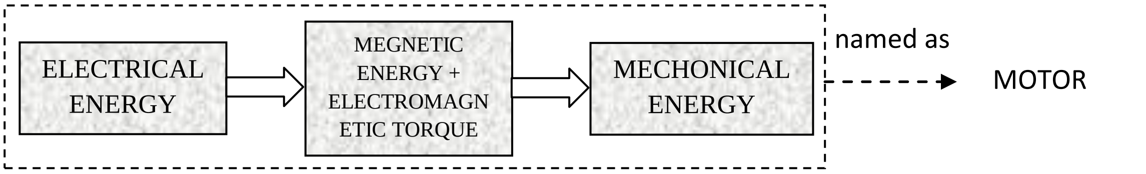
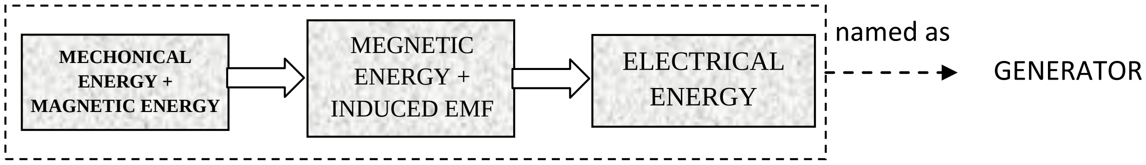
UNIT 2
ELECTRICAL MACHINES

Introduction

D.C. machines are the electro mechanical energy converters which work from a D.C. source and generate mechanical power or convert mechanical power into a D.C. power.





Types of DC machines

1. DC generators
2. DC motors

1. Types of DC generators.

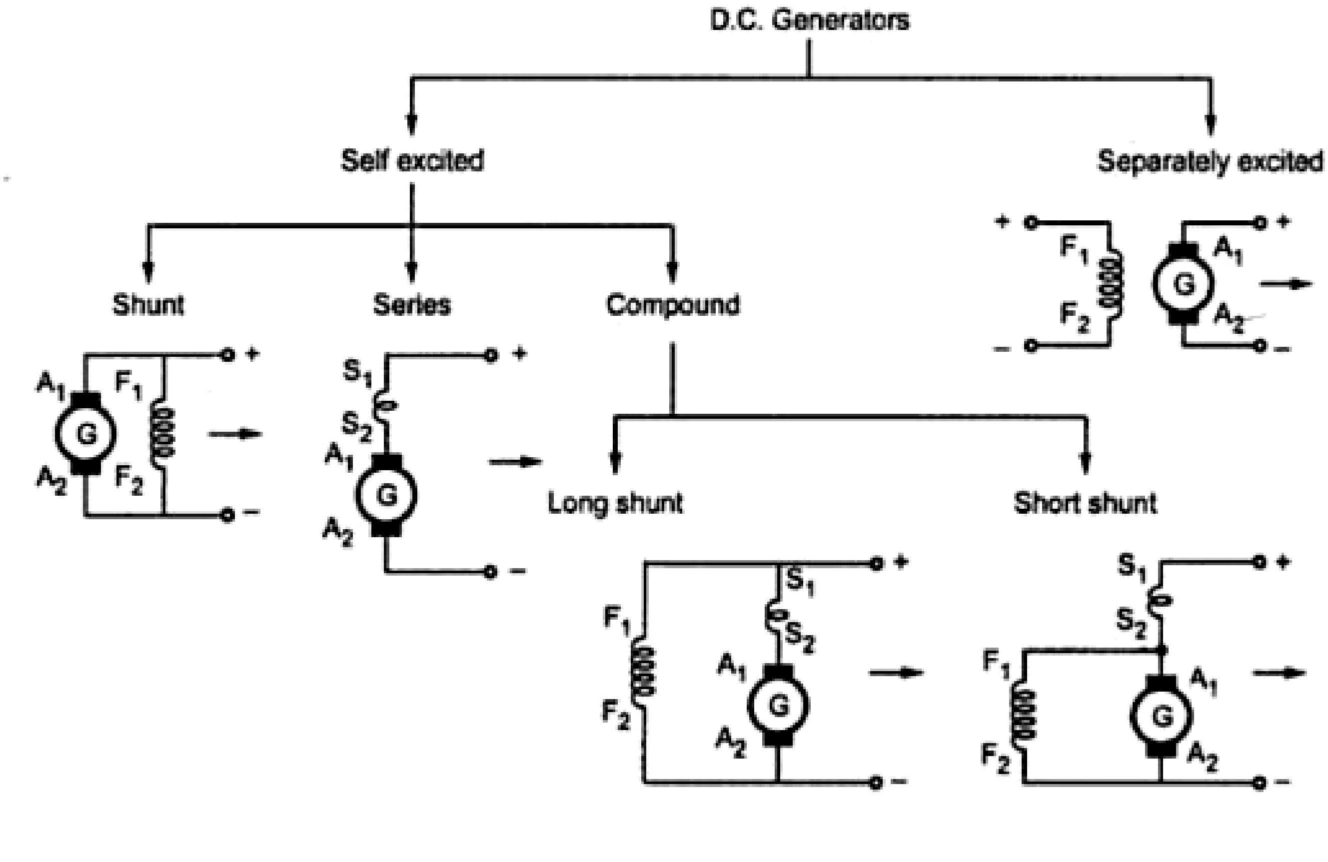


Figure: 1 - Types of DC generators

2. Types of DC motors.

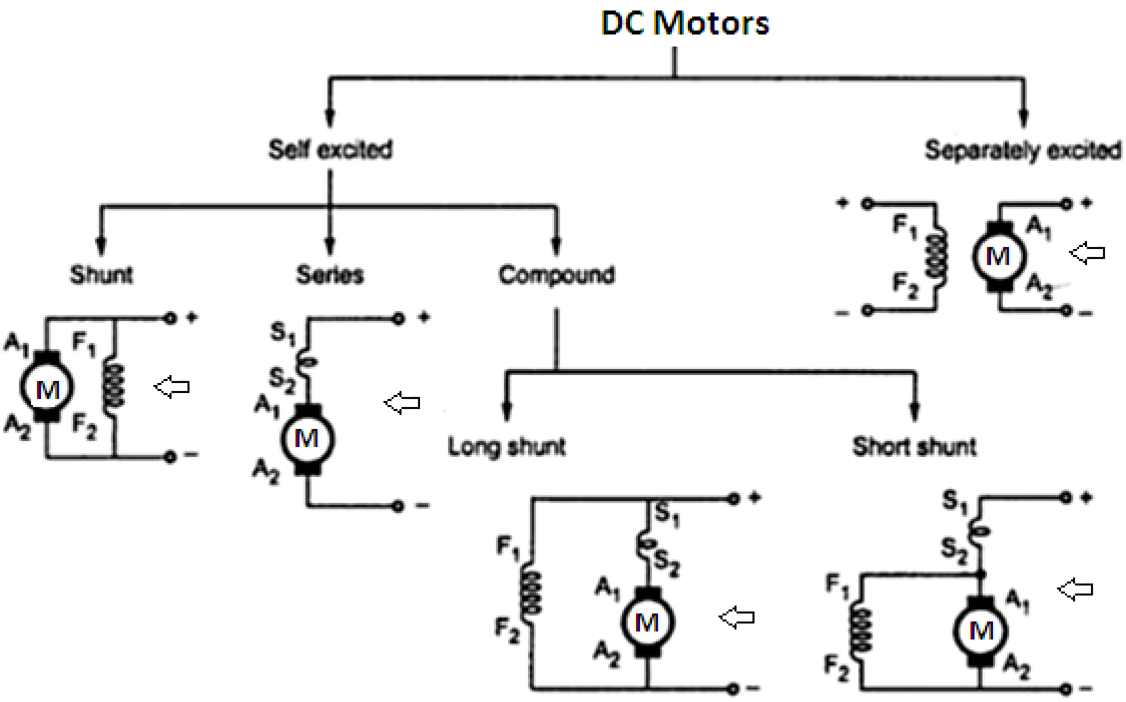


Figure: 2 - Types of DC motors

Construction details of DC Machine

A D.C. machine consists mainly of two part the stationary part called stator and the rotating part called armature (or) rotor.

The major parts are,

1. Yoke
2. Stator core and windings
3. Armature
4. Commutator and brush arrangement
5. Shaft and Other mechanical parts

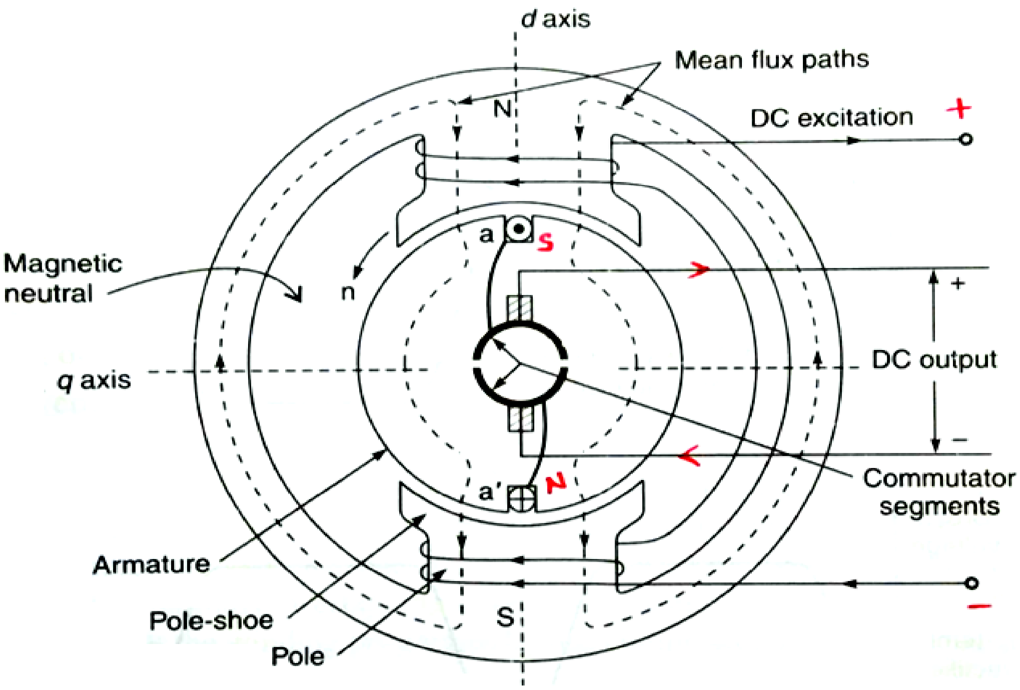


Figure: 3 - Cross sectional view of DC machine

1. **Yoke**.

* Manufactured by using cast iron material. Cast iron has high mechanical strength and corrosion free characteristics.
* Used to provide mechanical support to all internal parts and protect from external environment.

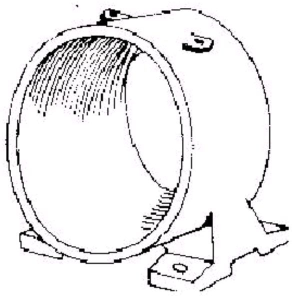
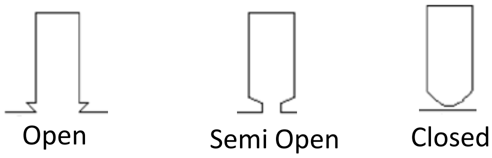


Figure: 4 - Yoke.

2. **Stator core and windings**

❖ ***Stator core***

* Stator core is used to hold field winding and used to provide magnetic flux path.
* This is a laminated stamped core, manufactured by using silicon steel.
* It contains several numbers of slots and inward projected poles.
* Types of slots are open, semi open and closed.

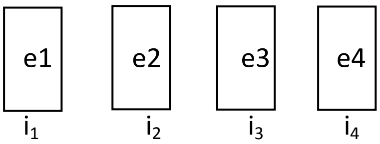


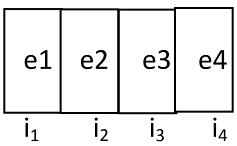
➢ **Hysteresis loss**

* To reduce hysteresis loss (H_{loss}),the flux density (B) has to be reduced. ($H_{loss} \alpha$ B)
* To reduce flux density (B), the flux path area (a) has to be increased. $(B \,\alpha \frac{1}{a})$
* For increasing flux path area large number of stamping are used to form a core instead of solid core.

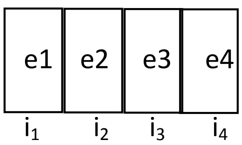
➢ **Eddy current loss**

* Due to flux linkage each stamping induces a minimum voltage (e) and a minimum circulating current (i_e) starts to circulate in each closed stamping.
* To reduce eddy current loss all stampings are insulated by using a thin layer of warmish coating and then stamped.





⇨ Without Insulation $i = i_1 + i_2 + i_3 + i_4$



⇨ With Insulation $i = i_1 = i_2 = i_3 = i_4$

❖ ***Field winding***

* Insulated copper conductors used to form field winding.
* Field winding placed inside the slot and around the pole.
* Field winding excited by DC supply to develop field flux.
* Types of windings: 1. Lap winding 2. Wave winding

* Lap winding can be used for high speed applications and number of parallel paths is equal to number magnetic poles (A= No. of mag. poles)
* Wave winding can be used for medium and low speed supplications and number of parallel paths is equal to number magnetic poles (A= 2)

3. Armature

* Armature core construction is similar to that of stator core.
* Armature is a rotating part which placed around the shaft.
* Armature winding excited by DC supply through commutator and brush arrangement.
* Air gap between field and armature must be constant and minimum as possible.

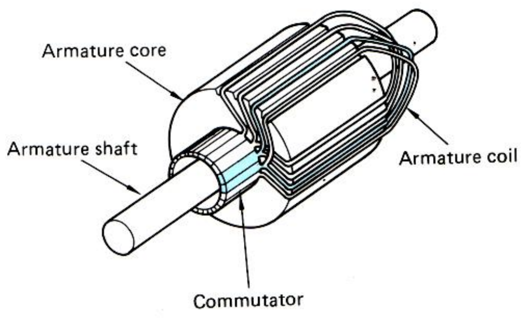


Figure: 5 - Armature

4. Commutator and brush arrangement

* Commutator has several no. of segments.
* The no. of commutator segments is equal to the number of slots or coils (or) half the number of conductors.

  No. of commutator segments = No. of slots = No. of coils
* It is because each coil has two ends and two coil connections are joined at each Commutator segment.
* Commutator acts as "Rotary converter"

  In Motor : DC to AC

  In Generator : AC to DC
* Carbon or Copper brushes are used.
* Commutator needs frequent maintenance.

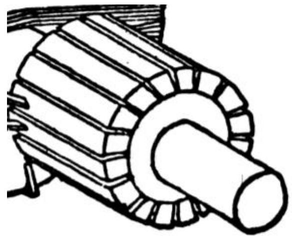


Figure: 6 - Commutator

5. Shaft and Other mechanical parts

* Solid iron bar used as shaft.
* shaft is used to provide mechanical support to armature and commutator arrangement
* And also used to deliver mechanical output (motor) and used to collect the mechanical input (generator)
* Cooling fans, Bearings and End shields are placed around the shaft at both ends.

  Cooling fan : To provide cooling by circulate fresh air.

  Bearing : To reduce mechanical friction.

  End shields : To protect the internal parts from external environment.

Working principle

* Field winding develops the constant magnetic field by exciting DC supply.
* The developed magnetic flux lines travels towards to armature through air gap.

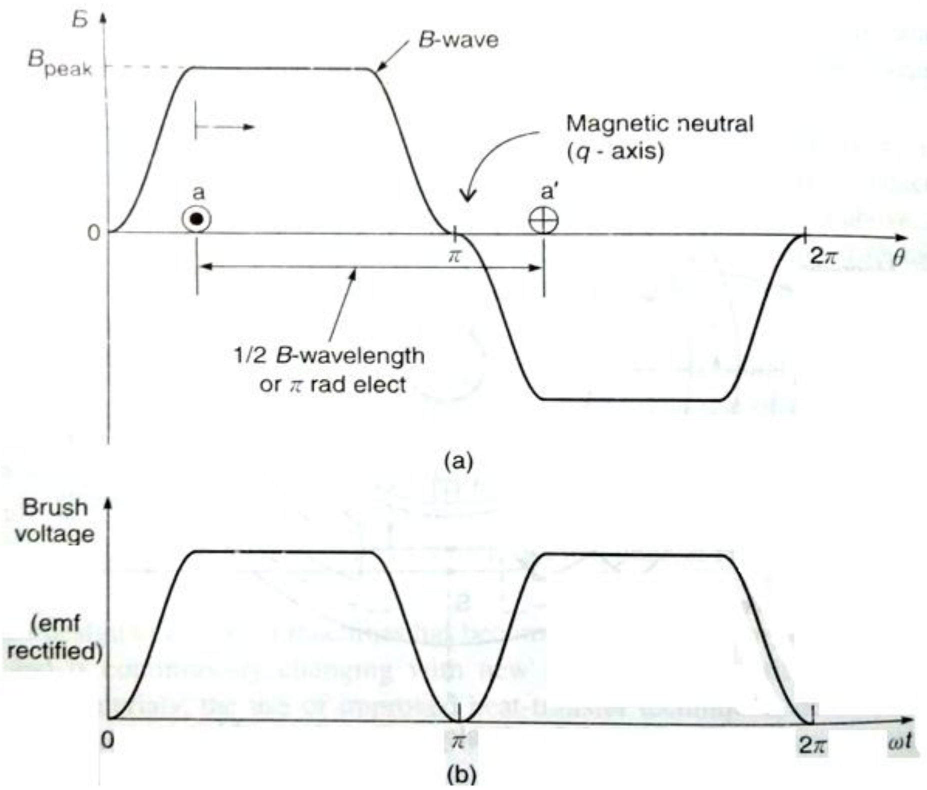
➢ **DC Motor**

* From figure – 3, armature excited by DC supply through commutator.
* Commutator act as a "Rotary Converter" and converts the DC in to AC. So finally armature receives AC supply and develops an alternating magnetic field.

* This alternating magnetic field interact with constant magnetic field and leads to develop the electromagnetic torque.
* The final mechanical output power delivered through shaft.

➢ **DC Generator**

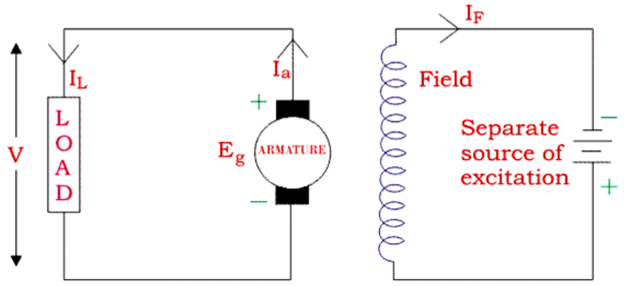
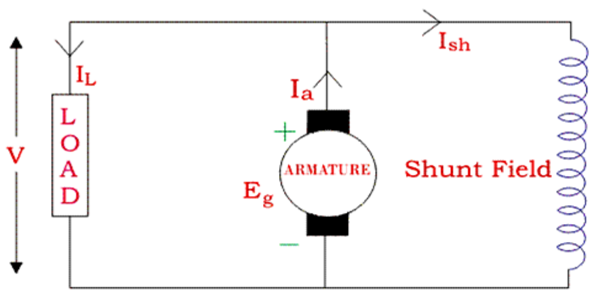
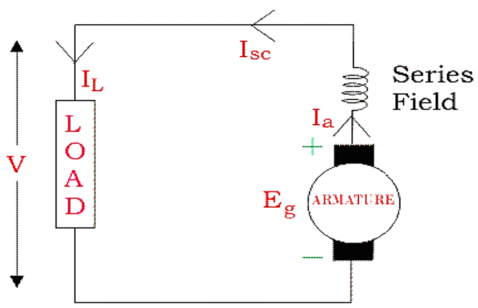
* From figure – 3, mechanical input (angular velocity) is given to the armature through shaft.
* Now the armature winding cuts the constant magnetic field.
* As per "faraday electromagnetic induction law", an AC emf induced in armature winding.
* Commutator act as a "Rotary Converter" and converts the AC in to DC. So finally it delivers DC supply, can collect across A_1 and A_2.



Types of DC Generators

General parameters for DC generators,

I_a = Armature current
I_F = Field current
I_L = Load current
V = Terminal voltage
E_g = Generated emf
R_{sh} = Shunt field resistance
R_{se} = Series field resistance
R_a = Armature resistance

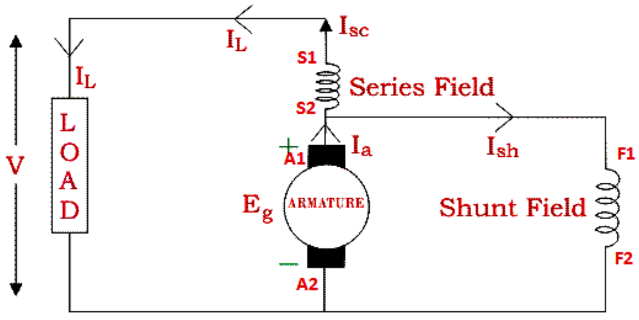
Types of DC Generator	Expressions
➢ **Separately Excited DC Generator** ∗ Field and armature windings excited separately. 	∗ Voltage drop in the armature = $I_a \times R_a$ ∗ Let, $I_a = I_L = I$ ∗ Now Voltage drop across the load, $V = I \times R_a$ ∗ Generated emf, $E_g = V$ ∗ Power generated, $P_g = E_g \times I = V \times I$. ∗ Power delivered to the external load, $P_L = V \times I$.
➢ **Self-excited DC Generators**	
1. Shunt wound generator ∗ Shunt field winding is connected with armature in parallel. ∗ Shunt field winding has large no. of turns and less cross sectional area of conductor. ∗ Shunt field and armature windings excited by single electrical source. ∗ Due to residual magnetism some flux is always present in the poles. 	∗ Shunt field current, $I_{sh} = \frac{V}{R_{sh}}$ ∗ Armature current, $I_a = I_{sh} + I_L$ ∗ Voltage across the load, $V = E_g - I_a R_a$ ∗ Generated emf, $E_g = V + I_a R_a$ ∗ Power generated, $P_g = E_g \times I_a$ $P_g = V + I_a^2 \times R_a$ ∗ Power delivered to the load, $P_L = V \times I_L$
2. Series Wound Generator ∗ Series field winding is connected with armature in series. ∗ Series field winding has less no. of turns and large cross sectional area of conductor. ∗ Series field and armature windings excited by single electrical source. 	∗ Series field current, $I_{sc} = I_a = I_L = I$ (say) ∗ Voltage across the load, $V = E_g - I(I_a \times R_a)$ $V = E_g - I_a^2 \times R_a$ ∗ Generated emf, $E_g = V + I_a^2 \times R_a$ ∗ Power generated, $P_g = E_g \times I$ ∗ Power delivered to the load, $P_L = V \times I$

3. *Compound Wound DC Generator*

- This type of DC generator has both series and shunt field windings.

3a. Short Shunt Compound Wound DC Generator

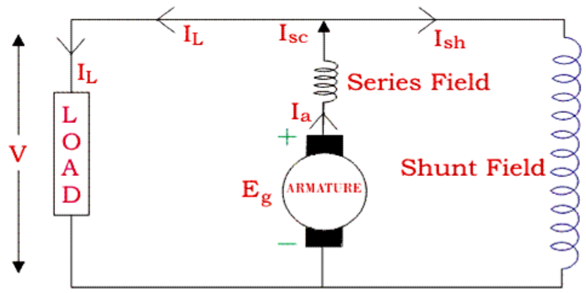
- F_1 terminal of shunt field winding is connected between S_2 and A_1



- Series field current,
$$I_{sc} = I_L$$
- Shunt field current,
$$I_{sh} = (V+I_{sc}\,R_{sc}) \,/\, R_{sh}$$
- Armature current,
$$I_a = I_{sh} + I_L$$
- Voltage across the load,
$$V = E_g - I_a\,R_a - I_{sc}\,R_{sc}$$
- Power generated,
$$P_g = E_g \times I_a$$
- Power delivered to the load, $P_L = V \times I_L$

3b. Long Shunt Compound Wound DC Generator

- F_1 terminal of shunt field winding is connected at S_1
- Depends current flow direction in series and shunt field windings, can classify as,
  1. Cumulative compounding – same direction
  2. Differential compounding– opposite direction



- Shunt field current,
$$I_{sh} = V/R_{sh}$$
- Armature current, I_a= series field current
$$I_a = I_{sc} = I_L + I_{sh}$$
- Voltage across the load,
$$V = E_g - I_a\,R_a - I_{sc}\,R_{sc}$$
$$V = E_g - I_a\,(R_a + R_{sc})$$
$$[\because I_a = I_{cs}]$$
- Power generated,
$$P_g = E_g \times I_a$$
- Power delivered to the load,
$$P_L = V \times I_L$$

➢ EMF Equation

- Assume full-pitch armature coils.
- Developed flux per pole $= \dfrac{\text{Flux}}{\text{pole}} = \dfrac{\varphi}{p}$
- Flux linkage per pole $\lambda_1 = N_C\,\varphi$

Where, λ_1 = Flux linkage at time t_1

N_c = Number of turns per coil

- As the coil moves through one pole pitch, now the flux linkage changes and it links in opposite polarity. Now the new flux linkage per pole at time t_2

$$\lambda_2 = -\,N_C\,\varphi$$

- During the movement t_1 to t_2 the change in flux ($\Delta\lambda$)

$$\Delta\lambda = \lambda_2 - \lambda_1$$

$$\Delta\lambda = -\,2\,N_C\,\varphi$$

- The time of flux travel through one pitch is, (time interval between t_2 and t_1)

$$\Delta t = \frac{2\pi}{p \times \omega_m}$$

Where, 2π = Circumference of armature core in metre.

ω_m = Armature speed in mechanical rad/sec.

p = Number of magnetic poles.

* As per faraday electromagnetic induction law, the average emf per coil is,

$$E_c = -\frac{\Delta\lambda}{\Delta t} = -\left\{\frac{-2N_c \times \varphi}{\left(\frac{2\pi}{p \times \omega_m}\right)}\right\}$$

$$E_c = \varphi \times \omega_m \times N_c \times p$$

* Now the average emf is $E_a = E_c \times \frac{\text{Coil span}}{\pi}$

* Coil span $(C_p) = \frac{\text{Number of coils}}{\text{parallel path}}$

* Average emf $E_a = \varphi \times \omega_m \times N_c \times p \times \frac{C_p}{\pi}$

* But we know that $N_c \times C_p = \frac{\left(\frac{Z}{2}\right)}{A} = \frac{\text{number of turns}}{\text{parallel path}}$

Where, Z = Number of conductors

* Average emf $E_a = \frac{\varphi \times Z \times \omega_m}{2\pi} \times \frac{p}{A}$

* Average emf can also written as, $\mathbf{E_a = \frac{\varphi \times Z \times n}{60} \times \frac{p}{A}}$ where, $\omega_m = \frac{2 \times \pi \times n}{60}$

Where n = armature speed in rps

Methods of Excitation

Various methods of excitation of the field windings are

1. Separately-excited generators
2. Self-excited generators: series generators, shunt generators, compound generators With self-excited generators, residual magnetism must be present in the machine iron to get the self-excitation process started.

The relation between the steady-state generated emf Ea and the armature terminal voltage Va is,

$$\mathbf{V_a = E_a - I_a R_a}$$

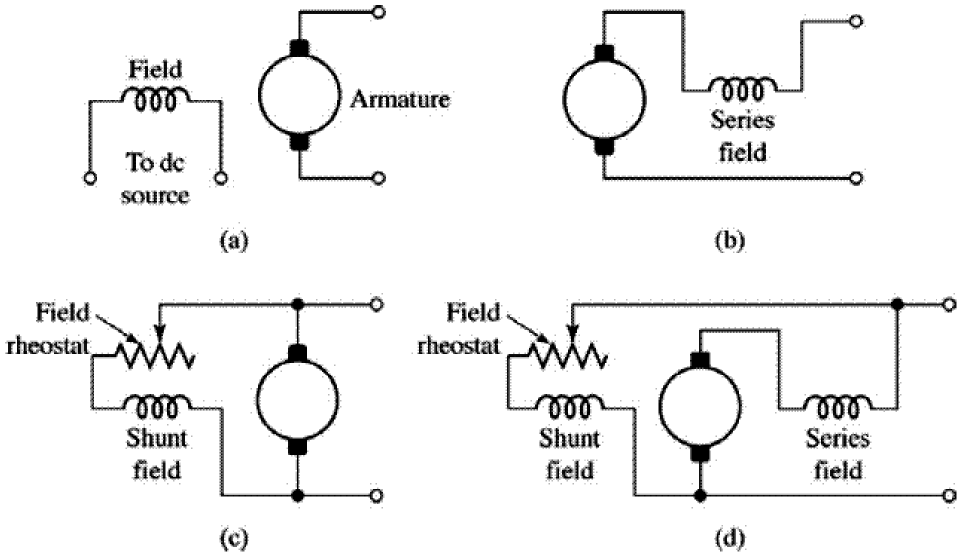
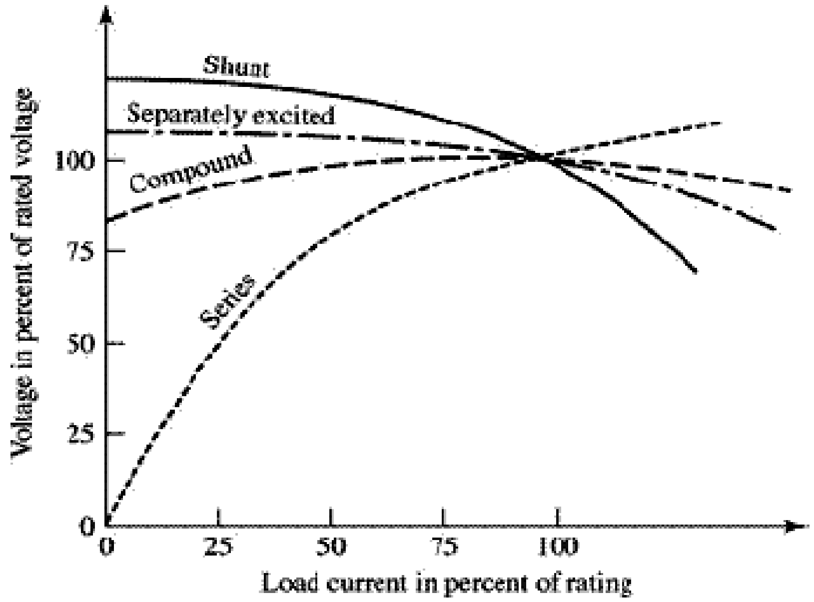


Fig. Methods of Excitation



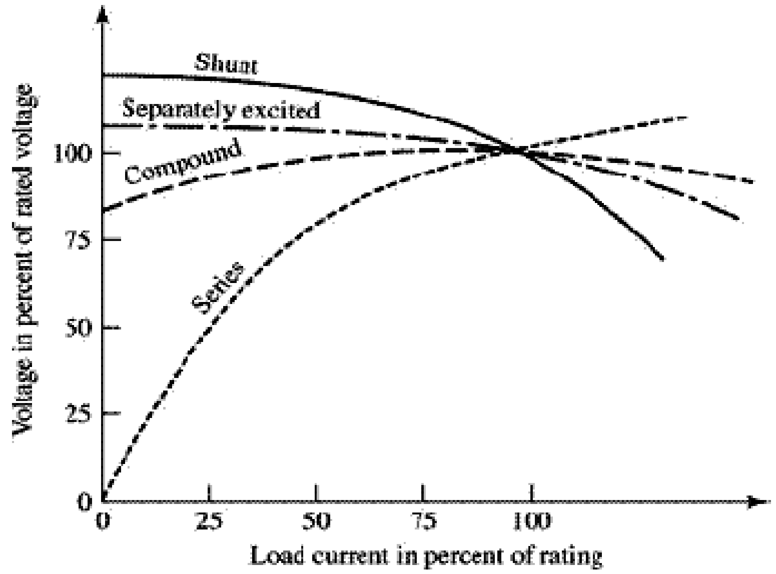


Fig. Load Curve

Typical steady-state dc-motor speed-torque characteristics are shown in figure. in which it is assumed that the motor terminals are supplied from a constant-voltage source.

In a motor the relation between the emf E_a generated in the armature and the armature terminal voltage V_a is,

$$\mathbf{V_a = E_a + I_a R_a}$$

DC MOTORS

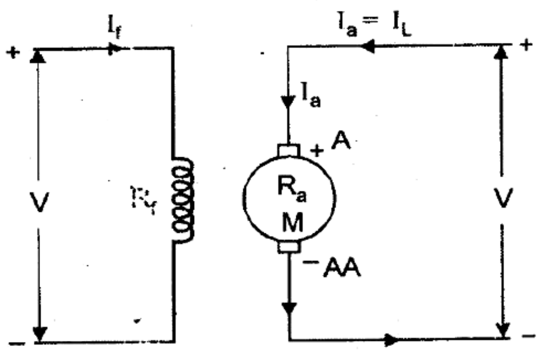
TYPES OF DC MOTORS

- Separately Excited DC motor.
- Self-excited DC motor.
  1. Series motor.
  2. Shunt motor.
  3. Compound motor.
     (a) Cumulative compound (b) Differential compound
     (1) Long Shunt compound motor. (2) Short Shunt compound motor.

Separately Excited DC motor

The supply is given separately to the field and armature windings

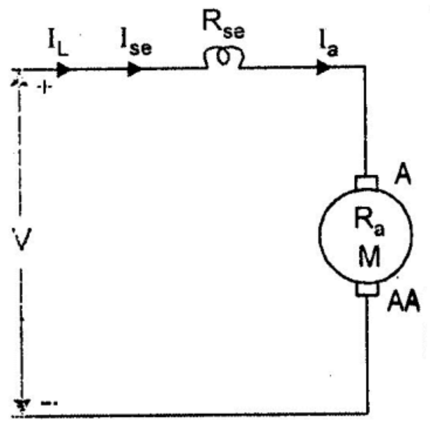
- The main distinguishing fact in these types of dc motor is that, the armature electric current does not flow through the field windings, as the field winding is energized from a separate external source of dc electric current



Self-excited DC motor

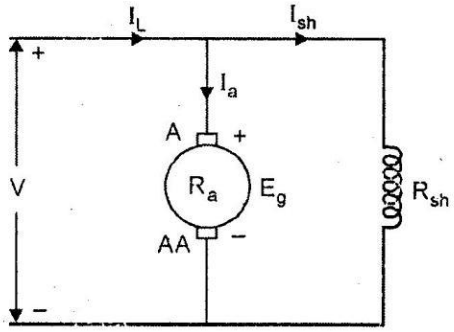
Series motor:

- The armature winding and field winding are connected in series
- The entire armature electric current flows through the field winding as its connected in series to the armature winding
- In a series wound dc motor, the speed varies with load
- $V = E_b + I_aR_a + I_aR_{se}$ $I_a = I_L$



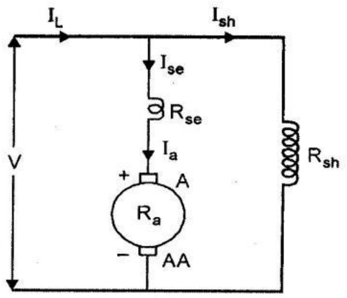
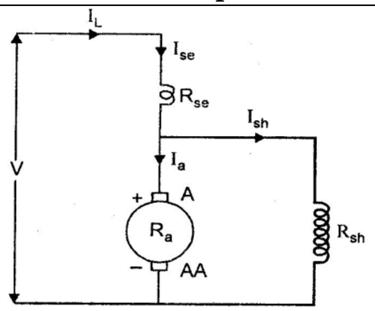
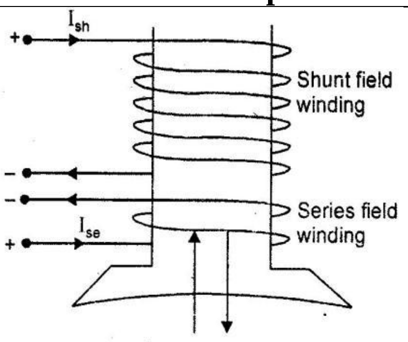
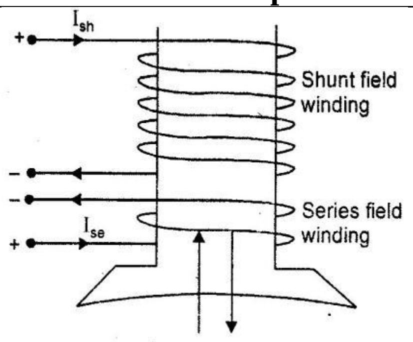
Shunt motor:

- The field winding is connected in parallel to the armature winding
- The voltage is same across field winding and armature winding
- The line current is the sum of armature current and field current
- The shunt wound dc motor is a constant speed motor, as the speed does not vary here with the variation of mechanical load on the output.
- $V = E_b + I_aR_a$ $I_a = I_L - I_{sh}$ $I_{sh} = V/R_{sh}$

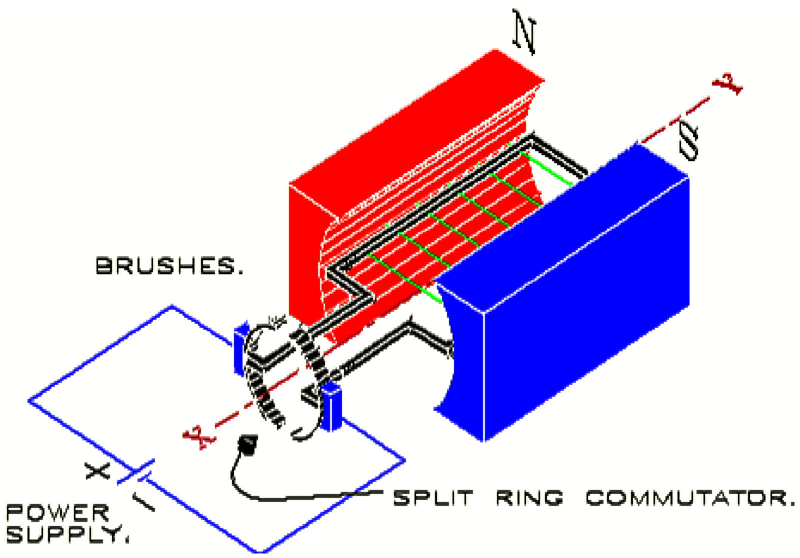


Compound Motor:

- The compound excitation characteristic in a dc motor can be obtained by combining the operational characteristic of both the shunt and series excited dc motor
- It contains the field winding connected both in series and in parallel to the armature winding
- If the shunt field winding is only parallel to the armature winding and not the series field winding then its known as short shunt dc motor
- If the shunt field winding is parallel to both the armature winding and the series field winding then it‟s known as long shunt type compounded wound dc motor
- When the shunt field flux assists the main field flux, produced by the main field connected in series to the armature winding then it is called cumulative compound dc motor
- In case of a differentially compounded self excited dc, the arrangement of shunt and series winding is such that the field flux produced by the shunt field winding diminishes the effect of flux by the main series field winding

Long Shunt compound motor	Short Shunt compound motor
 $V = E_b + I_aR_a + I_LR_{se}$ $V_{sh} = V - I_LR_{se}$ $I_a = I_{se}$ $I_L = I_a + I_{sh}$	 $V = E_b + I_aR_a + I_LR_{se}$ $V_{sh} = V - I_LR_{se}$ $I_{se} = I_L$ $I_L = I_a + I_{sh}$ $I_{sh} = V_{sh}/R_{sh}$
Cumulative compound	**Differential compound**
	

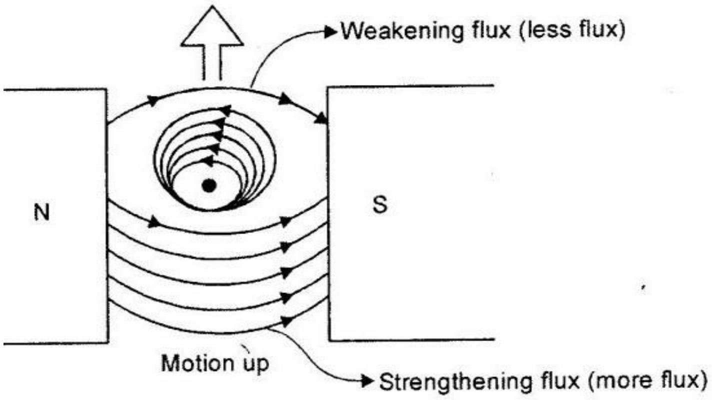
OPERATING PRINCIPLE OF DC MOTOR

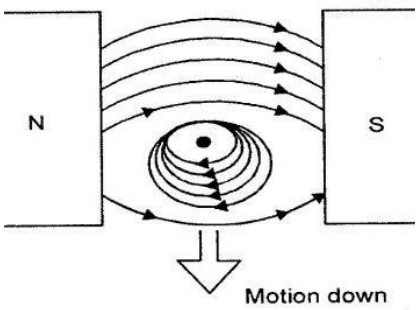


- This is a device that converts DC electrical energy to a mechanical energy
- Structurally and construction wise a direct electric current motor is exactly similar to a DC generator, but

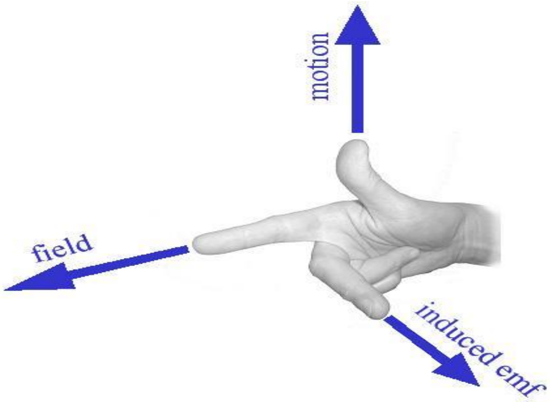
electrically it is just the opposite

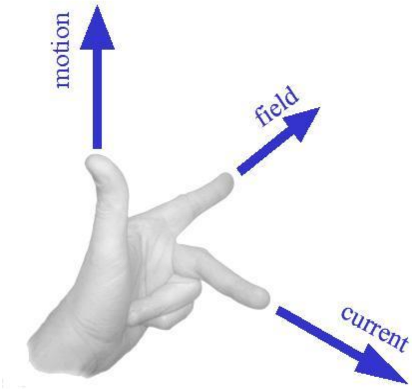
- This DC or **direct electric current motor** works on the principal, when a current carrying conductor is placed in a magnetic field, it experiences a torque and has a tendency to move
- This is known as motoring action
- If the direction of electric current in the wire is reversed, the direction of rotation also reverses
- When magnetic field and electric field interact they produce a mechanical force, and based on that the working principle of **dc motor** established
- The direction of rotation of a this motor is given by Fleming's left hand rule
- **Fleming's left hand rule:** if the index finger, middle finger and thumb of your left hand are extended mutually perpendicular to each other and if the index finger represents the direction of magnetic field, middle finger indicates the direction of electric current, then the thumb represents the direction in which force is experienced by the shaft of the **dc motor**





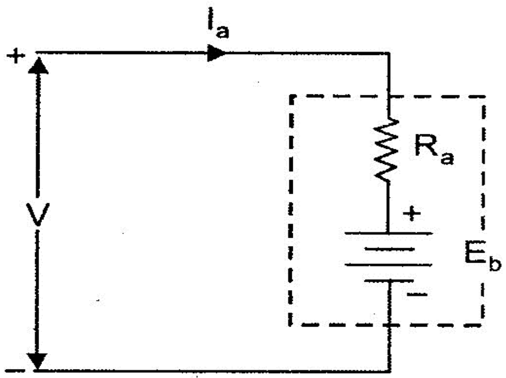
Fleming's Right & Left Hand Rule





Fleming's Right Hand Rule **Fleming's Left Hand Rule**

Equivalent Circuit



I_a = armature current

R_a = Armature resistance

E_b = Back EMF

Torque equation

* Whenever armature carries current in presence of flux, conductor experiences force which gives rise to the electromagnetic torque.
* The derivation of the torque expression is,

Let, I_a = Armature current

Average flux density $B_{AV} = \frac{\phi p}{\pi D L}$

Current flow through each conductor $= \frac{I_a}{a}$

Force on a single conductor $F = B_{AV} \frac{I_a}{a} L$

Torque on a single conductor $T_e = B_{AV} \frac{I_a}{a} L \frac{D}{2}$

Now put the expression of B_{AV} in T_e

$$T_e = \frac{\phi p}{\pi D L} \frac{I_a}{a} L \frac{D}{2}$$

$$T_e = \frac{\phi p}{\pi} \frac{I_a}{a} \frac{1}{2}$$

$$\mathbf{T_e = \frac{p}{2\pi a} \varphi I_a}$$

Torque on Z number of conductors

$$\mathbf{T_e = \frac{p Z}{2\pi a} \varphi I_a} \quad \text{in NM}$$

Where,

p	=	No of poles	ϕ	=	Flux per pole
D	=	Diameter of stator core	Z	=	Total number of conductors in winding
L	=	Length of stator core	B_{AV}	=	Average flux density
a	=	No of parallel path in winding			

<u>Characteristics of DC motor</u>

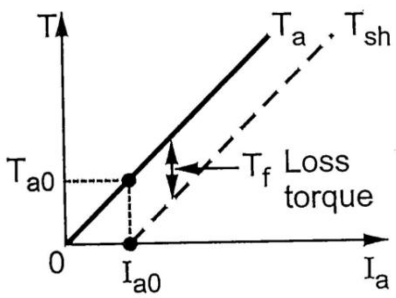
1. Torque Vs Armature Current Characteristics
2. Speed Vs Armature Current Characteristics
3. Speed Vs Torque Characteristics

<u>DC Shunt Motor</u>

1. Torque Vs Armature Current Characteristic

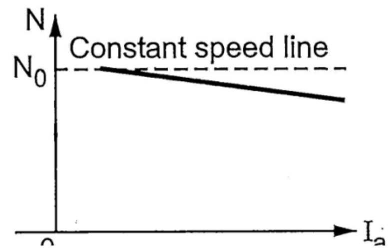
$$T_a \propto \phi I$$

- For DC Shunt motor, flux φ is constant.
- Armature torque is directly proportional to Armature current.
- Torque increases linearly with armature current.
- Torque spent to rotate armature is loss.
- The torque used to operate the load is called Shaft torque.



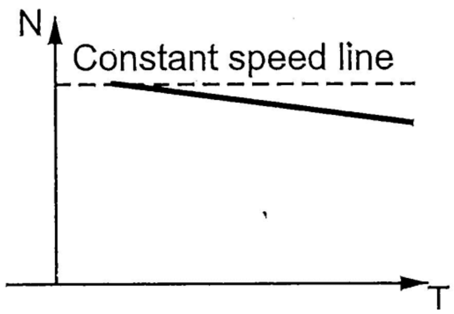
2. Speed Vs Armature Current Characteristics

- When load increases, armature current increases.
- When armature current increases, drop increases.
- When drop increases, speed reduces.



3. Speed Vs Torque Characteristics

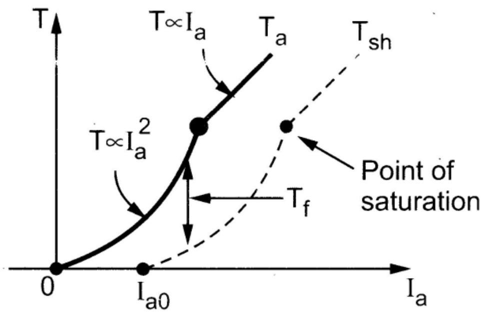
- This characteristic is similar to speed-armature current characteristics.
- When torque increases, speed reduces.
- The characteristic also varies with respect to armature current value, field resistance value and supply voltage.



<u>DC Series Motor</u>

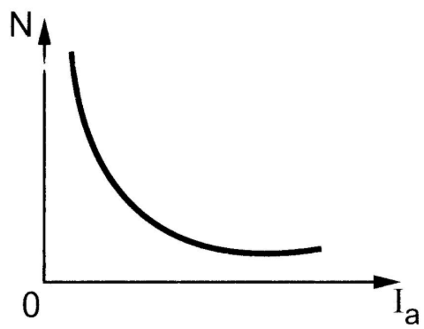
1. Torque Vs Armature Current

- Armature current and field current are same.
- At starting time, torque is proportional to square value of armature current and then torque is proportional to armature current.
- It can be used for high torque applications.



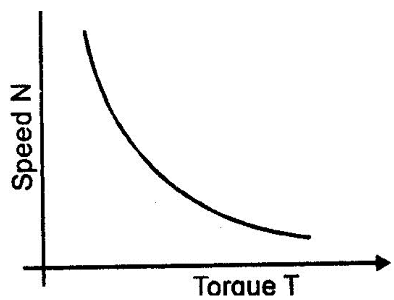
2. Speed Vs Armature Current Characteristics

- For series motor, speed is inversely proportional to flux.
- Flux is directly proportional to armature current.
- When armature current increases, speed reduces.



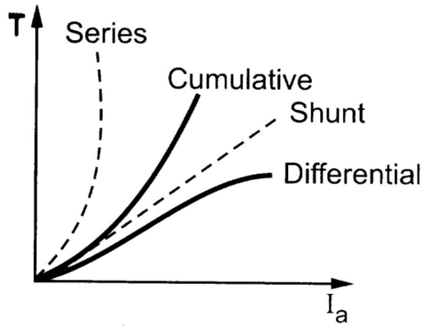
3. Speed Vs Torque Characteristics

- This characteristic is similar to speed-armature current characteristics.
- When torque increases, speed reduces.
- The characteristic also varies with respect to field current value and supply voltage.



DC Compound Motor

- The characteristic of this motor is depending on flux produced by shunt winding and series winding.
- For cumulative compound motor, the total flux is the sum of shunt field coil flux and series field flux.
- For differential compound motor, the total flux is the difference of shunt field coil flux and series field flux.
- Cumulative compound motor has capability of developing large amount of torque compared to differential compound motor



SPEED CONTROL OF DC MOTORS

Speed Control of Shunt Motor

* Flux Control

* Armature Voltage Control (Rheostatic Control)

* Applied Voltage Control

Speed Control of Series Motor

* Flux Control

* Rheostatic Control

* Applied Voltage Control

Ward- Leonard System of Speed Control

1. **Speed Control of Dc Shunt Motor:**

➢ **Flux Control**

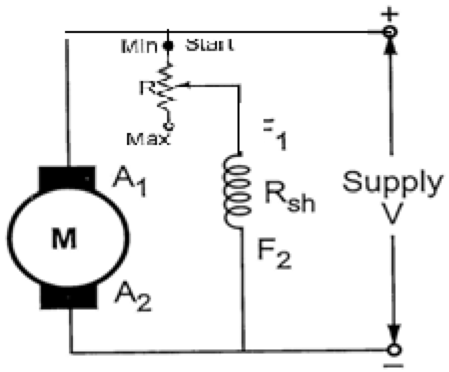
$$N \alpha \frac{E_b}{\varphi}; \qquad N \alpha \frac{V - I_a R_a}{\varphi}$$

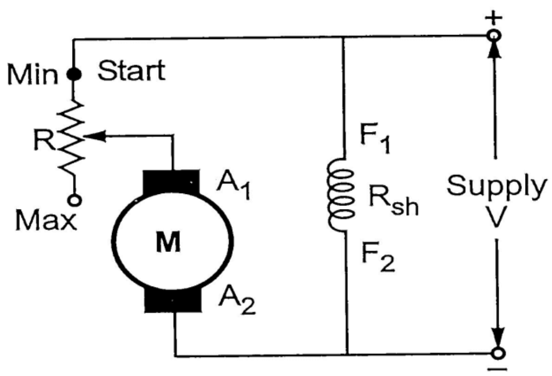
- Speed of the motor is inversely proportional to flux
- The speed can be controlled by varying flux
- To vary the flux, a rheostat is added in series with the field winding
- Adding more resistance in series with field winding will increase the speed, as it will decrease the flux
- Field current is relatively small and hence I^2R loss is small
- This method is quiet efficient

➢ **Armature Voltage Control**

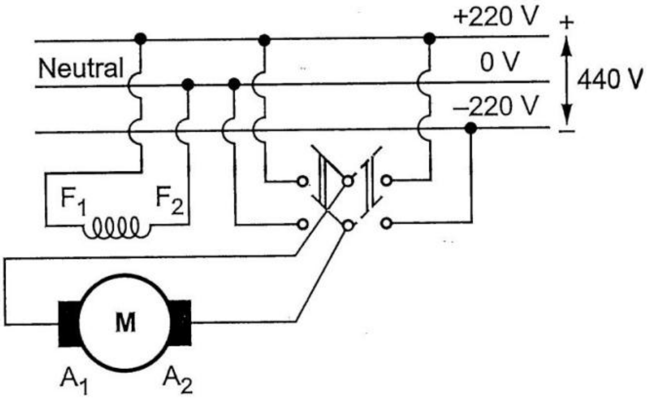
- Speed of the motor is directly proportional to the armature voltage
- When armature voltage varies, the armature current varies
- Speed is directly proportional to armature current I_a
- If we add resistance in series with armature, I_a decreases and hence speed decreases.
- The speed can be reduced by using this method.

- The speed can be reduced by using this method.



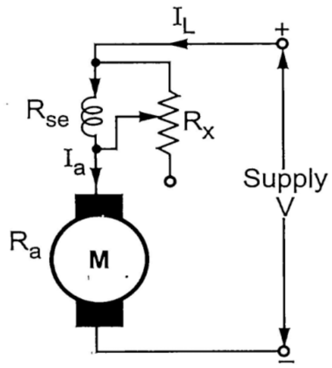


➢ **Applied Voltage Control:**
- The speed is approximately proportional to the voltage across the armature.
- Voltage across armature is changed with the help of a suitable switchgear
- Armature is supplied with different voltages to get varies speed
- The shunt filed is connected to a fixed exciting voltage

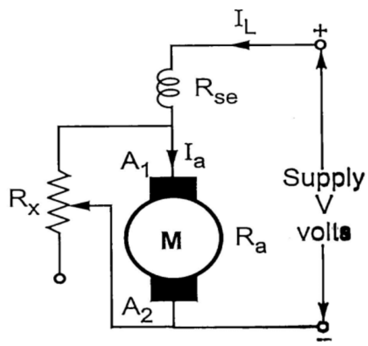


2. **Speed Control of Series Motor:**

➢ **Field Diverter Method:**
- A veritable resistance is connected parallel to the series field
- This variable resistor is called as diverter
- The desired amount of current can be diverted through this resistor and hence current through field coil can be decreased
- The flux can be decreased to desired amount and speed can be increased

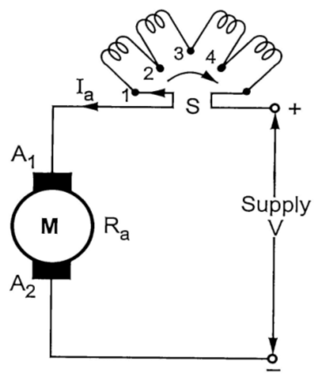


➢ **Armature Diverter Method:**
- The diverter is connected across the armature
- The desired amount of armature current can be diverted through this resistor and hence current through field coil and armature can be varied
- The flux is varied and speed can be increased



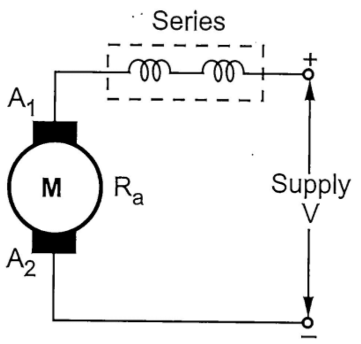
➢ **Tapped Field Method:**

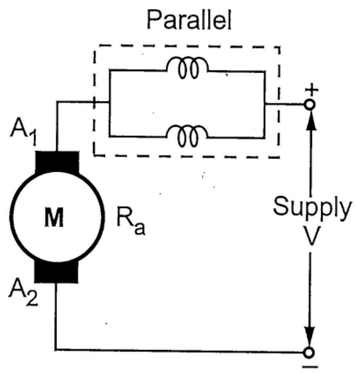
- The field coil is tapped
- The number of turns can be changed and hence the flux can be changed
- We can select different value of Ø by selecting different number of turns.
- The speed inversely proportional to flux Ø



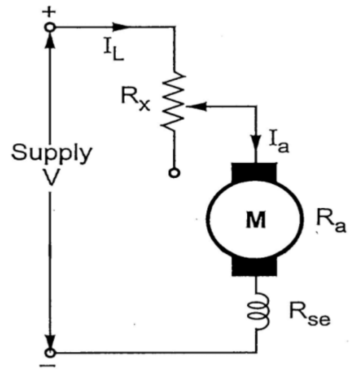
➢ **Series – Parallel Connection of Field:**
- This system is widely used in electric traction
- In this method, several speeds can be obtained by regrouping coils in parallel and series
- When the coils are in series, the same current passing through them and flux increases

- When the coils are in parallel, the current gets divided and flux reduces

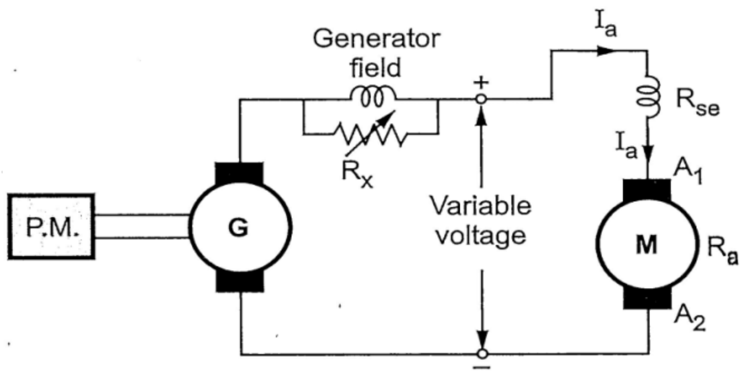




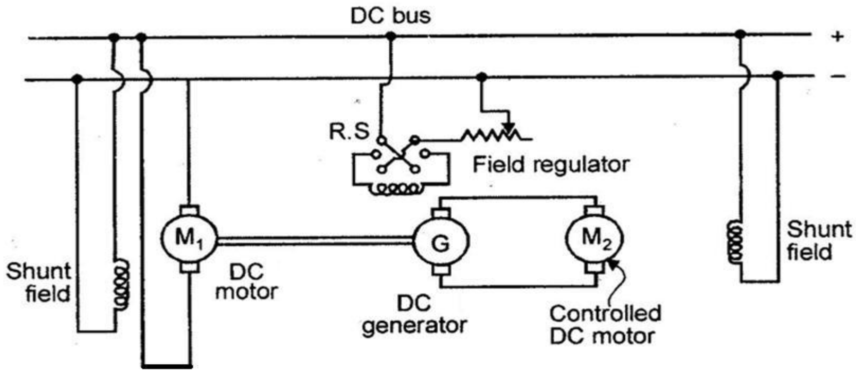
- **Rheostatic Control**
  - By introducing resistance in series with armature, voltage across the armature can be reduced.
  - And hence, speed reduces in proportion with it.

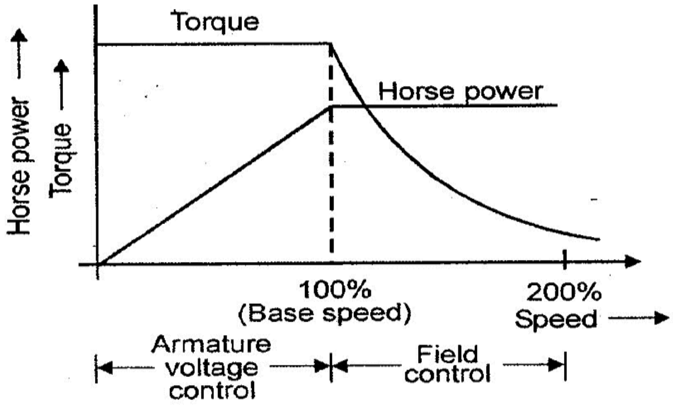


- **Applied Voltage Control**
- The speed is approximately proportional to the voltage across the armature and field winding
- Voltage across the armature and field is changed with the help of a Dc motor generator set
- Armature and field is supplied with different voltages to get varies speed
- The speed is approximately proportional to the voltage across the armature and field winding
- Voltage across the armature and field is changed with the help of a Dc motor generator set
- Armature and field is supplied with different voltages to get varies speed



Ward-Leonard control system





- This system is used where very sensitive speed control of motor is required (e.g electric excavators, elevators etc.)
- M_2 is the motor whose speed control is required
- M_1 may be any AC motor or DC motor with constant speed
- M_1 acts as prime mover to DC generator
- G is the generator directly coupled to M_1
- The output from the generator G is fed to the armature of the motor M_2 whose speed is to be controlled
- The output voltage of the generator G can be varied from zero to its maximum value, and hence the armature voltage of the motor M_2 is varied very smoothly

Very smooth speed control of motor can be obtained by this method.

AC MOTORS

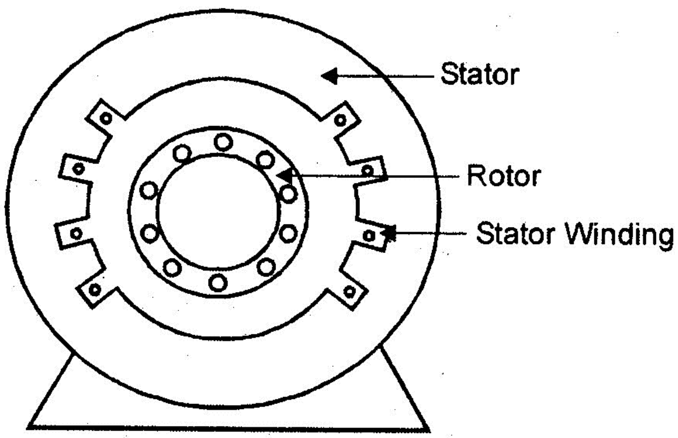
SINGLE PHASE INDUCTION MOTORS:

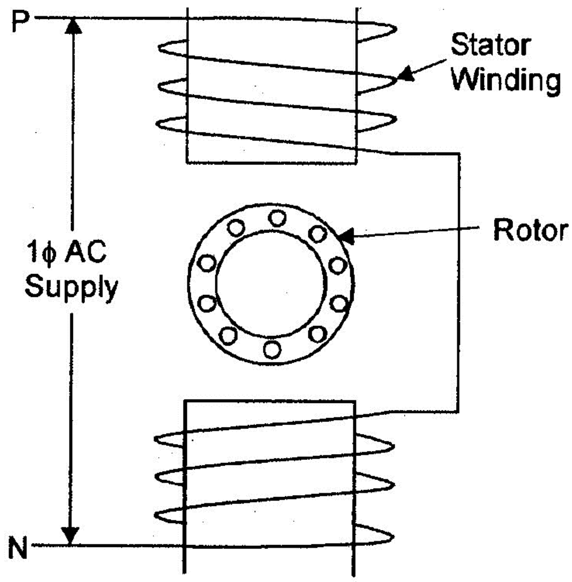
- Single phase motors are small motors.
- They have a power rating in fractional HP range.
- These motors are used in homes, offices, shops and factories.

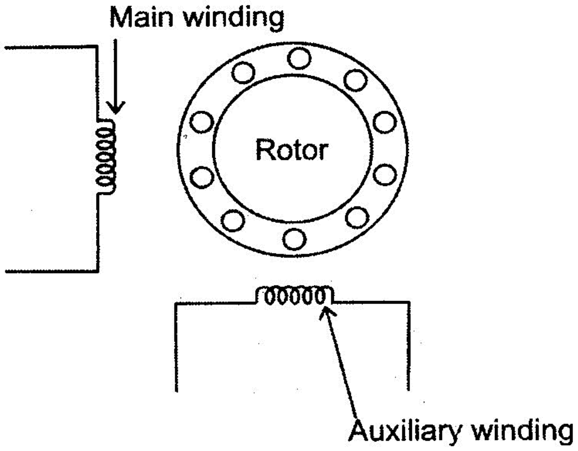
Disadvantages:

1. Lack of starting torque.
2. Reduced power factor.
3. Low efficiency.

CONSTRUCTION:







Stator Core

- It is made by laminated silicon plates.
- All silicon plates stamped together to form a solid core
  - Used to give mechanical support to stator windings.
  - Used to give magnetic flux path.
  - By using laminated and stamped core, the eddy current and hysteresis loss can be reduced.

Stator winding

- It is made by copper conductors.
  - For low speed motor – Wave winding.
  - For high speed motor – Lap winding.

Rotor core

- It is made by laminated silicon plates.
- All silicon plates stamped together to form a solid core
  - Used to give magnetic flux path.
  - By using laminated and stamped core, the eddy current and hysteresis loss can be reduced.

Rotor winding

- Copper bars placed in the slots and all ends are short circuited – called ***squirrel cage rotor.***

Yoke

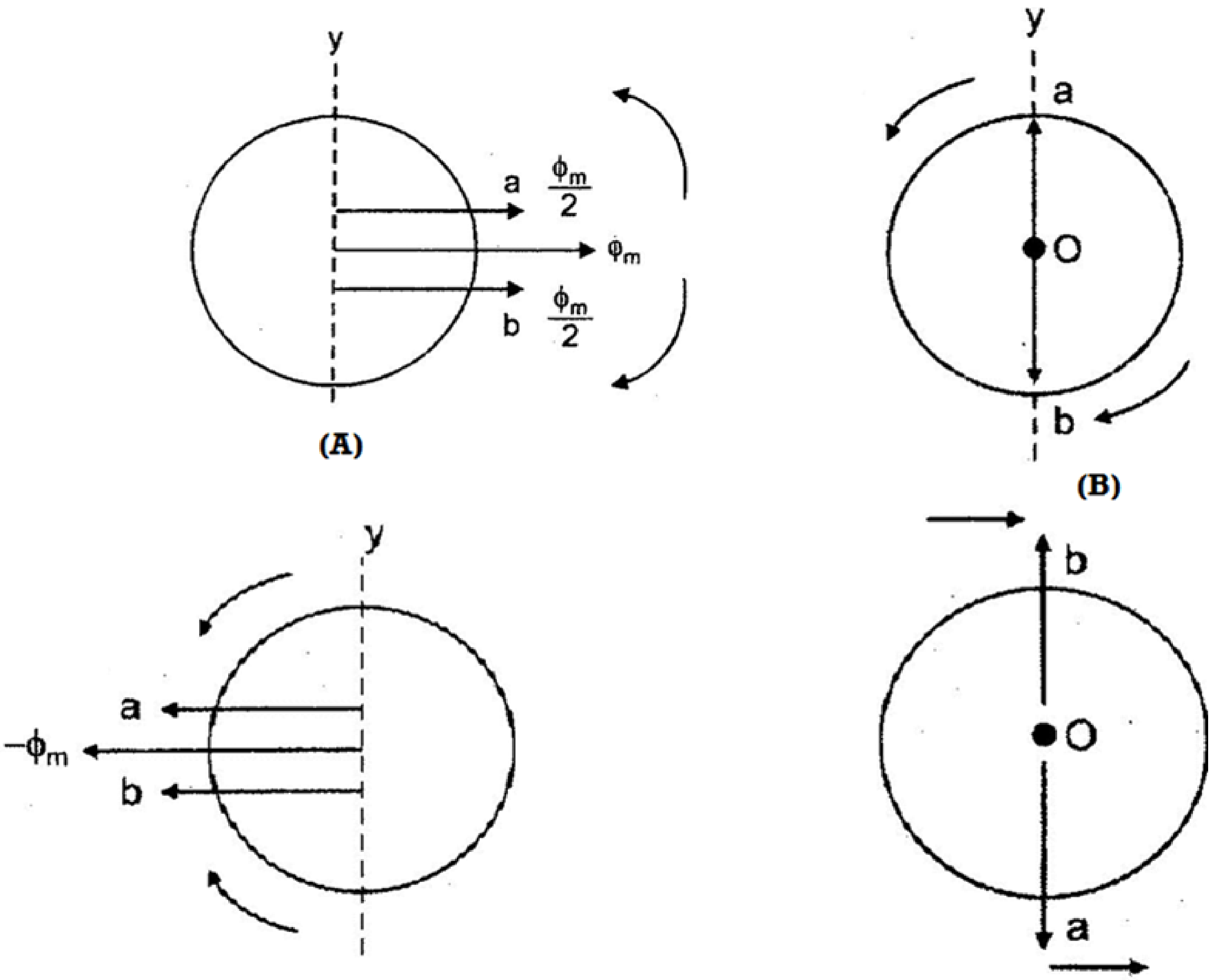
- It is made cast iron materials.
  - Used to give mechanical support to all internal parts.
  - Used to protect all internal parts from the external environment.

PRINCIPLE OF OPERATION:

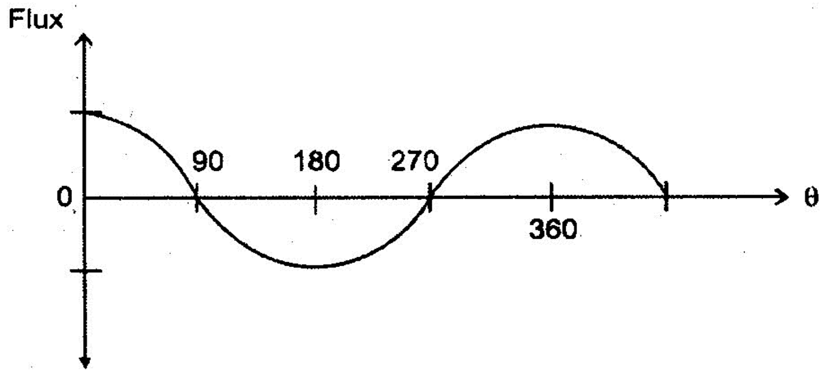
- The starting torque can be produced by using auxiliary winding.
- The angle between main winding and auxiliary winding should be 90 electrical degrees. The current passing through main winding and auxiliary winding should have some electrical angle to produce a rotating magnetic field.
- Rotating magnetic field produces high starting torque.
- The single-phase induction motor operation can be described by two methods:
  - Double revolving field theory; and
  - Cross-field theory.

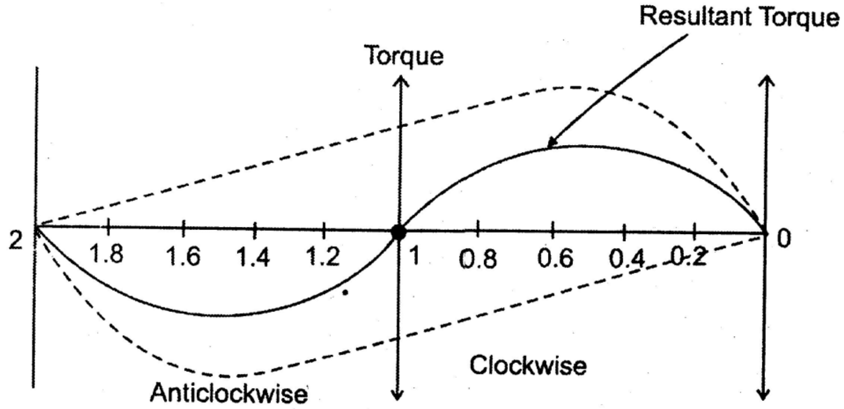
DOUBLE REVOLVING FIELD THEORY:

- A single-phase AC current supplies the main winding that produces a pulsating magnetic field.
- Mathematically, the pulsating field could be divided into two fields, which are rotating in opposite directions.
- The pulsating filed is divided a forward and reverse rotating field.
- The components „a‟ and „b‟ are forward and reverse rotating field respectively



(c) $\varphi_m, 0, -\phi_m, 0$ (D)



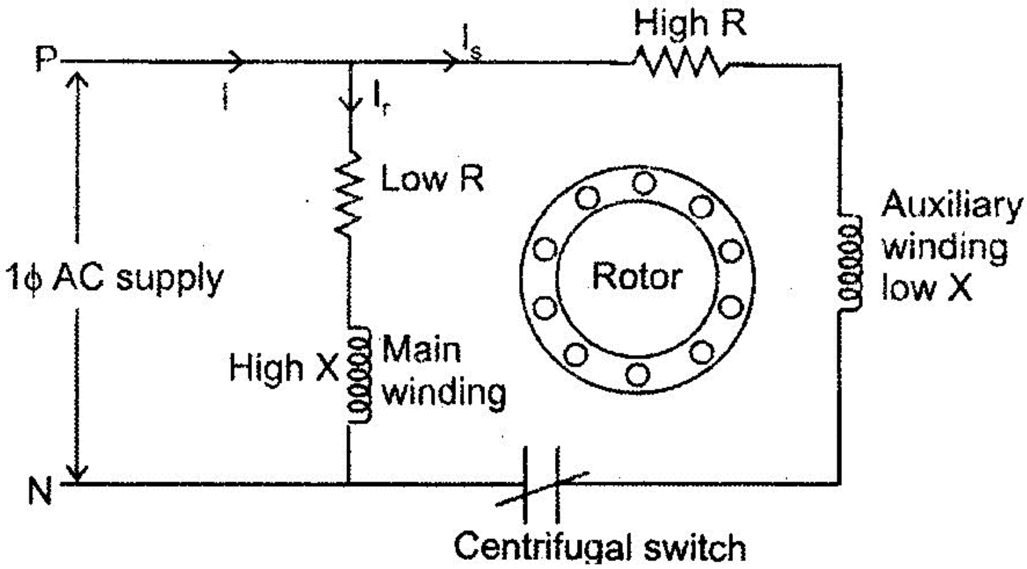


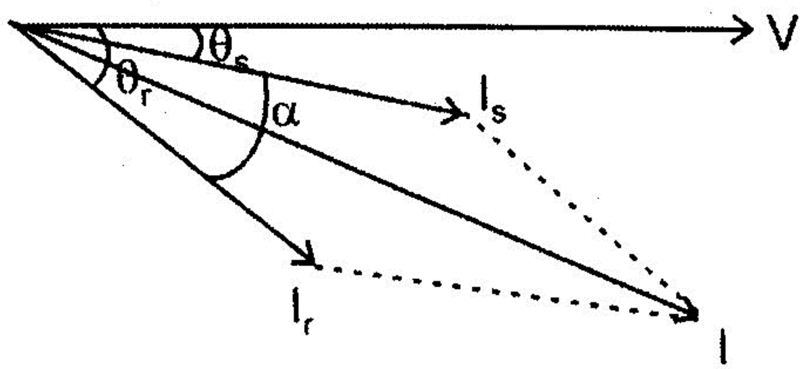
- At starting, the slip value of 1φ induction motor is „1‟.
- When slip is 1, the components „a‟ and „b‟ are producing equal and opposite torque.
- The resulting torque is zero.
- This motor has no starting torque.

TYPES OF SINGLE PHASE NDUCTION MOTORS (STARTING METHODS)

- Resistance – Start (Split phase) motor.
- Capacitor – Start induction motor.
- Capacitor – Run induction motor.
- Capacitor – Start and Capacitor – Run IM.
- Shaded – pole motor.

Resistance – Start (Split phase) motor:

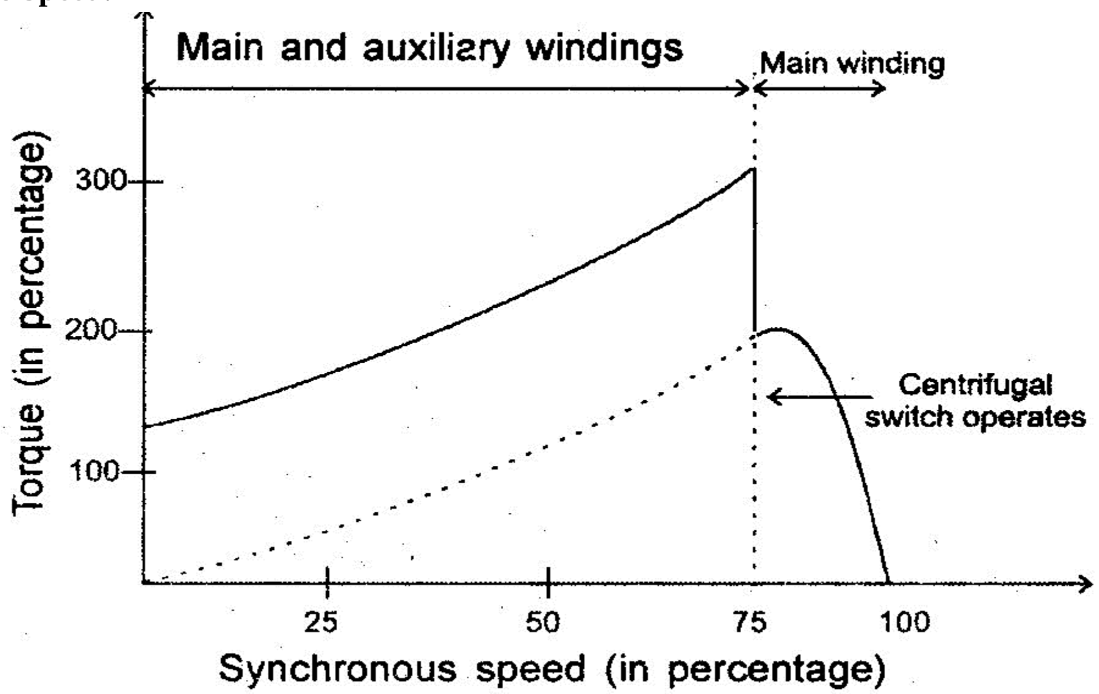




- It has two windings:
  - Main winding or Running winding
  - Auxiliary winding.
- These two winding axes are displaced by 90 electrical degrees.
- The main winding has high X (reactance) value and low R (resistance) value.
- The auxiliary winding has Low X value and High R value.
- This variation in the reactance makes two different phases.

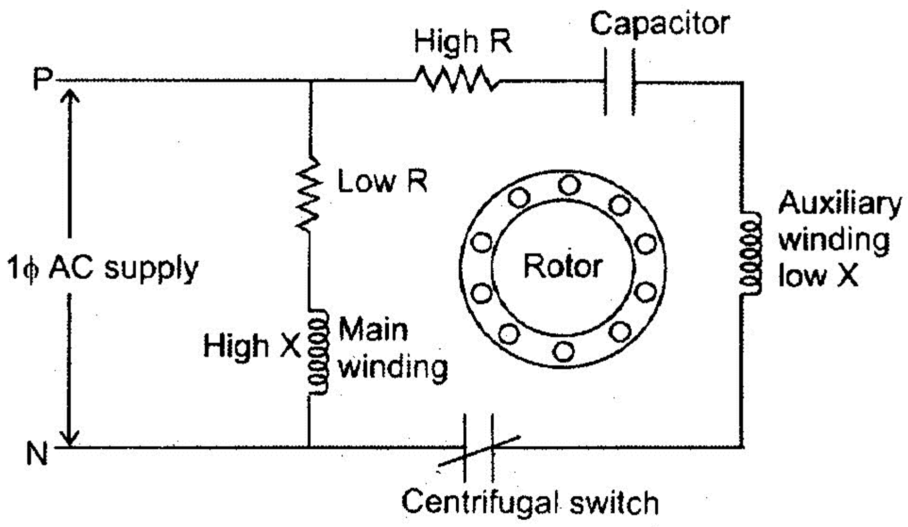
- Two phase supply constructs rotating magnetic field.
- The rotating magnetic field produces high torque at the starting time.
- The centrifugal switch disconnects the auxiliary winding from the circuit after the motor reaches synchronous speed.

Torque Vs Speed:



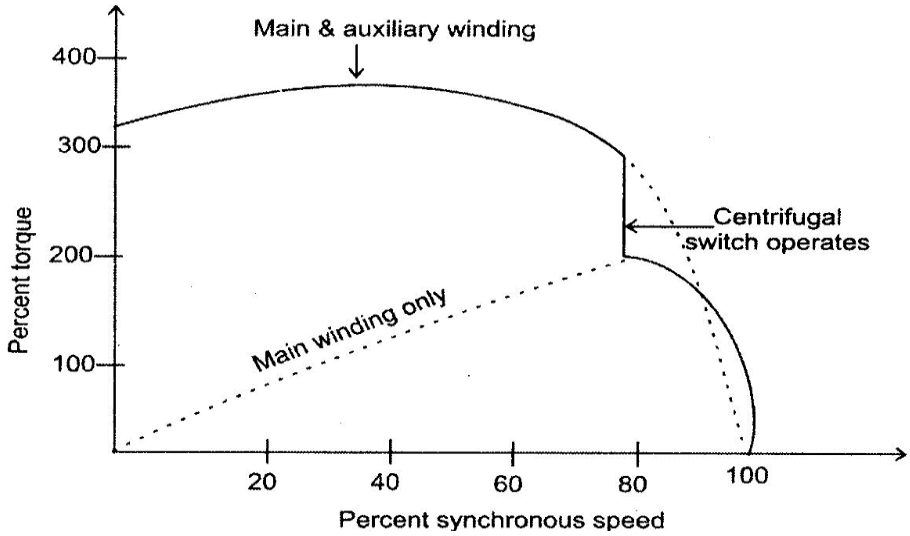
- **Applications:**
    - Fans, Blowers, Centrifugal pumps, washing machines

Capacitor – Start induction motor:



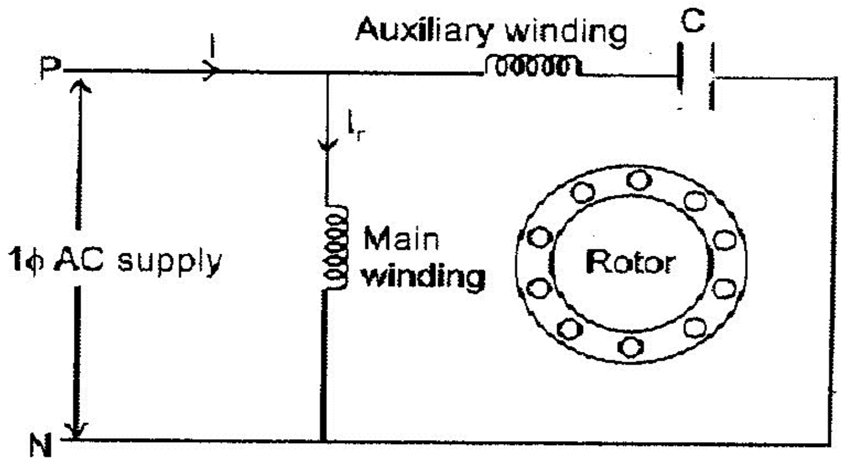
- A capacitor is connected in series with auxiliary winding to produce leading current in auxiliary winding.
- The high reactance (X) value of main winding produces lagging current.
- Voltage across two windings produces two different phases.
- Two phase supply constructs rotating magnetic field.
- The rotating magnetic field produces high torque at the starting time.
- The centrifugal switch disconnects the auxiliary winding and capacitor from the circuit after the motor reaches 75% of synchronous speed.

Speed Vs Torque:



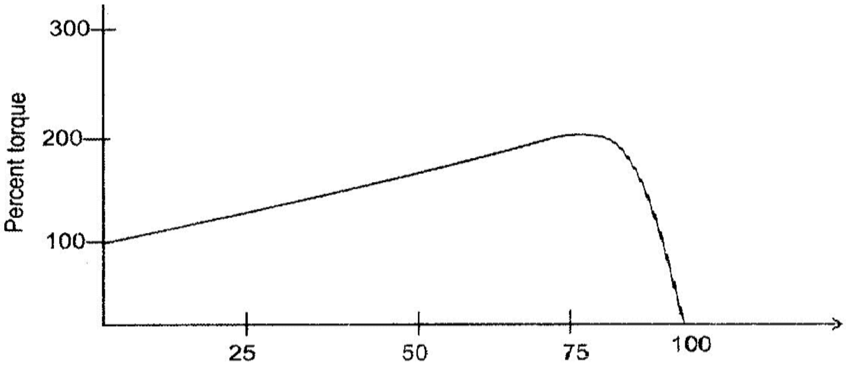
- **Applications:**
    - Compressors, Pumps, Conveyors, Refrigerators, Air conditioning
    - Equipments, Washing machines

Capacitor – Run induction motor:



- A capacitor is connected in series with auxiliary winding to produce leading current in auxiliary winding.
- The high reactance (X) value of main winding produces lagging current.
- Voltage across two windings produces two different phases.
- Two phase supply constructs rotating magnetic field.
- The rotating magnetic field produces high torque at the starting time.
- It does not use centrifugal switch.
- The capacitor is always connected with auxiliary winding so that the starting and running torque is high.

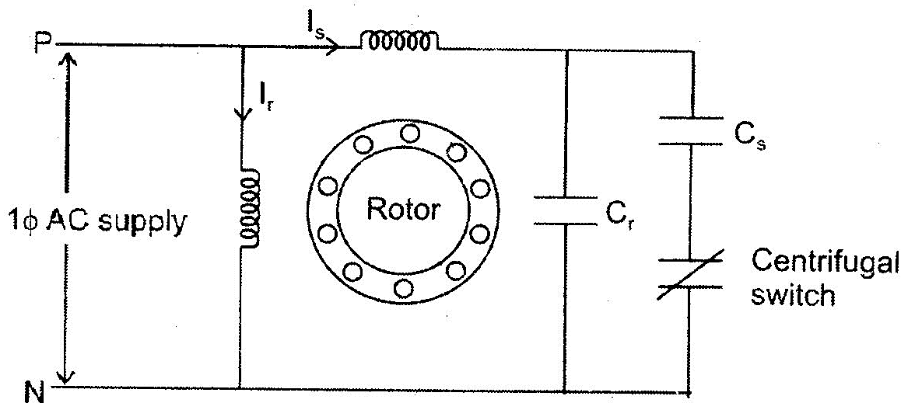
Speed Vs Torque:



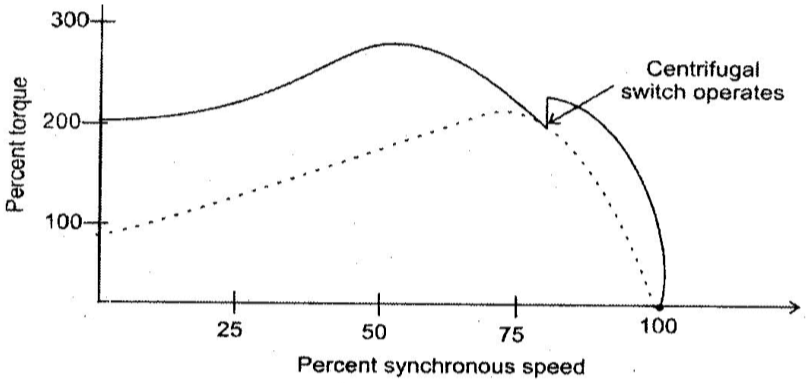
Applications:

- Fans, Blowers, Centrifugal pumps

Capacitor – Start and Capacitor – Run IM:



- It uses two capacitors, Running capacitor (Cr) and starting capacitor (Cs).
- Running capacitor always connected in series with auxiliary winding.
- Starting capacitor is disconnected from the circuit after the motor reaches 75% of synchronous speed by the help of Centrifugal switch.
- Starting torque and efficiency can be improved.
- **Speed Vs Torque:**



- **Applications:**
    - Compressors
    - Pumps
    - Conveyors
    - Refrigerators

STEPPER MOTOR

TYPES OF STEPPER MOTORS

(a) Variable reluctance (VR) stepper motor
(b) Permanent magnet (PM) stepper motor
(c) Hybrid Stepper motor

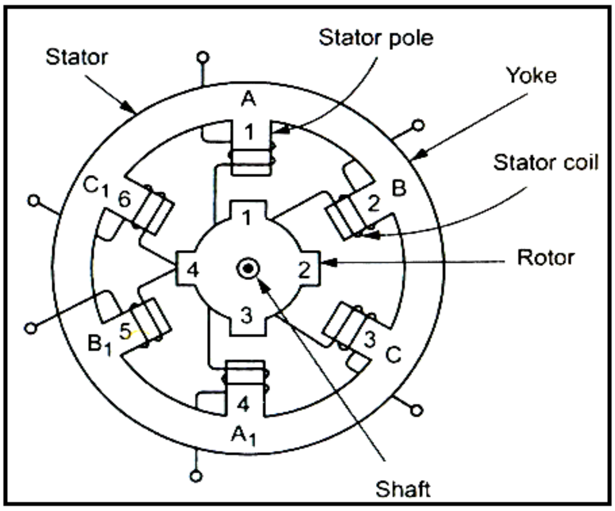
VARIABLE-RELUCTANCE STEPPING MOTOR

Types

1. Single-Stack variable reluctance stepper motor
2. Multi Stack variable reluctance stepper motor

Single-Stack variable reluctance stepper motor

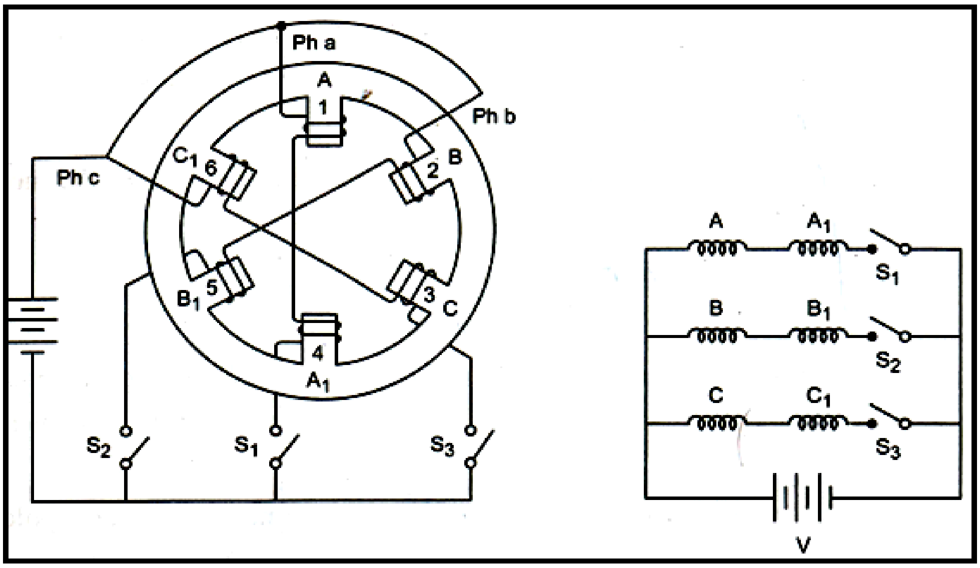
- It has no permanent magnet either on the rotor or the stator.
- It has salient pole (or tooth) stator and rotor.
- The stator has concentrated windings
- The rotor has no windings.
- The rotor is a slotted structure, made from ferromagnetic material.



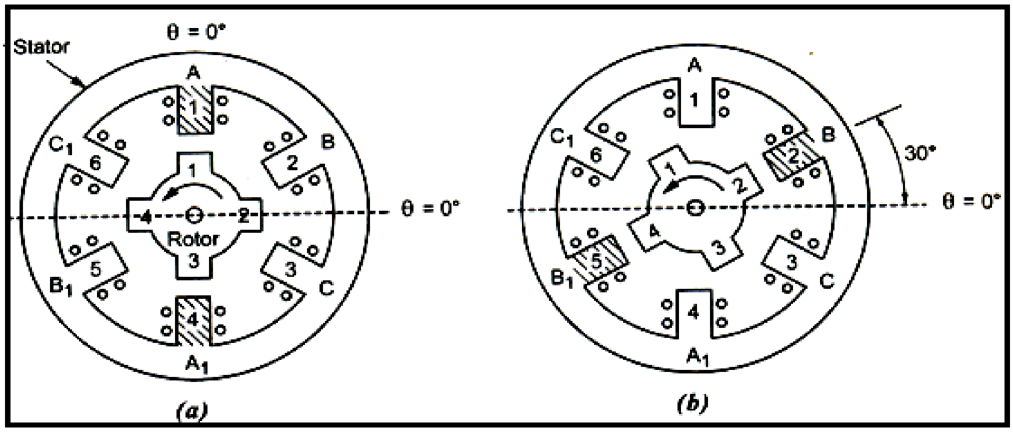
- S_{slots} (N_s) ≠ R_{slots} (N_r)
  (i) The self starting capability
  (ii) The ability of bidirectional rotation
- $N_r = N_s \pm (N_s /q)$
  q=Number of phases
- Current flow through the winding can be controlled by semiconductor switches.

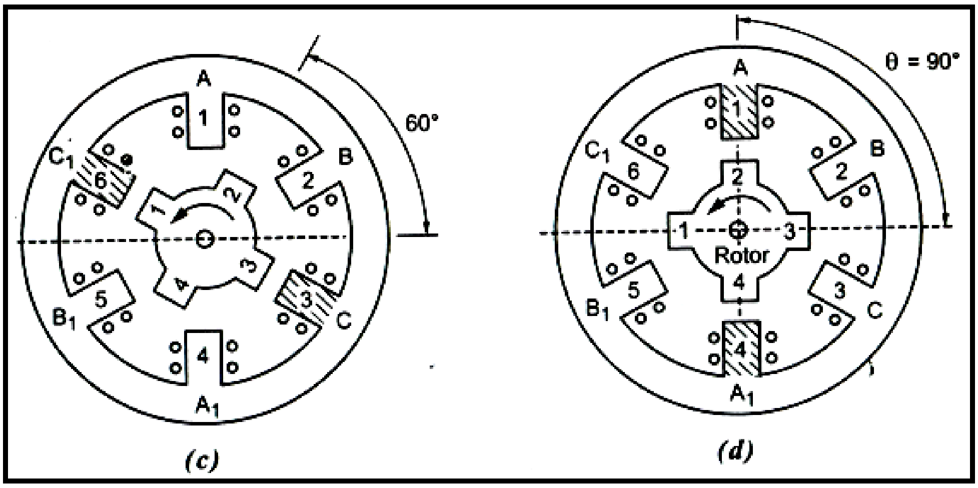
<u>Principle of operation</u>

- The operation is based on variable reluctance principle.
- The rotor is completely free to rotate.
- When anyone phase of the stator is excited, it produces its magnetic field whose axis lies along the poles, then the rotor moves.



Mode I : One-phase-on or full step operation





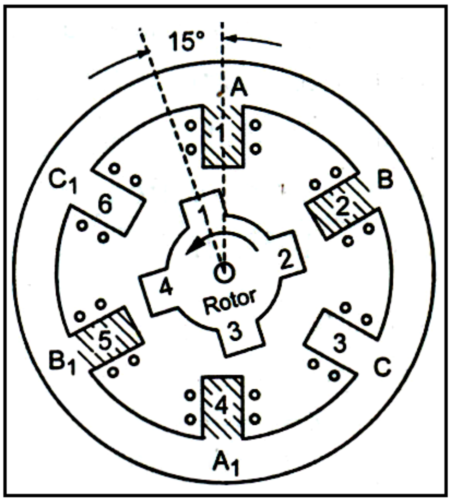
Clockwise Rotation (CW)

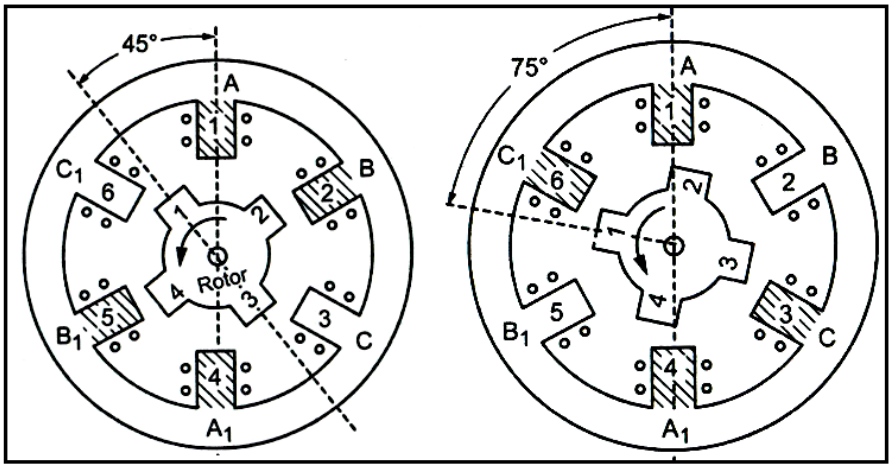
S_1	S_2	S_3	θ
✓	–	–	0°
–	–	✓	30°
–	✓	–	60°
✓	–	–	90°
–	–	✓	120°
–	✓	–	150°
✓	–	–	180°
–	–	✓	210°
–	✓	–	240°
✓	–	–	270°
–	–	✓	300°
–	✓	–	330°
✓	–	–	360°

Counter Clockwise Rotation (CCW)

S_1	S_2	S_3	θ
✓	–	–	0°
–	✓	–	30°
–	–	✓	60°
✓	–	–	90°
–	✓	–	120°
–	–	✓	150°
✓	–	–	180°
–	✓	–	210°
–	–	✓	240°
✓	–	–	270°
–	✓	–	300°
–	–	✓	330°
✓	–	–	360°

Mode 11: 2-Phase-on mode

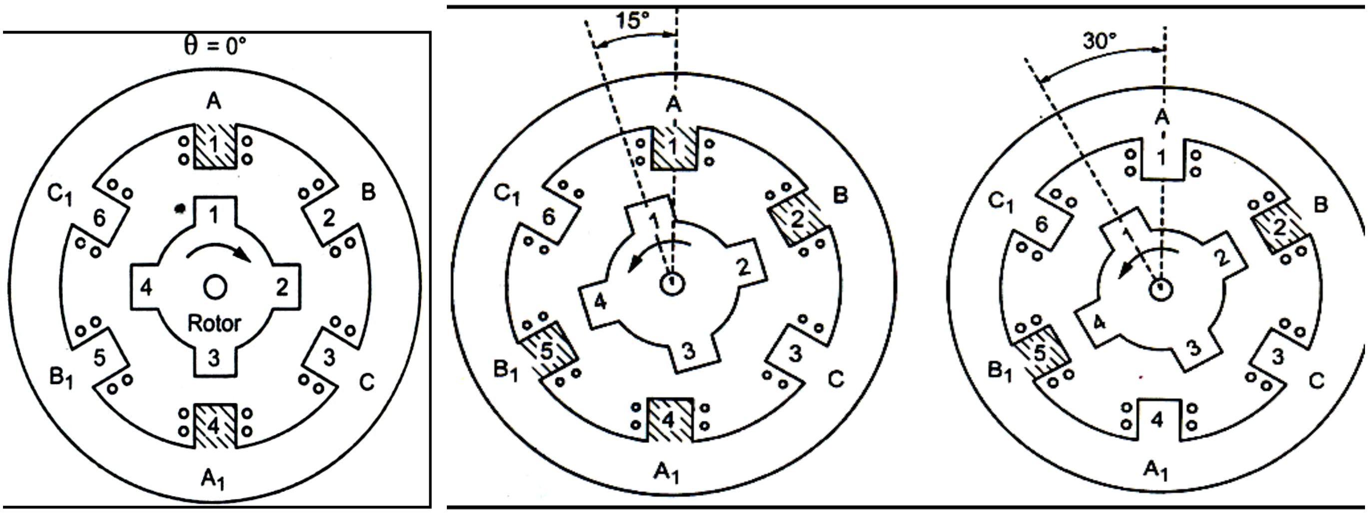




Truth Table of VR Stepper Motor in Two Phase on Mode for counter clockwise direction				
S_1	S_2	S_3	θ	
✓	✓	–	15°	AB
–	✓	✓	45°	BC
✓	–	✓	75°	CA
✓	✓	–	105°	AB
–	✓	✓	135°	BC
✓	–	✓	165°	CA
✓	✓	–	195°	AB
–	✓	✓	225°	BC
✓	–	✓	255°	CA
✓	✓	–	285°	AB

Truth Table of VR Stepper Motor in Two Phase on Mode for clockwise direction				
	S_1	S_2	S_3	θ
AC	✓	–	✓	15°
CB	–	✓	✓	45°
BA	✓	✓	–	75°
AC	✓	–	✓	105°
CB	–	✓	✓	135°
BA	✓	✓	–	165°
AC	✓	–	✓	195°
CB	–	✓	✓	225°
BA	✓	✓	–	255°
AC	✓	–	✓	285°

Mode - III - Half-step operation

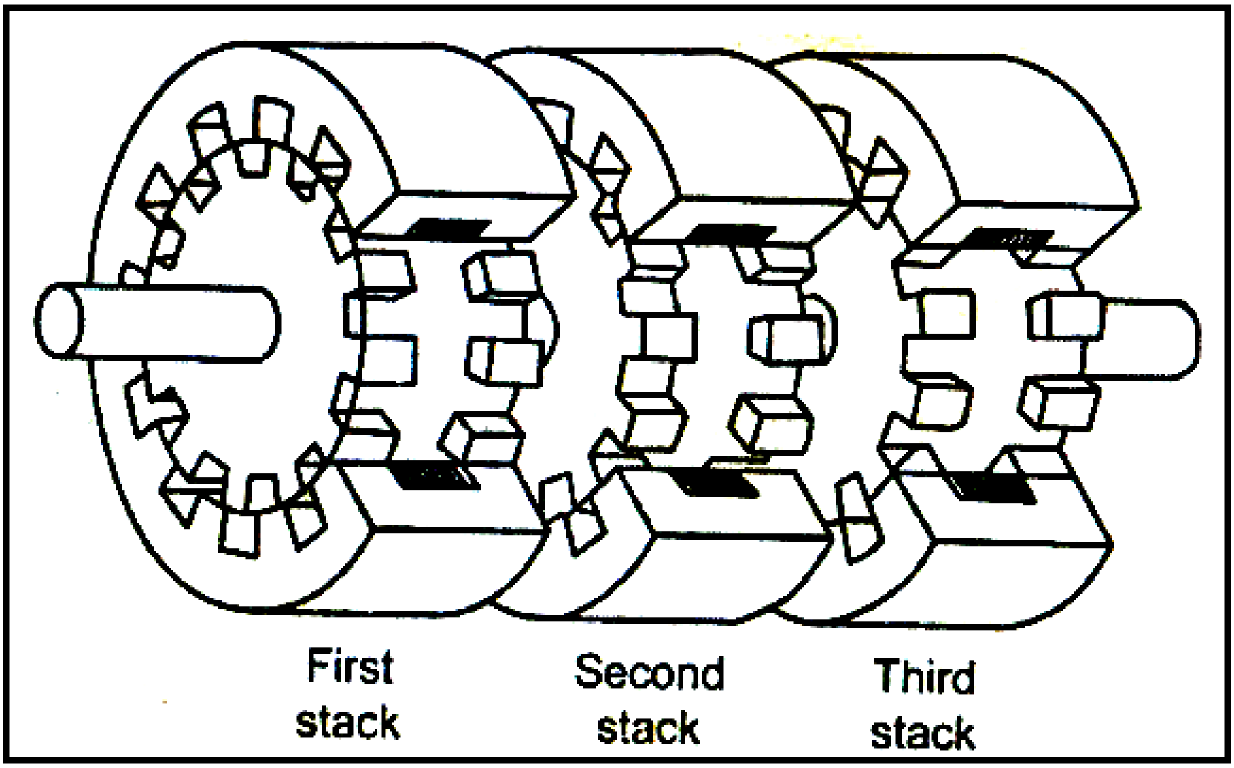


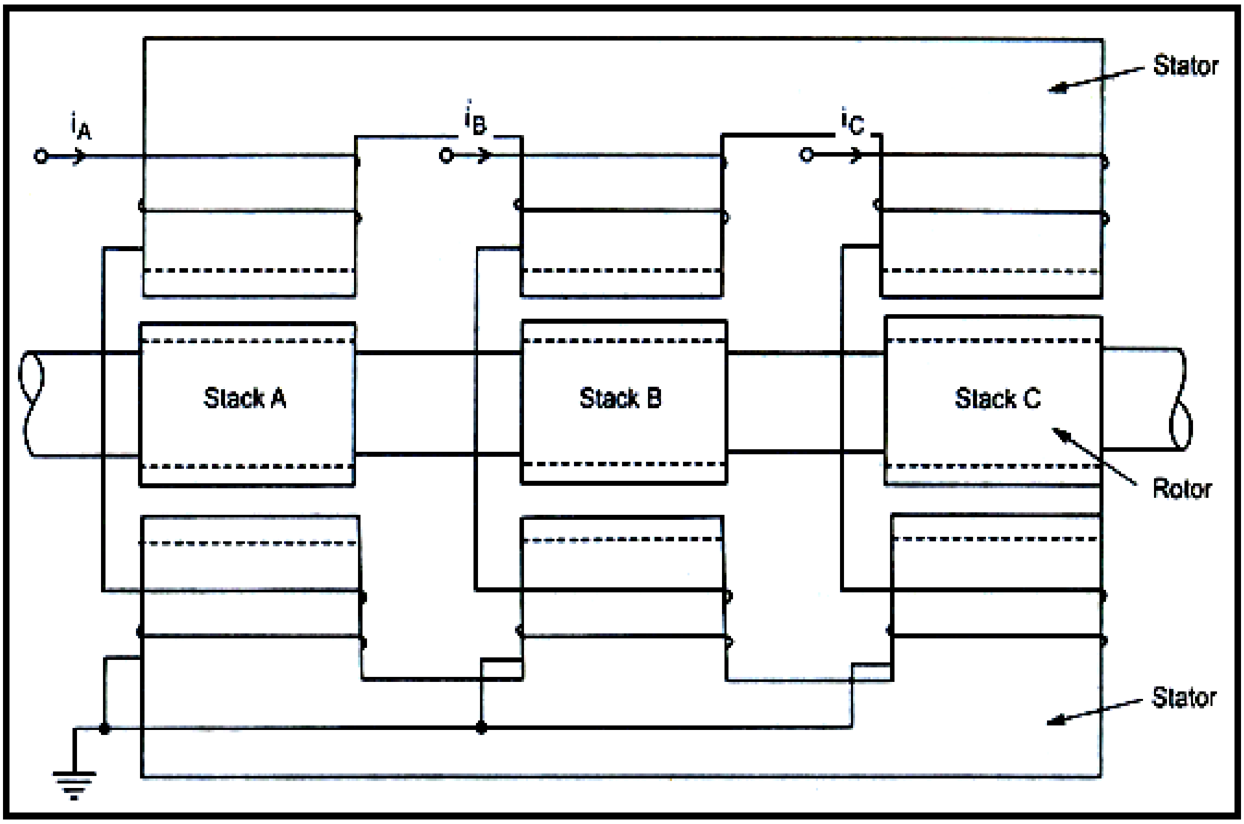
Truth Table of VR Stepper Motor Half Stepping Mode Operation Counter Clockwise Direction				
S_1	S_2	S_3	θ	
✓	–	–	0°	A
✓	✓	–	15°	AB
–	✓	–	30°	B
–	✓	✓	45°	BC
–	–	✓	60°	C
✓	–	✓	75°	CA
✓	–	–	90°	A
✓	✓	–	105°	AB
–	✓	–	120°	B
–	✓	✓	135°	BC
–	–	✓	150°	C
✓	–	✓	165°	CA

Truth Table of VR Stepper Motor Half Stepping Mode Operation Clockwise Direction				
	S_1	S_2	S_3	θ
A	✓	–	–	0°
AC	✓	–	✓	15°
C	–	–	✓	30°
CB	–	✓	✓	45°
B	–	✓	–	60°
BA	✓	✓	–	75°
A	✓	–	–	90°
AC	✓	–	✓	105°
C	–	–	✓	120°
CB	–	✓	✓	135°
B	–	✓	–	150°
BA	✓	✓	–	165°

Mode - IV - Micro Stepping

- Step angle of the VR stepper motor will be very small - *Mini-stepping*
- 2 phase-on mode - but with the two currents deliberately made *unequal*

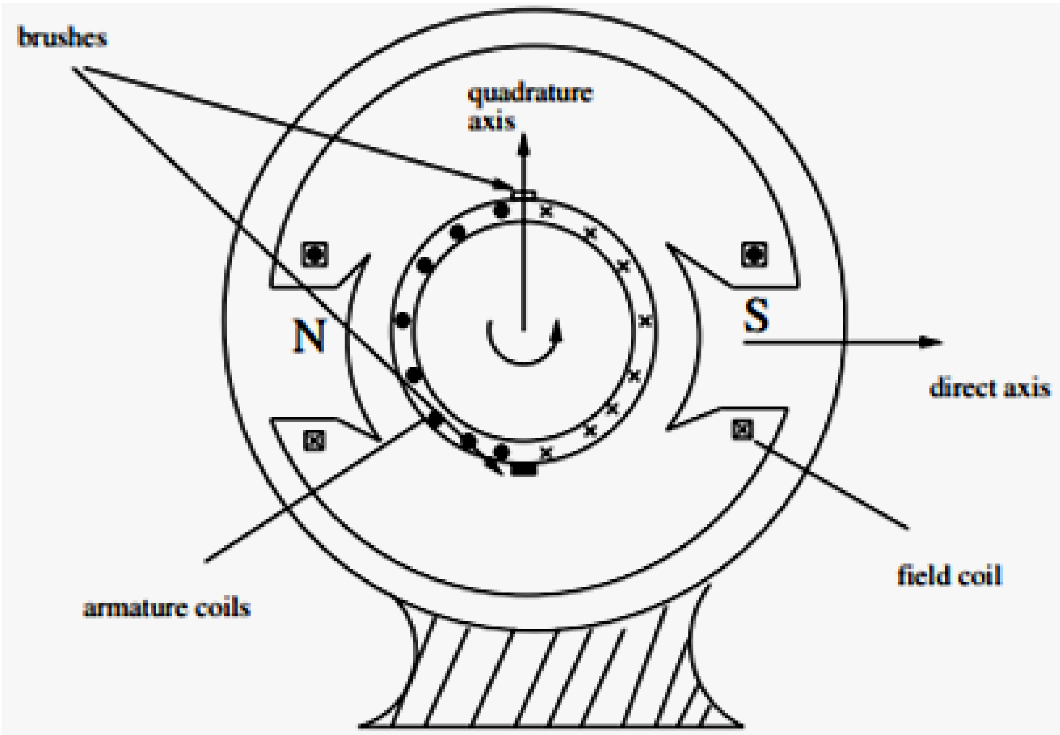




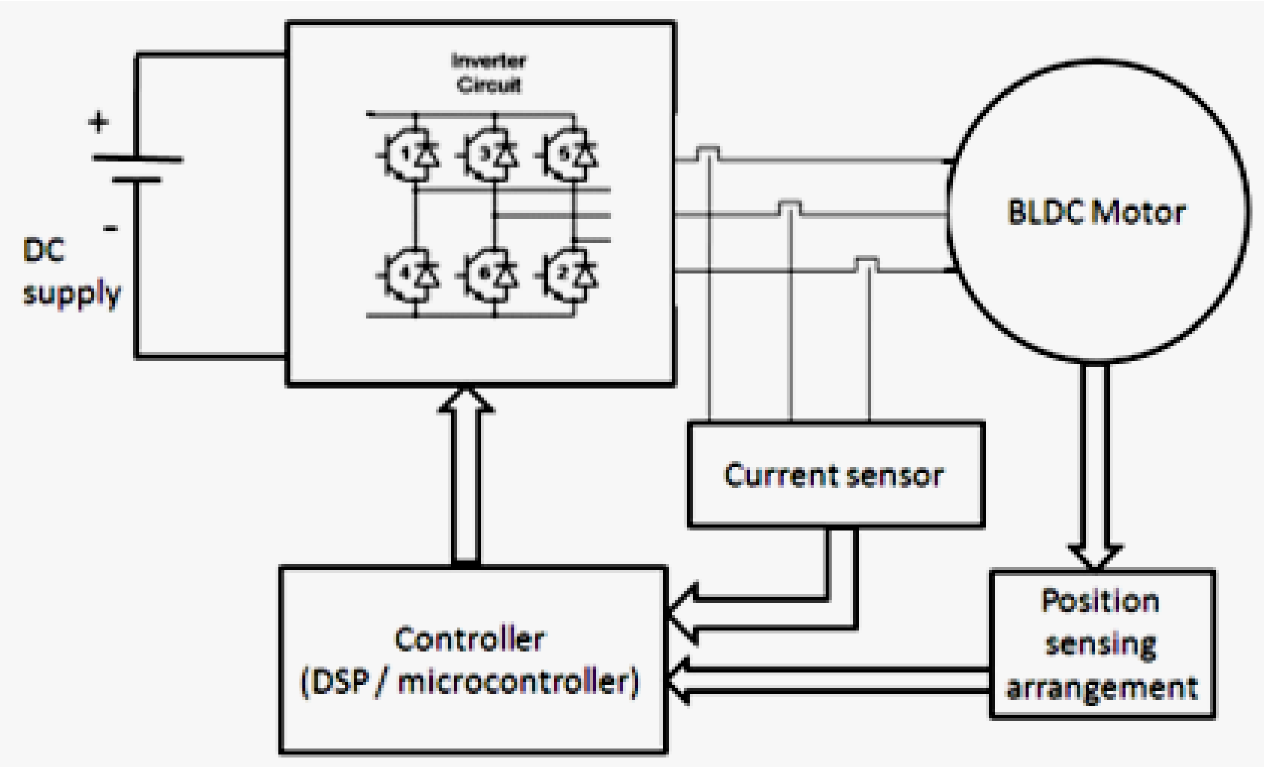
Brushless DC Motor

* In DC motors section, we have seen that brushes are required to convert alternating current generated in DC generators to direct current (and vice versa for DC motors).
* Now, if permanent magnets are placed on rotor, the armature winding will be stationary and hence brushes can be removed.
* This has two advantages –
    1. Resistive losses in brushes are completely eliminated
    2. Maintenance and safety issues are also taken care of.
* Thus, the DC motor with permanent magnets without brushes is called brushless DC motor or simply BLDC motor.

Operating principle



* The operating principle of BLDC motor is same as that of the DC motor.
* Conductors facing a particular magnet pole (say N pole) carry current in one direction while those facing the other pole carry current in opposite direction.
* By virtue of this, the fields created by magnet and armature conductors are always orthogonal to each other as shown in the Fig.
* Note the naming convention “direct axis” and “quadrature axis”.
* Suppose a two pole rotor is rotating under an armature. When N pole passes completely across a conductor, some mechanism is necessary to change the direction of current in that conductor.
* Otherwise direction of force on the conductor will be reversed.
* In a conventional DC motor, the number of commutator segments equals the number of conductors in the armature.
* When a commutator segment switches from one brush to the other, there is a change in supply direction (in case of motor).
* In BLDC machine, this reversal of direction of current is done via power electronic switches.
* Now, the instant of reversing the direction is a function of position of rotor.
* Hence, sensing of position is required which is “fedback” to the power electronics drive which “drives and controls” the supply given to the motor.
* Hence complete block diagram of a BLDC drive is as shown in Fig.
* It consists of 3 parts
    * BLDC machine
    * Power electronics (DC-AC converter)
    * Position sensing and drive control system



Advantages

- Increased Reliability & Efficiency
- Longer Life
- Elimination of Sparks from Commutator
- Reduced Friction
- Faster Rate of Voltage & Current

Disadvantages

- Requires Complex Drive Circuitry
- Requires additional Sensors
- Higher Cost
- Some designs require manual labor (Hand wound Stator Coils)

Applications

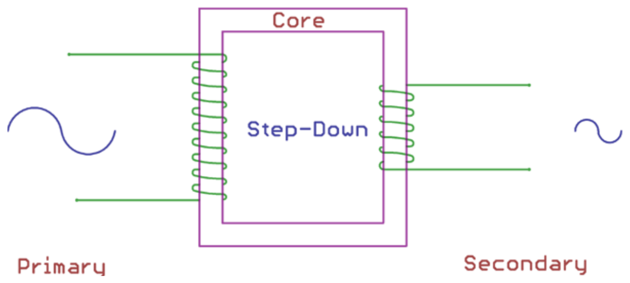
- Consumer: Hard Drives, CD/DVD Drives, PC Cooling Fans, toys, RC airplanes, air conditioners
- Medical: Artificial heart, Microscopes, centrifuges, Arthroscopic surgical tools, Dental surgical tools and Organ transport pump system.
- Vehicles: electronic power steering ,personal electric vehicles
- Airplanes: an electric self launching sailplane, flies with a 42kW DC/DC brushless motor and Li-Ion batteries and can climb up to 3000m with fully charged cells

TRANSFORMER----------------REFERE BOOK--------------

1. Step-Down Transformer

∗ The overall winding ratio of primary and secondary always remains greater than 1.

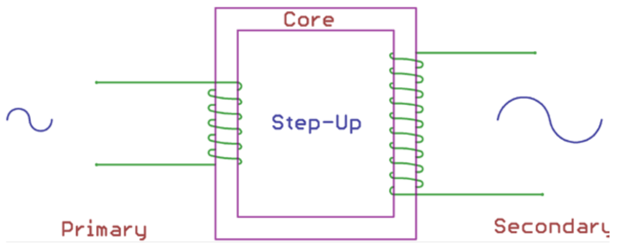
∗ Secondary voltage < Primary voltage



2. Step-Up Transformer

∗ The overall winding ratio of primary and secondary always remains less than 1.

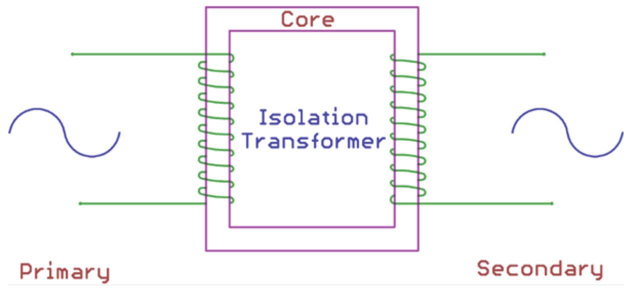
∗ Secondary voltage > Primary voltage



3. Isolation Transformer

∗ The overall winding ratio of primary and secondary always remains equal to 1.

∗ Secondary voltage = Primary voltage



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