Module 3 : D.C.Machines

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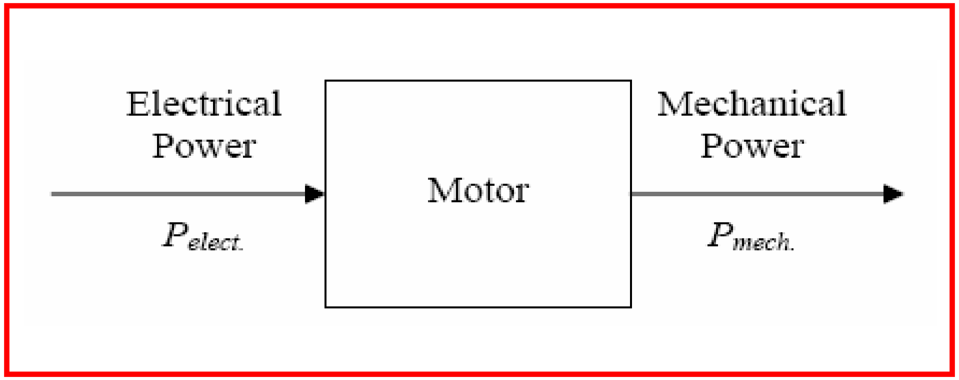
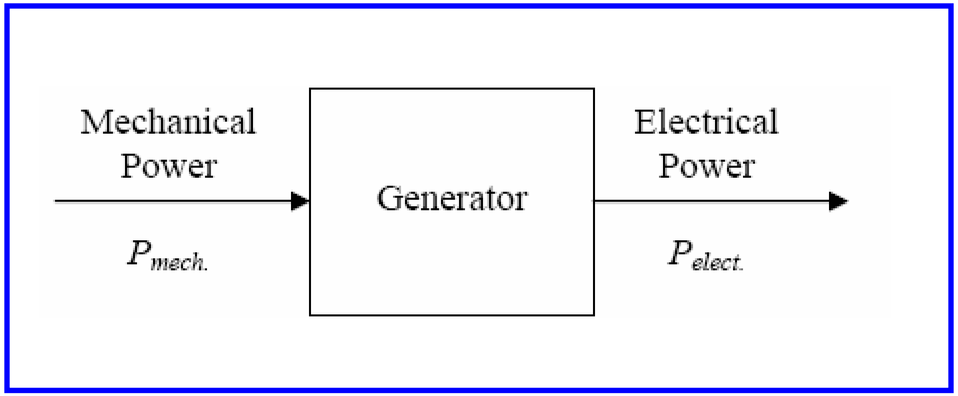
Contents-

- Construction, Working Principle and types of DC generator and motor
- Voltage and speed control methods
- Speed-Torque characteristics
- Principle,construction,working and application of stepper, servo and universal motors

Introduction: What are DC Machines?

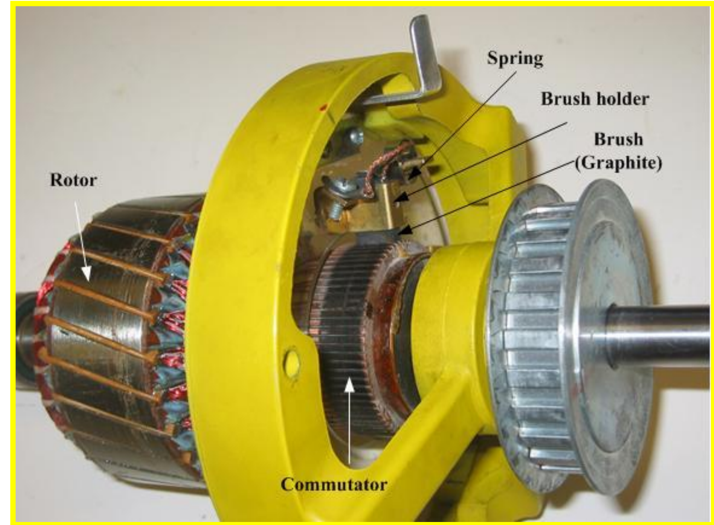
- DC generators that convert mechanical energy to DC electric energy.
- DC motors that convert DC electric energy to mechanical energy.





Introduction

- DC machine can be used as a **motor** or as a **generator**.
- DC Machine is most often used for a motor.



Cutaway view of a dc motor

- DC motors are found in many special industrial environments Motors drive many types of loads from fans and pumps to presses and conveyors
- The major advantages of dc machines over generators are easy to control speed and torque regulation.
- However, their application is limited to mills, mines and trains. As examples, trolleys and underground subway cars may use dc motors.
- In the past, automobiles were equipped with dc dynamos to charge their batteries.

Types of DC Motors

- DC motors are classified according to electrical connections of armature windings and field windings.

  Armature windings: a winding which a voltage is induced

  Field windings: a winding that produces the main flux in machines

- Five major types of DC motors:-
  - Separately excited DC motor
  - Shunt DC motor
  - Permanent Magnet DC motor
  - Series DC motor
  - Compounded DC motor

Working principle of D. C. Generator

- A generator works on the principle of Faraday's law of electromagnetic induction.

- Whenever a conductor is moved in the magnetic field , an emf is induced and the magnitude of the induced emf is directly proportional to the rate of change of flux linkage.

- This emf causes a current flow if the conductor circuit is closed .

Lenz's Law

The direction of induced emf is given by Lenz's law .

According to this law, the induced emf will be acting in such a way so as to oppose the very cause of production of it .

$$e = -N\ (d\text{Ø}/dt)\ \text{volts}$$

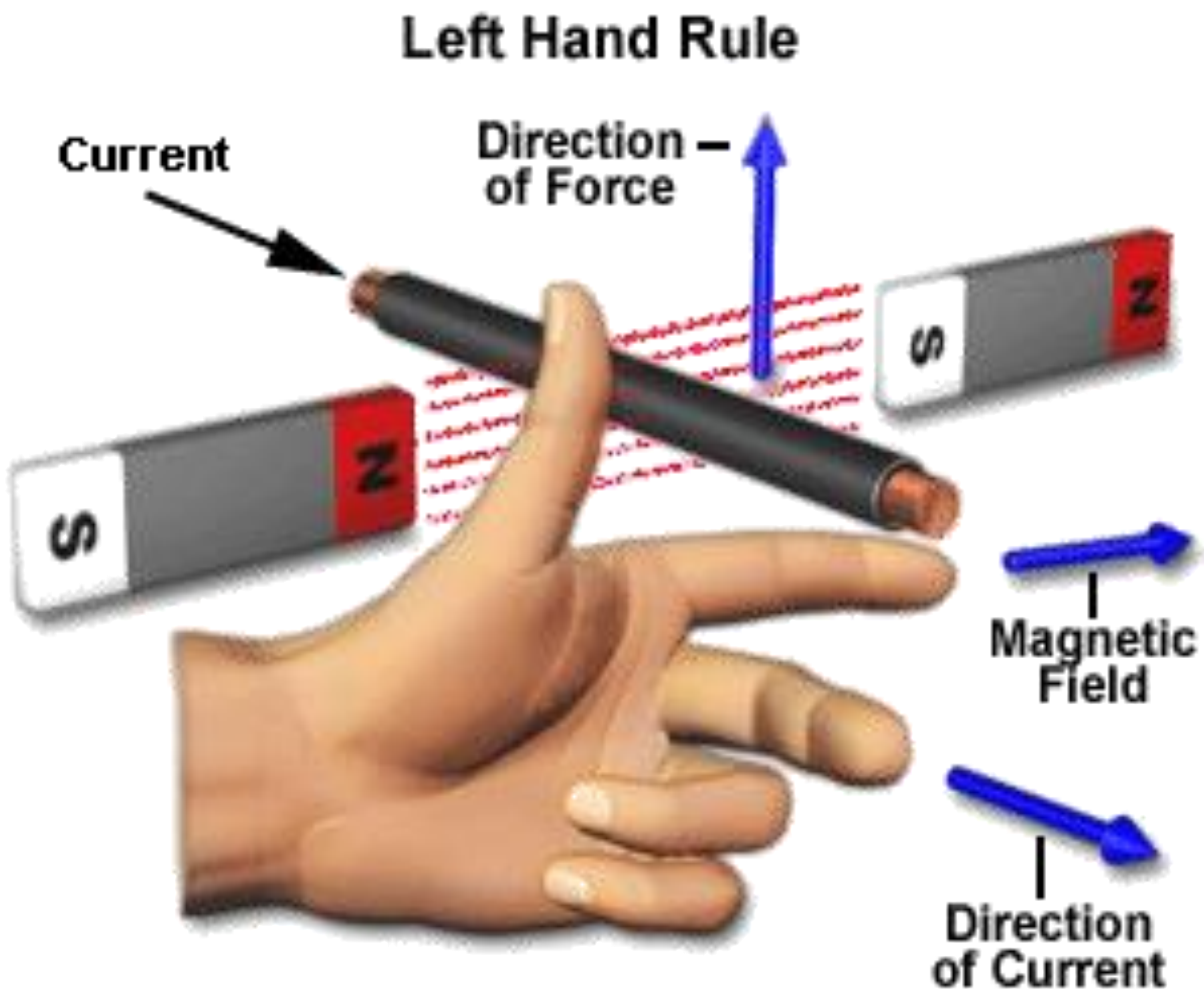
Fleming’s left hand rule

- Used to determine the direction of force acting on a current carrying conductor placed in a magnetic field .
- The middle finger , the fore finger and thumb of the left hand are kept at right angles to one another .

- The middle finger represent the direction of current
- The fore finger represent the direction of magnetic field
- The thumb will indicate the direction of force acting on the conductor .

This rule is used in motors.

Fleming's left hand rule

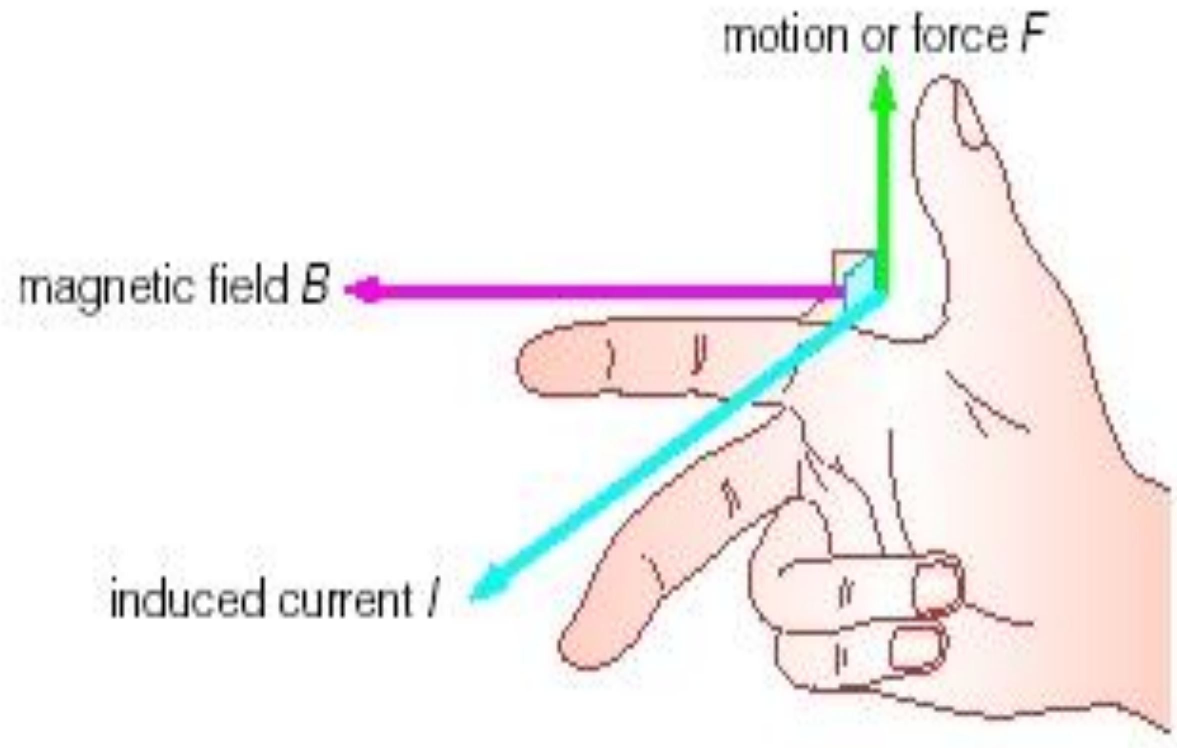


Fleming’s Right hand rule

- Used to determine the direction of emf induced in a conductor .
- The middle finger , the fore finger and thumb of the right hand are kept at right angles to one another.
- The fore finger represent the direction of magnetic field
- The thumb represent the direction of motion of the conductor
- The middle finger will indicate the direction of the inducted emf .

This rule is used in DC Generators

Fleming's Right hand rule



According to faradays law of electromagnetic induction, to induce an emf the following components are provided in the construction:

- Magnetic field system
- Conductor system
- Mechanism to obtain relative motion between field system and conductor system.

Relative motion between field and conductor can be obtained

- ✓ By stationary field and rotating armature
- ✓ By stationary armature and rotating field
- ✓ By rotating both, but there must exist relative speed

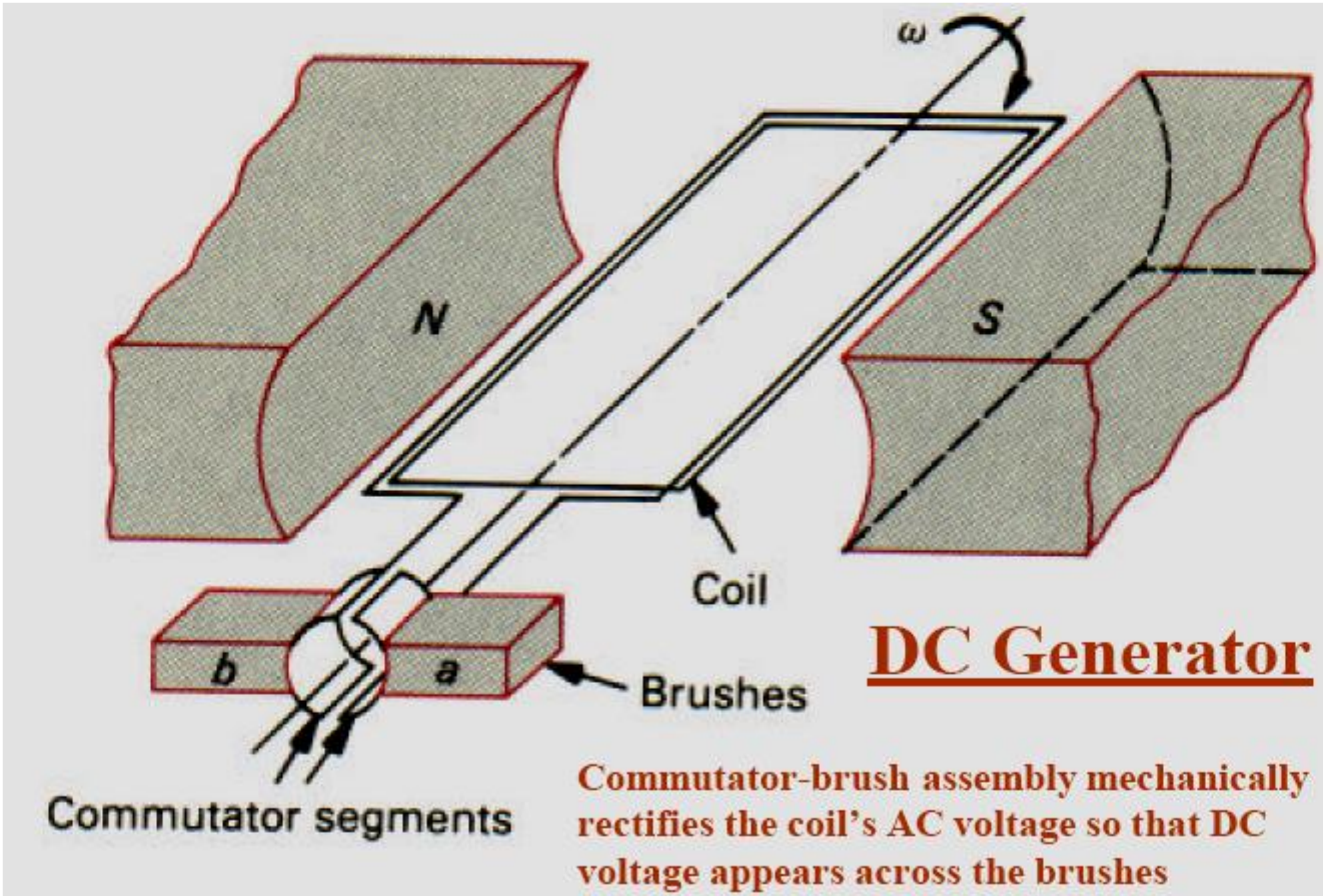
In all machines , the induced emf in conductor is dynamically induced emf and is always alternating in nature.

In dc generator the dc voltage is obtained due to commutator action that converts ac into dc.

Principle operation of Generator

- A generator works on the principle of Faraday's law of electromagnetic induction
- Whenever a conductor is moved within a magnetic field in such a way that the conductor cuts across magnetic lines of flux, voltage is generated in the conductor.
- The AMOUNT of voltage generated depends on:
    i. the strength of the magnetic field,
    ii. the angle at which the conductor cuts the magnetic field,
    iii. the speed at which the conductor is moved, and
    iv. the length of the conductor within the magnetic field

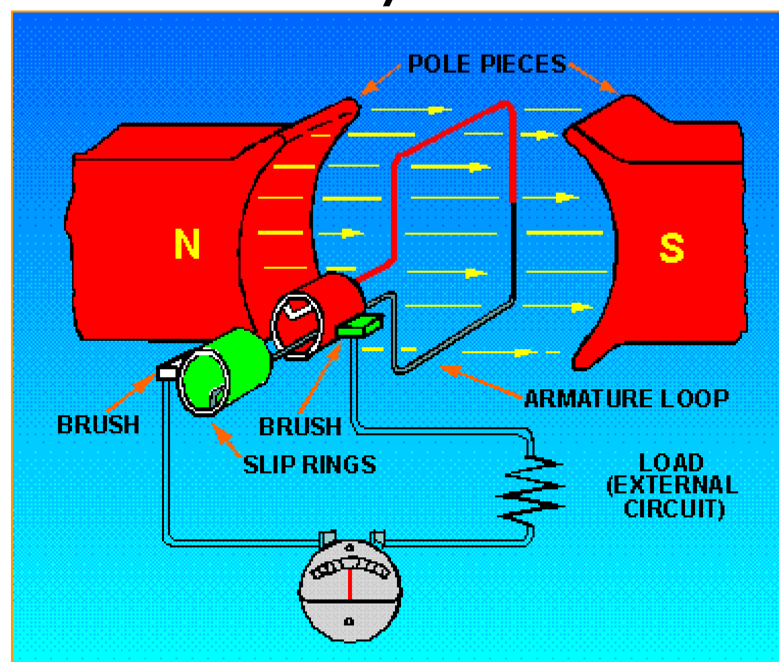
Principle of operation (Cont)

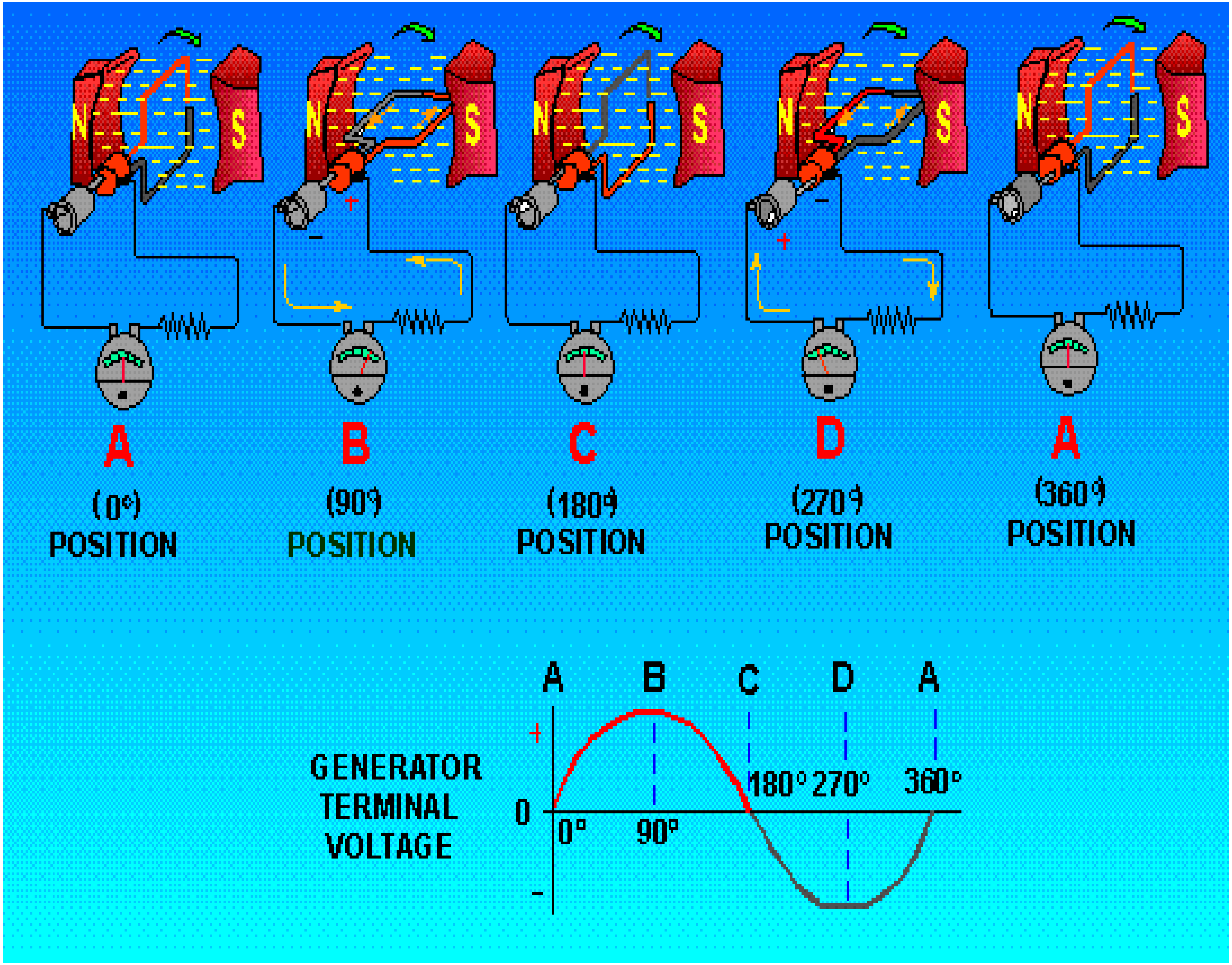


•The pole pieces (marked N and S) provide the magnetic field. The pole pieces are shaped and positioned as shown to concentrate the magnetic field as close as possible to the wire loop.

• The loop of wire that rotates through the field is called the ARMATURE. The ends of the armature loop are connected to rings called SLIP RINGS. They rotate with the armature.

•The brushes, usually made of carbon, with wires attached to them, ride against the rings. The generated Voltage appears across these brushes.

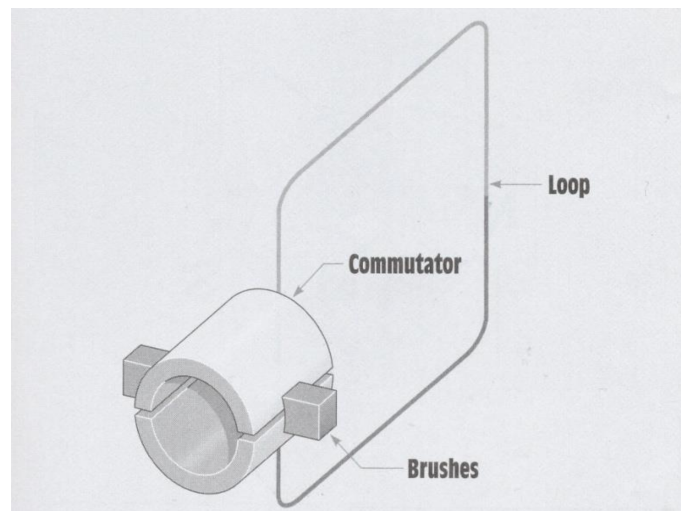




N
S
A
(0°)
POSITION
B
(90°)
POSITION
C
(180°)
POSITION
D
(270°)
POSITION
A
(360°)
POSITION
GENERATOR
TERMINAL
VOLTAGE
A
B
C
D
A
+
0
-
0°
90°
180°
270°
360°

Elementary dc generator

- Since DC generators must produce DC current instead of AC current, a device must be used to change the AC voltage produced in the armature windings into DC voltage.
- This job is performed by the **commutator.**
- Brushes riding against the commutator segments carry the power to the outside circuit.
- The commutator in a dc generator replaces the slip rings of the ac generator. This is the main difference in their construction.
- The commutator mechanically reverses the armature loop connections to the external circuit.

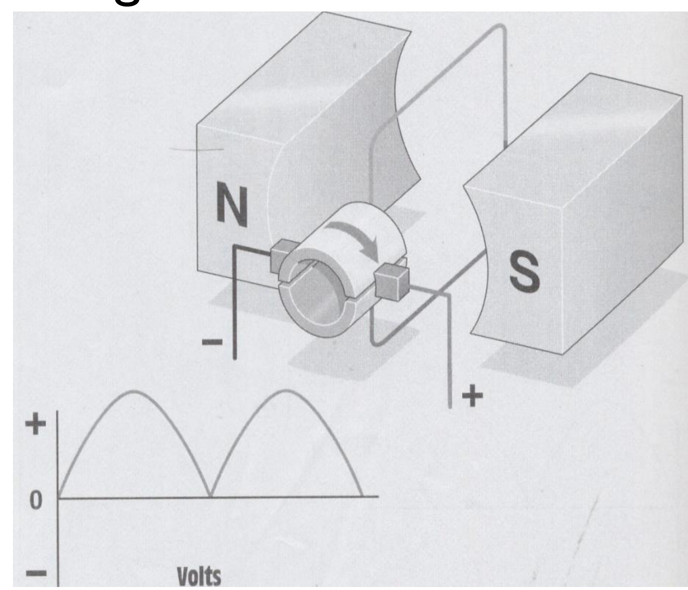


Elementary dc generator

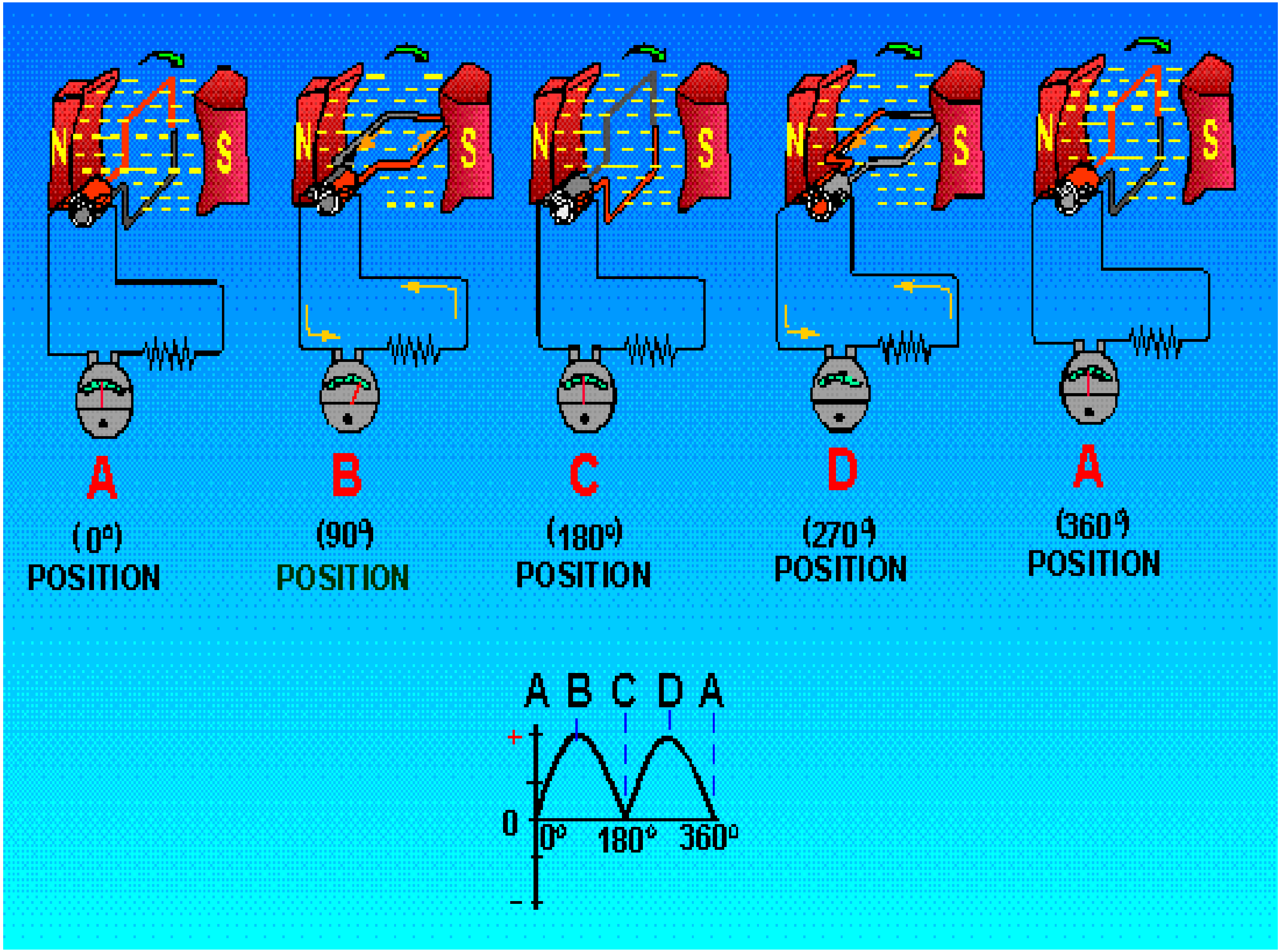
- As the loop continues to rotate, the induced voltage again decreases to zero when the conductors become parallel to the magnetic lines of flux.

- Notice that during this 360^0 rotation of the loop the polarity of voltage remained the same for both halves of the waveform. This is called rectified DC voltage.

- The voltage is pulsating. It does turn on and off, but it never reverses polarity. Since the polarity for each brush remains constant, the output voltage is DC.

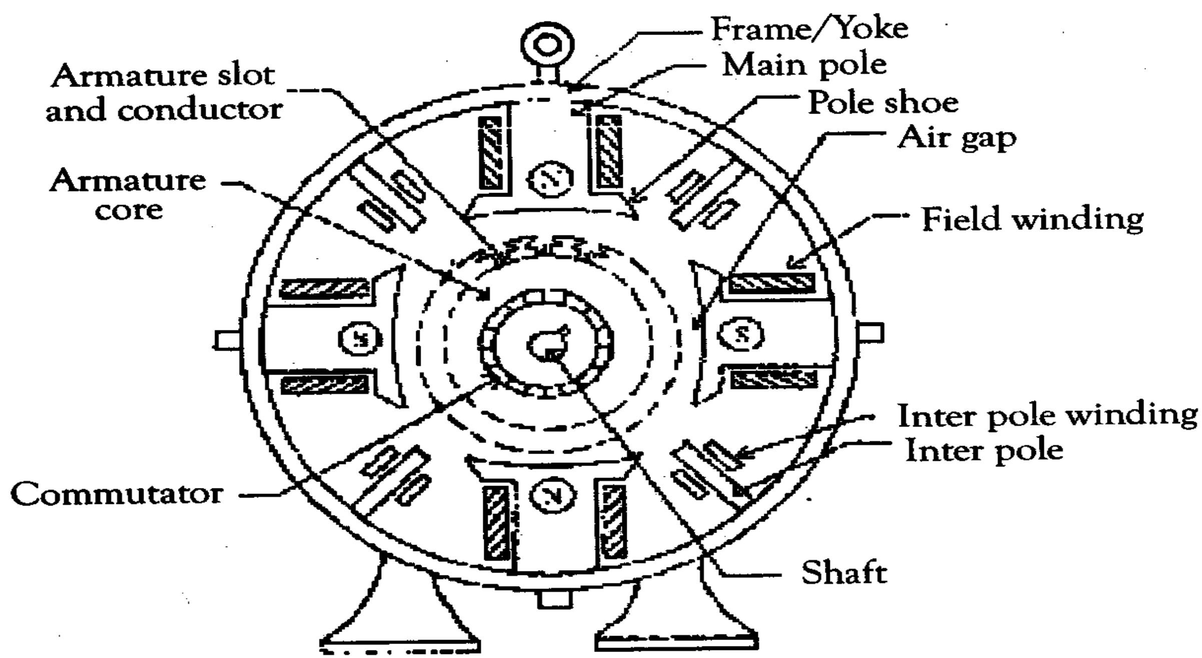


0^0 Position (DC Neutral Plane)



N
S
A
(0°)
POSITION
B
(90°)
POSITION
C
(180°)
POSITION
D
(270°)
POSITION
A
(360°)
POSITION
A B C D A
+
0
-
0°
180°
360°

Construction of DC machine



➢ Stationary part of dc generator:

- Frame/yoke
- Main poles
- Inter poles
- Brushes
- Lifting eye
- Terminal box

➢ Rotating parts consists of:

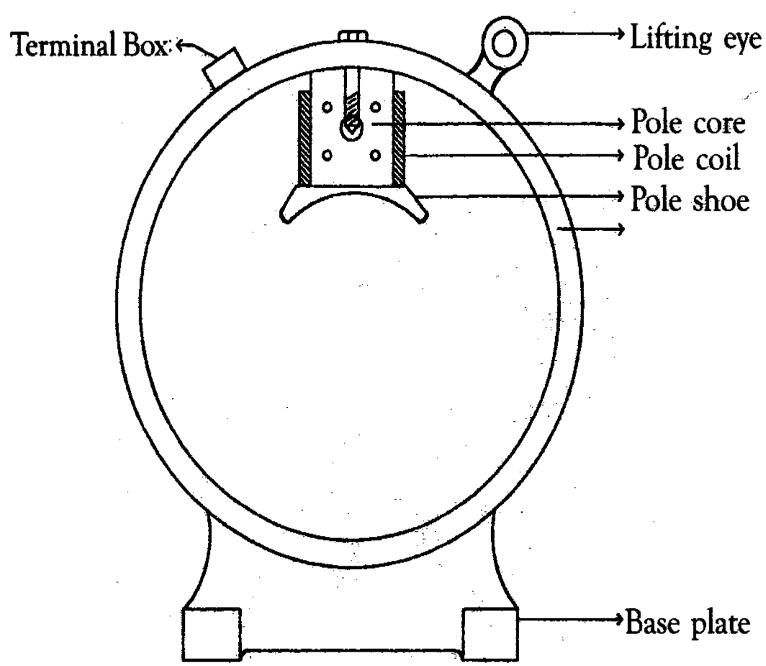
- Armature core
- Armature winding
- Commutator
- shaft

Yoke/Frame:

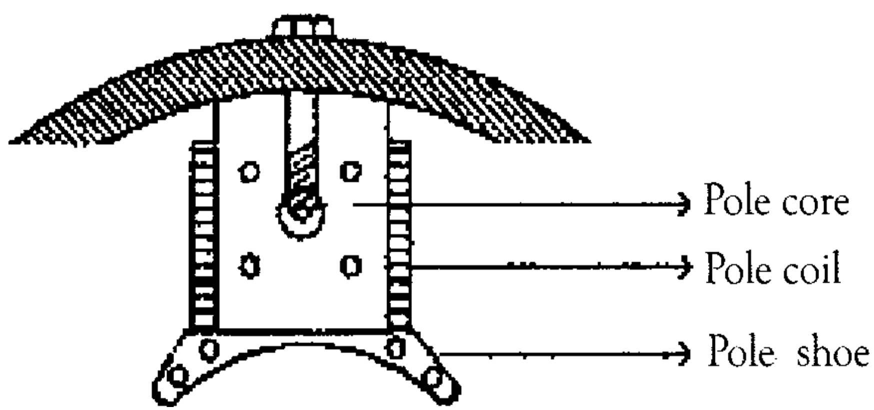
- For low capacity machines the yoke is made up of cast iron and for higher capacity machines it is made up of cast steel because magnetic saturation level of cast iron is less than that of cast steel
- The Yoke gives mechanical support to the entire machine
- It also forms the path for the magnetic flux.

Main poles:

- It include pole core, pole shoe and main field windings



- Pole core:
- It is made up of steel having high permeability. Laminated pole core are used to keep eddy current losses minimum.
- Thin sheets of steel alloy insulated from one another and pressed together are used to form the core.
- Pole shoe:
- It is the enlarged position of pole core and is the end portion of the poles
- To spread out the flux in the air gap uniformly
- To support the field coil
- To reduce the reluctance of magnetic path, by having large cross sectional area.



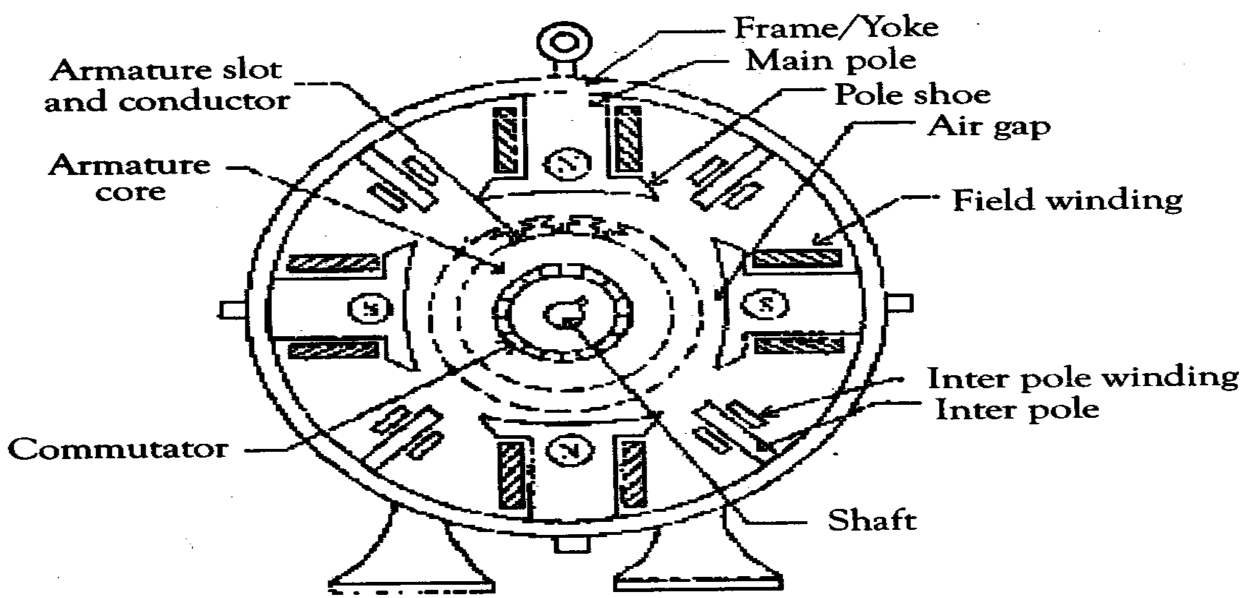
- Field coils:
- The coils of copper wire wound around the poles are called field coils
- When current flows through these coils the pole get magnetized by having flux created in it.
- Each pole is provided with shunt field or series field or both
- Shunt: Thin copper wire, large no of turns
- Series: Thick copper wire, less no of turns

➢ Interpoles:

- These poles are comparatively smaller than main poles.
- Fixed between two main poles
- Flux provided by these poles gives sparkless commutation and it is also called as commutating poles.

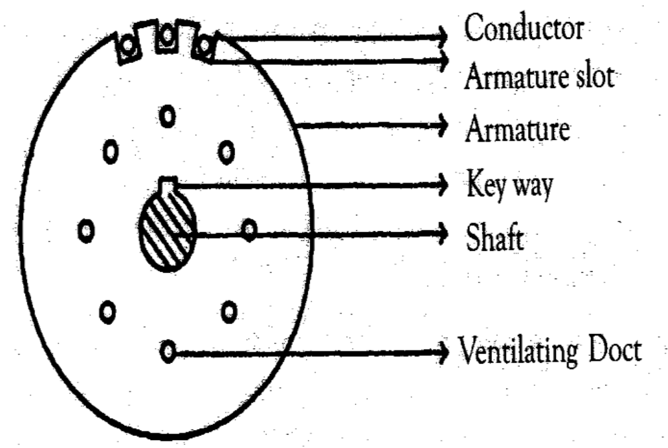
➢ Air-gap

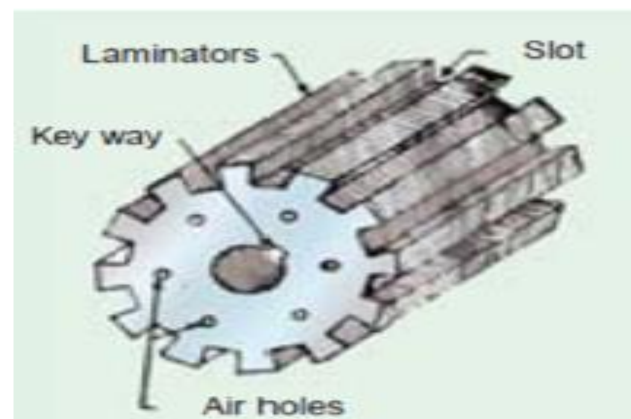
- Radial spacing between main pole faces and surface of armature
- The length of air gap varies from 1mm to 5mm depending on capacity and size of the machine



- Armature:
- Armature core:
- It is made up of steel laminations about 0.4 to 0.6mm thick, insulated from one another.
- The laminations are rigidly clamped.
- Slots are cut on the periphery of the Armature core.
- The conductors are housed in the slots and are insulated from one another.
- Armature winding:

1. Lap winding
2. wave winding

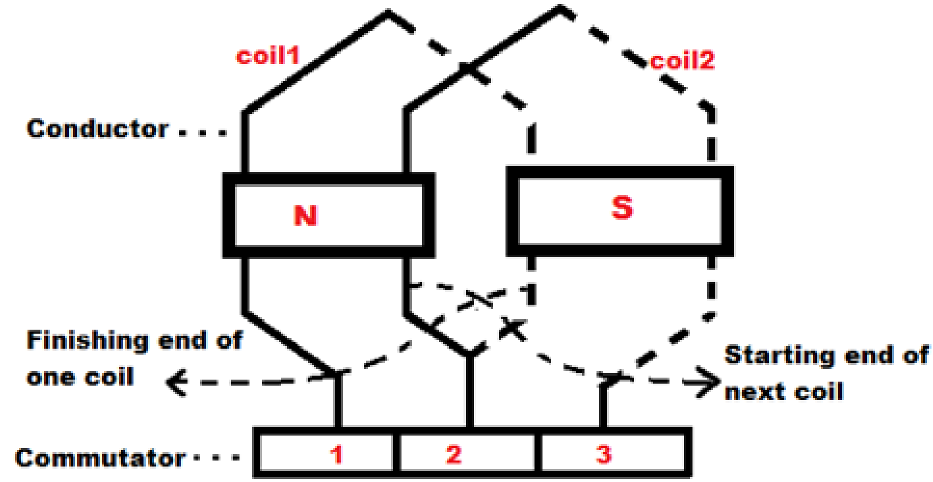




LAP & WAVE WINDING

- **LAP Winding:**

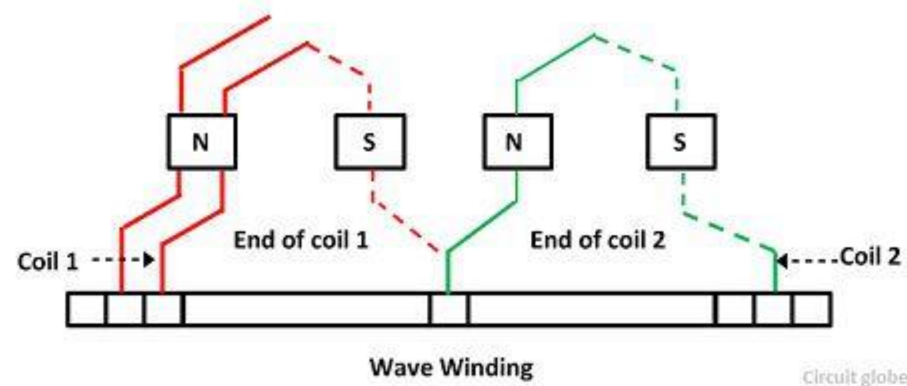
Single turn coils are presented. The finishing end of one coil is connected to the commutator segment & the starting end of the adjacent coil situated under the same pole.



LAP winding

- **WAVE winding:**

Conductor under one pole is connected at the back to the Conductor which position under next pole.



Wave Winding

- **Commutator:**
- Its function is to convert alternating emf in dc.
- Cylindrical in shape
- The commutator segments are insulated from one another and from shaft using thin layer of mica sheet.
- **Brushes:**
- Brushes are usually made up of carbon.
- They are housed in brush holders. No. of brush holders is equal to the no of poles
- Function of brushes is to collect current from rotating commutator and deliver it to the external load.
- **Shaft and bearings:**
- The steel shaft gives mechanical support to the armature and commutator.
- The rotor assembly is supported and is allowed freely by two bearings fitted between the two end covers and the shaft
- The function of the bearing is to reduce friction between rotating and stationary parts of the machine.

EMF equation of dc machine

Let,

- Ø= flux per pole in Weber
- Z = Total number of conductors
- P = Number of poles
- A = Number of parallel paths
- N =armature speed in rpm
- Eg = emf generated in any one of the parallel path

- Flux cut by 1 conductor in 1 revolution = P * Ø
- d Ø = P * Ø
- No. of revolutions/second = N/60
- Time for one revolution, dt =60/N second
- Avg emf generated in 1 conductor
  dØ /dt= PφN/60 volts
- No. of conductors in each parallel path = Z /A
- EMF generated/path

$$\boxed{\mathbf{Eg = PØNZ/60A \quad volts}}$$

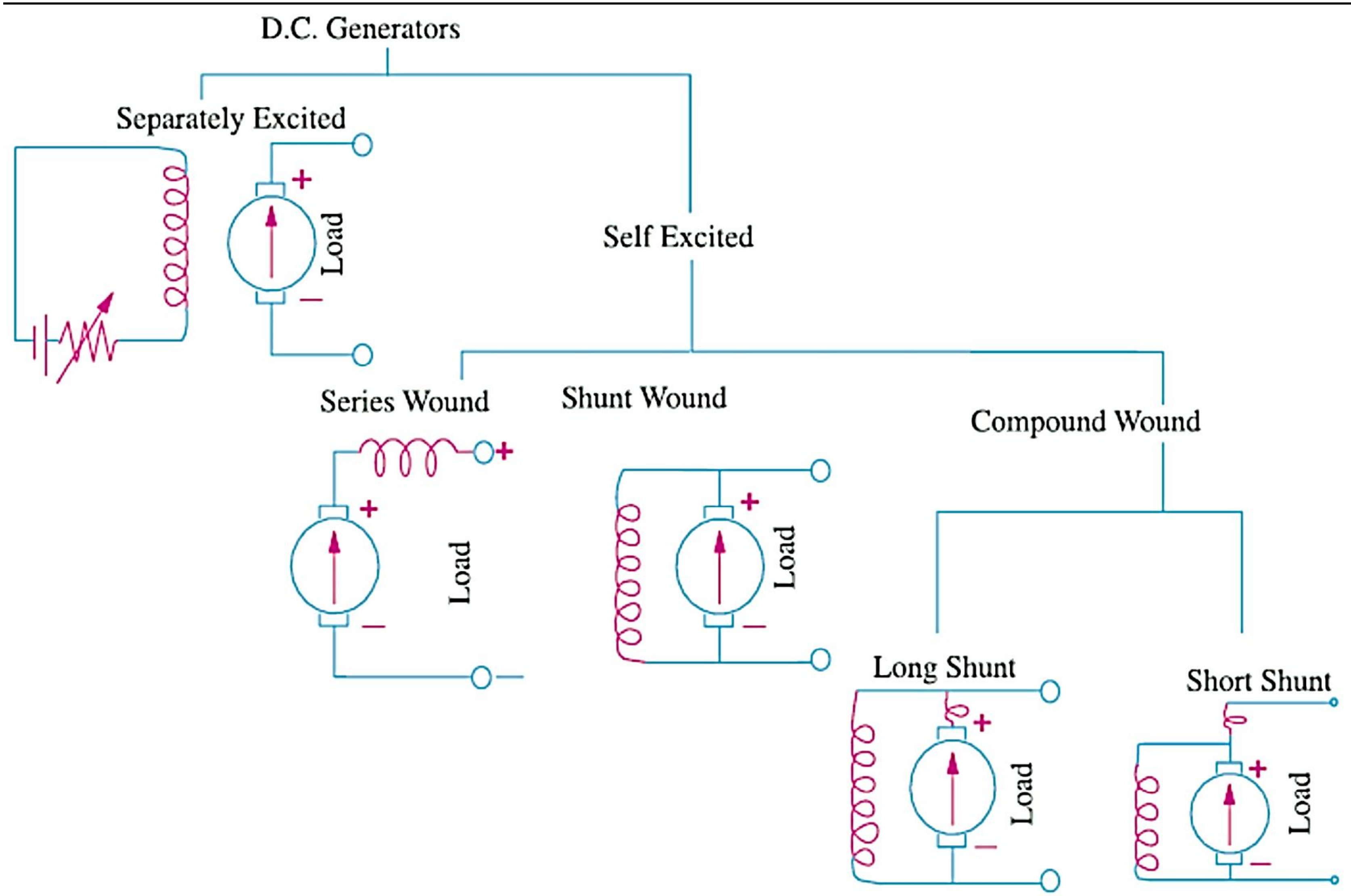
Types of DC Generator

DC generators are generally classified according to their method of excitation .

(a) Separately-excited generators are those whose field magnets are energized from an independent external source of dc current.

(b) Self-excited generators are those whose field magnets are energized by the current produced by the generators themselves. There are three types of self-excited generators named according to the manner in which their field coils (or windings) are connected to the armature.

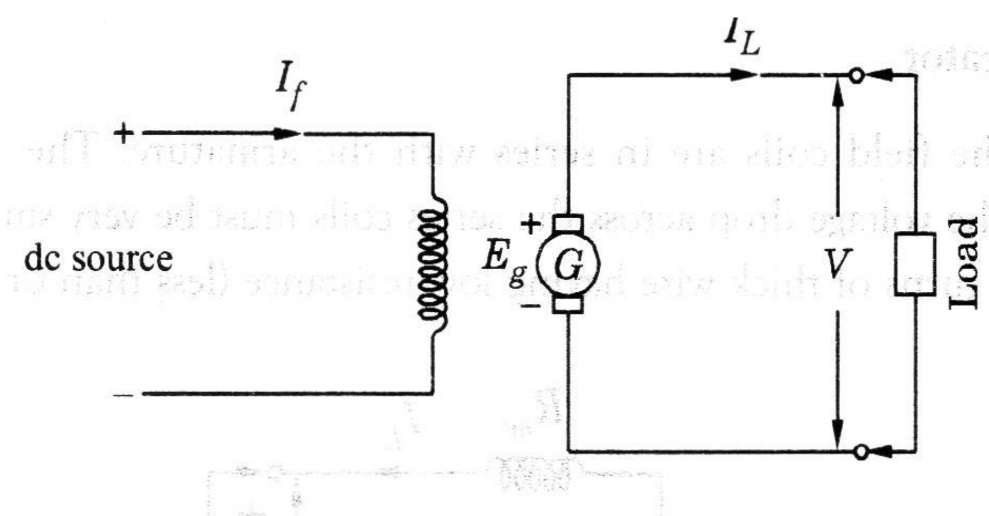
- Series wound generator
- Shunt wound generator
- Compound wound generator: Short shunt & Long shunt , Cumulatively compound & Differentially compound



D.C. Generators
Separately Excited
Load
Self Excited
Series Wound
Shunt Wound
Compound Wound
Load
Load
Long Shunt
Short Shunt
Load
Load

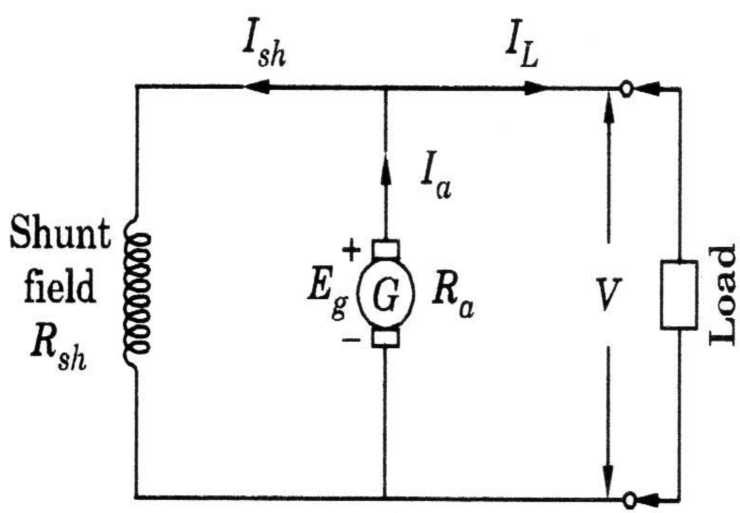
Separately excited DC generator

- Field current is supplied from an external source may be battery or small generator called as exciter
- $I_a = I_L$
- $V = E_g - I_a R_a$
- R_a = armature resistor
- Power developed= $E_g I_a$ watts



Shunt Generator

- Field coils are connected parallel to the armature
- Full generated voltage is applied across the field coils.
- Shunt field winding consist of many turns having considerable resistance (few hundred ohm)



$$I_{sh} = \frac{V}{R_{sh}} = \frac{E_g - I_a R_a}{R_{sh}}$$

$$I_a = I_L + I_{sh}$$

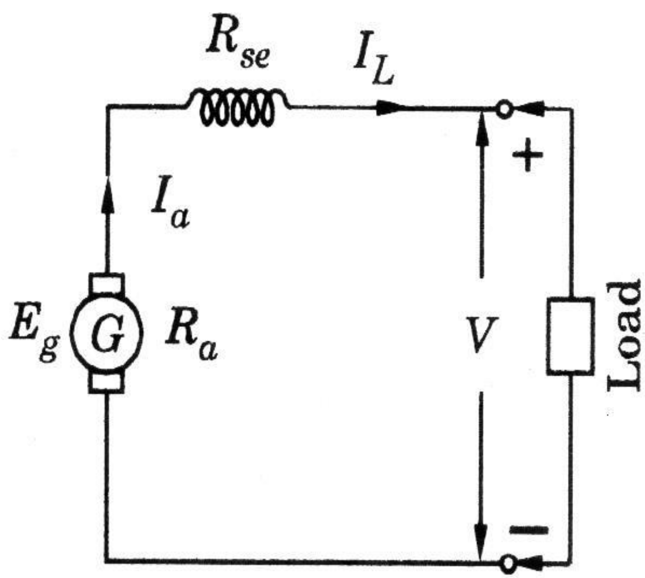
$$V = E_g - I_a R_a$$

Power developed= $E_g I_a$ watts

Power delivered= $V I_L$ watts

Series generator

- Field coils are connected in series with the armature
- The series coil carry the same armature current.
- Voltage drop across series coil must be very small.
- Hence resistance of series field winding is very small (less than 1 ohm).



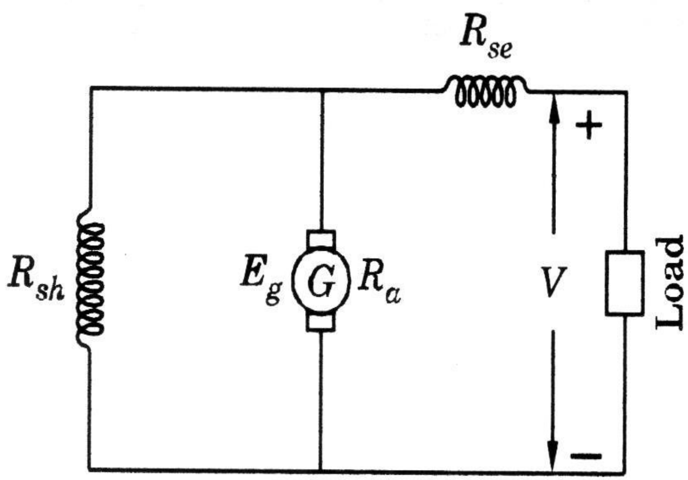
$$I_a = I_{se} = I_L$$

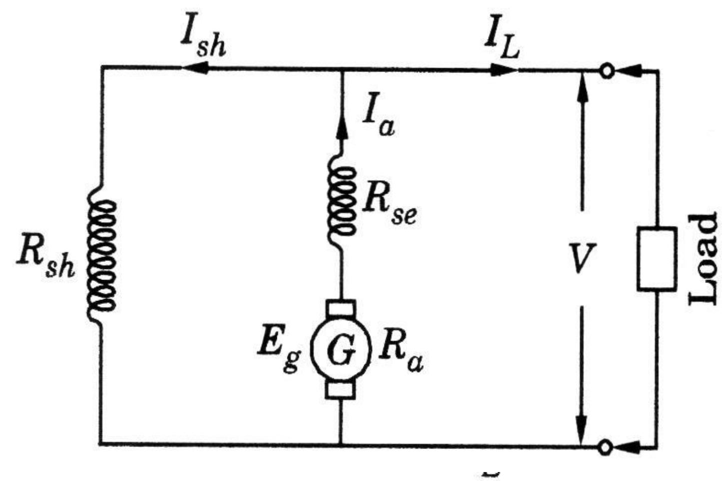
$$V = E_g - I_a R_a - I_{se} R_{se}$$

$$= E_g - I_a (R_a + R_{se}) \quad (\because I_a = I_{se})$$

Power delivered= VI_L watts

Compound generator





Short Shunt:

series field current $I_{se} = I_L$

Shunt field current $I_{sh} = \dfrac{V + I_{se}R_{s}}{R_{sh}}$

$$V = E_g - I_a R_a - I$$

Power developed= $E_g I_a$ watts

Power delivered= VI_L watts

Long Shunt:

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

$$V = E_g - I_a R_a - I_a R_{se}$$

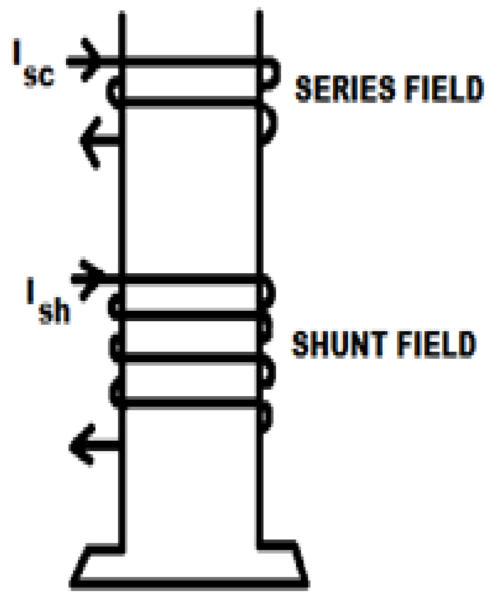
$$= E_g - I_a (R_a + R_{se})$$

$$I_{sh} = \frac{V}{R_{sh}}$$

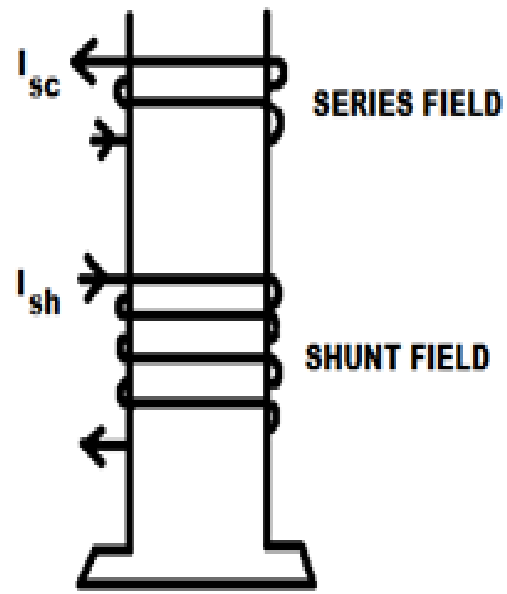
Power developed= $E_g I_a$ watts

Power delivered= VI_L watts

In cumulative wound generators the series field assists the shunt field, whereas in differential wound generators, series field opposes the shunt field.

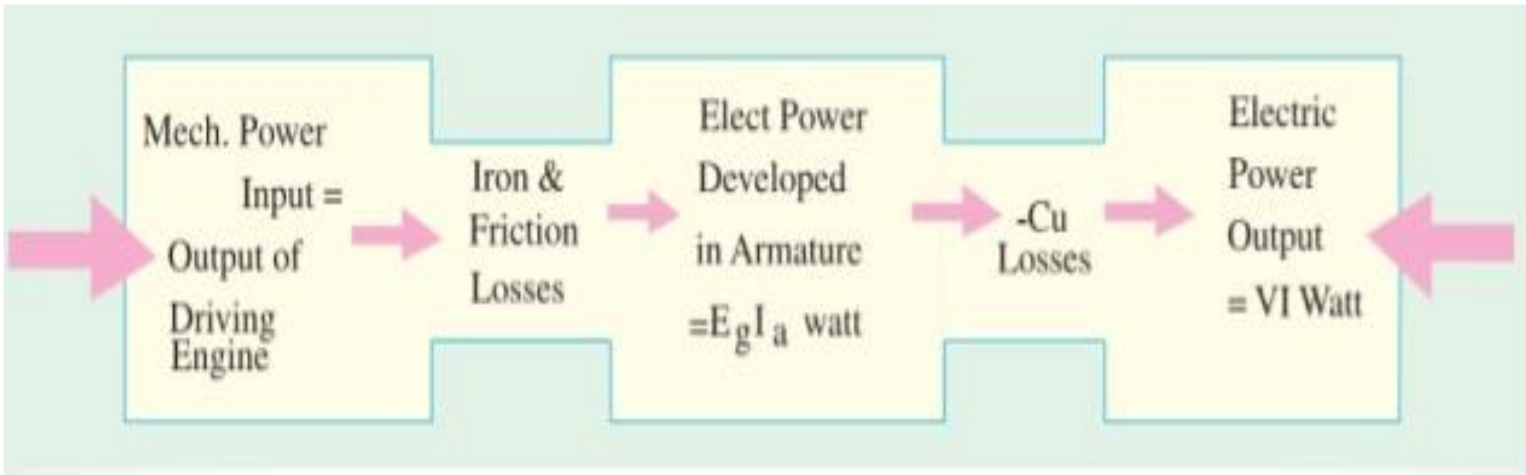


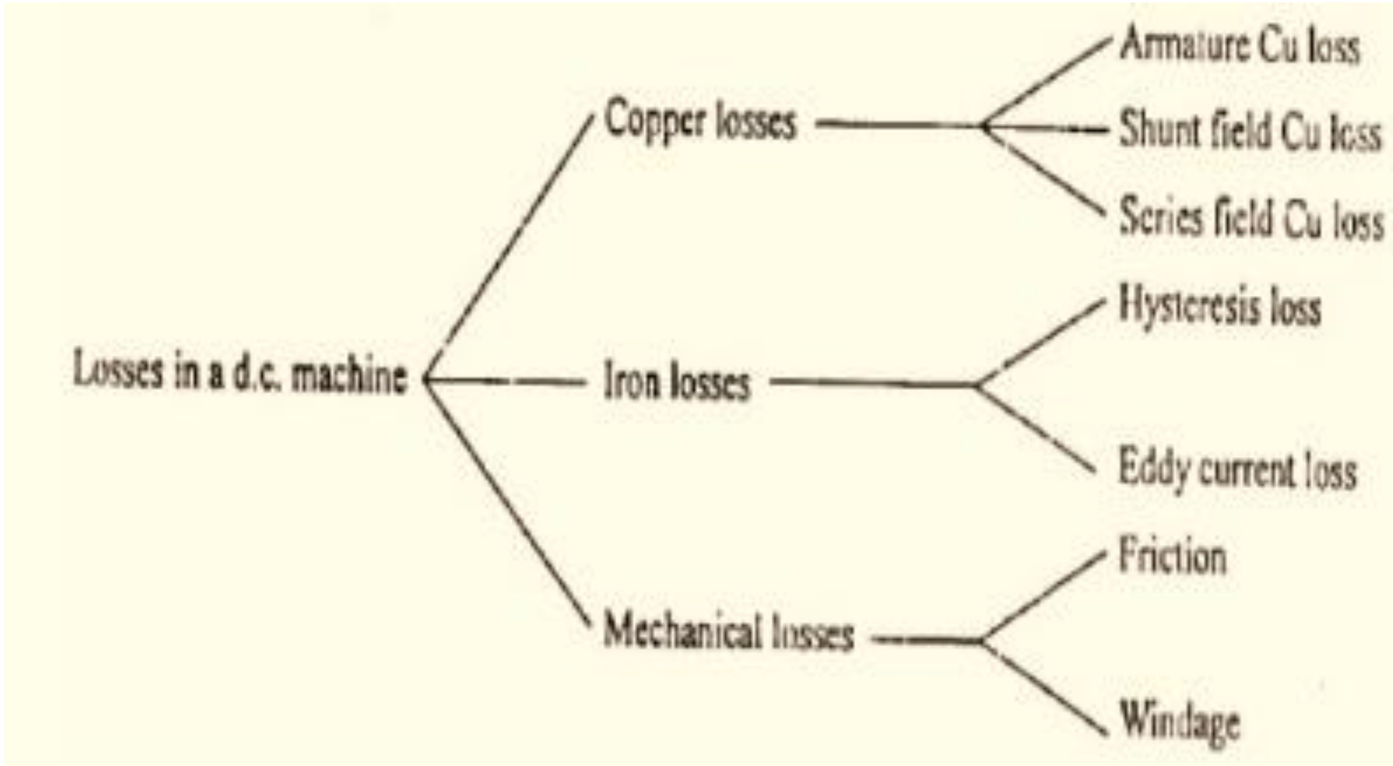
CUMULATIVE COMPOUNDING



DIFFERENTIAL COMPOUNDING

Power Stages





$$Efficiency\,(\eta) = \frac{output}{input} \cdots\cdots(1)$$

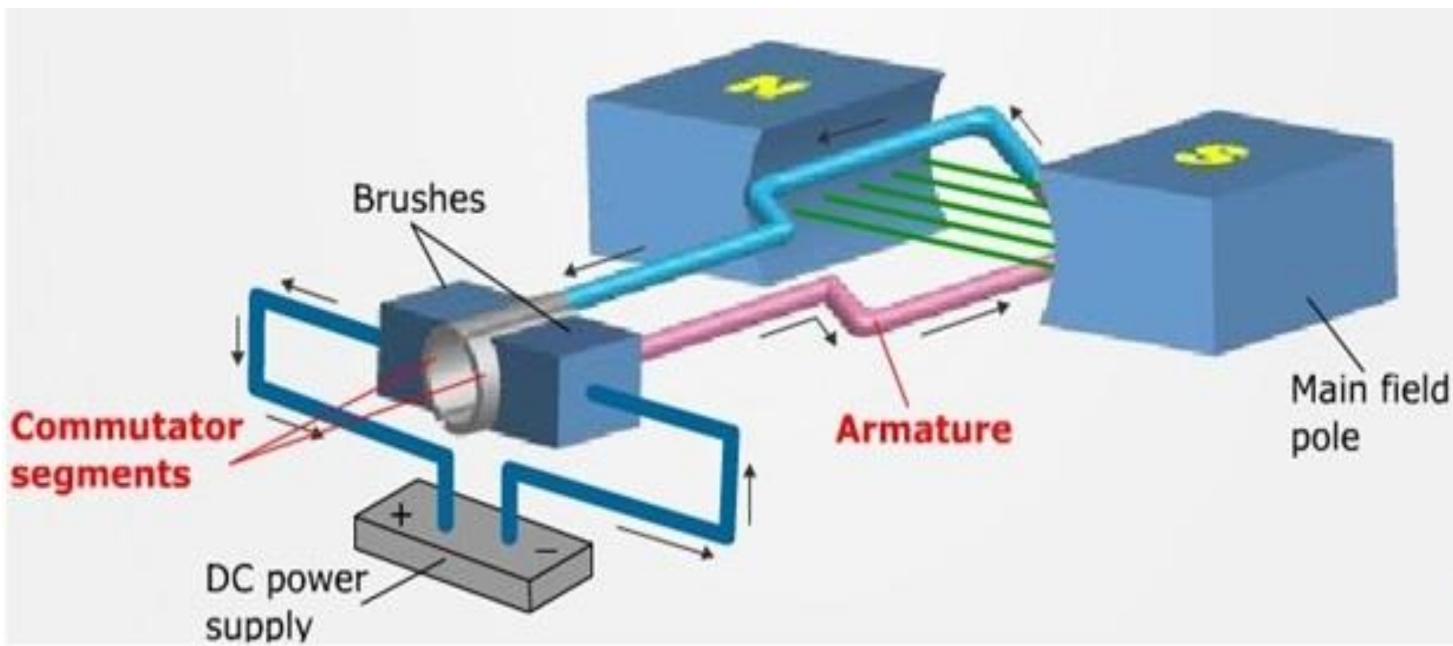
$$or,\ \eta = \frac{input - losses}{input} \cdots\cdots(2)$$

$$or,\ \eta = \frac{output}{output + losses} \cdots\cdots(3)$$

DC MOTOR

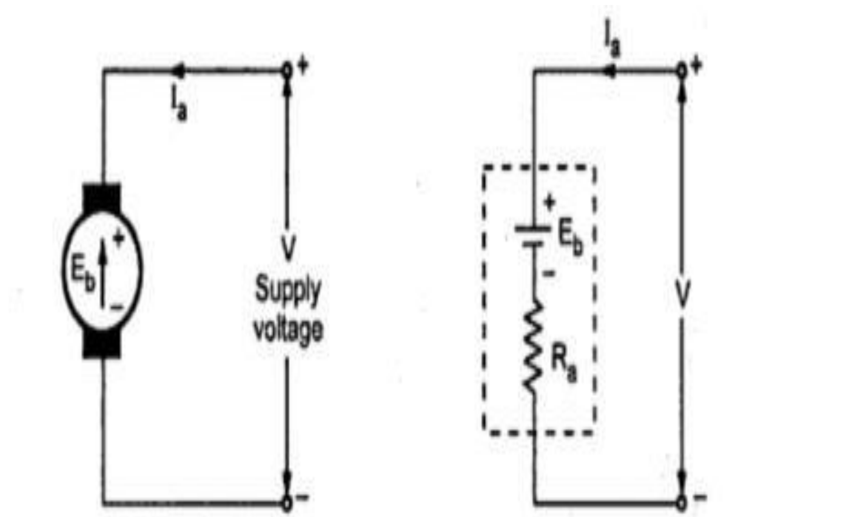
- A DC motor is a device for converting DC electrical energy into rotary (or linear) mechanical energy

“when a current carrying conductor is placed in a magnetic field, it experiences a mechanical force". The direction of force is given by Fleming's left hand rule



Significance of BACK EMF:

- When the motor armature rotates the conductors also rotates hence cuts the flux. So emf is induced in the armature according to electromagnetic induction.
- So some emf is present in armature by generation rule. This is called counter emf or Back emf (Eb). So V has to drive Ia against the opposition of Eb.
- Voltage =Eb+ IaRa



(a) Back e.m.f. in a d.c. motor (b) Equivalent circuit

Speed Control Methods Of DC Motor

Eg = PØNZ/60A volts

$N = \dfrac{V - I_a R_a}{Z\phi}\left(\dfrac{60A}{p}\right) = K\dfrac{V - I_a R_a}{\phi}$ where R_a= armature circuit resistance. It is obvious that the speed can be controlled by varying

(*i*) Flux/pole, Φ (Flux Control)

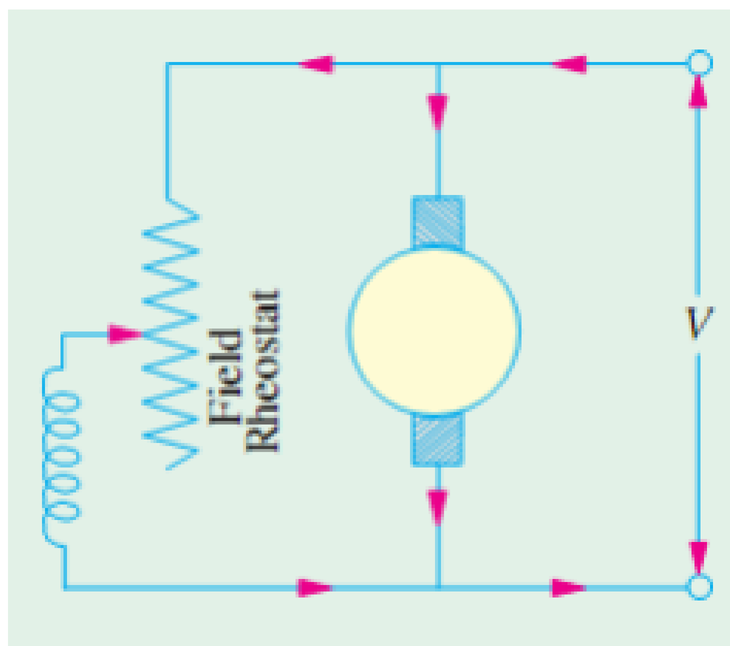
(*ii*) Resistance R_a of armature circuit (Rheostatic Control) and

(*iii*) Applied voltage V (Voltage Control).

Speed Control of Shunt motor:

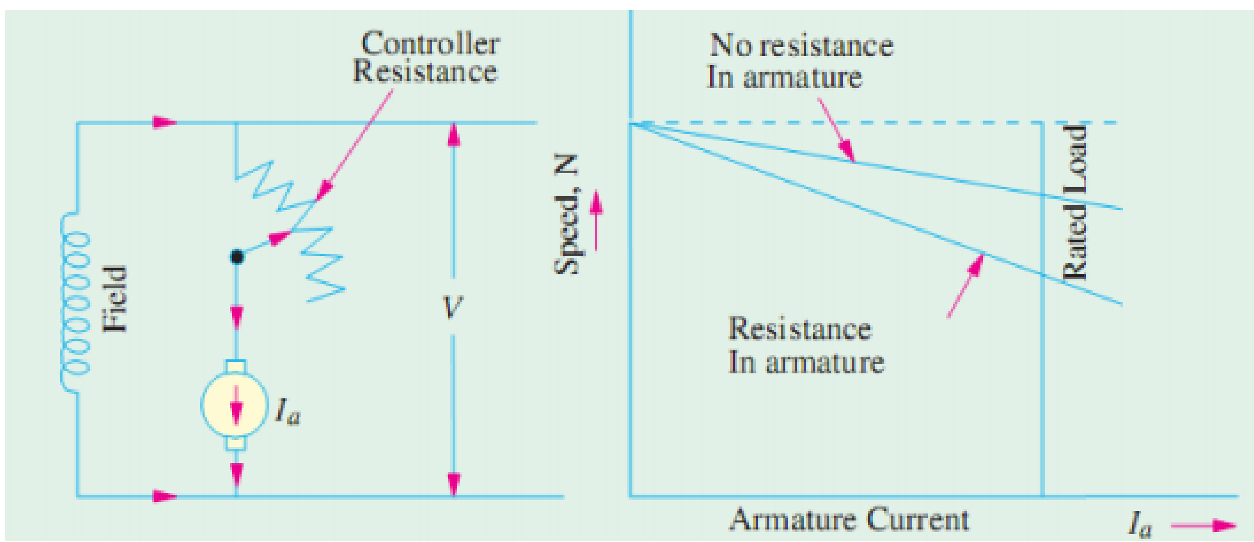
Flux Control Method:

By decreasing the flux, the speed can be increased and vice versa. The flux of a dc motor can be changed by changing Ish with help of a shunt field rheostat. Since Ish is relatively small, shunt field rheostat has to carry only a small current, which means Ish^2R loss is small, so that rheostat is small in size.



Armature or Rheostatic Control Method:

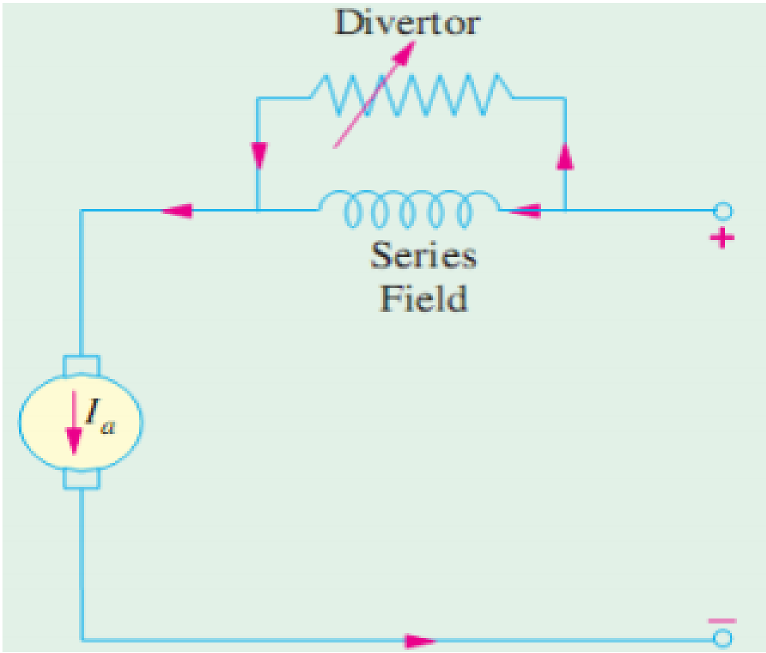
This method is used when speeds below the no-load speed are required. As the supply voltage is normally constant, the voltage across the armature is varied by inserting a variable rheostat in series with the armature circuit. As controller resistance is increased, voltage across the armature is decreased, thereby decreasing the armature speed. For a load constant torque, speed is approximately proportional to the voltage across the armature.



Speed Control of Series Motors:

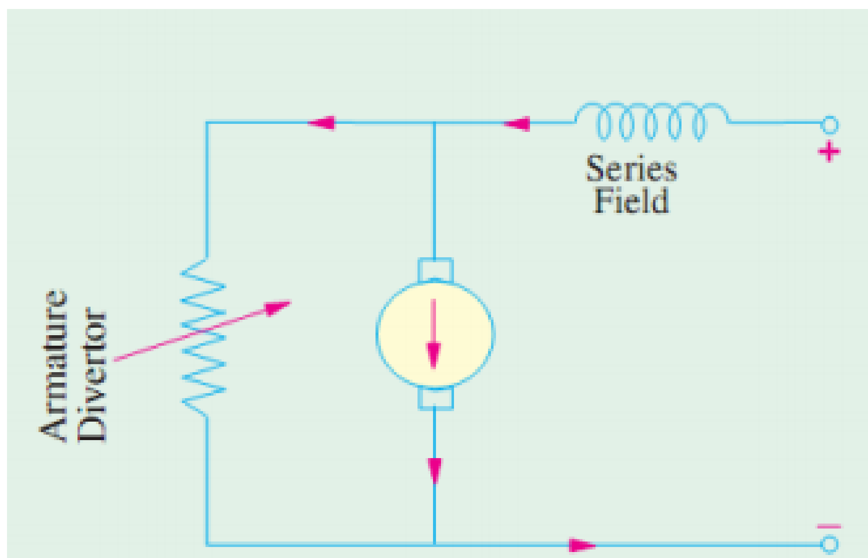
1.Flux Control Method:

(a) Field Diverters: The series winding are shunted by a variable resistance known as field diverter. Any desired amount of current can be passed through the diverter by adjusting its resistance. Hence the flux can be decreased and consequently, the speed of the motor increased.



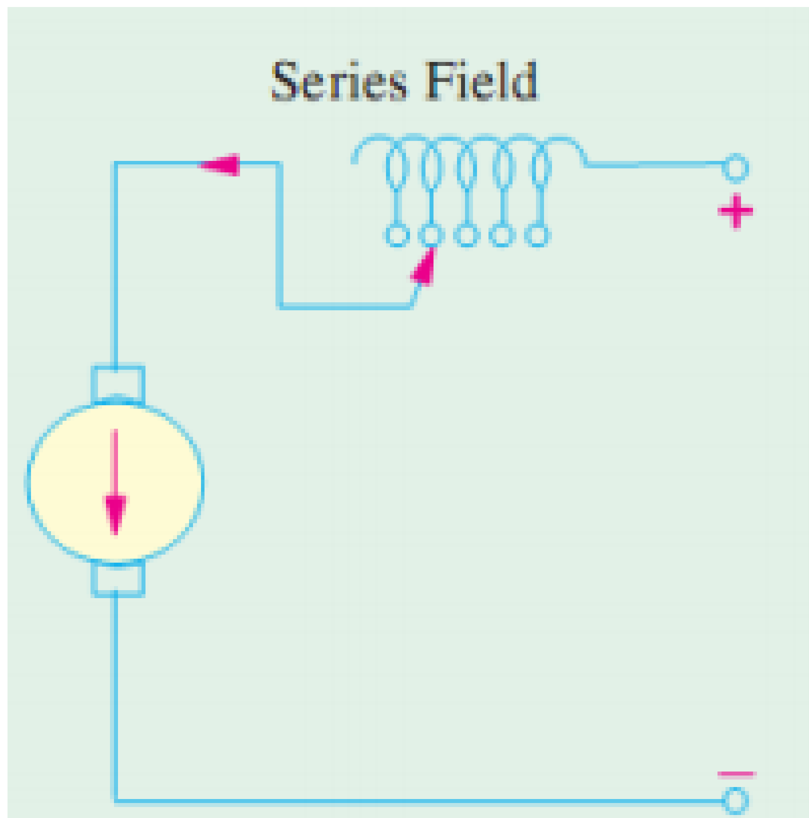
(b) Armature Diverter:

A diverter across the armature can be used for giving speeds lower than the normal speed. For a given constant load torque, if Ia is reduced due to armature diverter, the Ø must increase ($\because T_a \propto \phi I_a$)This results in an increase in current taken from the supply (which increases the flux and a fall in speed $(N \propto I/\phi)$. The variation in speed can be controlled by varying the diverter resistance.



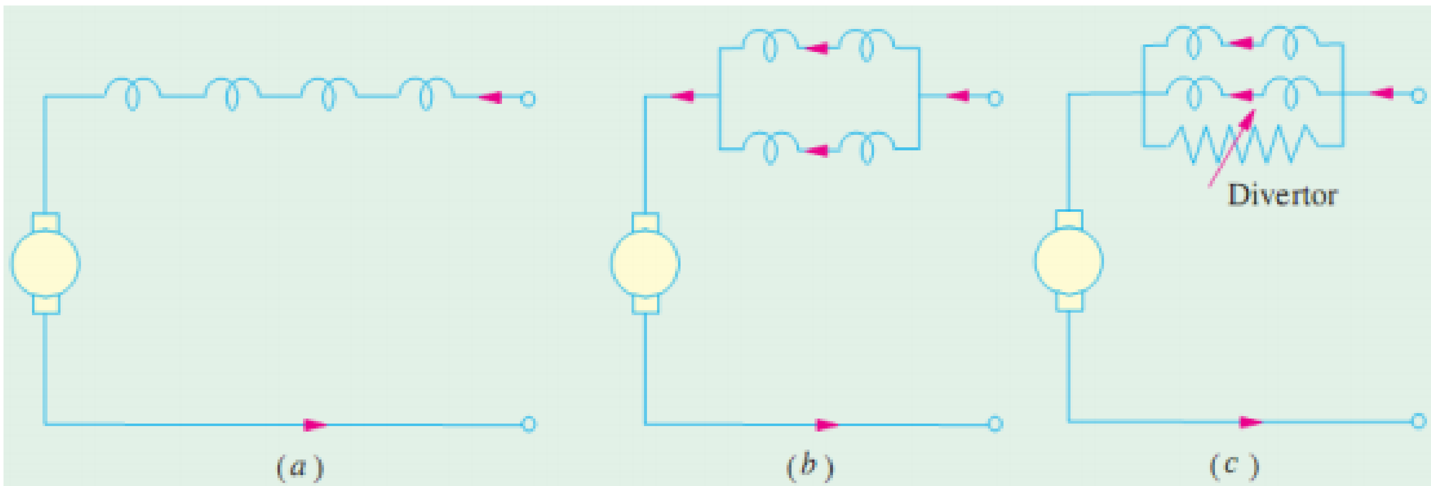
(c) Tapped Field Control Field:

The number of series filed turns in the circuit can be changed. With full field, the motor runs at its minimum speed which can be raised in steps by cutting out some of the series turns.



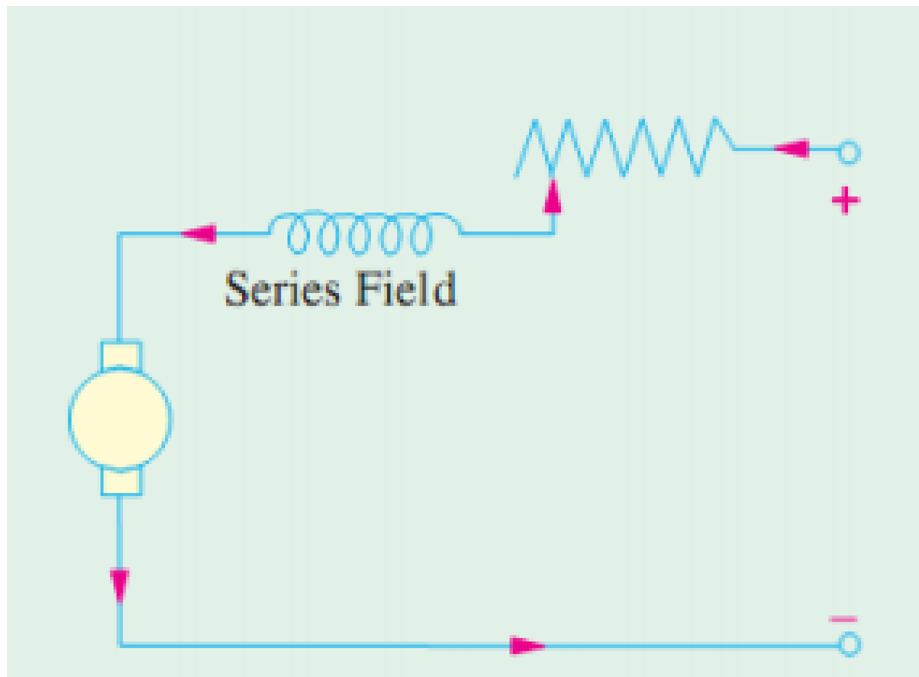
(d) Paralleling Field coils:

This method used for fan motors;several speeds can be obtained by regrouping the field coils.



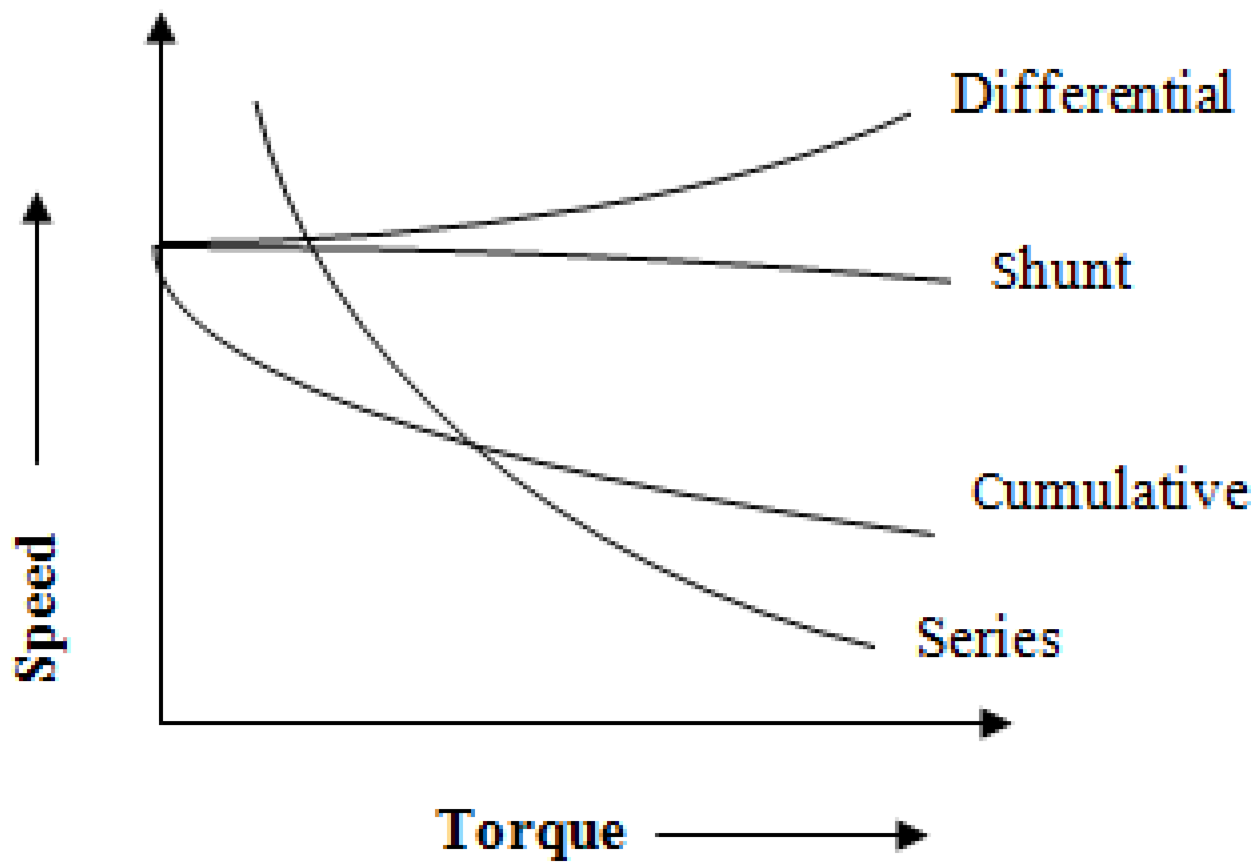
2. Variable Resistance in Series with Motor:

By increasing the resistance in series with the armature the voltage applied across the armature terminals can be decreased. With reduced voltage across the armature, the speed is reduced.



(a)

Speed-Torque characteristics



Applications of DC Generators

- in electro plating
- for battery recharging
- as exciters for AC generators
- As boosters
- As lighting arc lamps

Application D.C.Motor

- **D.C Shunt Motors:**
  - Lathes
  - Drills
  - Boring mills
  - Shapers
  - Spinning and Weaving machines
  - Elevators
  - Air compressor
  - Vacuum cleaner
  - Hair drier
  - Sewing machine
- **D.C Series motor:**
  - Electric traction
  - Cranes
- **D.C Compound motor:**
  - Presses Shears
  - Reciprocating machine