DC Motor/Generator Theory

Subject Name: Electrical Fundamentals

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Approved By:

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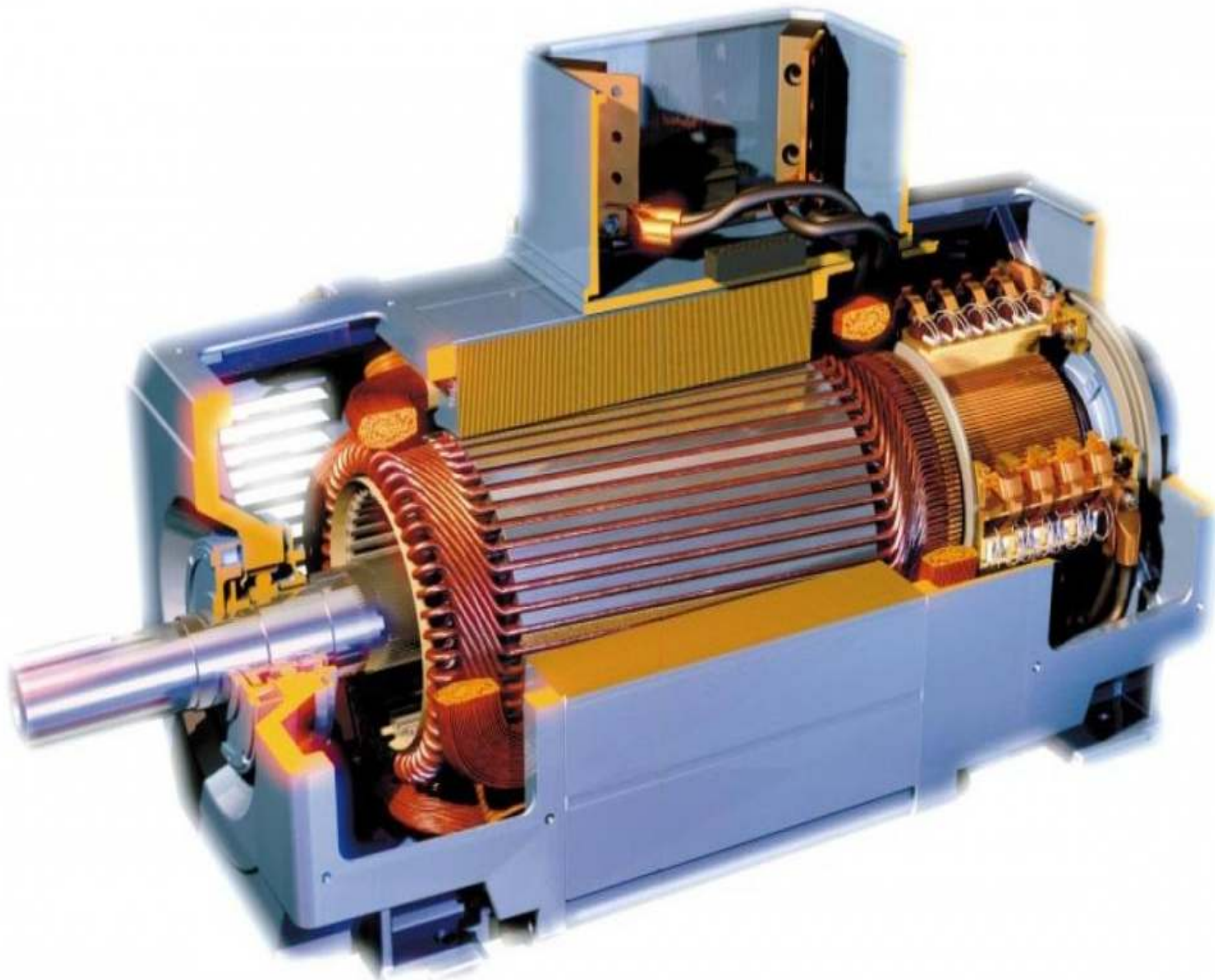
DC Motor/Generator



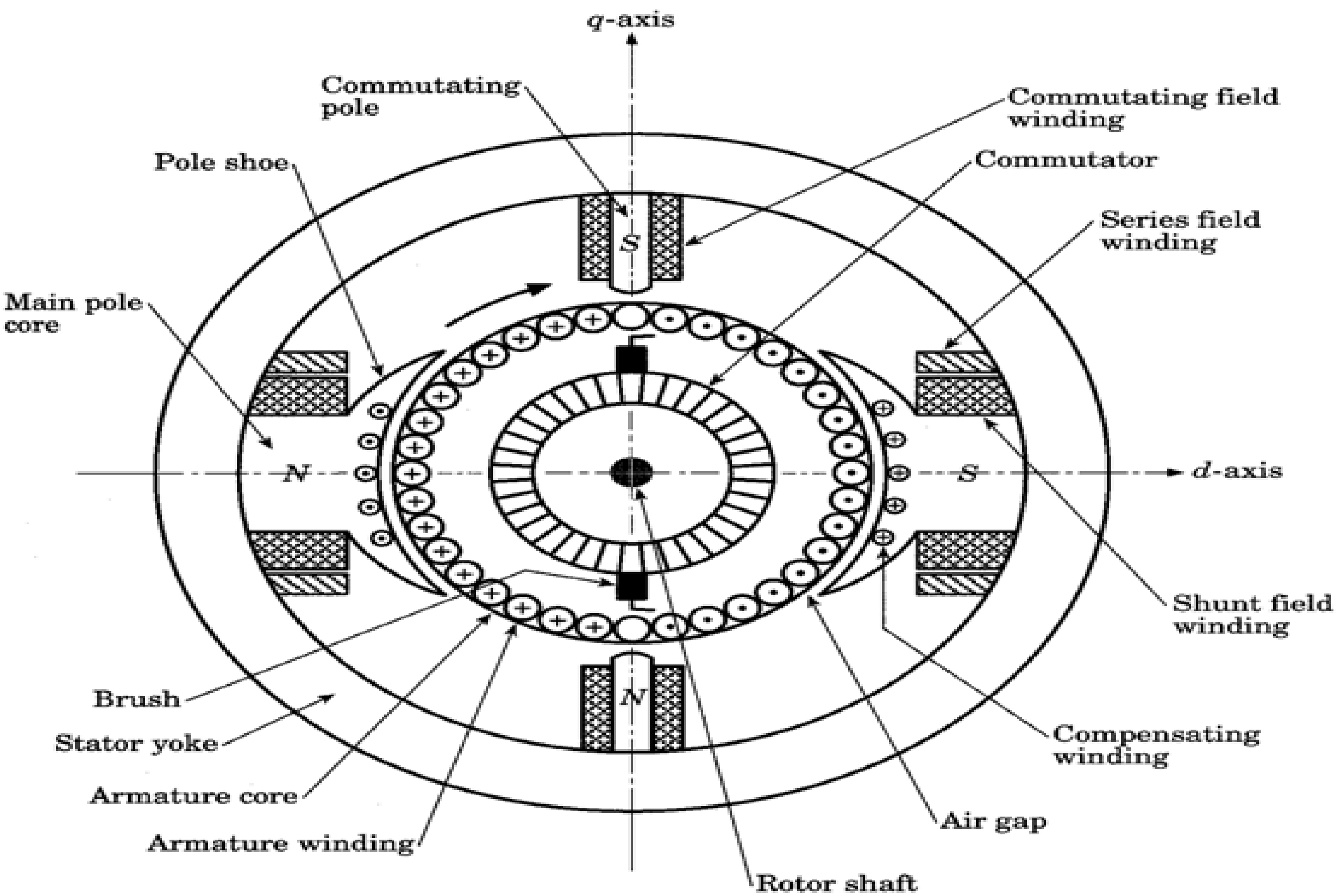
DC Motors/Generator

What is an Electric Motor?

An electrical machine which converts mechanical energy into electrical energy is called an **electric generator.**

An electrical machine which converts an electrical energy into the mechanical energy is called an **electric motor.**

DC Machine Construction



General arrangement of a dc machine
(Cross- section of typical d.c. machine)

Parts of a D.C Generator

Some of the most important parts of a D.C generators are:

1) **Yoke**

2) **Field system**
  a. Pole core
  b. Pole shoe

$YF\ C^2\ BS$

3) **Conductor system**
a. Armature core
b. Armature winding

4) **Commutator**

5) **Brushes and brush-gears**

6) **Shaft and bearings**

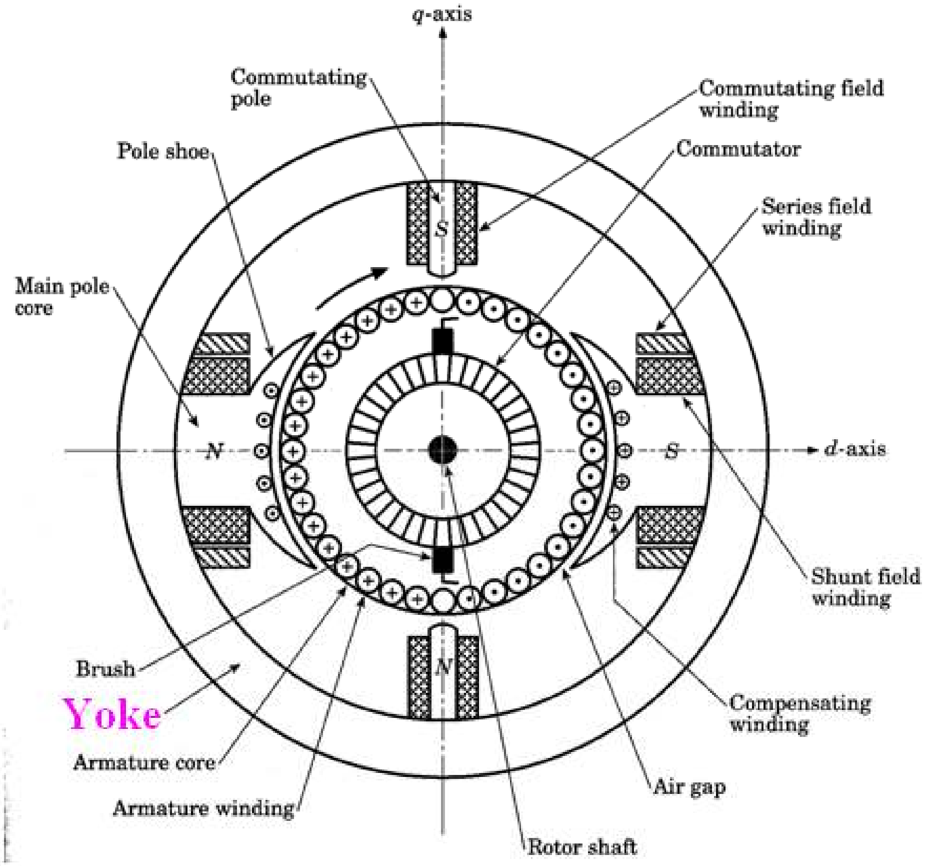
1) Yoke

Functions:

- Outermost cover of the d.c. machine. So that the insulating materials get protected from harmful atmospheric elements like moisture, dust & various gas like SO_2, acidic fumes etc.

- It provides mechanical supports to the poles

- This provides a path for the low reluctance magnetic flux.

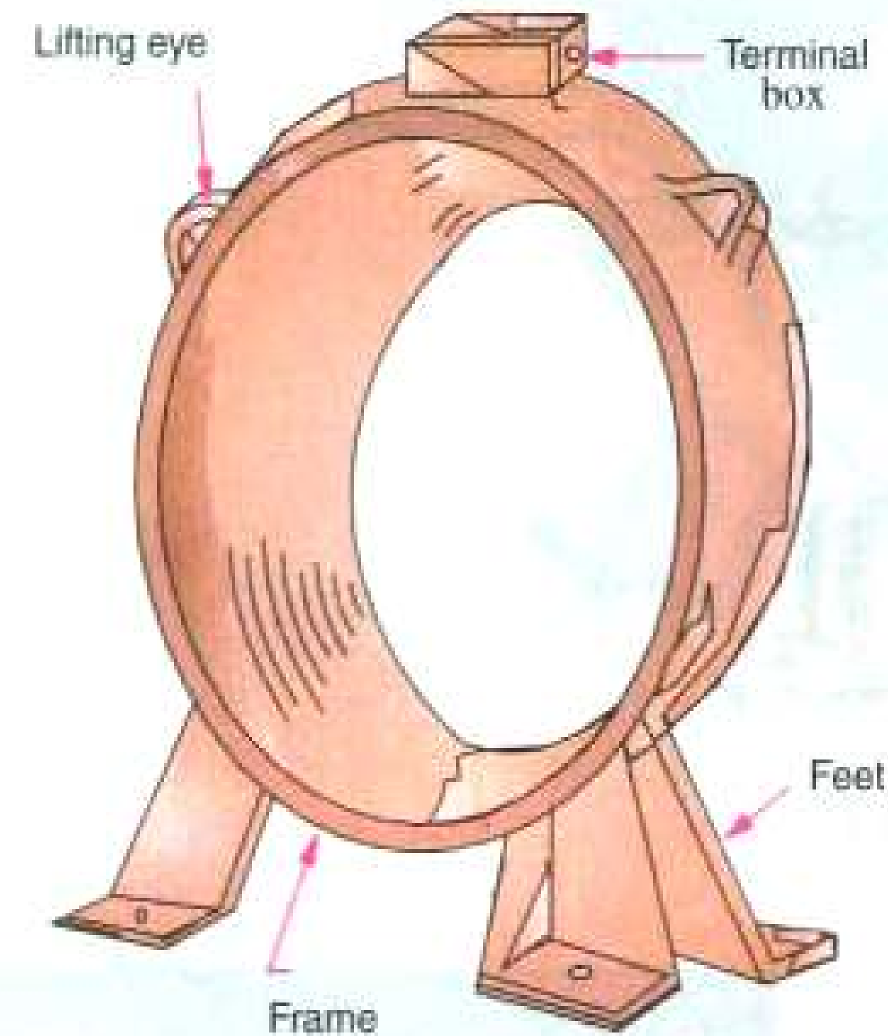


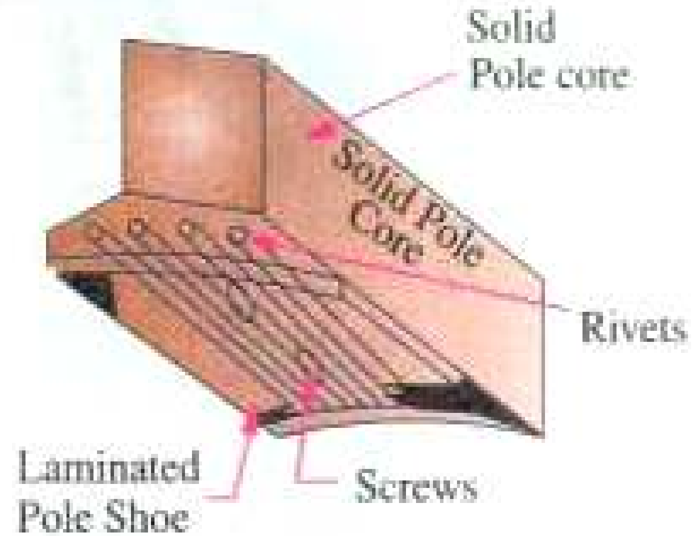
Material:

It is made up of some magnetic material.

It is prepared by using cast iron because it is cheapest.

For large machines rolled steel, cast steel, silicon steel is used which provides high permeability.


Lifting eye
Terminal box
Feet
Frame


Solid Pole core
Solid Pole Core
Rivets
Laminated Pole Shoe
Screws

2) Poles

There are two types of poles

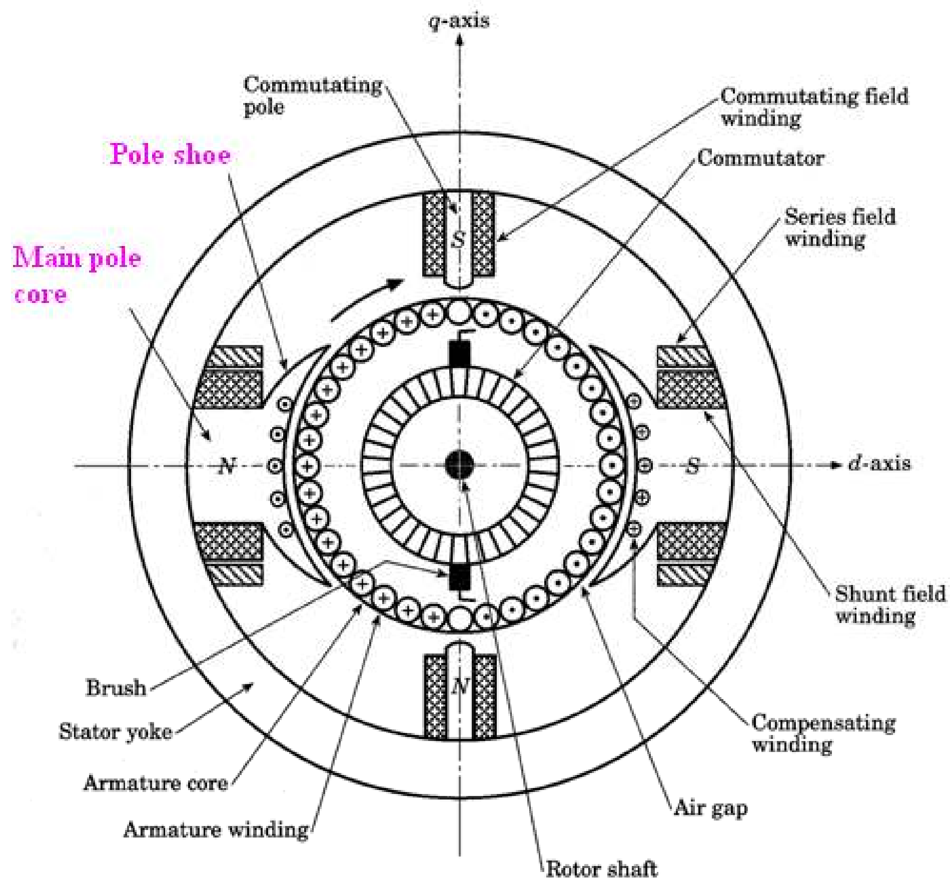
i) Pole core ii) Pole shoe

➢Pole Core:

➢In general a pole core is a rectangular cross- section.

➢Generally used materials for the manufacturing of pole core are either cast iron or wrought iron.

➢Pole core is also called as pole body. The main function of pole body is to act as support for the field coil, which is to be wound around it.

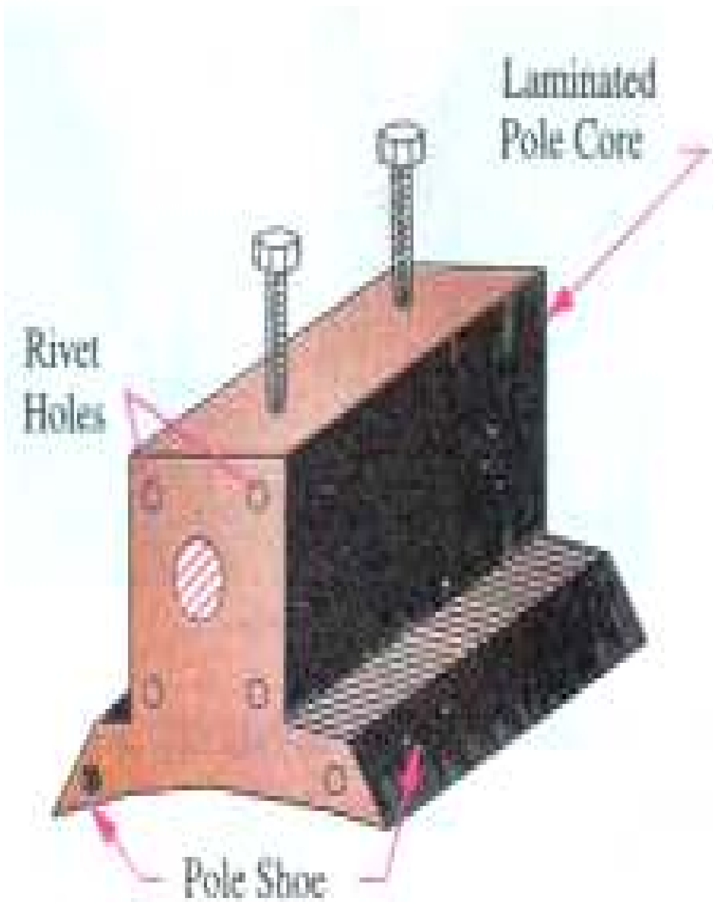


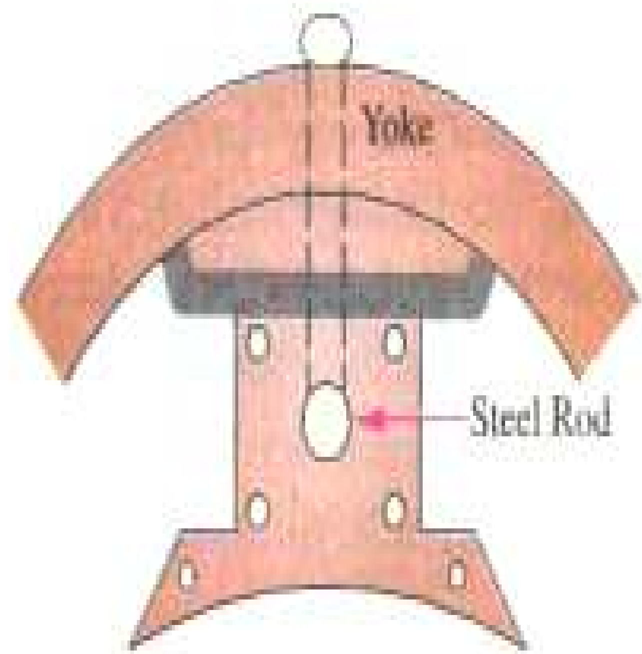
➢Pole shoe :

➢Naturally pole shoe is a projection over pole core and is always with connection with pole body and fills the gap between the yoke and the pole body.

Functions

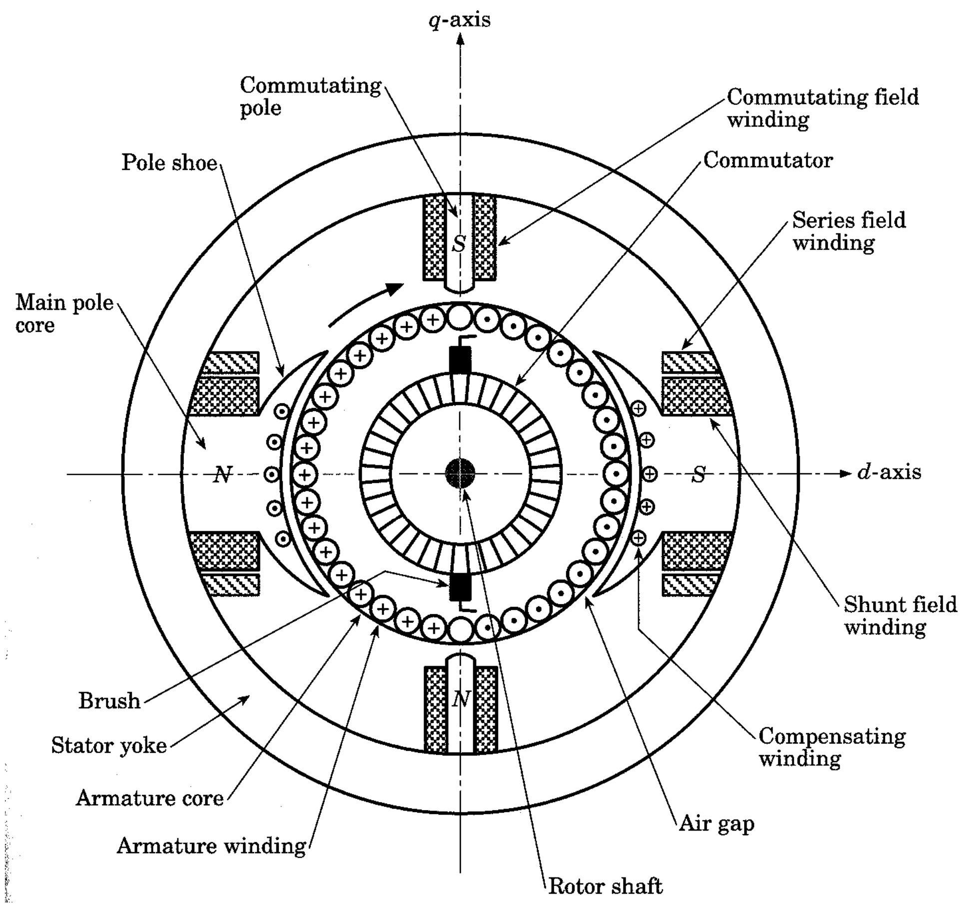
- Supports field coil
- Spreads out magnetic flux over a larger area of the air gap
- Enables the lines of magnetic flux to cross the gap radially.
- The amount air gap under the pole is increased.


Laminated
Pole Core
Rivet
Holes
Pole Shoe


Yoke
Steel Rod

Field Winding:

➢The Field winding is wound on the pole core with a definite direction.

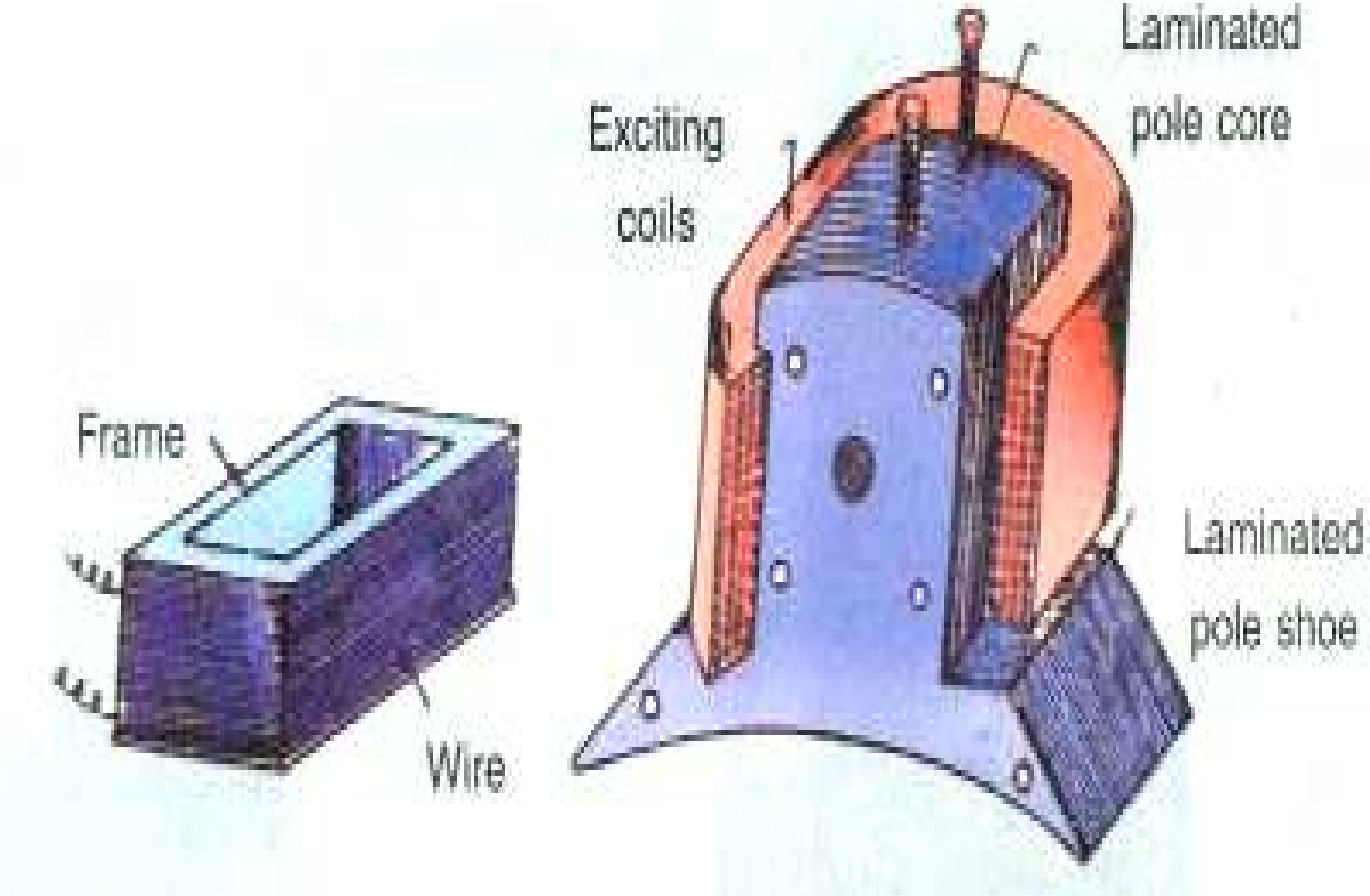


Functions:

➢ To carry current due to which pole core, on which the field winding is placed behaves as an electromagnet, producing necessary flux.

Material:

Made up of conducting material.

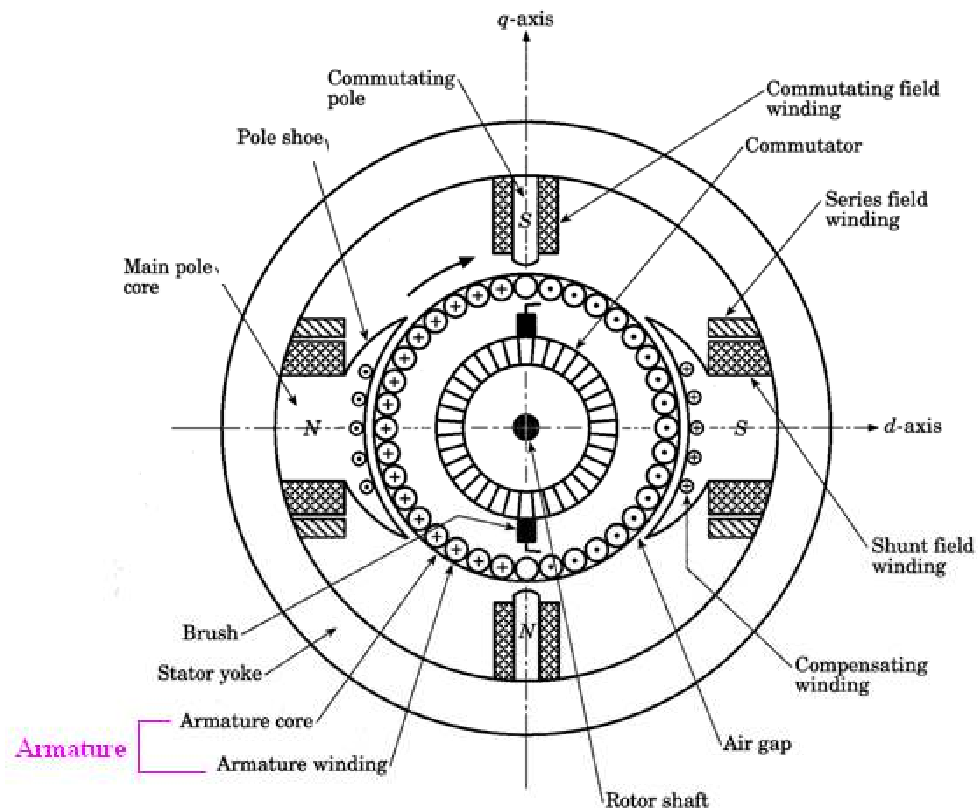

Frame
Wire
Exciting
coils
Laminated
pole core
Laminated
pole shoe

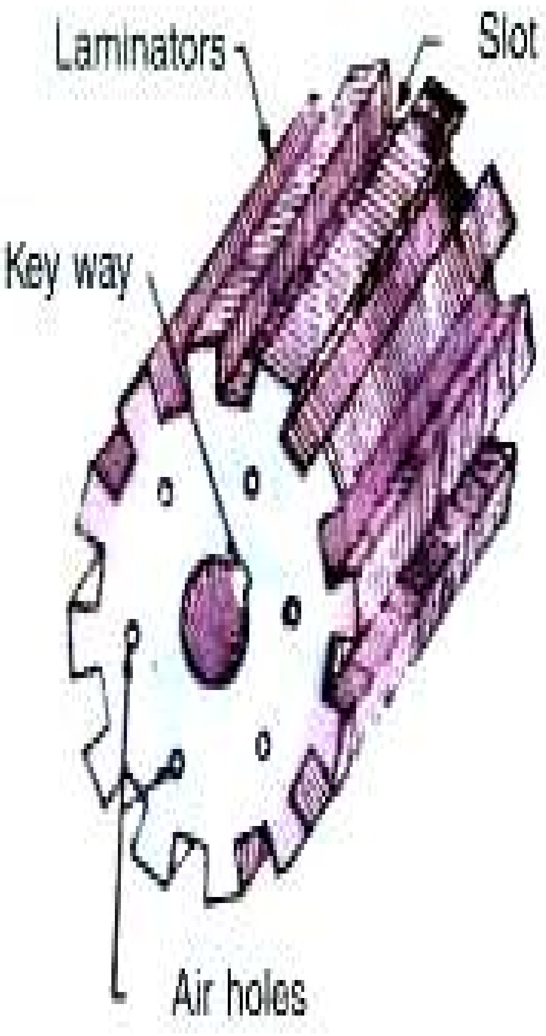
Armature

Armature
a. Armature core
b. Armature winding

Armature core:

- The armature core is a cylindrical structure built in laminations, Mounted on the shaft,
- which is usually made of high grade silicon sheet steel. High grade silicon is used in order to minimize the current losses due to hysteresis.
- Armature core has a main function to act as a support to armature winding.





Laminators
Slot
Key way
Air holes

Slot
Teeth
Key way
Air holes

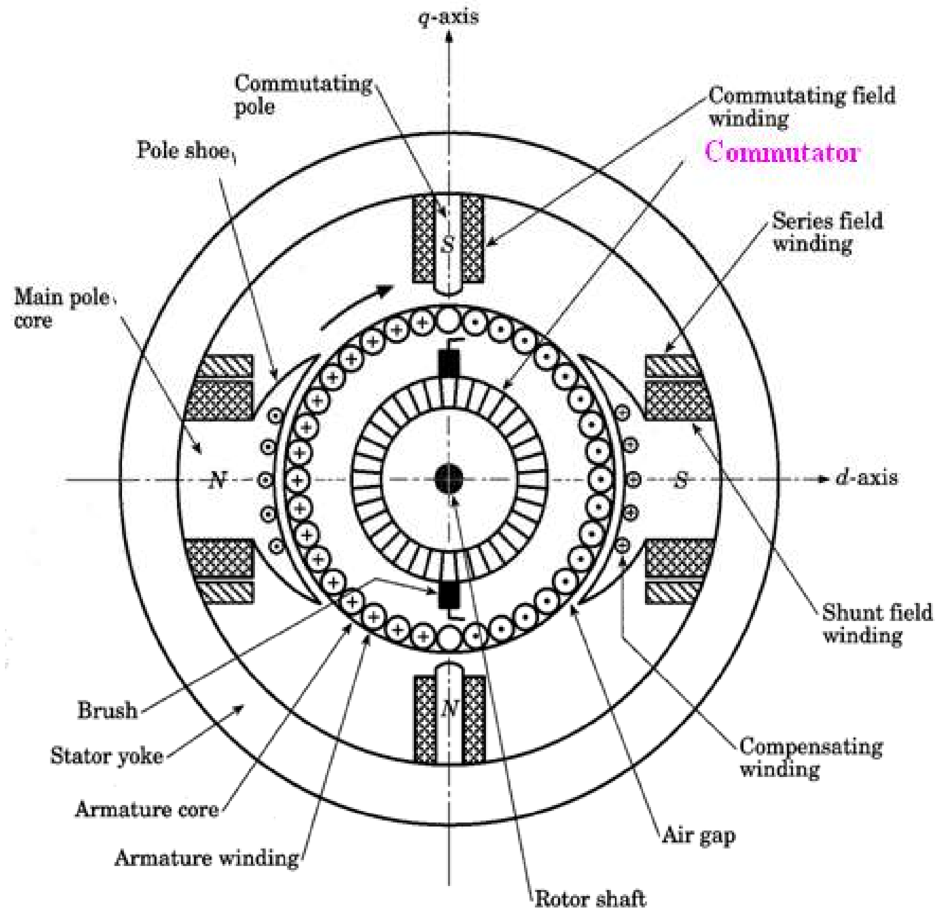
Commutator:

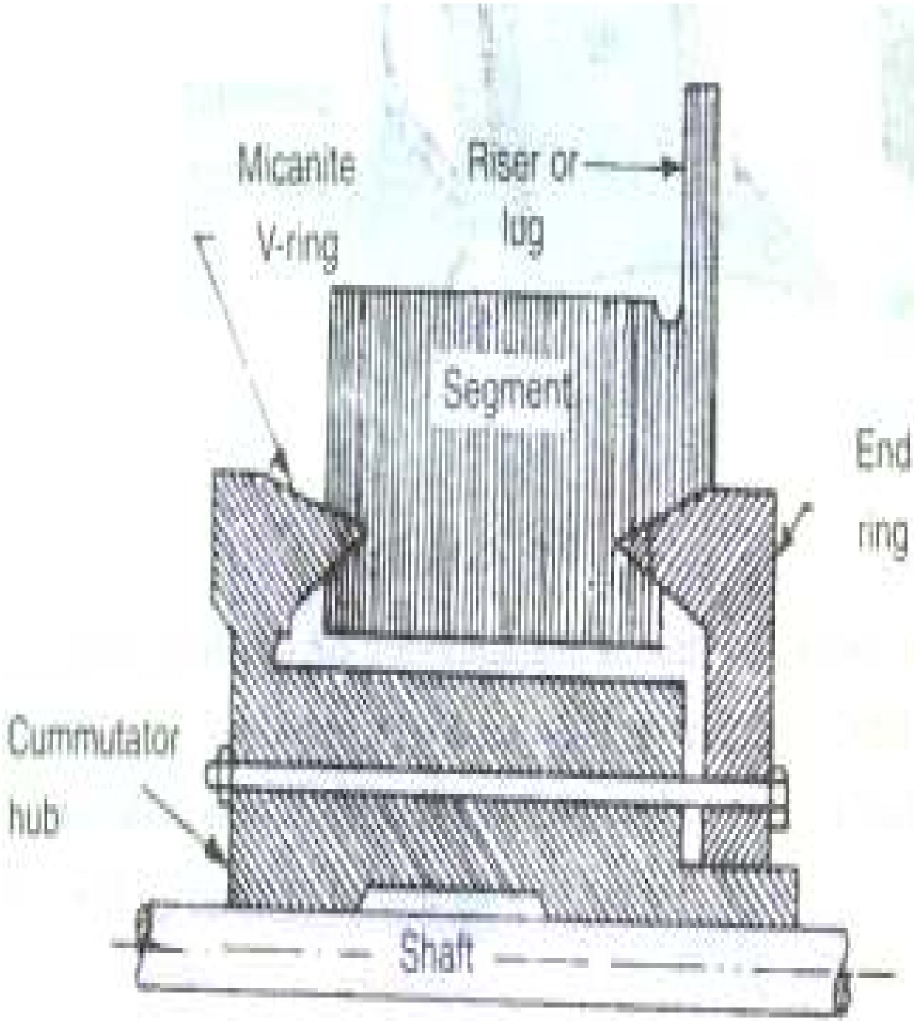
➢Commutator is a most important and vital part in a D.C generator without which the generator fails to work.

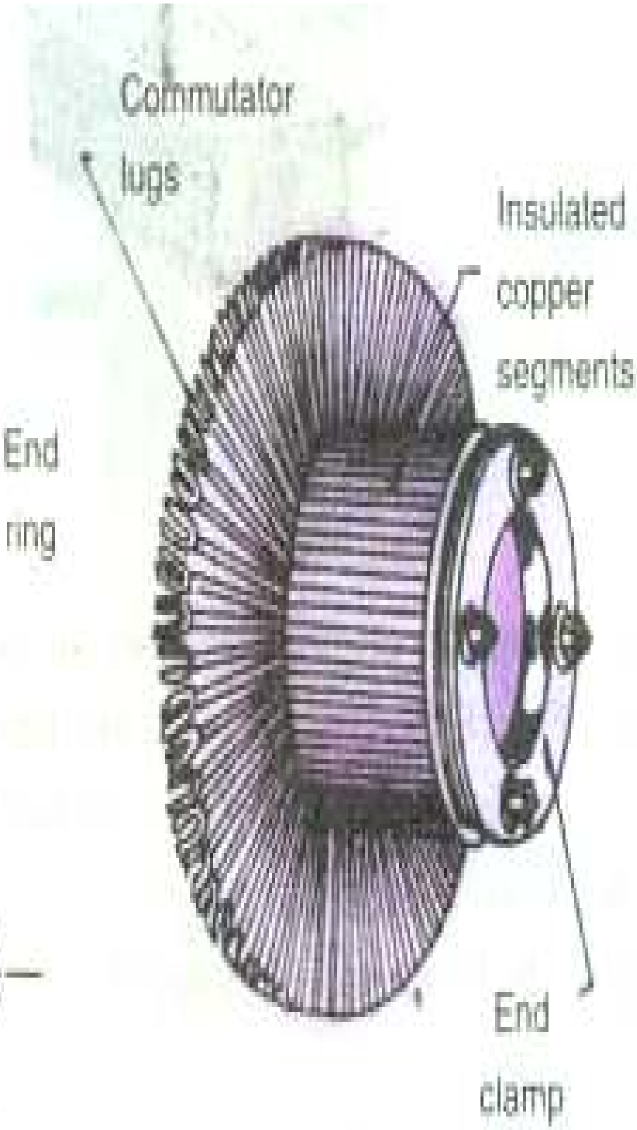
➢Commutator is the part through which one can determine weather the generator is a D.C generator or an A.C.

➢Rectification of current is the main function of the Commutator.

➢It converts the alternating current induced in the armature winding in to un directional current.



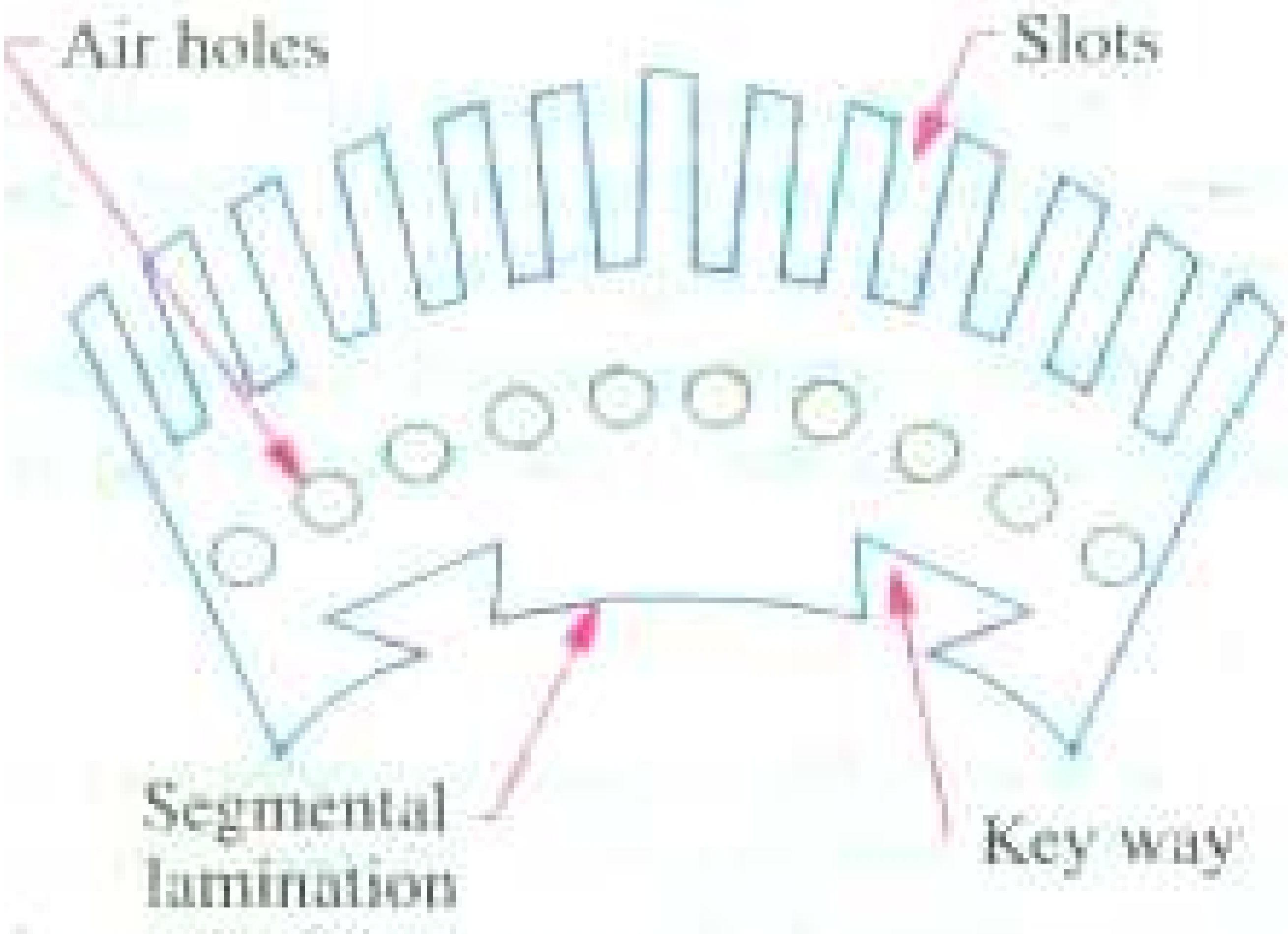

Micanite
V-ring
Riser or
lug
Segment
End
ring
Cummutator
hub
Shaft


Commutator
lugs
Insulated
copper
segments
End
clamp

Armature Winding

Armature winding

Stampings



Brush & Shafts:

➢Brush

➢Brushes and brush gears are used for the transmission of current from the Commutator to the external load circuit.

➢In general carbon is used for the manufacturing of these brushes.

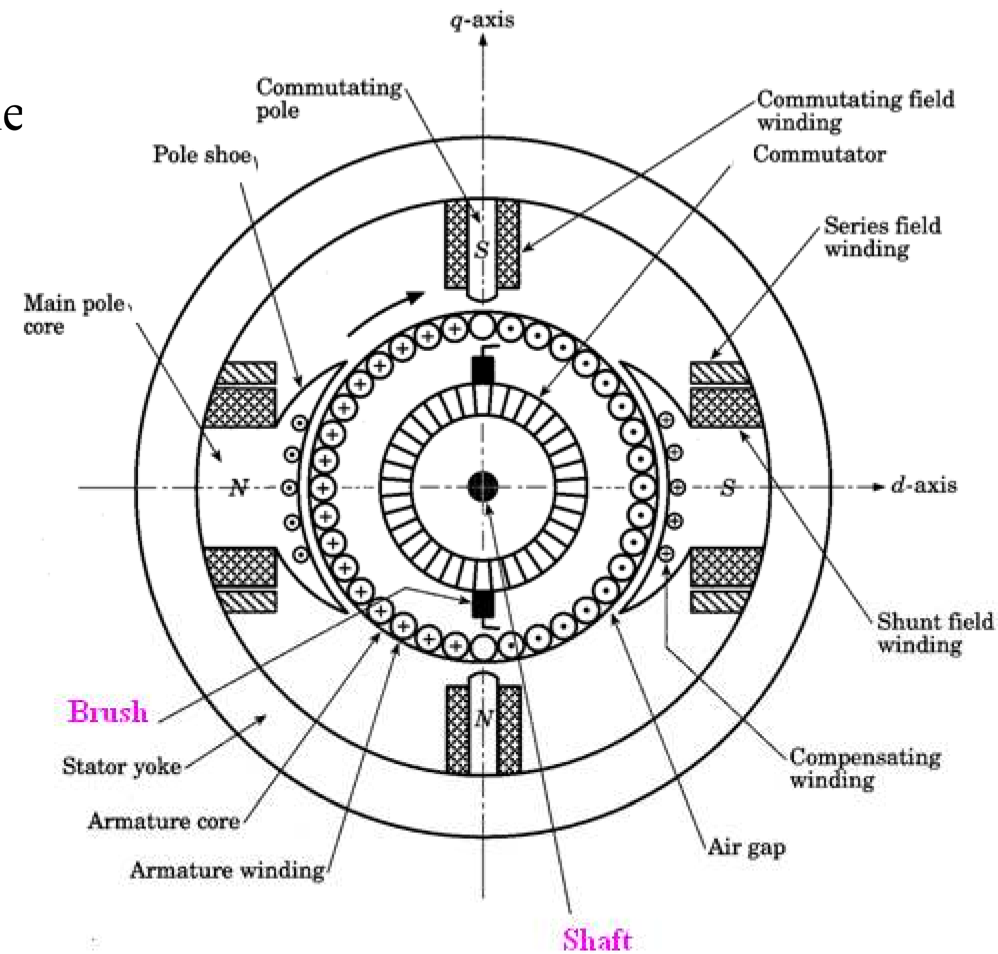
➢They are housed in a box type brush holders which are open at both the ends.

➢Shafts

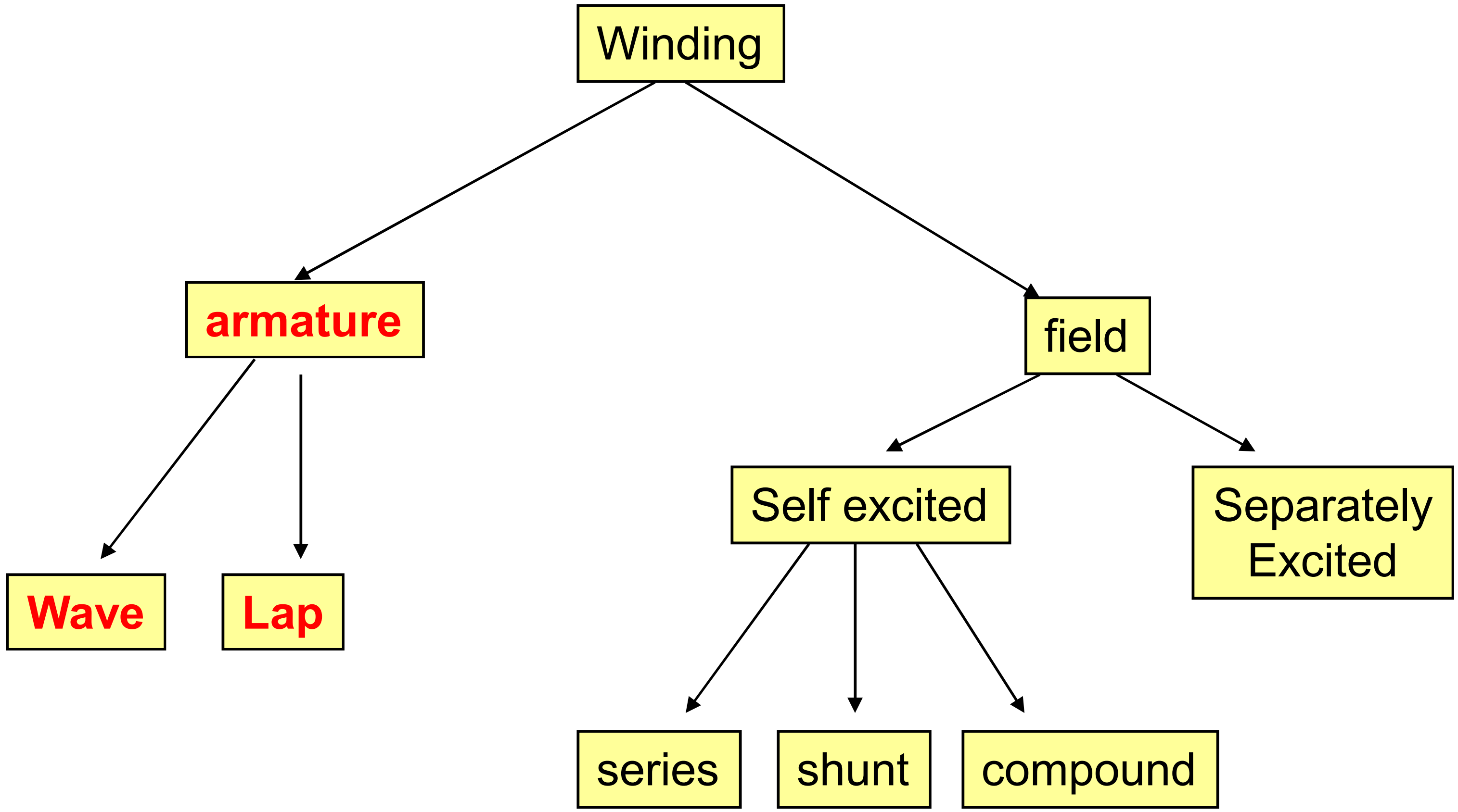
➢Shaft is the central one over which the whole parts are loaded.

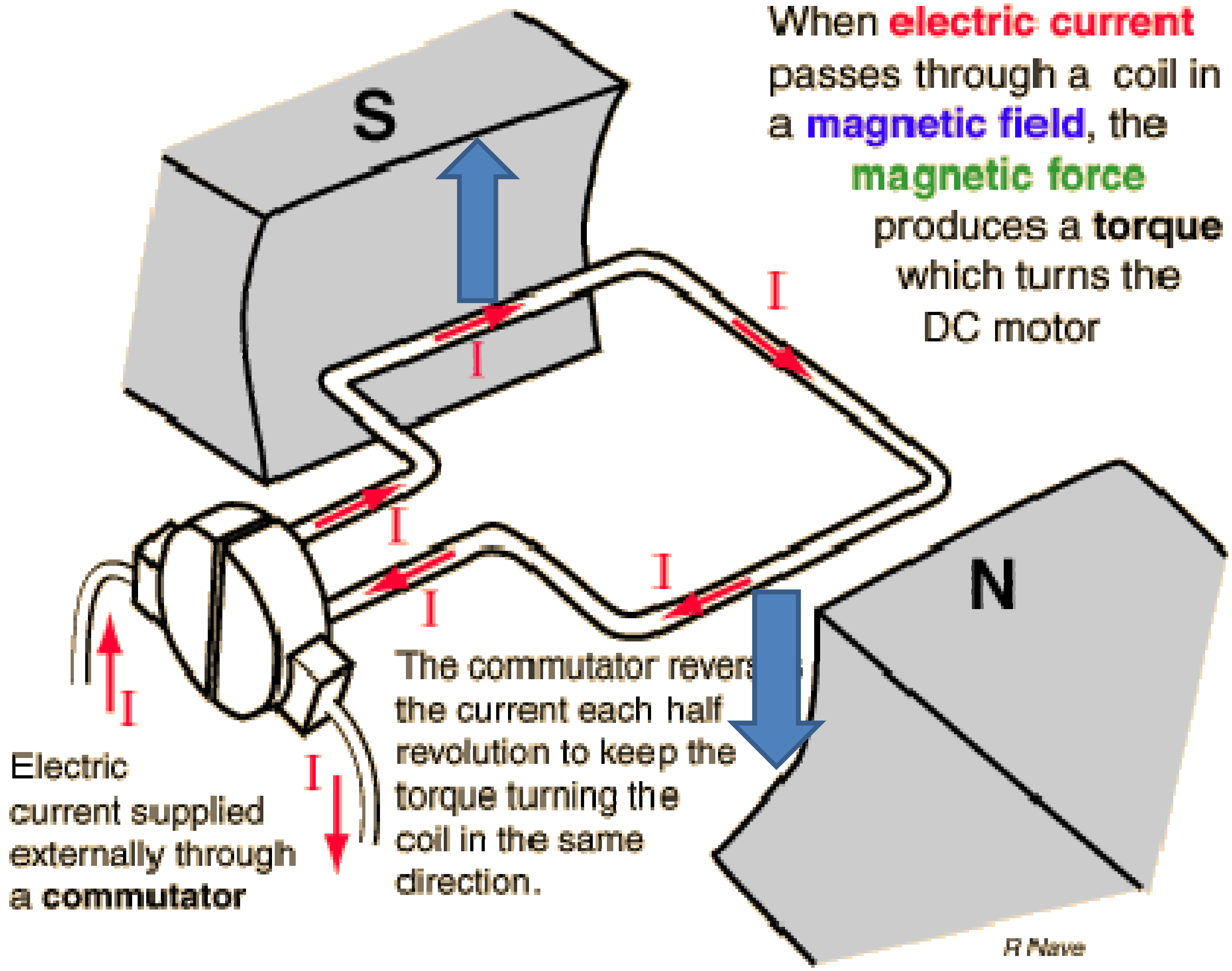
➢Shaft is the only part which transfers the generated power to the storage cell or to the required operation.

➢The shaft is supported on both the ends by bearings which help in easy movement of the shaft as it is the moving part mounted inside non moving parts.



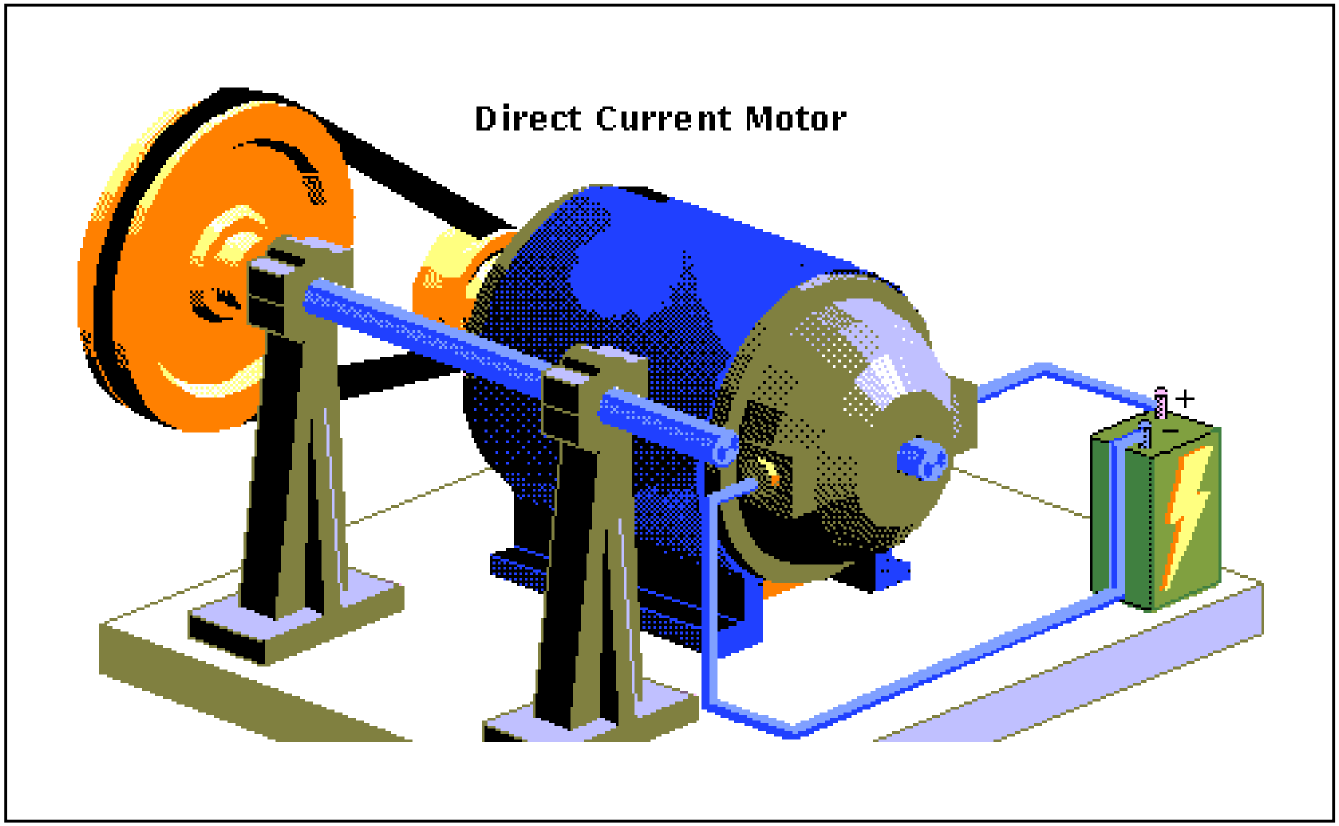
MACHINE WINDINGS





When electric current passes through a coil in a magnetic field, the magnetic force produces a torque which turns the DC motor
S
N
I
The commutator revers[es] the current each half revolution to keep the torque turning the coil in the same direction.
Electric current supplied externally through a commutator
R Nave

Electric Motor



D.C. Motor Principle

- Its operation is based on the principle that when a current carrying conductor is placed in a magnetic field, the conductor experiences a mechanical force.

- Basically, there is no constructional difference between ad.c. motor and a d.c. generator. The same d.c. machine canbe run as a generator or motor.

- The use of a particular motor depends upon the mechanical load it has to drive.

Direction of Rotation of Motor

- The direction of this force is given by Fleming¶s left hand rule and magnitude is given by

$$F = BIl \text{ Newtons}$$

Where,

B = Flux density due to the flux produced by the field winding

l = Active length of the conductor

I = Magnitude of the current passing through the conductor.

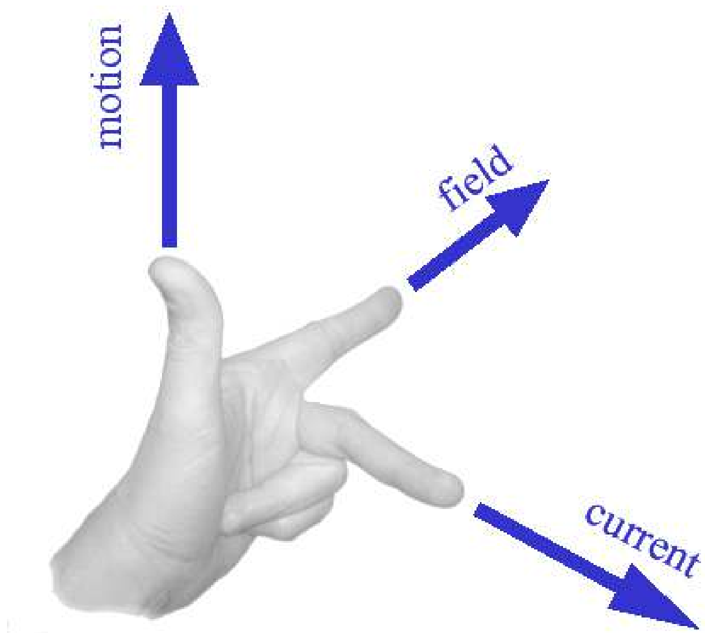
- The direction of such force

i.e. the direction of rotation of motor can be determined by Fleming¶s left hand rule

- Fleming¶s left hand rule is to determined direction of force experienced

i.e. for motoring action.

Fleming’s Left Hand Rule



- Also known as the **Motor Rule** this is a way of determining the direction of a force on a current carrying conductor in a magnetic field.
- The thumb, the first and the second fingers on the left hand are held so that they are at **right angles** to each other
- If the **first finger** points in the direction of the magnetic field
- **Second finger** the direction of the current in the wire,
- **Thumb** will point in the direction of the force on the conductor.

Back or Counter E.M.F.

- When the armature of a d.c. motor rotates under the influence of the driving torque, the armature conductors move through the magnetic field and hence e.m.f. is induced in them.

- As in a generator The induced e.m.f. acts in opposite direction to the applied voltage V(Lenz¶s law) and is known as back or counter e.m.f. Eb.

- It is denoted by Eb.

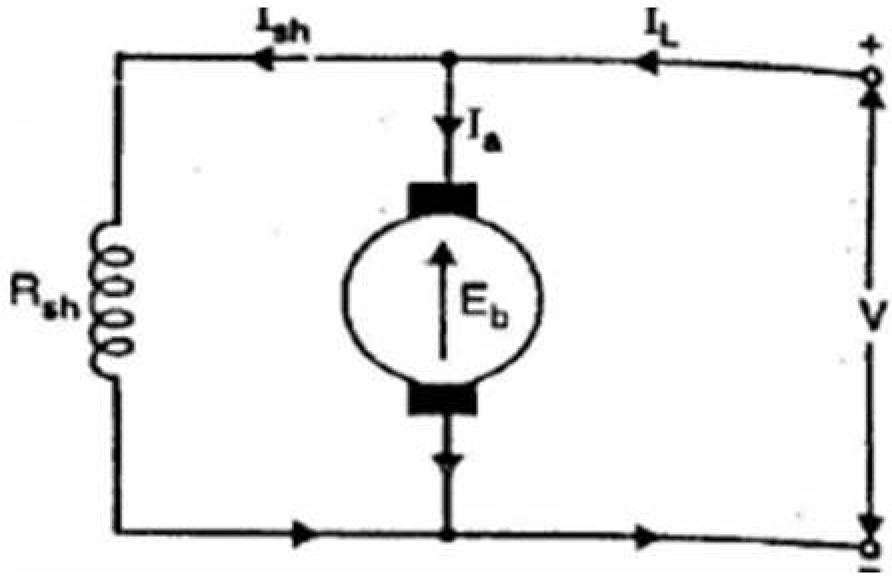
- The back e.m.f.

$$E_b = \frac{\emptyset PNZ}{60A}$$

Eb is always less than the applied voltage V.

Voltage Equation of D.C. Motor :

Let in a d.c. motor (See Fig.),
V = applied voltage
Eb = back e.m.f.
Ra = armature resistance
Ia = armature current



➢Since back e.m.f., Eb acts in opposition to the applied voltage V, the net voltage across the armature circuit is V- Eb.

➢The armature current Ia is given by

$$I_a = \frac{V - Eb}{Ra}$$

or

$$V = E_b + I_a R_a$$

This is known as voltage equation of the d.c. motor.

Power Equation

The voltage equation of d.c. motor is given by,

$$V = E_b + I_a R_a$$

If Eq. above is multiplied by la throughout, we get,

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

This is known as **power equation** of the d.c. motor.

$V I_a$ = electric power supplied to armature(armature input)(Watts)

$E_b I_a$ = power developed by armature(armature output)

$I_a^2 R_a$= electric power wasted in armature(armature Cu loss)

Thus out of the armature input, a small portion (about 5%) is wasted as $I_a^2 R_a$

and the remaining portion $E_b I_a$ is converted into mechanical power within the armature.

This is known as power equation of the d.c. motor.

Condition For Maximum Power:

The Mechanical Power developed by the motor $P_m = E_b I_a$

$$P_m = Gross\ mechanical\ power\ developed$$

$$= VI_a - I_a^2 R_a$$

For Maximum Power P_m , $\frac{dP_m}{dI_a} = 0$

$$0 = V - 2I_a R_a$$

$$I_a R_a = \frac{V}{2}$$

Substituting in voltage equation,

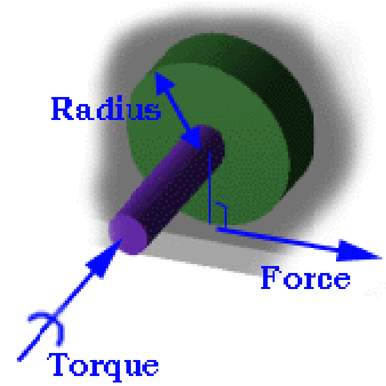
$$V = E_b + I_a R_a$$

$$E_b = \frac{V}{2}$$

Hence mechanical power developed by the motor is maximum when back e.m.f is equal to half the applied voltage .

Torque Equation of a D.C Motor :

- Torque is the turning moment of a force about an axis and is measured by the product of force (F) and radius (r)at right angle to which the force acts .



- Consider a pulley of radius r meter acted upon by a circumferential force of F newton which causes it to rotate at N r.p.m. (See Fig.)

- Then angular speed of the wheel is , $\omega = \frac{2\pi N}{60}\ rad/_{sec}$

So workdone in one revolution is,

$$W = F \times distance\ travelled\ in\ one\ revolution$$

$$= F \times 2\pi R \quad Joules$$

$$P = Power\ developed = \frac{Workdone}{time}$$

$$= \frac{F \times 2\pi R}{time\ for\ 1\ rev} = \frac{F \times 2\pi R}{\frac{60}{N}}$$

$$P = (F \times R) \times \frac{2\pi N}{60}$$

$$P = T \times \omega \quad \text{watts}$$

$$T = \text{Torque in N - m}$$

$$\omega = \text{Angular speed in rad/sec}$$

- Let Ta be the gross torque developed by the armature of the motor.It is also called armature torque.
- The gross mechanical power developed in the armature is Eb Ia (from the power eqn)

$$\text{Power in armature} = \text{Armature torque} \times \omega$$

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

$$E_b = \frac{\phi PNZ}{60A}$$

$$\frac{\phi PNZ}{60A} \times Ia = Ta \times \frac{2\pi N}{60}$$

$$\mathbf{Ta} = \frac{1}{2\pi}\,\varphi\,\mathbf{Ia} \times \frac{\mathbf{PZ}}{\mathbf{A}}$$

$$\mathbf{Ta} = 0.159\,\varphi\,\mathbf{Ia}\,\frac{\mathbf{PZ}}{\mathbf{A}} \quad \mathbf{N\text{-}m}$$

- This is the **torque equation** of a d.c motor

Since Z, P and A are fixed for a given machine

$$\mathrm{Ta} \propto \phi\,\mathrm{Ia}$$

- Hence torque in a d. c motor is directly proportional to the flux per pole and armature current

Shaft Torque

- The torque which is available for doing useful work is known as shaft torque T_{sh} It is so called because it is available at the shaft. The motor output is given by;

OUTPUT = T_{sh} X 2πN Watt provided T_{sh} is in N-m and N in r.p.s.

$$T_{sh} = \frac{\text{OutPut in watts}}{2\pi N/60} \text{ N - m}$$

$$= \frac{60}{2\pi}\frac{OutPut}{N} N - m$$

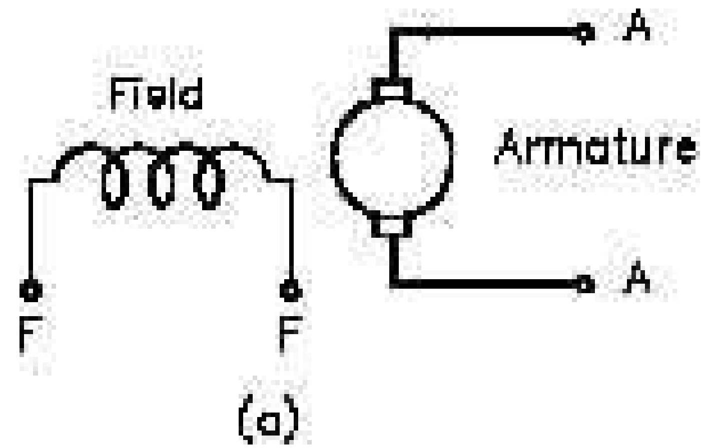
$$= 9.55\frac{Output}{N} N - m$$

The difference (Ta – Tsh) is known as lost torque and is due to iron and friction losses of the motor.

Types of D.C. Motors

➢There are three types of d.c. motors characterized by the connections of field winding in relation to the armature.

➢The circular symbol represents the armature circuit, and the squares at the side of the circle represent the brush commutator system

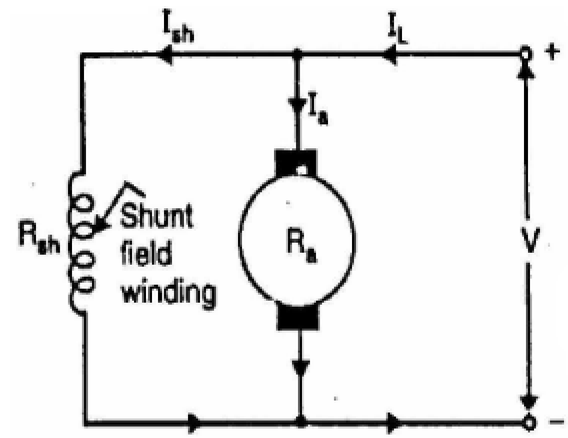


D.C.Motor

- **D. C. Shunt Motor**
- **D.C. Series Motor**
- **D. C. Compound Motor**
  - **Long Shunt**
  - **Short Shunt**

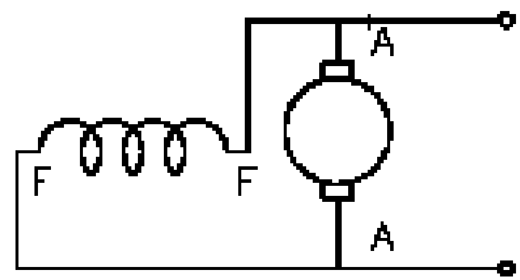
D.C. Shunt Motor

➢In which the field winding is connected in parallel with the armature.



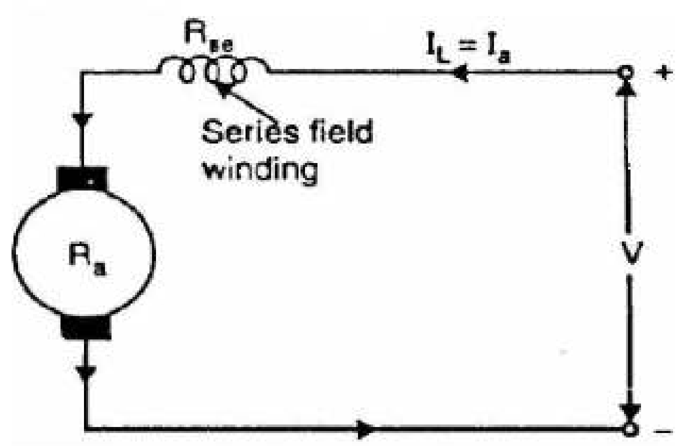
Rsh = The resistance of shunt field winding

Ra = Resistance of armature Winding



➢The Value of Ra is very small while Rsh is quite large.
Hence shunt field winding has more number of turns with less cross sectional area.

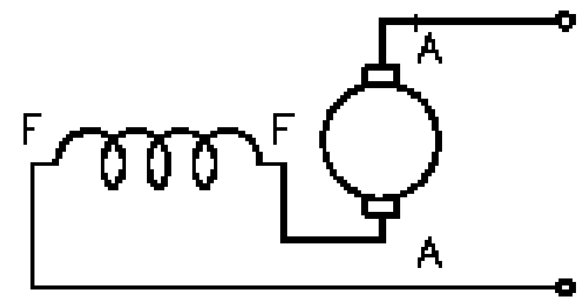
D.C. Series Motor



➢Series motor in which the field winding is connected in series with the armature.

Rse = The resistance of series field winding

Ra = Resistance of armature Winding



➢Rse is very small and it is made of small number of turns having large cross sectional area.

Comparison Between Shunt & Series Field winding

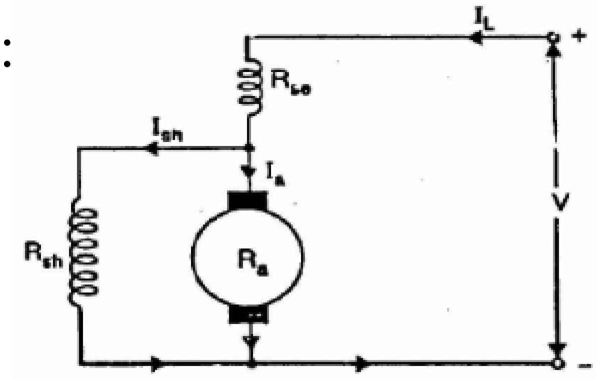
Sr No	Shunt Field Winding	Series Field Winding
1	The resistance is High.	Resistance is Low.
2	The cross sectional area is small thus wire is thin.	The Cross-sectional area is more thus wire is thick.
3	The length is more thus has large number of turns.	The length is small thus has less number of turns.
4	The Current rating is low.	The Current rating is High.
5	Always connected in parallel with the armature.	Always connected in Series with the armature.

D. C. Compound Motor

- Compound-wound motor which has two field windings; one connected in parallel with the armature and the other in series with it.

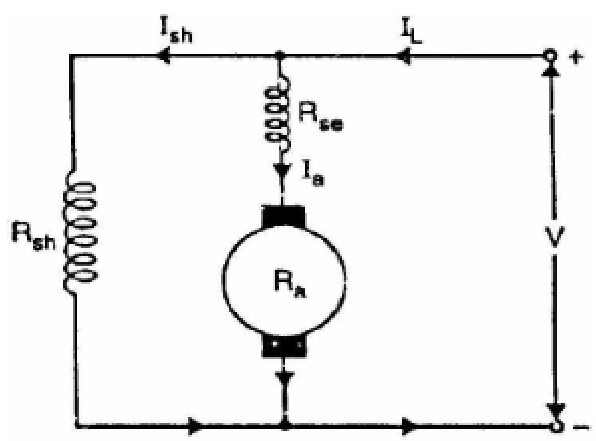
- There are two types of compound motor connections:

- When the shunt field winding is directly connected across the armature terminals , it is called short-shunt connection.



Short-shunt connection

- When the shunt winding is connected that it shunts the series combination of armature and series field.,it is called long-shunt connection.



Long-shunt connection

D.C. Motor Characteristics

Characteristics of Shunt Motors:

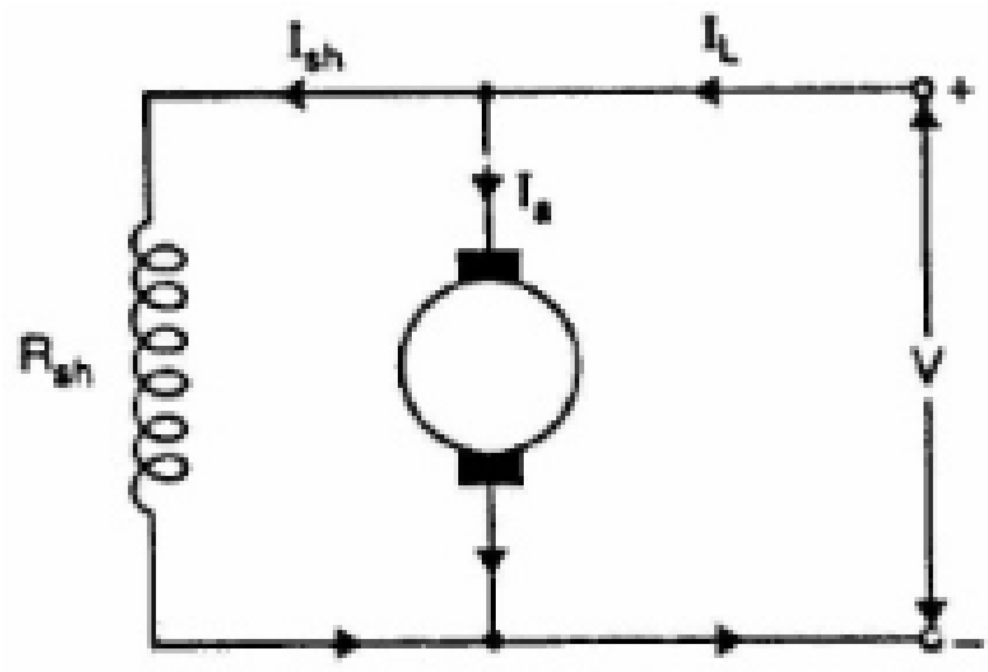


Fig. shows the connections of a d.c. shunt motor. The field current Ish is constant since the field winding is directly connected to the supply voltage V which is assumed to be constant.

Hence,the flux in a shunt motor is approximately constant.

- There are three principal types of d.c. motors viz.,shunt motors, series motors and compound motors. Both shunt and series types have only one field winding wound on the core of each pole of the motor.
- The compound type has two separate field windings woundon the core of each pole

- The performance of a d.c. motor can be judged from its characteristic curves known as motor characteristics,

(i) Torque and Armature current characteristic (Ta/Ia)

- It is the curve between armature torque Ta and armature current I of a d.c. motor. It is also known as electrical characteristic of the motor.

(ii) Speed and armature current characteristic (N/ia)

- It is the curve between speed N and armature current Ia of a d.c. motor. It is very important characteristic as it is often the deciding factor in the selection of the motor for a particular application.

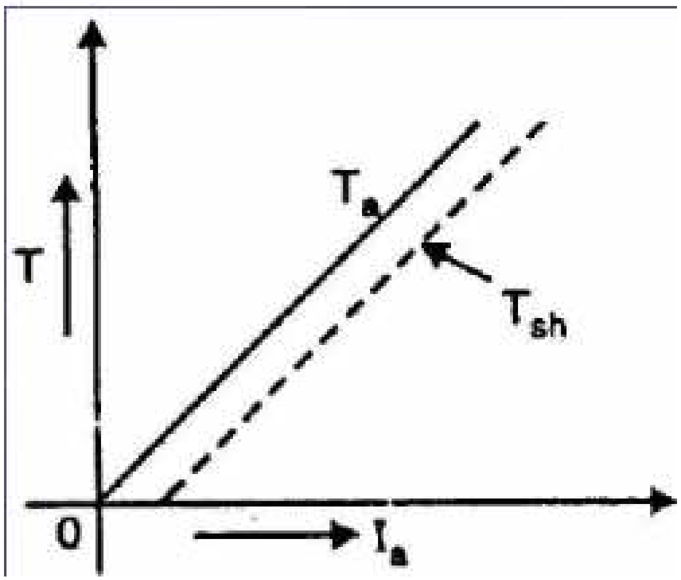
(iii) Speed and torque characteristic (N/Ta)

- It is the curve between speed N and armature torque Ta of a d.c. motor. It is also known as mechanical characteristic.

(i) Ta/Ia Characteristic :

We know that in a d.c. motor

$$T \propto \phi Ia$$



➢Since the motor is operating from a constant supply voltage, flux is constant.

$$Ta \propto Ia$$

Hence Ta/Ia characteristic is a straight line passing through the origin as shown in Fig.

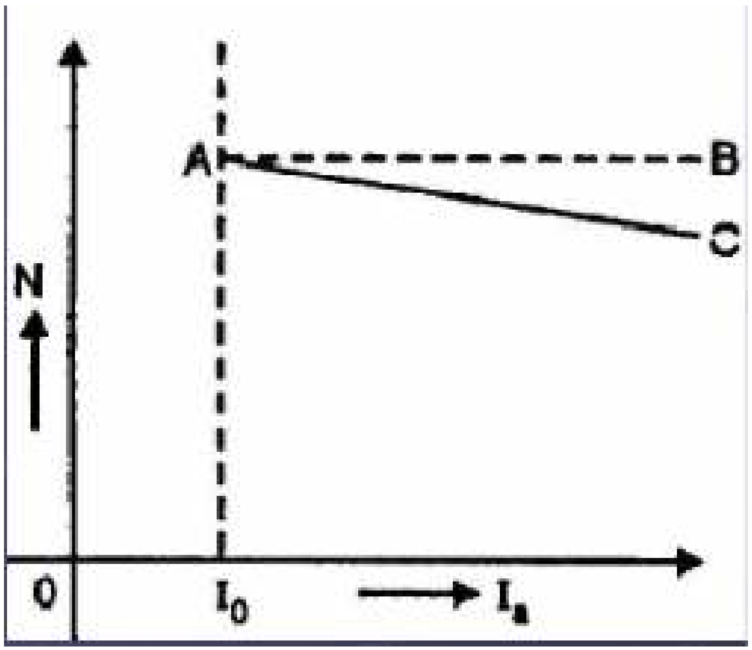
➢The shaft torque (Tsh) is less than Ta and is shown by a dotted line.
➢It is clear from the curve that a very large current is required to start a heavy load.
➢Therefore, a shunt motor should not be started on heavy load.

(ii) N/Ia Characteristic :

The speed N of a. d.c. motor is given by

$$N \propto \frac{E_b}{\phi}$$

The flux ∅ and back e.m.f. Eb in a shunt motor are almost constant under normal conditions

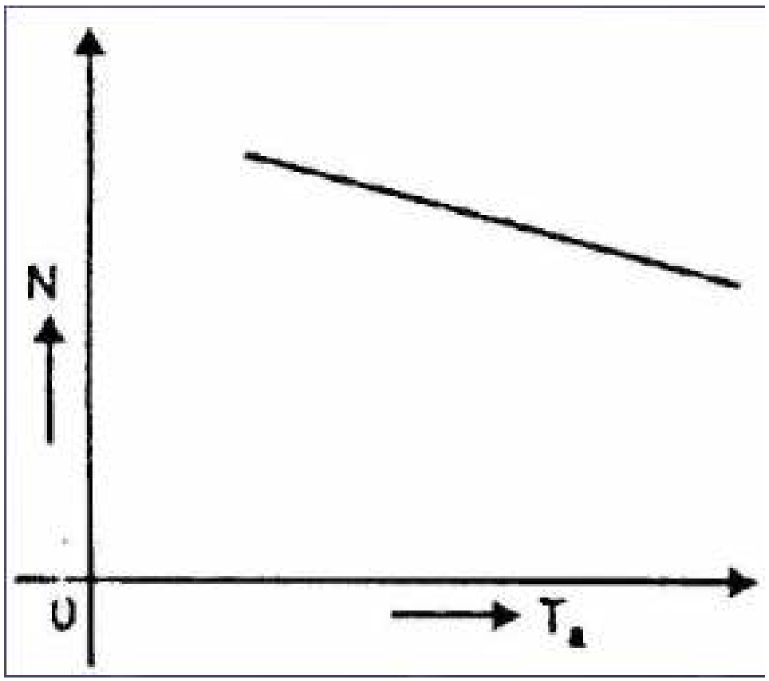


- Therefore, speed of a shunt motor will remain constant as the armature current varies (dotted line AB in Fig.).
- Strictly speaking, when load is increased, Eb (= V- IaRa) and ∅ decrease due to the armature resistance drop.
- However, Eb decreases slightly more than ∅ so that the speed of the motor decreases slightly with load (line AC).

(iii) N/Ta Characteristic :

➢The curve is obtained by plotting the values of N and Ta for various armature currents (See Fig.).

➢It may be seen that speed falls somewhat as the load torque increases.



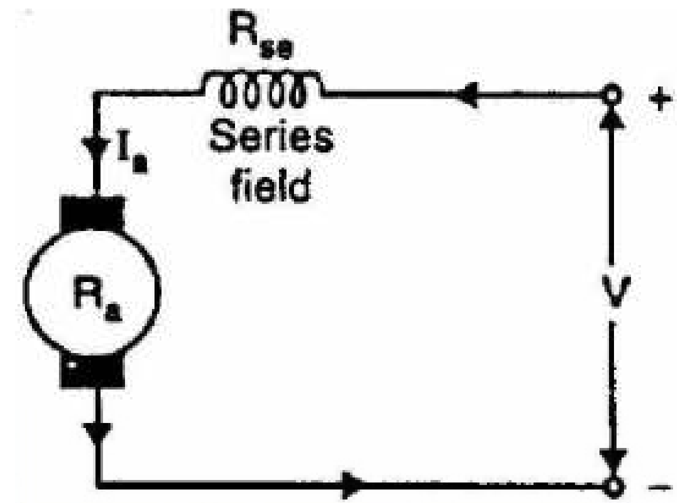
Characteristics of Series Motors

- Fig. shows the connections of a series motor.

- Note that current passing through the field winding is the same as that in the armature.

- If the mechanical load on the motor increases, the armature current also increases.

- Hence, the flux in a series motor increases with the increase in armature current and vice-versa.



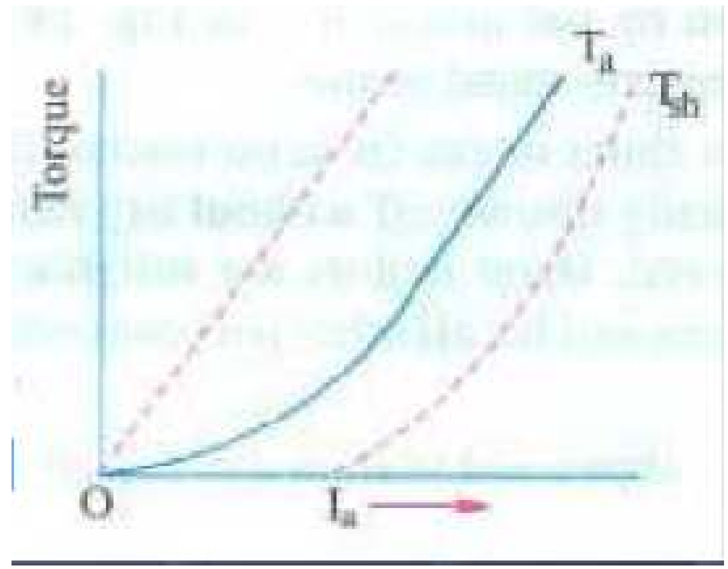
(i) Ta/ Ia Characteristic:

know that $T \propto \phi Ia$

Upto magnetic saturation $\phi \propto Ia$

So that $Ta \propto Ia^2$

After magnetic saturation ,
Ø is constant so that $Ta \propto Ia$



➢Thus upto magnetic saturation, the armature torque is directly proportional to the square of armature current.

➢ If Ia is doubled, Ta is almost quadrupled.

➢Therefore, Ta/Ia curve upto magnetic saturation is aparabola (portion OA of the curve in Fig.).

(ii) N/Ia Characteristic :

The speed N of a series motor is given by

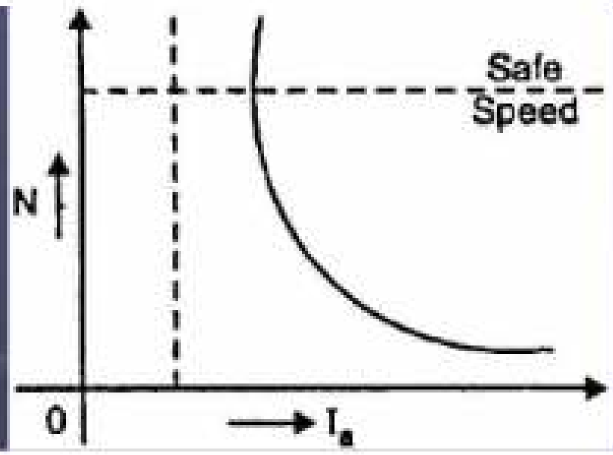
$$N \propto \frac{E_b}{\phi} \qquad \text{where} \qquad E_b = V - I_a(R_a + R_{se})$$

When the armature current increases, the back e.m.f. E_d decreases due to $I_a(R_a + R_{se})$ drop while the flux ϕ increases. However, $I_a(R_a + R_{se})$ drop is quite small under normal conditions and may be neglected.

$$\therefore \quad N \propto \frac{1}{\phi}$$

$$\propto \frac{1}{I_a} \quad \text{upto magnetic saturation}$$

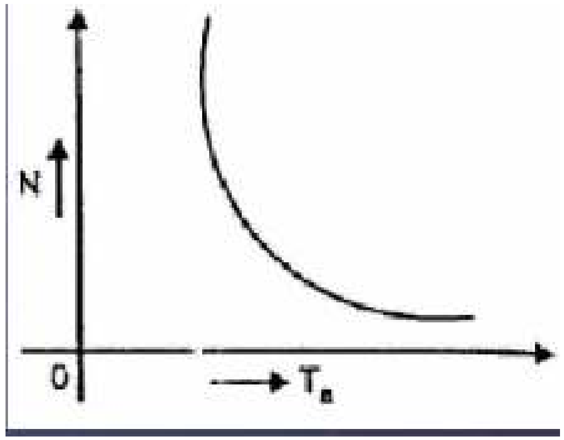
Thus, upto magnetic saturation, the N/I_a curve follows the hyperbolic path as shown in Fig. After saturation, the flux becomes constant and so does the speed.



(iii) N/Ta Characteristic :

The N/Ta characteristic of a series motor is shown in Fig.

It is clear that series motor develops high torque at low speed and vice-versa.



It is because an increase in torque requires an increase in armature current, which is also the field current.

The result is that flux is strengthenedand hence the speed drops. $(\because N \propto 1/\phi)$

Reverse happens should the torque below.

Compound Motors :

A compound motor has both series field and shunt field.

The shunt field is always stronger than the series field. Compound motors are of two types:

(i)Cumulative-compound motors in which series field aids the shunt field.

(ii)Differential-compound motors in which series field opposes the shunt field.

Differential compound motors are rarely used due to their poor torque characteristics at heavy loads.

Characteristics of Cumulative Compound Motors :

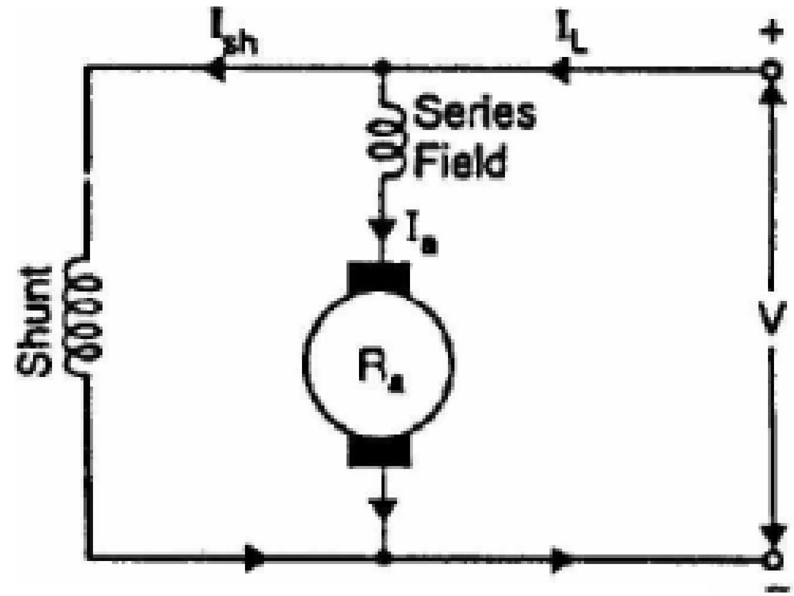
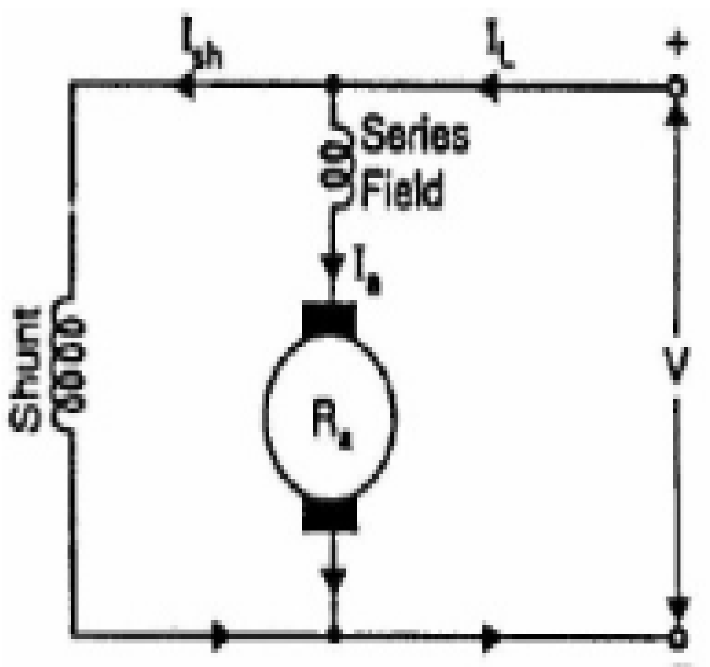
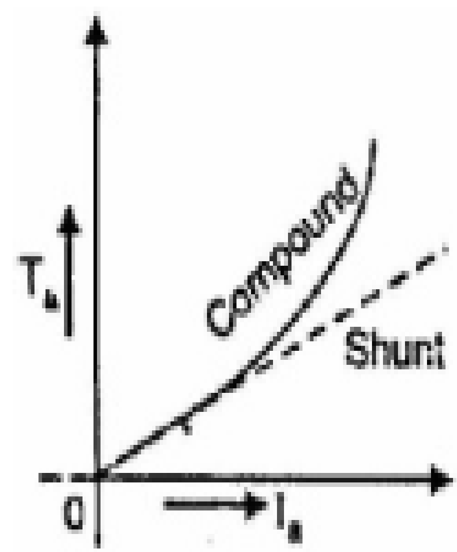


Fig. shows the connections of a cumulative-compound motor. Each pole carries a series as well as shunt field winding the series field aiding the shunt field.

Ta/Ia Characteristic

- As the load increases, the series field increases but shunt field strength remains constant.
- Consequently, total flux is increased and hence the armature torque (Ta∝ φIa).
- It may be noted that torque of a cumulative-compound motor is greater than that of shunt motor for a given armature current due to series field.



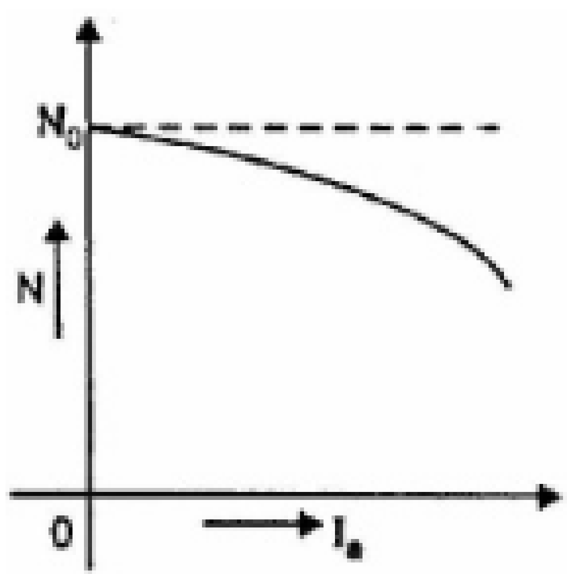


(ii)N/IaCharacteristic

As explained above, as the lead increases, the flux per pole also increases. Consequently, the speed ($N \propto 1/\varphi$) of the motor tails as the load increases (See Fig).

It may be noted that as the load is added, the increased amount of flux causes the speed to decrease more than does the speed of a shunt motor.

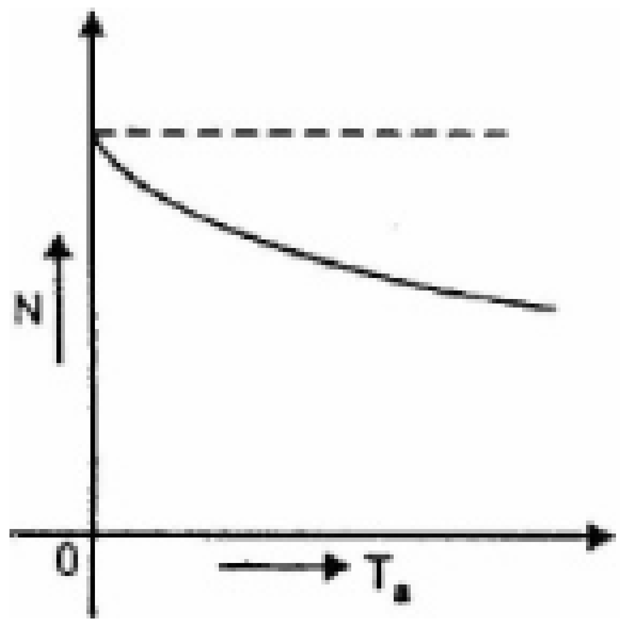
Thus the speed regulation of a cumulative compound motor is poorer than that of a shunt motor.



(iii)N/TaCharacteristic

Fig. shows N/Ta characteristic of a cumulative compound motor.

For a given armature current, the torque of a cumulative compound motor is more than that of a shunt motor but less than that of a series motor.



D.C. shunt motor starter

STARTERS

- **Starters are used for large dc Motors**

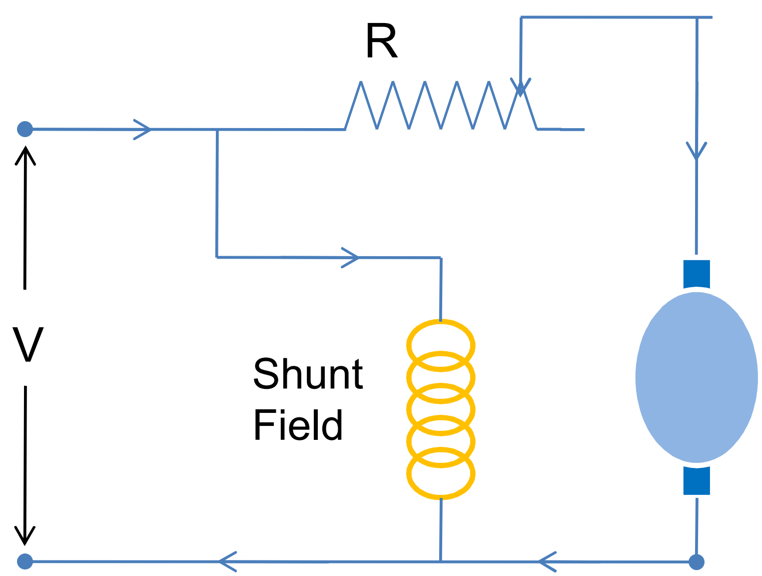
Necessity of a starter:

- **To reduce damage the commutator and brushes due to high current at starting.**

TYPES OF D.C MOTOR STARTER

1. Two point starter
2. Three point starter
3. Four point starter

- The starting operation of a d.c. motor consists in the insertion of external resistance into the armature circuit to limit the starting current taken by the motor and the removal of this resistance in steps as the motor accelerates.
- When the motor attains the normal speed, this resistance is totally cut out of the armature circuit.



At Starting

$$V = I_a R_a + E_a$$

$$I_a = \frac{V - E_a}{R_a}$$

Necessity of D.C. Motor Starter:

➢At starting, when the motor is stationary, there is no back e.m.f. in the armature. Consequently, if the motor is directly switched on to the mains, the armature will draw a heavy current ($I_a = V/R_a$) because of small armature resistance.

➢As an example, 5 H.P., 220 V shunt motor has a full-load current of 20 A and an armature resistance of about 0.5Ω.If this motor is directly switched on to supply, it would take an armature current of 220/0.5 = 440 A which is 22 times the full-load current. This high starting current may result in:

➢This high starting current may result in:
(i) burning of armature due to excessive heating effect,
(ii) damaging the commutator and brushes due to heavy sparking

➢In order to avoid excessive current at starting, a variable resistance (known as starting resistance) is inserted in series with the armature circuit. This resistance is gradually reduced as the motor gains speed (and hence E_b increases)

➢The value of starting resistance is generally such that starting current is limited to1.25 to 2 times the full-load current.

Types of D.C. Motor Starters:

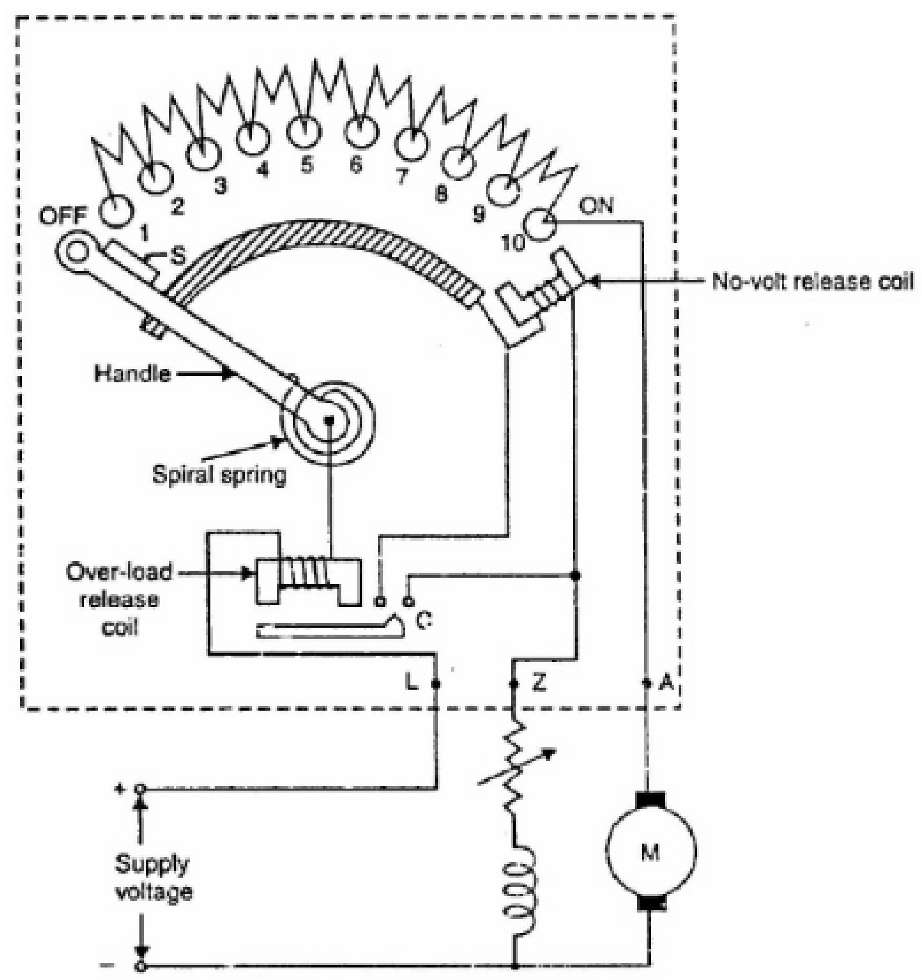
1) Three-point starter

2) Four-point starter

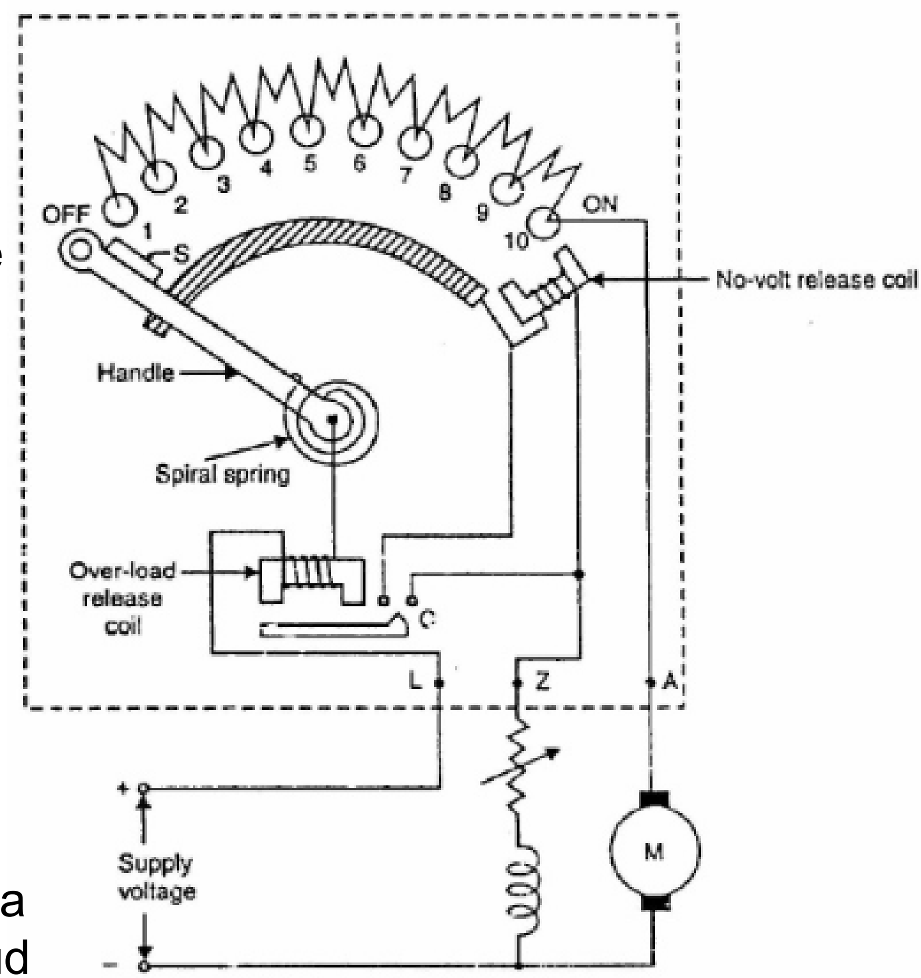
Three-Point Starter:

➢ This type of starter is widely used for starting shunt and compound motors.

➢ Shows the schematic diagram of a three-point starter for a shunt motor with protective devices. It is so called because it has three terminals L, Z and A.



- The starter consists of starting resistance divided into several sections and connected in series with the armature.



- The tapping points of the starting resistance are brought out to a number of studs.
- The three terminals L, Z and A of the starter are connected respectively to the positive line terminal, shunt field terminal and armature terminal.
- The other terminals of the armature and shunt field windings are connected to the negative terminal of the supply.
- The no-volt release coil is connected in the shunt field circuit.
- One end of the handle is connected to the terminal L through the over-load release coil.
- The other end of the handle moves against a spiral spring and makes contact with each stud during starting operation

Operation

(i) To start with, the d.c. supply is switched on with handle in the OFF position.

(ii) The handle is now moved clockwise to the first stud. As soon as it comes in contact with the first stud, the shunt field winding is directly connected across the supply, while the whole starting resistance is inserted in series with the armature circuit.

(iii) As the handle is gradually moved over to the final stud, the starting resistance is cut out of the armature circuit in steps. The handle is now held magnetically by the no-volt release coil which is energized by shunt field current.

iv) If the supply voltage is suddenly interrupted or if the field excitation is accidentally cut, the no-volt release coil is demagnetized and the handle goes back to the OFF position under the pull of the spring. If no-volt release coil were not used, then in case of failure of supply, the handle would remain on the final stud. If then supply is restored, the motor will be directly connected across the supply, resulting in an excessive armature current.

(v) If the motor is over-loaded (or a fault occurs), it will draw excessive current from the supply. This current will increase the ampere-turns of the over-load release coil and pull the armature C, thus short-circuiting the no-volt release coil. The no-volt coil is demagnetized and the handle is pulled to the OFF position by the spring. Thus, the motor is automatically disconnected from the supply.

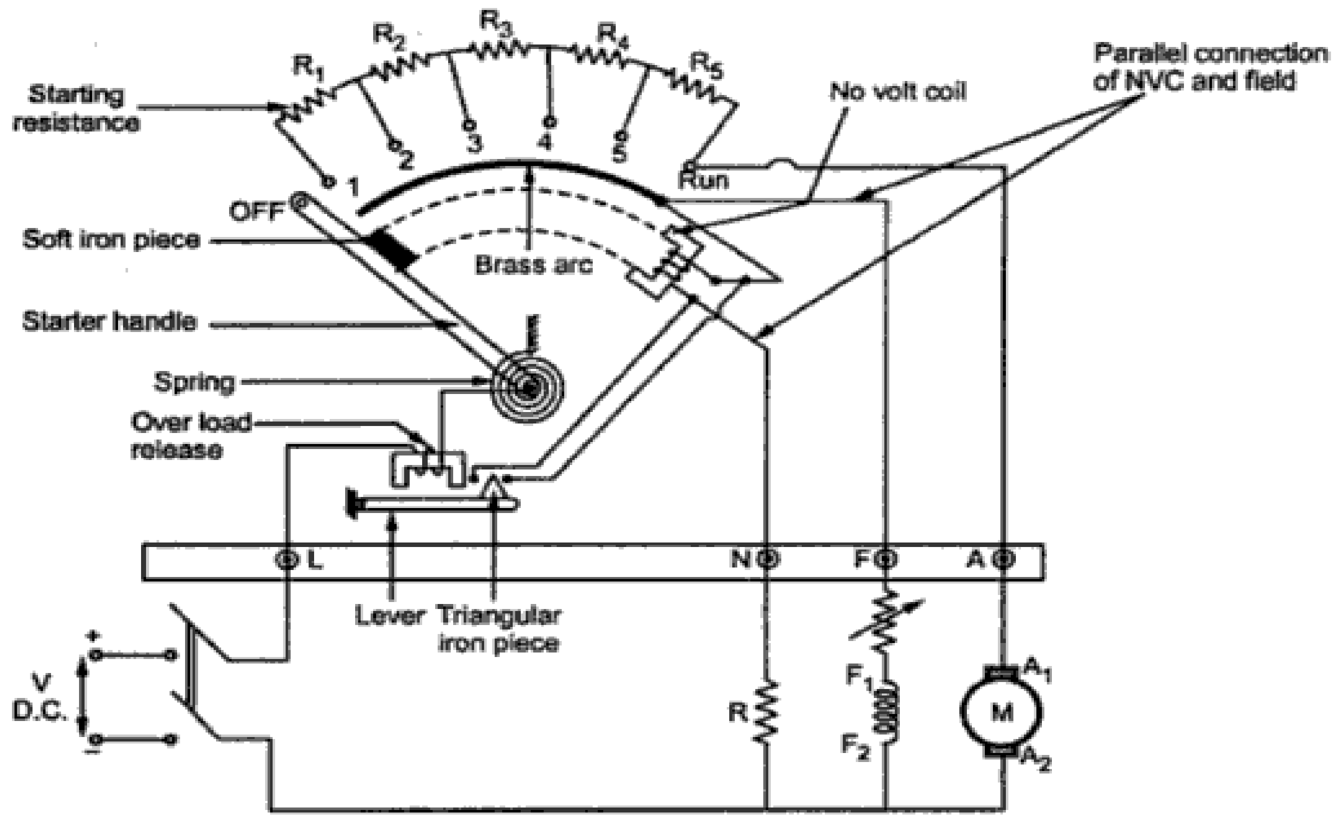
➢Drawback:

In a three-point starter, the no-volt release coil is connected in series with the shunt field circuit so that it carries the shunt field current. While exercising speed control through field regulator, the field current may be weakened to such an extent that the no-volt release coil may not be able to keep the starter arm in the ON position. This may disconnect the motor from the supply when it is not desired. This drawback is overcome in the four point starter.

Four-Point Starter:

➢In a four-point starter, the no-volt release coil is connected directly across the supply line through a protective resistance R.

➢Now the no-volt release coil circuit is independent of the shunt field circuit. Therefore, proper speed control can be exercised without affecting the operation of no-volt release coil



4 point Starter

Applications of D.C. Motors :

1. Shunt motors :The characteristics of a shunt motor reveal that it is an approximately constant speed motor.
   It is, therefore, used

(i)where the speed is required to remain almost constant from no-load to full-load

(ii) where the load has to be driven at a number of speeds and any one of which is required to remain nearly constant

Industrial use: Lathes, drills, boring mills, shapers, spinning and weaving machines etc

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2. Series motors :

It is a variable speed motor.
i.e., speed is low at high torque and vice-versa.
However, at light or no-load, the motor tends to attain dangerously high speed. The motor has a high starting torque. It is, therefore, used

(i) where large starting torque is required e.g., in elevators and electric traction
(ii) where the load is subjected to heavy fluctuations and the speed is automatically required to reduce at high torques and vice-versa
Industrial use: Electric traction, cranes, elevators, air compressors, vacuum cleaners, hair drier, sewing machines etc.

3. Compound motors :

Differential-compound motors are rarely used because of their poor torque characteristics.

However, cumulative-compound motors are used where a fairly constant speed is required with irregular loads or suddenly applied heavy loads.

Industrial use: Presses, shears, reciprocating machines etc.