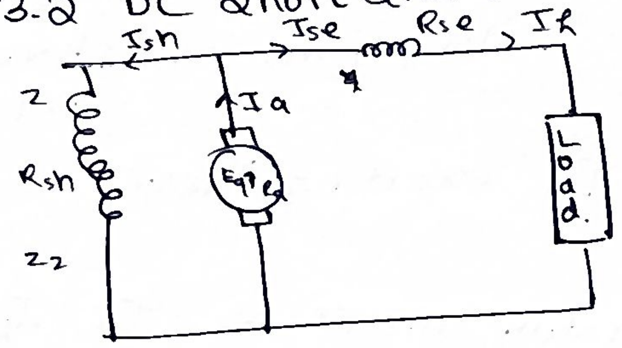


Armature Current : $I_a = I_{sh} + I_L$

Emf eqn:

$E_g = V + I_a(R_a + R_{se})$

2.3.2 DC Short Shunt



Armature Current : $I_a = I_L + I_{sh}$

$= I_{se} + I_{sh}$

Emf eqn : $E_g = V + I_a R_a + I_L R_{se}$

* Do examples on pg 132, 133

Applications of DC Generators

(i) Separately excited DC Generator : in laboratories

(ii) DC Shunt Generator : battery charging, electroplating

(iii) DC Series Generator : series arc light, incandescent

(iv) Compound Generator : arc welding, heavy power supply

2) DC Motors

A DC motor converts electrical ~~motor~~ energy into mechanical energy.

Principle : When a current carrying conductor is placed in a magnetic field, it experiences a mechanical force

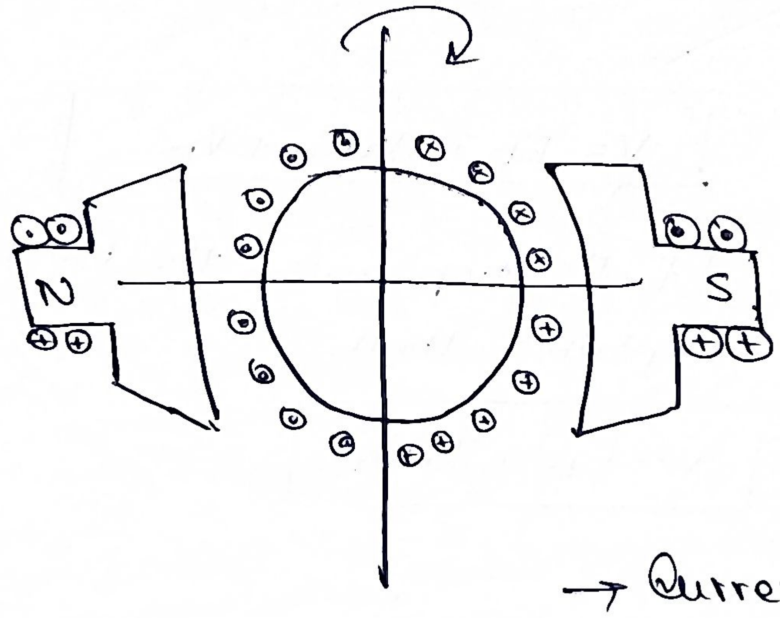
→ The direction of the force is determined using Fleming's left-hand rule.

Construction : same as AC generator

note that : commutator → converts alternating torque to unidirectional torque

→ the armature winding is given a separate supply to produce the required torque

Working



→ When the field windings wound on the poles are excited by a DC source, the poles get magnetized and a strong magnetic flux is produced

→ Current flows through the coil, and the armature coil creates its own magnetic field.

→ The resultant field has the tendency to align itself with the main field .

→ Hence, a torque develops on the armature coil.

* Back Emf

→ When the armature of the motor is rotating, the armature conductors are also cutting the magnetic flux lines. An emf is induced in the armature conductors.

→ The direction of this induced emf is that it opposes the armature current.

→ The magnitude of back emf is $E_a = \dfrac{Z N \phi P}{60 A}$

Significance of Back emf

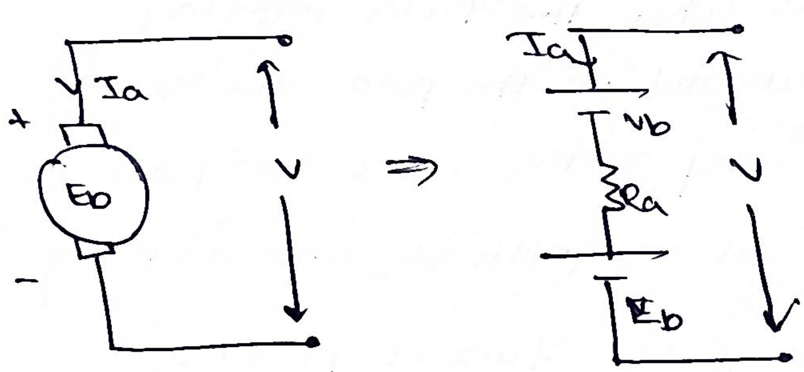
→ If a dc motor is suddenly loaded, the load will cause a decrease in the speed.

→ Due to the decrease in speed, the back emf will also decrease allowing more armature current.

→ Increased armature current will increase the torque to satisfy the load requirement.

→ The back emf makes a dc motor self-regulating.

* Voltage and Power Equation



$$\boxed{V = E_b + I_a R_a + V_b}$$

If the drop across the brushes is negligible, then

$$\boxed{V = E_b + I_a R_a}$$

Multiply both sides by I_a

$$\underbrace{V I_a}_{\text{input power}} = \underbrace{E_b I_a}_{\text{mech power developed}} + \underbrace{I_a^2 R_a}_{\text{copper loss}} \quad \Rightarrow P_i = P_m + P_c$$

* Condition for maximum power developed

$P_i = P_m + P_c$

$P_m = P_i - P_c$

$P_m = V I_a - I_a^2 R_a$

diff. w.r.t I_a

$0 = V - 2 I_a R_a$

$V = 2 I_a R_a$.

$I_a R_a = \frac{V}{2}$ also, $V = E_b + I_a R_a$.

$\boxed{E_B = \frac{V}{2}}$

* Motor Efficiency

$\eta = \frac{\text{mech power}}{\text{electrical power}} = \frac{P_m}{P_i} = \frac{E_b I_a}{V I_a} = \frac{E_b}{V}$

* Torque and Speed Equations

→ Consider a wheel rotating at a speed of N rpm

The angular speed is $\omega = \frac{2\pi N}{60}$

work done in 1revolution ⇒ $W = F \times \text{distance}$

$= F \times 2\pi R$

Power $= \frac{\text{Work}}{\text{Time}} \times \frac{N}{60} = T\omega$

$= \frac{F \times 2\pi R N}{60} = T\omega$ $F \times R = T$

$\omega = \frac{2\pi N}{60}$

But $P_m = E_b I_a$

$T_a \times \frac{2\pi N}{60} = E_b I_a$ $\boxed{T_a = 9.55 \times \frac{E_b I_a}{N}}$

$$E_b = \frac{\phi Z N P}{60 A}$$

$$\boxed{T_a = 0.159 \times \frac{\phi Z P I_a}{A} \text{ Nm}}$$

* **Shaft Torque** → actual torque available at shaft to do useful mechanical work

Output $= T_{sh} \times 2\pi N$

$$T_{sh} = \frac{\text{output}}{2\pi N}$$

if N is in rpm, then $T_{sh} = \dfrac{\text{Output}}{\frac{2\pi N}{60}} = \dfrac{9.55 \; O/P}{N}$

$$\boxed{T_{sh} = 9.55 \times \frac{\text{Output}}{N}}$$

* **Speed Equation**

$$E_b = V - I_a R_a = \frac{\phi Z N P}{60 A}$$

$$N = \frac{V - I_a R_a}{\phi} \times \frac{60 A}{Z P}$$

or $$N = \frac{E_b}{\phi} \times \frac{60 A}{Z P}$$

* **Speed Regulation** → the change in speed when the load is reduced from the rated value to zero.

$$\% \text{ speed regulation} = \frac{N_{NL} - N_{FL}}{N_{FL}} \times 100$$

Do eq. on pg 46-52

\+ pg. 146 Eq. 3.4

* Types of DC Motors

same as DC Generator

Do eq. 3.4, pg. 146

Applications

(i) DC Shunt Motor : centrifugal pumps, fans

(ii) DC Series Motor : electric locomotives, cars, trolleys

(iii) DC Compound motor : elevators, conveyor belts, printing press

(3) Stepper Motor

→ A stepper motor is an electric motor whose main feature is that its shaft rotates by performing steps, by moving a fixed amount of degrees

→ The specific angle through which the stepper motor rotates is called the step.

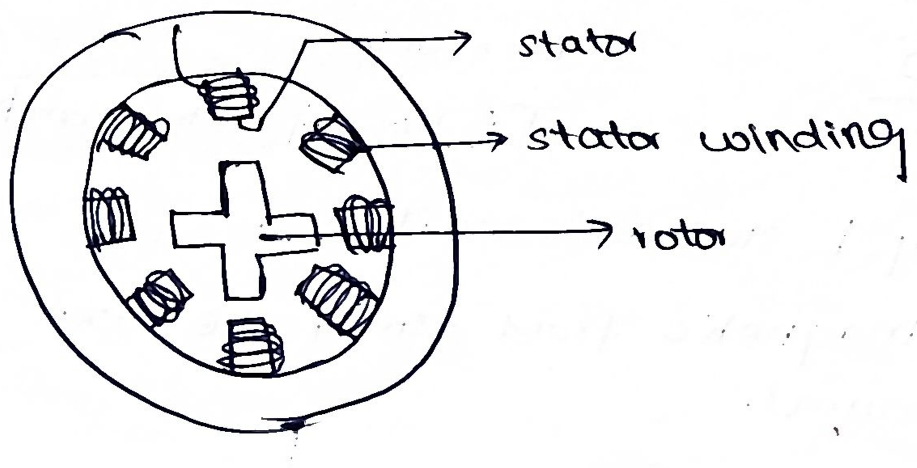
→ The electrical pulses are received from the control unit of the stepper motor.

Principle : By energizing one or more of the stator phases, a magnetic field is generated by the current flowing through the coil, and the rotor aligns with this field.

Construction : → has a stationary part = stator

moving part = rotor

→ coils are wound around the stator



* Classification of a Stepper Motor

(i) On the basis of type of rotor

(a) Variable reluctance stepper motor

(b) Permanent magnet stepper motor

(c) Hybrid stepper motor

(ii) on the basis of the windings on the stator

(a) 2-phase stepper motor

(b) 3-phase stepper motor

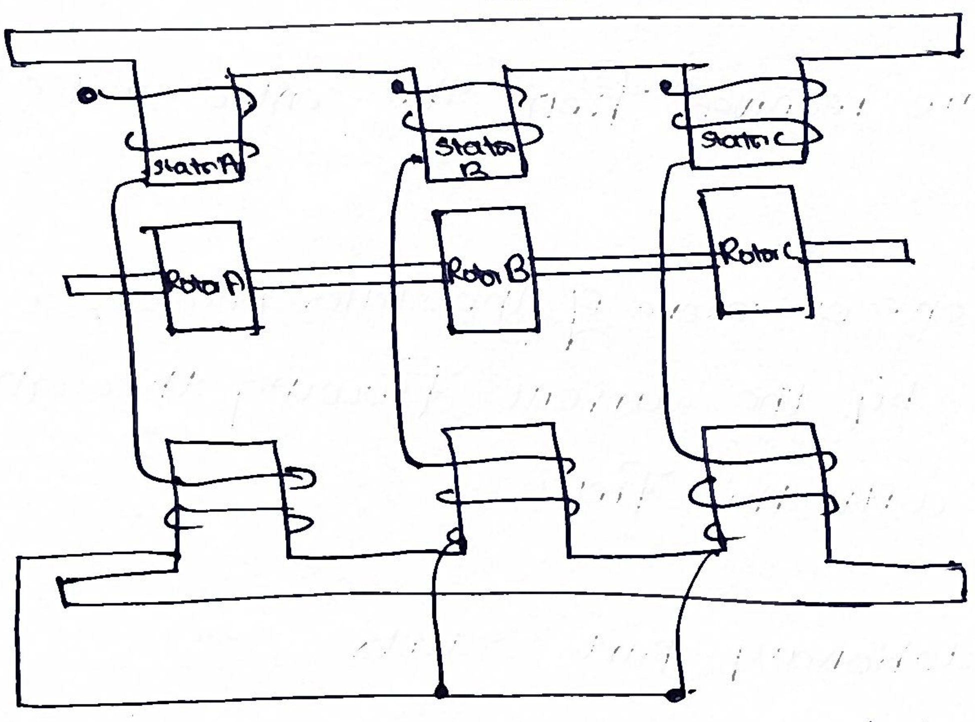
(c) 4-phase stepper motor

A. Variable Reluctance Stepper Motor

Principle: Based on the different reluctance positions of the rotor w.r.t the stator

Construction: → has single or several stacks of stators & rotors

→ The stators have a common frame
rotors have a common shaft



The diff. in angular displacement of the stator and the rotor when the teeth of the rotor are perfectly aligned is:

$$\alpha = \frac{360^\circ}{nT}$$

n = stacks

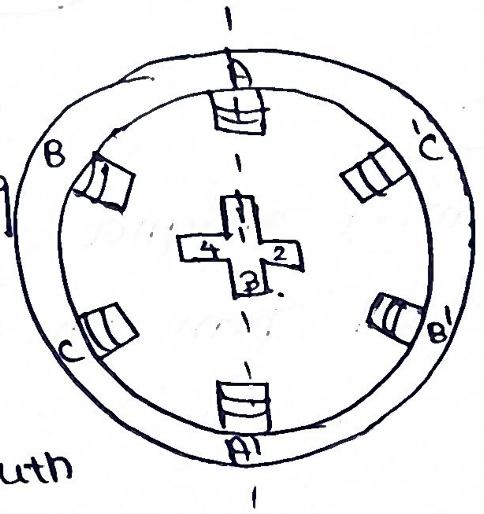
T = no. of rotor teeth

Working: → Any 1 stator is excited

→ A magnetic field along the axis of the stator is produced.

→ The rotor rotates in a particular direction so that the reluctance position between the stator and the rotor is minimum.

→ The magnetic field axis of the stator passes through any 2 rotor poles.



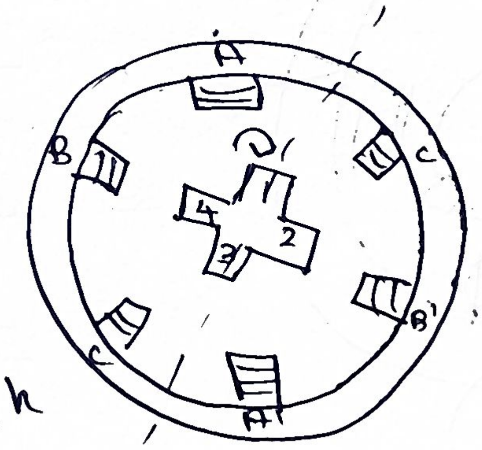
Step1 :→ A-A' is supplied with a DC supply, the corresponding windings become a magnet.

$\theta = 0°$

→ One tooth becomes the North pole, the other the South

→ By the force of attraction, the stator North attracts the nearest rotor tooth of opp. polarity

→ The rotor adjusts its min. reluctance position, where both magnetic axes match.



Step2 → B-B' is magnetized.

here $\theta = 30°$

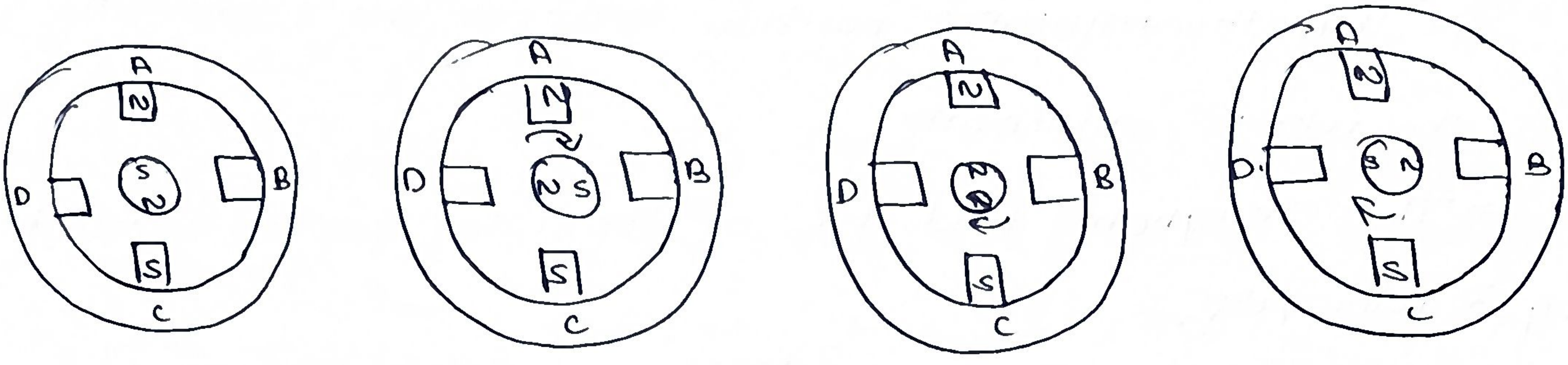
Thus, the stepper motor rotates through angles step by step.

* Torque on rotor : $T = \frac{1}{2} i^2 \frac{dL}{d\theta}$ L = inductance.

B. Permanent - Magnet Stepper Motor

→ The rotor is a permanent magnet that aligns with the magnetic field generated by the stator circuit.

When stators A, B, C, D are excited in order :

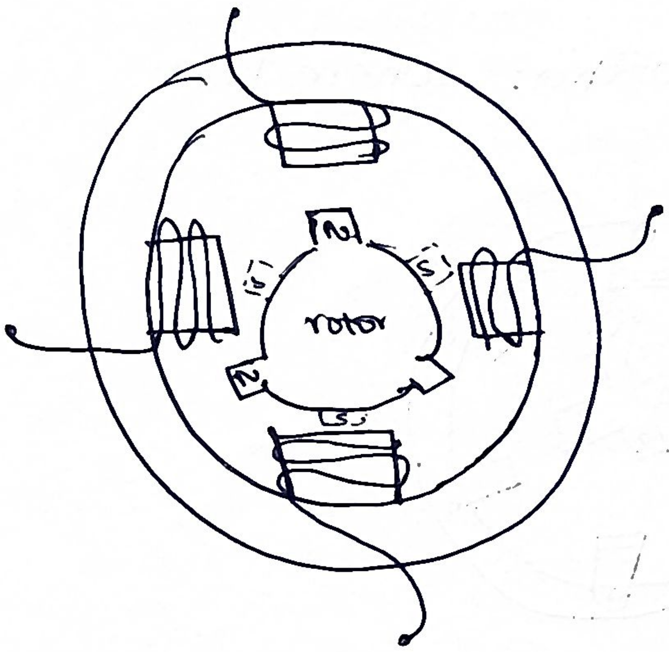


c. Hybrid Stepper Motor

→ similar to a permanent magnet stepper motor, with the constructional features adapted from the variable-reluctance stepper motor

→ Teeth of the rotor on opp ends have opp. polarities

→ 2 sets of teeth in the rotor are displaced from eachother.



Applications
digital cameras
elevators
conveyor belts

*Operation of the stepper motor depending on angle

(1) Full - Step operation → moves 1 full step for every input pulse

$$\text{Full step} = \frac{360}{N_R \times N_s}$$

N_R = no. of rotor poles

N_s = no. of stator pole pairs

(2) Half - step operation → moves 1/2 a full step for every input pulse (if full = $x°$, half = $x°/2$)

(3) Micro - step → movement through angles of 1/10, 1/16, 1/32,
→ Provides finer resolution.

(4) Brushless Direct Current Motor (BLDC)

→ a derivative of the DC motor

→ the major difference is that the BLDC does not have brushes.

→ Instead of a physical commutator, electric current powers a permanent magnet of the motor through an electronically commutated system to produce the required torque.

Principle: The Lorentz force law → whenever a current carrying conductor is placed in a magnetic field, it experiences a force.

Construction : The parts are

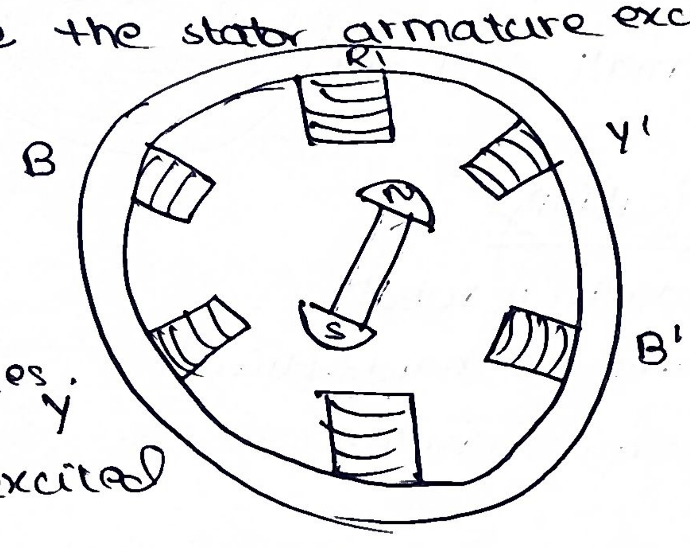
(i) permanent - magnet rotor : has a circular core with permanent magnets on the periphery

→ Elements like Neodymium (Nd) & Ferrite and Boron (NdFeB) are used

(ii) Stator : → stator electromagnets placed in stacked steel laminations + stator windings

→ windings arranged in either star or delta connected forms

(iii) Hall-Effect sensors : to synchronize the stator armature excitation with the rotor position.



Working

→ Stator windings are excited based on different switching sequences.

→ The corresponding windings are excited as ~~high and low~~ north and south poles.

→ The north & south poles of the permanent - magnet rotor will align with the stator poles, causing the motor to rotate.

→ Torque is produced when there is attractive force between the north-south poles / during repulsion.

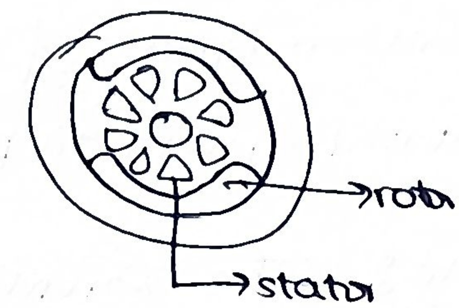
→ Thus, the motor rotates in a clockwise direction

* Classification

(1) Depending on arrangement of rotor & stator

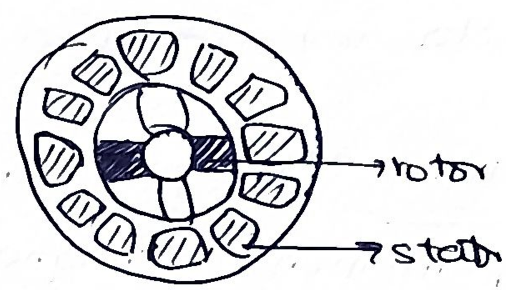
(a) Outer rotor design → rotor permanent magnets surrounds stator windings

→ permanent magnet acts as an insulator



(b) Inner rotor design → stator windings surround the permanent magnet rotor.

→ this arrangement helps in easy heat dissipation



(2) Depending on configuration of stator windings

(a) single phase motor

(b) two phase motor

(c) three phase motor

Advantages

(i) effective operation

(ii) high speed due to absence of brushes

(iii) small & light.

Disadvantages

(i) needs complex circuitry

(ii) needs additional hall sensors

Applications

(i) industrial robots

(ii) computer hard drives.

(iii) electric vehicles.

(5) Single-Phase Transformer

A transformer is a static device used to couple 2 or more electric circuits.

Principle : Faraday's law of electromagnetic induction and mutual induction.

Whenever a current-carrying conducts cuts the magnetic flux, an emf is inducad the inductor. When another coil is brought near the first coil, emf is induced in the second coil due to mutual induction.

Construction : The major components of a single phase transformer are:

(i) magnetic core
(ii) primary and secondary windings
(iii) a time varying magnetic flux.

The components can be grouped as follows:

Magnetic Circuit

(a) core → provides a continuous magnetic path
(b) limb → vertical position of the core on which the coil is wound
(c) yoke → horizontal position of core

Electric Circuit ↔ comprises of 1° & 2° windings made of copper

Dielectric Circuit → to insulate the conducting parts from each other and to reduce eddy current losses.

Tanks and Accessories

(a) Conservator → a cylindrical tank on top of the transformer

→ it is the transformer - cooling medium, acts as a reservoir as well.

(b) Cooling Medium → a loaded transformer has losses, seen in the form of heat

→ a cooling medium in the form of air or oil maintains temperature

(c) Breather → transports fresh air in and out of the transformer

→ has silica gel to eliminate moisture content

(d) Explosion Vent → an Al pipe at the ends of the transformer to prevent it from damage

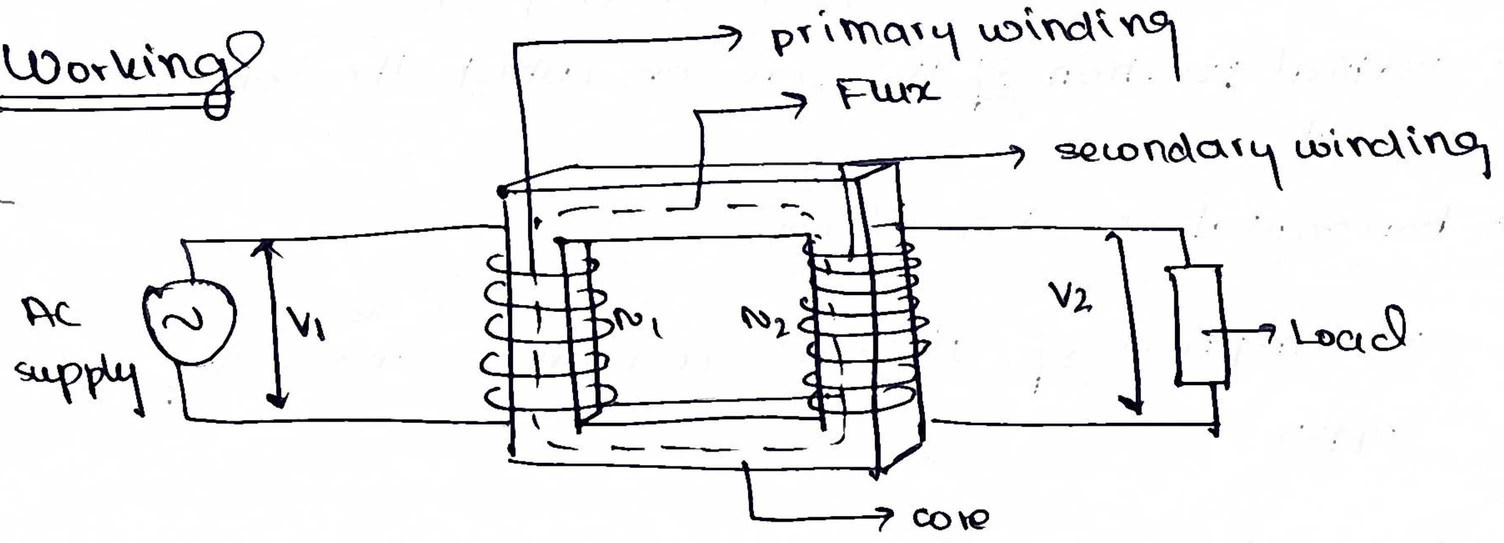
→ maintains pressure inside the transformer

(e) Buchholz Relay → a gas-actuated relay to detect internal fault

→ If there is a fault, the oil inside evaporates due to an increase in temperature.

→ The evaporated gas activates the Bucholz relay & alerts personnel.

Working:



→ An AC voltage excites the primary winding, an AC current is produced.

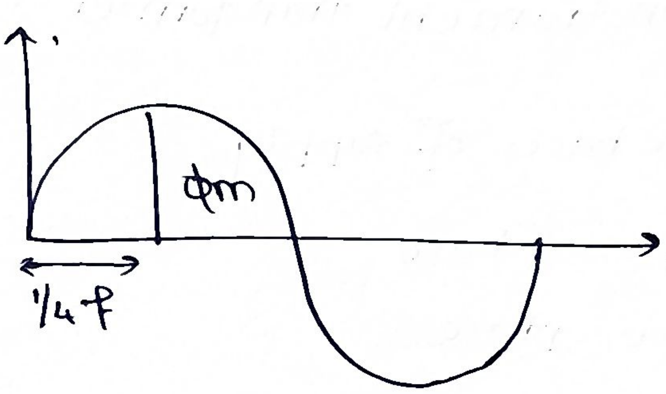
→ The current produces an alternating flux ϕ

→ By means of mutual inductance, an induced emf develops in the secondary winding.

If the emfs in the primary and secondary windings are E_1 & E_2, ~~and the~~ then

$$\frac{E_1}{E_2} = \frac{N_1}{N_2} = K = \text{Turns Ratio}$$

EMF Equation



The flux changes from 0 to ϕm in one quarter of a cycle

rate of change of flux : $\frac{d\phi}{dt} = \frac{\phi m - 0}{\frac{1}{4f} - 0} = 4f\phi m$ wb/sec.

$$\boxed{\text{avg. emf} = 4f\phi m \text{ V}}$$

$$\text{Form factor} = \frac{\text{rms value}}{\text{average value}} = 1.11$$

Rms value $= 1.11 \times 4f\phi m$

For N_1, $\boxed{E_1 = 4.44 f \phi_m N_1}$

IIIly $\boxed{E_2 = 4.44 f \phi m N_2}$

In an ideal transformer $V_1 = E_1$ & $V_2 = E_2$

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

Types of Transformers

1. Based on transformation ratio, K

   (a) Step-up $\Rightarrow N_2 > N_1$, $K > 1$

   (b) Step-down $\Rightarrow N_1 > N_2$, $K < 1$

2. Based on the service it provides

   (a) power transform~~ation~~er

   (b) distribution transformer

   (c) instrument transformer

3. On the basis of supply

   (a) single-phase

   (b) three-phase

4. On the basis of cooling medium

   (a) air cooled

   (b) oil cooled

Types of Transformer Cores

(a) Core-Type Transformer → has rectangular frame laminations
→ 1° & 2° windings on 2 diff limbs

(b) Shell-Type Transformer → center limb carries entirety of flux generated.

Core-Type	Shell-Type
1. windings on side limbs	1. windings on central limbs
2. laminations are in the form of L, I, U, shapes	2. laminations are E & I shaped.
3. more insulation needed	3. less insulation needed
4. equal flux distribution	4. unequal flux distribution

5. flux leakage is more	5. less flux leakage
6. high o/p	6. low o/p
7. 2 magnetic circuits formed	7. only 1 magnetic circuit

* Why is a DC supply not used as a source?

→ DC ~~&~~ supply ⇒ constant flux ⇒ no emf is generated in 1°

⇒ no emf in secondary

→ There would be heavy current flow in the 1°, leading to the failure of the transformer.

* Why are transformers rated in kVA?

→ manufacturers do not know what sort of load will be connected, may be R, L or C.

→ The power factor at the 2° would be different based on diff. loads

→ So, transformers are rated in kVA rather than kW

Do examples on slides 103-105

6 Three Phase Induction Motor

A 3-phase induction motor converts 3 phase input power electrical power into output mechanical power.

Principle: When a 3-phase balanced AC voltage is applied to a balanced 3-phase winding, a rotating magnetic field with a constant magnitude & speed is produced.

Construction : The 2 important parts are :

(i) Stator : → comprising of stationary three-phase windings

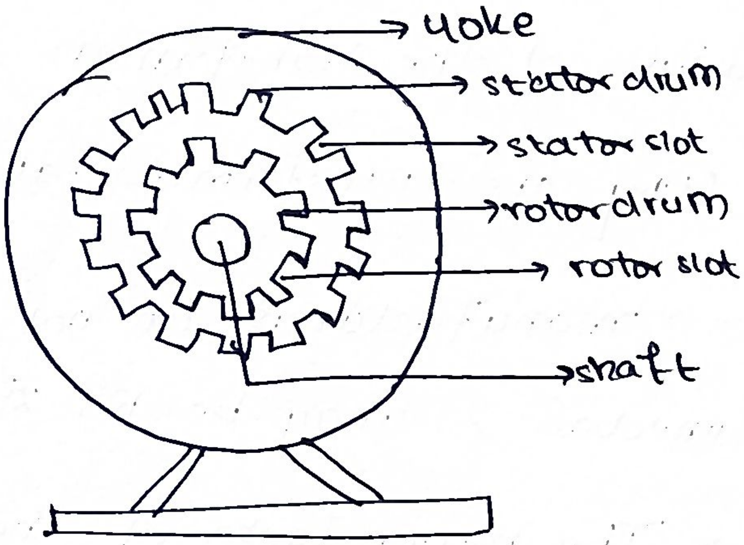
→ made of no. of laminations of silicon-steel

→ inner periphery has slots

→ A 3-phase winding is distributed across these slots

(ii) Rotor : → rotating part of the 3-phase induction motor

→ cylindrical, laminated core w/ parallel slots



Working

→ When a 3-phase balanced AC voltage is applied to the balanced three-phase winding, a rotating magnetic field with constant magnitude and speed is produced.

→ The speed in rpm at which the rotating magnetic field rotates is called the synchronous speed

$$N_{sn} = \frac{120f}{P} \text{ rpm}$$

→ Initially, when the rotor is stand still, the flux of the rotating magnetic field cuts every solid conductor of the rotor.

→ As the rotor conductors are stationary, and the stator ~~is~~ ~~rotat stato~~ has a rotating magnetic field, there will be a change in flux linkage with the rotor conductor.

→ As a result, there is an induced current in the rotor conductors.

→ When current flows through the conductor, it reacts w/ the magnetic field ⇒ rotor experiences a torque.

→ The rotor tries to achieve the speed of the synch. mag. field.

→ If the speeds become equal, then there is no net motion between the rotor & ~~stat~~ rotating mag. field

⇒ the rotor slows down, as no emf is produced

→ The deceleration again sets up a relative speed between the rotor and the mag. field, ⇒ current is again induced in the rotor, it again accelerates.

→ This phenomenon means that the rotor will never reach the speed of the rotating magnetic field, and it will continue to work until the supply is switched off.

→ The speeds at which rotor speed < N_{synch} is call sub-synchronous speed.

* Slip of an ~~[illegible]~~ Induction motor = diff between synchronous & sub-synchronous speed

slip = $(N_{syn} - N)$ rpm

Fractional slip (s) = $\dfrac{N_{syn} - N}{N_{syn}}$

Solve eg on pg 183, 184

~~PPt~~ 113, 114

* Difference between a 3 phase induction motor & a transformer :

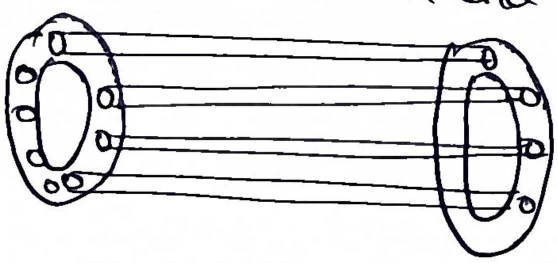
Three-phase induction motor	Transformer
1. made of Stator and rotor	1. made of 1° & 2° windings
2. AC supply given to starter	2. AC supply given to the primary winding
3. called a rotating transformer	3. called a stationary transformer
4. emf frequencies are diff in stator & rotor	4. emf frequencies are the same in 1° & 2° windings.
5. part of the energy is mechanical part is electrical	5. all of the energy is electrical
6. $K = \frac{\text{rotor turns per phase}}{\text{stator turns per phase}}$	6. $K = \frac{N_2}{N_1}$

* Types of Rotors

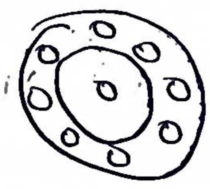
① Squirrel-Cage Rotor : → cylindrical in shape with slots

→ the slots have copper / Al conductors

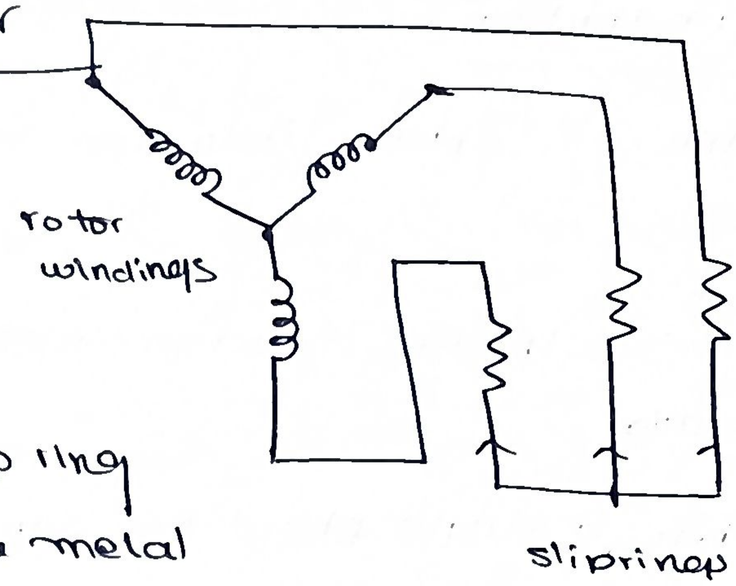
→ the conductors are permanently shorted using an end ring



representation :



Slip-ring | wound-ring rotor



→ rotor slots are electrically connected to form a balanced 3-phase winding.

→ the windings are connected to a slip ring & brush, and are connected to a metal collar

~~→ rotating~~

Slip Ring Rotor	Squirrel-Cage Rotor
1. has 3-phase winding	1. bar shaped conductors, shorted w/ end rings
2. complicated structure	2. simple structure
3. expensive	3. cheap
4. can add external resistance	4. cannot add external resistance
5. frequent maintenance needed	5. required less maintenance
6. high copper loss	6. low copper loss
7. low efficiency	7. high efficiency

7 Single Phase Induction Motor

→ A motor that works using a single phase AC supply
→ very similar to a 3phase induction motor

Principle: electromagnetic induction: When a 1phase supply is connected to a stator winding, a pulsating magnetic field is produced

Construction

same as 3 phase induction motor

Working

→ a 1phase induction motor must have 2 fluxes for its operation

→ When a single phase AC supply is connected to the stator winding, a rotating magnetic flux. is produced.

→ The main flux links with the stationary rotor conductor.

→ Using transformer action, an emf is induced in the rotor.

→ As rotor current flows through the rotor, a rotor flux is produced.

→ The 2 fluxes, main & rotor fluxes interact ∴ a torque is developed in the rotor & hence the rotor rotates.

→ Single phase DC motors are not self-starting. This is explained using the Double-revolving field theory.

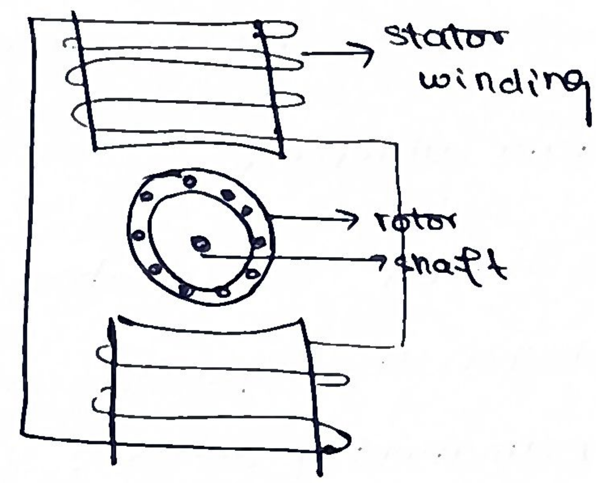
* Double Revolving Field Theory - When any alternating quantity is resolved into 2 rotating components, such that the magnitude of these quantities is exactly half the magnitude of the original alternating qty, and the 2 components rotate in opp direction

→ When the rotor is stationary, the two torques produced are equal and opposite.

→ The net torque is zero. (⇒ not self-starting)

→ However, if the rotor is given an initial rotation ~~by~~ in any direction, the torque due to the rotating magnetic field in either direction of initial rotation, will be more than the torque due to the other rotating magnetic field.

→ The motor keeps running in the same direction as the initial rotation.



Types of Single Phase Induction Motor

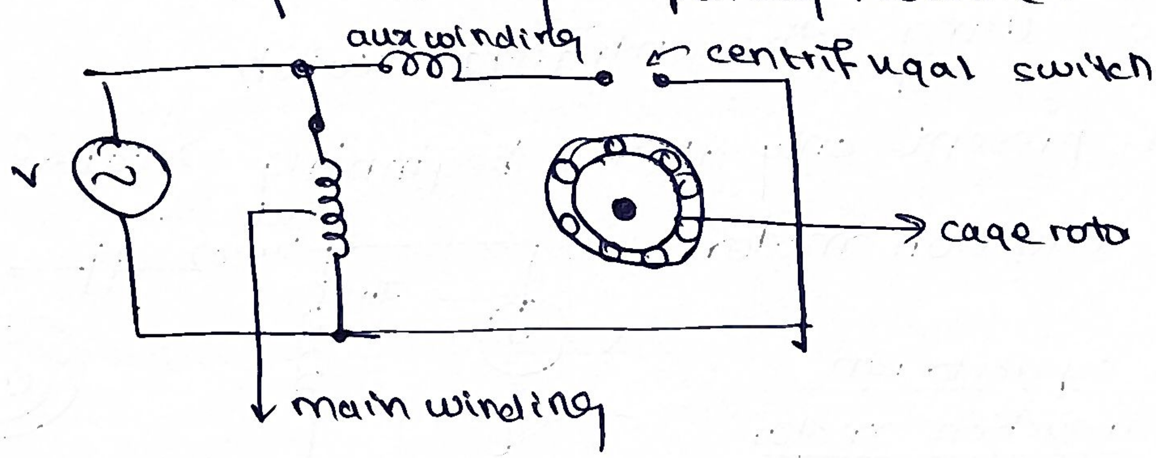
1 Phase inductors are classified based on the method of producing a rotating magnetic field.

A. Split - Phase Induction Motor

→ Stator has 2 windings : main & auxilliary (starting)

main winding = purely inductive,

auxilliary winding = purely resistive.



→ Im lags Ist

→ There is a large phase diff. between Im & Ist

→ Two fluxes are produced, with a phase angle α.

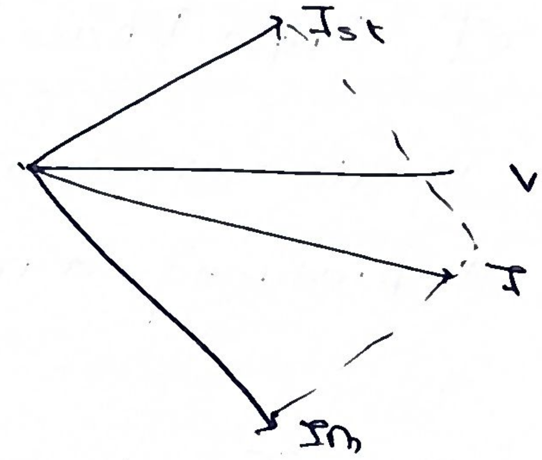
→ Resultant of these fluxes produces a rotating magnetic field and a starting torque is produced.

→ There is a centrifugal switch that is used to disconnect the auxiliary windings when the motor attains 75-80% of synchronous speed.

B. Capacitor Induction Motor

→ Same as split phase, but the centrifugal switch is connected in series with the capacitor

→ Due to the presence of the capacitor, I_{st} & I_m have a larger difference.



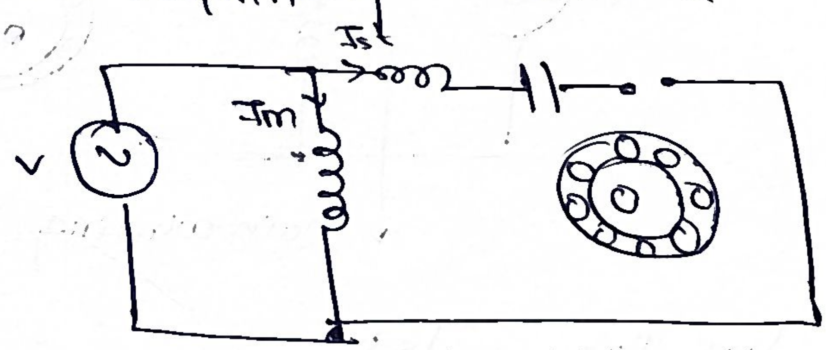
→ Further classification is done based on whether the capacitor remains in the circuit permanently or not.

(a) Capacitor - start induction motor.

→ α is large ⇒ torque is α

→ when 75-80% of the synchronous speed is attained, the starting winding & capacitor are disconnected using the centrifugal switch

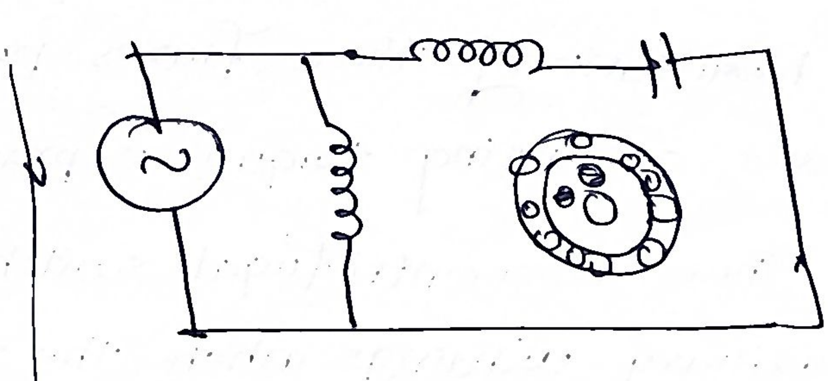
→ capacitor present only at the beginning ⇒ called a capacitor - start induction motor.



(b) Capacitor - start capacitor run induction motor

→ no centrifugal switch as the capacitor is present throughout operation

→ has an improved power factor



C. Shaded Pole Induction Motor

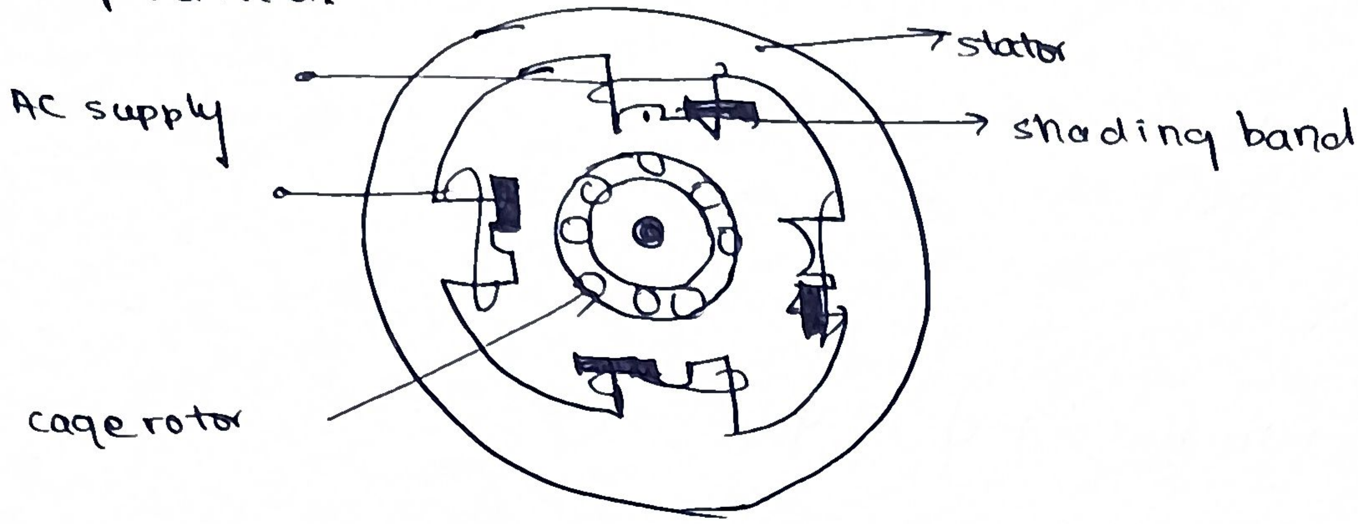
→ has prominent projected poles where stator windings are wound

→ when current flows through the stator winding, a flux called main flux is produced.

→ when current flows through the copper band, a flux called shaded ring flux is produced

→ The magnetic axis lies at the position where there is more flux.

→ When the magnetic flux shifts, a rotating magnetic flux is produced.



3) __Alternator / 3 Phase Generator__

→ generates an alternate emf

→ rotates at synchronous speed N_s, also called a synchronous generator.

__Principle__: a stationary conductor placed in a moving mag. field has an emf induced in it

__Construction__: same as 3 phase induction motor + (rotor has an even no. of heavy-iron poles projecting from the rotor core surface).

__Working__: → Field windings are energized with a DC supply

→ alternate N, S poles are produced, & a mag flux is produced.

→ This changing mag. flux causes the rotor to rotate.

→ The stationary armature conductors are cut by the magnetic flux.

→ By the principle of EMI, emf is induced in the stator conductors

→ Since the rotor poles are alternative in nature, the induced emfs in the stator conductors are also alternating

→ The Frequency of the induced emf is :

$$f = \frac{PN_s}{120}$$

EMF Equation

Total flux for 1 conductor $= P\phi = \phi_T$

Time for 1 revolution $\Rightarrow t = \frac{60}{N_{syn}}$

$$E_p = \frac{\phi_T}{t} = \frac{P\phi N_{syn}}{60}$$

$$\phi \left(\frac{P N_{syn}}{\cancel{120}_{2}}\right) = \frac{P\phi N_{syn}}{\cancel{60}}$$

$$\therefore E_{ph} = 2f\phi$$

$$E_{ph\ avg} = 4f\phi \underbrace{T_{ph}}_{\text{no. of turns}}$$

$$\text{form factor} = \frac{\text{rms}}{\text{avg. value}} = 1.11$$

$$E_{rms} = 4.44 f\phi T_{ph}$$

$$\boxed{\text{in general: } E_{ph} = 4.44 K_c K_d f \phi T_{ph}}$$

K_c = pitch coil factor : ratio of emf when coil is short pitched to when the coil is full pitch $K_c = \cos\left(\frac{\alpha}{2}\right)$ → short pitch angle

K_d = distribution factor : The factor by which the emf induced gets reduced due to coil distribution

$$K_d = \sin\left(\frac{m\beta}{2}\right) \Big/ m\sin(\beta/2)$$

m = no. of slots

β = slot angle