Unit - 4
Electrical Machines

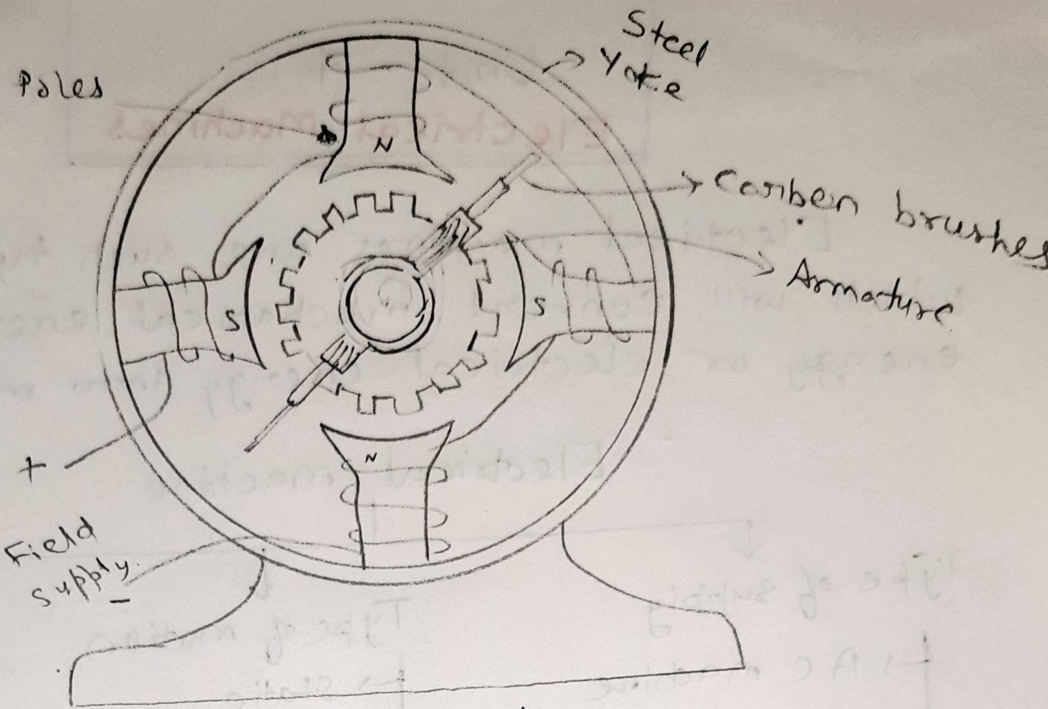
Electrical machines are such type of device which will convert mechanical energy into electrical energy or electrical energy into mechanical energy.

Electrical machine
- Type of supply
  - AC machine
  - DC machine
- Type of motion
  - Static
  - Dynamic
    - Generator
    - Motor
- Phase of supply
  - Single phase
  - Three phase

AC machine → Induction & synchronous

DC machine → Separtely excited DC machine, Compound, shunt and seriec dc machine.

Motor	Generator
electrical energy → $\boxed{\text{motor}}$ → mech. energy.	mech energy → $\boxed{\text{generator}}$ → electrical energy
Based on magnetic effect of ~~induction~~ current	Based on electromagnetic induction
when a current carrying coil placed in on external megnetic field, it will experienced by a force by magnetic field.	when a relative motion between a magnetic field & coil or Conductor, then an Emf will induce across that coil or conductor.



DC machine

Parts

- Yoke → outer frame
  → Protect machine from moisture, dust.
  → designed with cast iron, cast steel.

- Pole & Pole core
  → Electromagnet
  → field winding is wounded among pole.
  → Annealed steel lamination for reducing eddy current.
  → Cast steel & cast iron is used.

- Pole shoe
  → Spread out flux with air gap.
  → material → Cast iron, cast steel.

- Field winding
  → Source of magnetic field.
  → material → copper.

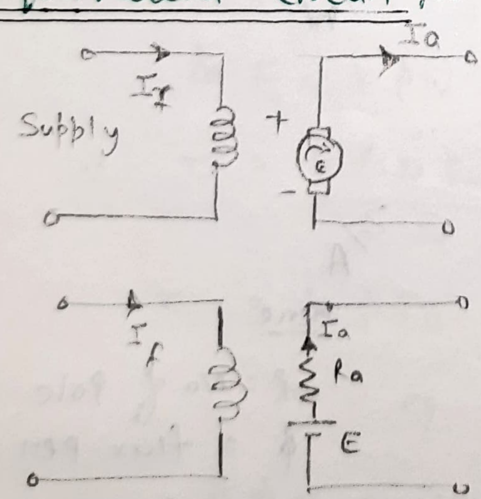
- **Armature Core**
  - → rotating part
  - → material = cast iron, cast steel.
  - → Armature core includes a huge number of slots.

- **Armature winding**
  - → Role = conductor
  - → material = copper.
  - → Placed in armature slot.

- **Commutator**
  - → Collects the current from the armature conductor as well as supply current to the load brush.
  - → Built with huge number of segments of hard copper

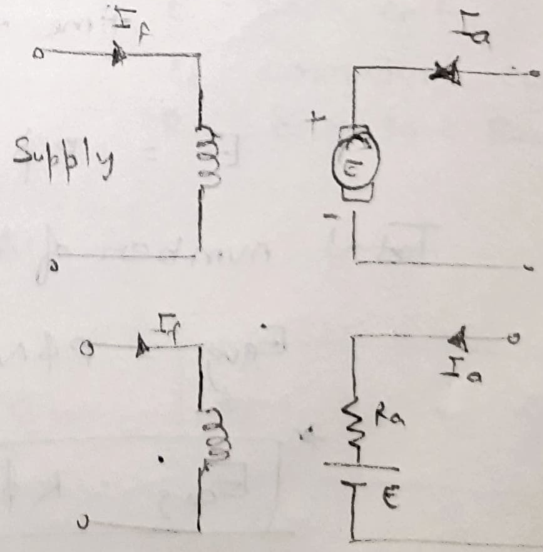
- **Brushes**
  - → Gather the current from the commutator & supply it to exterior load.
  - → material = graphite or carbon.

Equivalent circuit :-



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

Generator



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

Motor

Motor Equation

$$\because V = E + I_a R_a$$

multiplied by I_a

$$V I_a = E I_a + I_a^2 R_a$$

$VI_a \to$ Input Power, $EI_a \to$ Output power, $I_a^2 R_a \to$ Heat loss

Let τ = Torque of motor

ω = Rotational speed

Then

$$E I_a = \tau \omega \quad \text{(output power)}$$

$$\tau = \frac{E I_a}{\omega}$$

$$\because E = k \phi N$$

$$\omega = 2\pi N$$

$$\boxed{\tau = \frac{k \phi I_a}{2\pi}}$$

EMF equation

$$\text{EMF} = \frac{\text{Total flux}}{\text{time taken}} = \frac{P\phi}{1/N}$$

$$E = P \phi N$$

Total number of brushes $= Z/A$

$$E_{avg} = P\phi N \cdot \frac{Z}{A}$$

$$\boxed{E_{avg} = k \phi N}$$

$$\boxed{\frac{PZ}{A} = k}$$

here

P = No of pole

ϕ = flux per pole

N = Revolution / sec

Z = No of conductors

A = No of parallel path

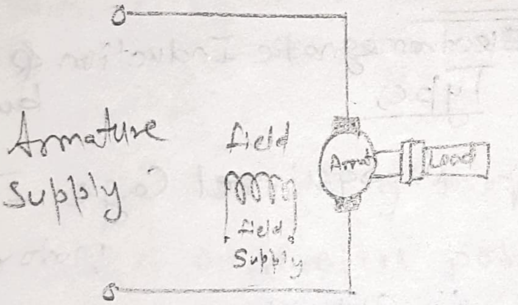
• Type of DC Motor

DC motor

- Seperately Excited
- Self excited
- Permanent E magnet

Seperately Excited DC motor

→ Armature current doesn't move across the field winding as the field winding is powered from a separate external supply of DC



→ fixed DC voltage is applied to induce the field coil.

by motor's equation

$$V = E + I_a R_a \quad \text{---(i)}$$

v = Terminal voltage
E = back emf
I_a = armature current
R_a = armature Resistance.

& $E = K\phi N$

$$\therefore \tau = \frac{K\phi N I_a}{2\pi N} = E I_a / \omega$$

$$\tau = K'\phi I_a \quad \text{---(ii)}$$

by eq (i)

$$K\phi N = V - \frac{\tau}{K'\phi} R_a$$

$$\boxed{N = \frac{V}{K\phi} - \frac{\tau}{K'K\phi^2} R_a}$$

$$\boxed{N\downarrow \rightarrow \tau\uparrow}$$

Speed control for a Separately Excited DC motor

- **Field control**

$$\because N = \frac{V}{K\phi} - \frac{\tau}{K' K \phi^2} R_a$$

If $\phi \downarrow$ then $N \uparrow$.

When V Armature terminal voltage is fixed.

- **Armature control**

$$\because N = \frac{V}{K\phi} - \frac{\tau}{K' K \phi^2} R_a$$

we can decrease R_a

or can increase V where ϕ is fixed.

★ Three Phase Induction Motor

Based on Electromagnetic Induction & Lenz's law.

Advantage

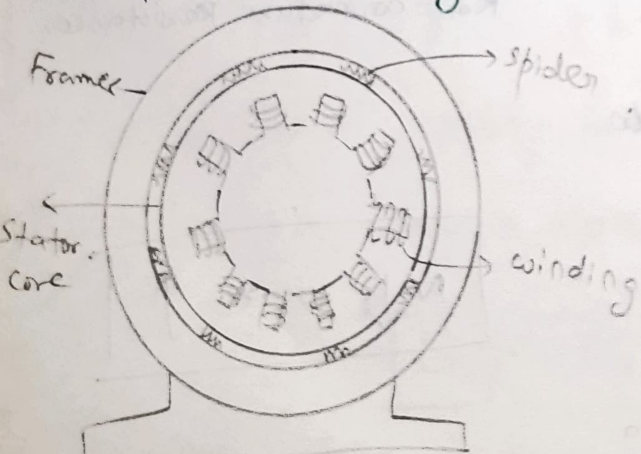
- Simple design
- Reliable operation
- Low initial cost
- Simple maintainence
- Speed control
- High efficiency.
- *Self started (No extra arrangment is needed)

Types

(i) Squirrel Cage Induction motor

(ii) Slip ring induction motor

(i) Squirrell cage induction motor :-



Stator

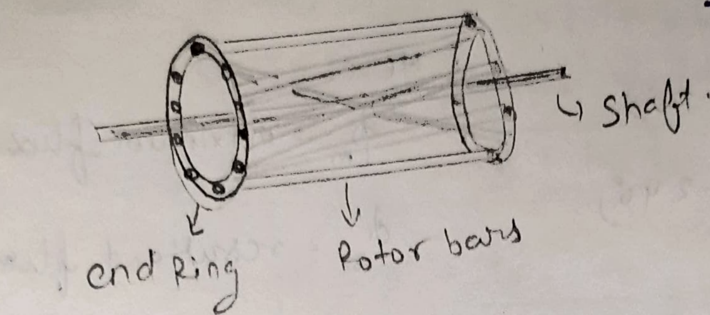
→ Stator is stationary part.

→ laminated steel core.

→ Slot consists windings

→ All are placed in 120° electric degree. (Star or delta)

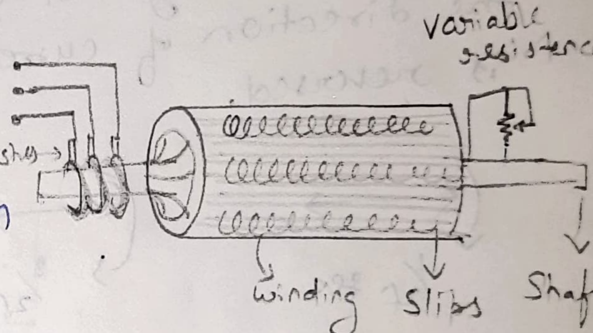
→ Produce rotating magnetic field



→ In slots coppor conductor bars mounted.
→ They are short circuited by en end rings.

→ It is commenly used.
for decreasing edd current loss ⇒ Leminated conducting bars.
→ High efficiency & less losses.
Starting torque is less.

(ii) Slip Ring Induction Motor

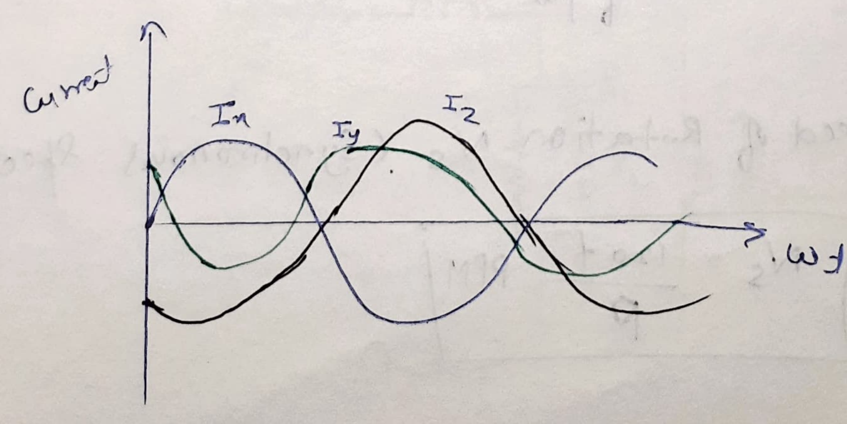


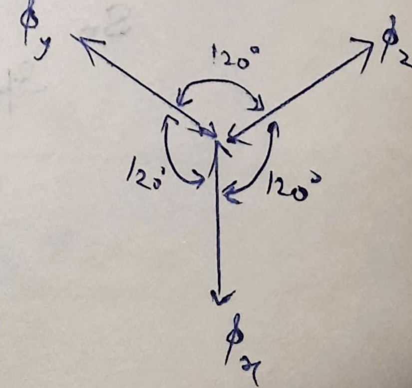
Stator part is same as in squirrel cage induction motor.

→ High starting torque
→ Speed control is possible due to variable resistance
→ Cost is high & Complicated structure
→

- Rotating Magnetic Field :- (RMF)

when a 3ϕ winding is energized from a 3 phase supply. a Rotating Magnetic field is produced.





$\phi_x = \phi_m \sin\omega t$

$\phi_y = \phi_m \sin(\omega t - 120^\circ)$

$\phi_z = \phi_m \sin(\omega t - 240^\circ)$

Here

ϕ_m = maximum flux

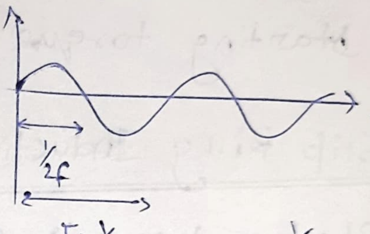
ϕ_r = resultant flux.

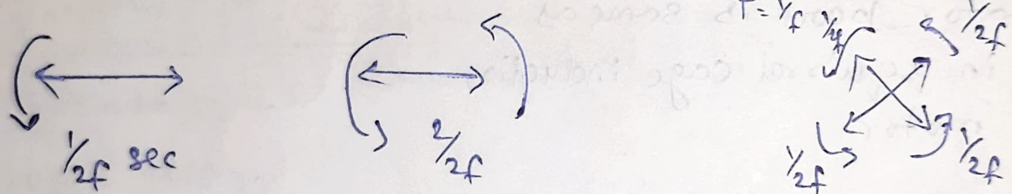
$\boxed{\phi_r = 1.5\, \phi_m}$ Constant magnetic field. Produce

- **Speed of Rotating magnetic field:-**

It is connected to AC current

After each & every half cycle the direction of current is reversed.





Time taken in one rotation of magnetic field. $= \dfrac{\text{no. of Pole}}{2f}$ sec

in 1 sec $= \dfrac{2f}{\text{no. of Pole}}$ RPM

for 60 sec $= \dfrac{120 f}{\text{no of pole}}$ RPM

So

Speed of Rotation N_s (Synchronous Speed)

$$\boxed{N_s = \frac{120 f}{P} \text{ RPM}}$$

Slip

Rotor speed (N) is always less than the rotating stator field speed (N_s)

$$\boxed{N_r < N_s}$$

$$\boxed{\% \text{ slip} = \frac{N_s - N}{N_s} \times 100}$$

Difference between the synchronous speed N_s of the rotating stator field speed and the actual rotor speed N is called Slip.

* $\boxed{\text{Slip}(s) = N_s - N}$

Rotor current frequency

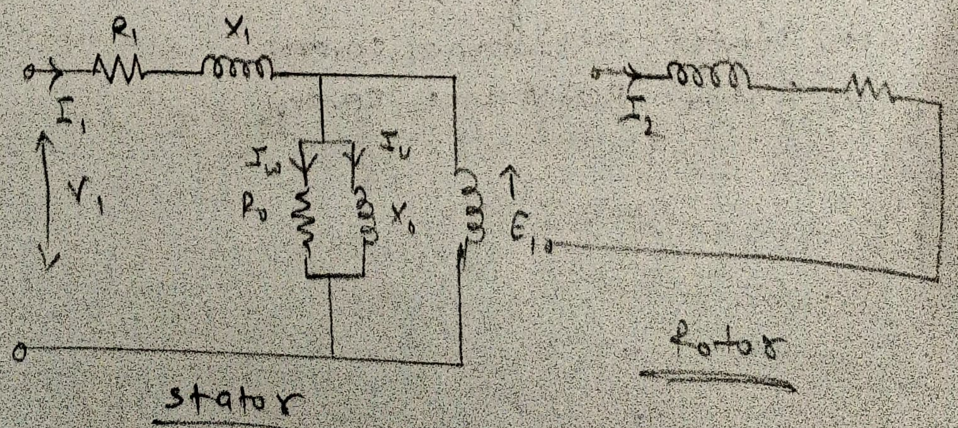
* $$\boxed{f' = sf = \frac{(N_s - N)P}{N_s \; 120}}$$

* Losses

(i) Fixed loss
- Stator iron loss
- Friction & windage loss

(ii) Variable loss
- Stator copper loss
- Rotor copper loss.

Equivalent circuit :-



Torque equation

$$\boxed{T_g = \frac{3}{2\pi N_s} \times \frac{S E_2^2 R_2}{R_2^2 + (S X_2)^2}}$$

Here R_2 = Rotor resist.
N_s = Synchro speed (rps)
S = Slip
X_2 = Leakag resist of rotor
E_2 = Rotor emf

when $R_2 = SX_2$ then
Torque will be maximum.

$$\boxed{T_{max} = \frac{3}{2\pi N_s} \times \frac{E_2^2}{2X_2}}$$

& $T_g \propto \frac{1}{S}$ when the slip less then but near about 1

when s becomes less then 0 then motor will work as generetor.

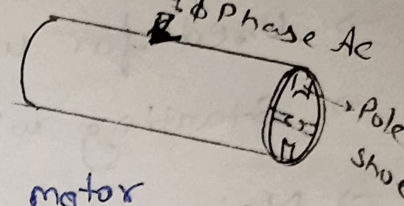
here
$0 < S < 1 \Rightarrow$ motoring mode.
$S < 0 \rightarrow$ generating mode
$S > 1 \rightarrow$ breaking mode

* Starting method

(i) DOL (Direct on line)
(ii) Star-Delta
(iii) Auto transformer
(iv) Stator resistance control
(v) Rotor Resistance control

* Single Phase Induction motor

Construction is similar to of a 3-ϕ induction motor.



-> It has only one winding.

-> Not self starting motor.

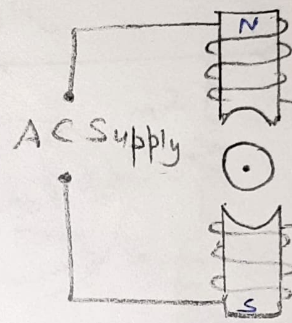
-> Squirrel cage rotor is used in this motor

-> we have to apply a starting torque. => Double Revolving field theory.

- **Method of starting**

(i) Split phase starting

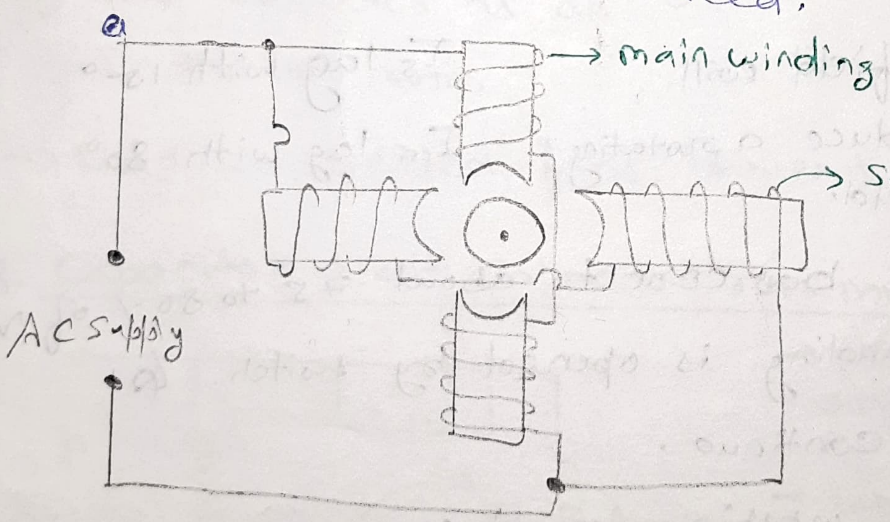
(ii) Shaded pole starting



(i) Split phase starting

It has 2 windings -> Main winding, Starting winding } -> both are applyed with supply.

It produce rotating magnetic field and torque is induced.



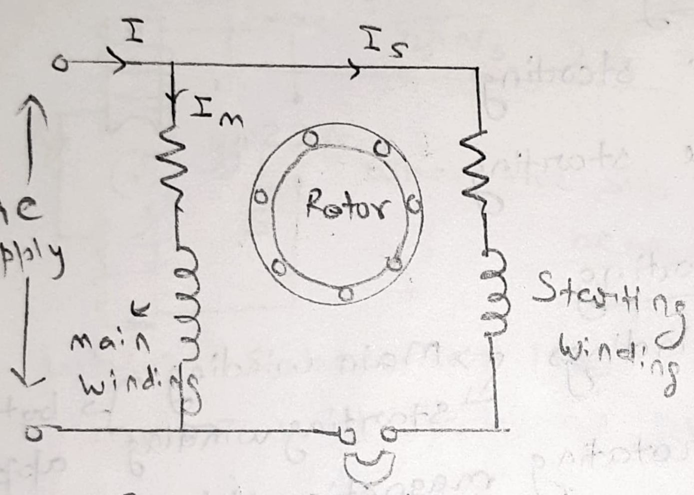
They are 3 types of - (i) Resistance start induction run motor

(ii) Capacitor start induction run motor

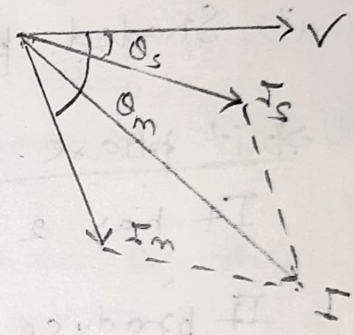
(iii) Capacitor start Capacitor run motor

1. Resistance-start Induction Run motor

- Used for upto 0.5HP
- Starting winding — higher resistance, lower reactance
- Main winding — higher Inductance, lower resistance



(a) Schematic diagram



(b) vector diagram

Their magnetic field will combine to produce a rotating magnetic field.

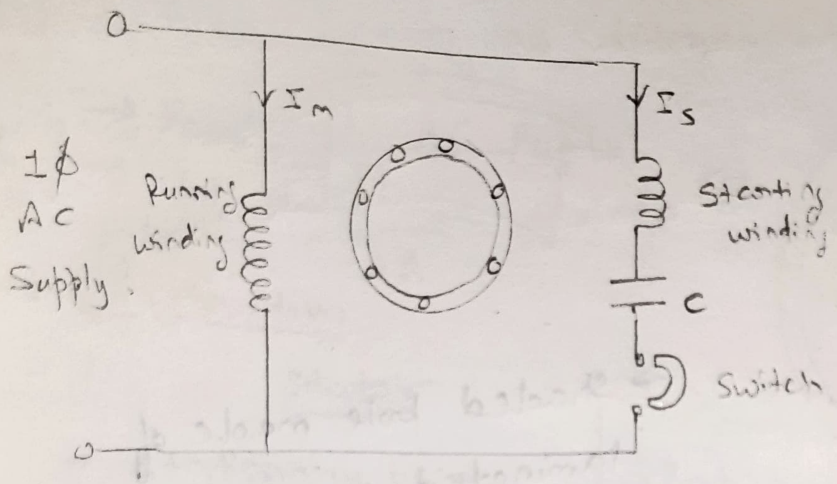
I_s lag with 15°

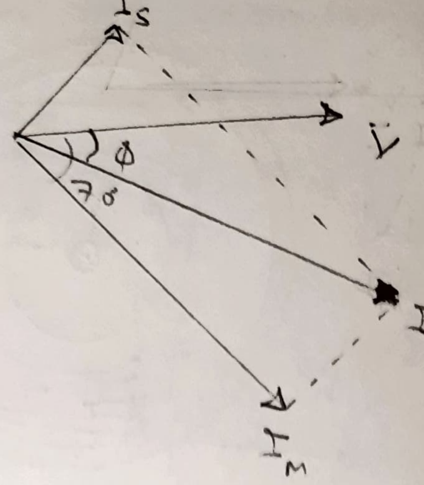
I_m lag with 80°

- When motor has come to about 75 to 80 % of N_s starting winding is opened by switch. & motor will continue.

used in fans, washing machines.

2. Capacitor Start Induction run motors:-





→ makes the Power factor high.

$I_s \perp I_m$

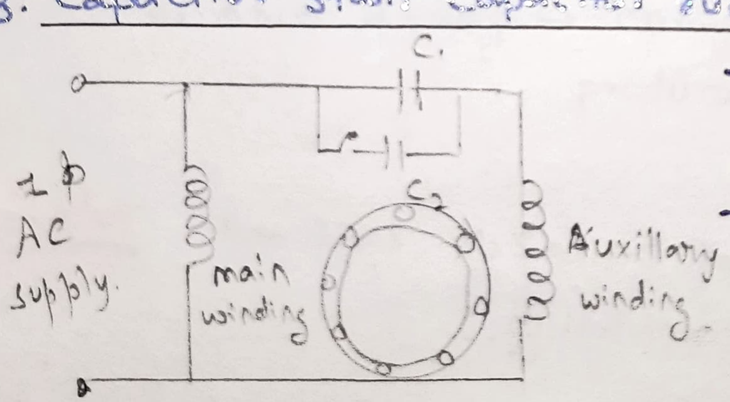
and I_m is lagged with $70°$ to V

So V lags $20°$ to I_s

→ After attaining 75% of rated speed, the Switch turns off and motor operates as an Induction motor.

→ Used in belted fans, blowers dryers, pumps etc.

3. Capacitor start Capacitor run motor:-



→ used when ~~torque i~~ required torque is high.

→ works same as Capacitor start Induction run motor.

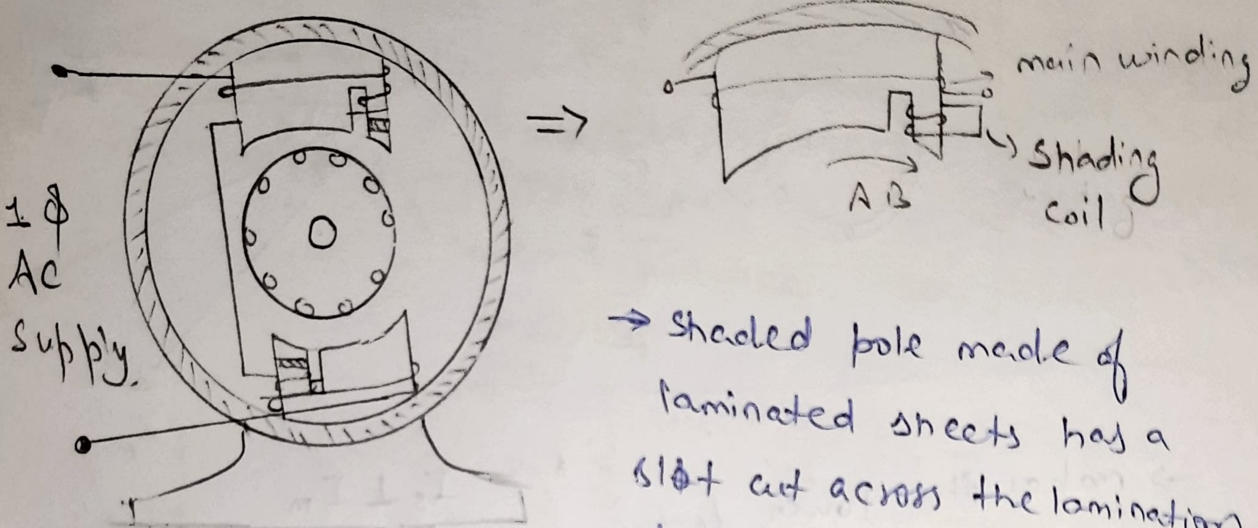
→ starting torque = 300% of full torque

→ Starting current is low.

→ Power factor is good

→ efficiency is high.

2: Shaded pole starting:-



→ Shaded pole made of laminated sheets has a slot cut across the lamination at about a 1/3 distance from the edge.

→ a short-circuit ~~pole~~ copper ring is placed which is shading coil. this part → shaded part.

→ when flux is passed through the shaded part then in shading coil Emf induced & current will flow. This will force unshaded part and motor get self start.

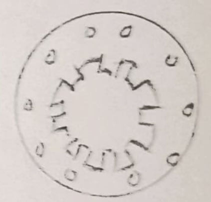
* Synchronous Generator

→ Also known as Alternators or AC Generator.
→ Produces AC power.
→ It must be driven at synchronous speed.

* Construction

Stator	Rotor
→ stationary part	→ Rotating Part
→ Carries Armature winding in which voltage is generated.	→ Produce main field flux through the slip rings

Stator



Frame → cast iron (small size)
welded Steel (large size)

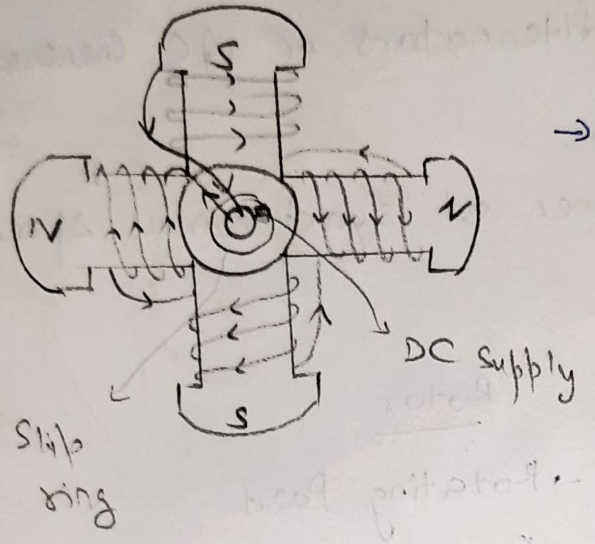
Core → high grade silicon content steel lamination,
[Reduce edd current & hystrisis loss]

Armature winding → connected in star
produces an essential emf.

Rotor

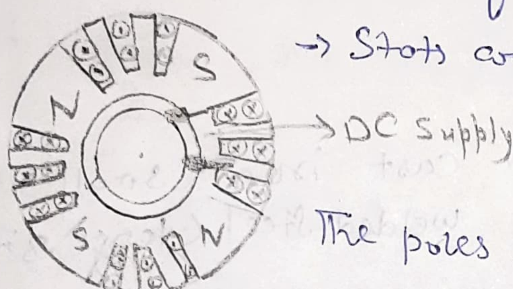
two types (i) Salient pole type
(ii) cylindrical rotor type.

- **Salient Pole Rotor**



Used in low & ~~high~~ medium speed. (120 to 400 rpm)
→ large diameter & short axial length.

- **Cylindrical Rotor**



→ made from Ni + Cr + Mo steel
→ Slots are cut at regular interval & parallel to the rotor shaft.
The poles formed are non-salient.
Used in high speed (1500 to 3000 rpm)
→ It provides greater mechanical strength.
→ noiseless operation at high speed.
Also known as turbo alternator or turbo generators.

Working Principle :- Electromagnetic Induction.

When DC ~~sy~~ supplys to this, Alternator is energized ~~from~~, N & S poles develops.
It rotates in Anti clock wise, the armature conductor placed on the stator are cut by the magnetic field of the Rotor poles. Emf is induced.

$$\boxed{f = \frac{N_s P}{120}}$$