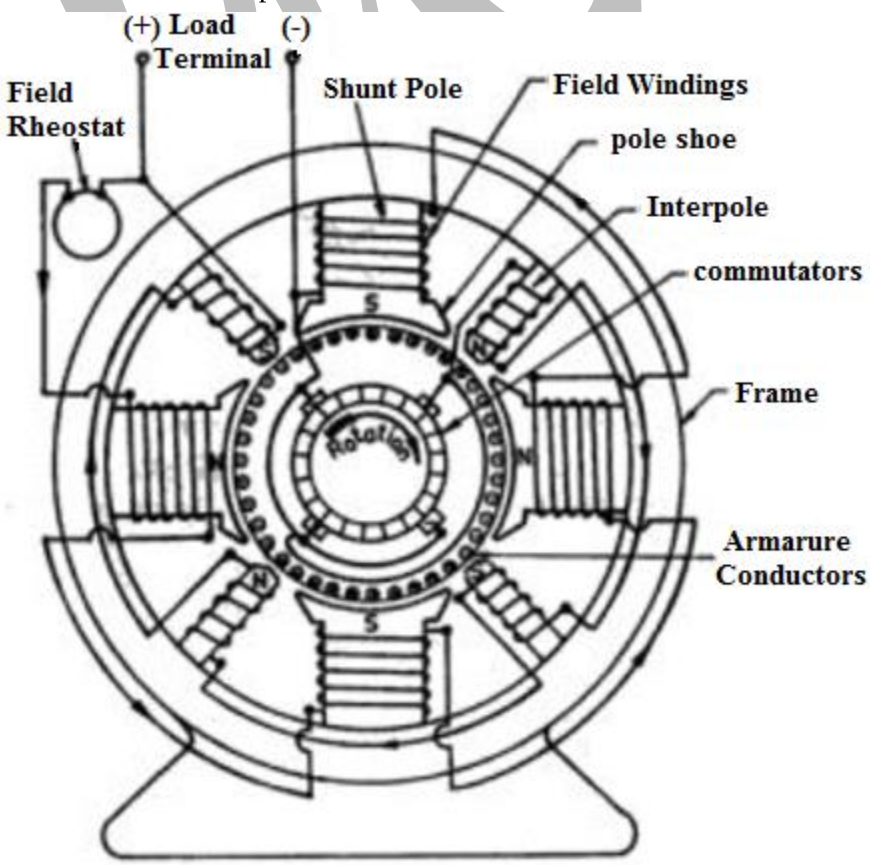
UNIT- 3rd - Rotating Electric Machine

✓ D.C. MACHINES

- **Principles of D.C. machines**:- D.C. machines are the electro mechanical energy converters which either work from a d.c. source and generate mechanical power or convert mechanical power into a d.c. power.

Generator action: An emf(voltage) is induced in a conductor if it moves through a magnetic field.
Motor action:A force is induced in a conductor that has a current going through it and placed in a magnetic field
Note:- Any DC machine can act either as a generator or as a motor.

- **Construction of DC machines:-** A D.C. machine consists of two part the stationary part called stator and the rotating part called rotor. The stator consists of main poles used to produce magnetic flux ,commutating poles or interpoles in between the main poles to avoid sparking at the commutator .In case of small machines the interpoles may be avoided and finally the stator is housed in the frame or yoke which forms the supporting structure of the machine. The rotor consist of an armature i.e. a cylindrical metallic body or core with slots in it to place armature windings ,a commutator and brush gears . The magnetic flux path in a motor or generator is called the magnetic structure of generator or motor. The major parts of a DC machine are
1. Frame & Yoke **2.** Poles **3.**Windings **4.** Armature **5.** Commutator and brush gear **6.** Commutating poles **7.** End shield & wearing **8.** Shaft & some Other mechanical parts



1) Frame Frame is the stationary part of a machine on which the main poles and commutator poles are bolted and it forms the supporting structure by connecting the frame to the bed plate. The ring shaped body portion of the frame which makes the magnetic path for the flow of magnetic fluxes from the main poles and interpoles is called **Yoke.**
***It provides mechanical protection to the inner part of the machine.**
***It provide the low reluctance path for the flow of magnetic flux.**

Why we use cast steel instead of cast iron for the construction of Yoke?
In early days Yoke was made up of cast iron but now it is replaced by cast steel.This is because cast iron is saturated by a flux density of 0.8 Wb/sq.m where as saturation of cast iron steel is about 1.5 Wb/sq.m.So for the same magnetic flux density the cross section area needed for cast steel is less than cast iron hence the weight of the machine can be reduced using cast steel.If we use cast iron there may be chances of blow holes in it while casting , now rolled steels are developed and these have consistent magnetic and mechanical properties.

2) Main poles: Solid poles of fabricated steel with separate/integral pole shoes are fastened to the frame by means of bolts. Pole shoes are generally laminated. Sometimes pole body and pole shoe are formed from the same laminations. The pole shoes are shaped so as to have a slightly increased air gap at the tips. Inter-poles are small additional poles located in between the main poles. These can be solid, or laminated just as the main poles. These are also fastened to the yoke by bolts. Sometimes the yoke may be slotted to receive these poles. The inter poles could be of tapered section or of uniform cross section. These are also called as commutating poles or com poles. The width of the tip of the com pole can be about a rotor slot pitch.

3) **Field windings**(Exciting Coil) :- Anamelled copper wire is used for the construction of field or exciting coils. The coils are wound on the former and then placed around the pole core. When direct current is passed through the field winding, It magnetises the poles which produce the required flux. The field coils of all the poles are connected in series in such a way that when current flows through them, the adjacent pole attain opposite polarity.

4) Armature:-The moving conductors are located in the armature. The armature is constructed by stacking laminated sheets of silicon steel. Thickness of these lamination is kept low to reduce eddy current losses. As the laminations carry alternating flux the choice of suitable material, insulation coating on the laminations, stacking it etc are to be done more carefully. The core is divided into packets to facilitate ventilation. The winding cannot be placed on the surface of the rotor due to the mechanical forces coming on the same. Open parallel sided equally spaced slots are normally punched in the rotor laminations. These slots house the armature winding. Large sized machines employ a spider on which the laminations are stacked in segments. End plates are suitably shaped so as to serve as 'Winding supporters'. Armature construction process must ensure provision of sufficient axial and radial ducts to facilitate easy removal of heat from the armature winding.

5) Armature Windings :- The insulated conductors housed in the armature slots are suitably connected using armature windings. On the basis of connection the armature windings are of two types.

a) Lap Windings:- In the Lap windings, conductors are connected in such a way that the number of parallel paths are equal to the no of poles. If machine has P poles & Z armature conductors ,then there will be P parallel paths , each path will have Z/P conductors in series. The no. of brushes are also equal to the no. parallel path ,half of the brushes are positive and remaining half are negative.

b)Wave Winding :- In the Wave winding ,the conductors are so connected that they are divided into two parallel path irrespective of the no. of poles. If machine has Z conductors then there will be only 2 parallel path each having Z/2 conductors.

6) Commutator :-It is the most important part of a d.c. machine which is of cylindrical shape and made up of wedge shaped hard drawn copper segments, these segments are insulated by a thin sheet of mica and serves following purpose

a) It connects the rotating armature conductors to the stationary external circuit through brushes.

b)In case of generator , It converts the alternating current induced in the armature conductors into unidirectional current in the external load circuit .

In case of Motor, It converts the alternating torque into unidirectional & continuous torque produced in the motor.

7) End Shields or Bearings

If the armature diameter does not exceed 35 to 45 cm then in addition to poles end shields or frame head with bearing are attached to the frame.

If the armature diameter is greater than 1m , **pedestral type bearings** are mounted on the machine bed plate outside the frame. These bearings could be ball or roller type. If the diameter of the armature is large a **brush holder yoke** is generally fixed to the frame.

8) Shaft :- the shaft is made of mild steel with a maximum breaking strength. The shaft is used to transfer mechanical power from or to the machine. The rotating parts like armature core , commutator, cooling fan etc are keyed to the shaft.

- **EMF Equation of DC Machine:-**

Let Φ = flux/pole in Weber
Z = total number of armature conductors = No.of slots x No.of conductors/slot
P = No.of poles of machine
A = No.of parallel paths in armature
N = armature rotation in revolutions per minute (r.p.m)
E = e.m.f induced in any parallel path in armature
Average e.m.f geneated /conductor = **dΦ/dt** volt (n=1)
Now, flux cut/conductor in one revolution **dΦ = ΦP** Wb
No.of revolutions/second = N/60
Time for one revolution, **dt = 60/N** second
Hence, according to Faraday's Laws of Electroagnetic Induction, **E.M.F generated/conductor is**

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

The no. of Conductors connected in series in each parallel path = Z/A
Average induced emf across each parallel path is

$$E = \frac{P\, Z\, \phi\ N}{60\ A}\ volts$$

A(no. of parallel path) = P (no. of poles) in Lap winding
A = 2 In Wave Winding

When d.c. Machine is working as generator the induced emf is called generated emf & given as

$$E_g = \frac{P\, Z\, \phi\ N}{60\ A}\ volts$$

When d.c. Machine is working as motor the induced emf is called back emf & given as

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

Numerical analysis

Q.1) A six pole lap wound armature has 840 conductors and 0.018 Wb flux per pole. Calculate the emf generated , when machine run at 600rpm?

Ans. 151.2 Volt

Q.2) A 4 poles generator with wave wound armature has 51 slots each having 24 conductors. The flux per pole is 0.01Wb. At what speed must the armature rotate to give an induced emf of 220 V. What will be the voltage developed if the winding is lap connected and the armature rotates at the same speed.

Ans. N = 539.21 rpm & emf for lap winding is 110V

Q.3) A six pole , 2 circuit , wave connected armature has 300 conductors, that runs at 1000 rpm. The emf generated on open circuit is 400Volt. Find the useful flux per pole.

Ans. 0.0267 Wb

Q.4) A 4 poles wave connected dc generator having 60 slots on its armature with 6 conductors per slots ,runs at 750 rpm and generates and open circuit voltage of 230 Volt.

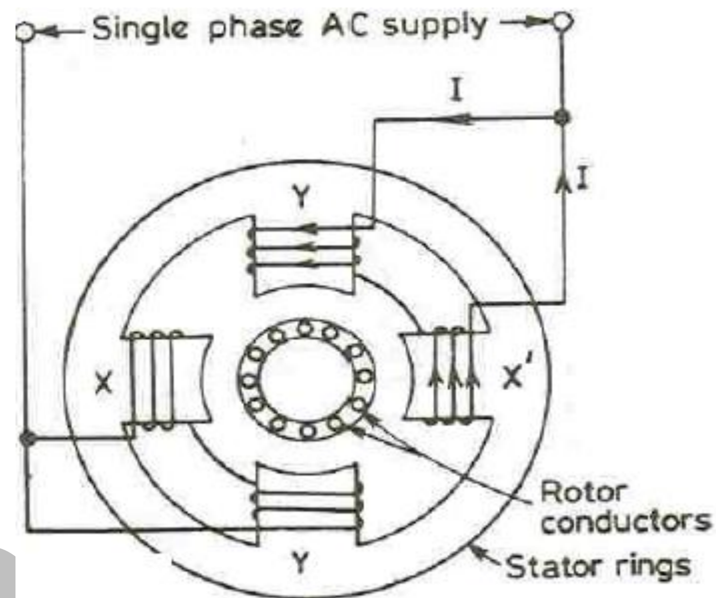
a) Find the useful flux per pole needed ?

b) Keeping the flux constant, suggest the change in armature of the generator, so that generator is capable to generate no load voltage of 115V,when running at same speed.

Ans. a) 0.0255 Wb b) Z/A = 90 ,Generator will be lap connected

- **1ϕ Induction Motor**

Working : Construction of a single -phase induction motor is similar to that of a three -phase induction motor except that the stator is provided with a single- phase winding. Thus,it has a stator with slots, and squirrel cage rotor with a small air-gap in between. When it is connected to single- phase ac supply, alternating current flows in its stator winding and the polarity of stator poles would alternately be N and S. The field so produced will be pulsating i.e. polarities will be alternating with the flux rising and falling in strength. The current induced in the rotor will tend to turn it in both directions alternately and thus the rotor will be at standstill due to inertia. If rotor is given a push by hand or by another means in any direction, it will rotate in the same direction developing operating torque. Thus a single –phase induction is not self- starting and requires special starting means.



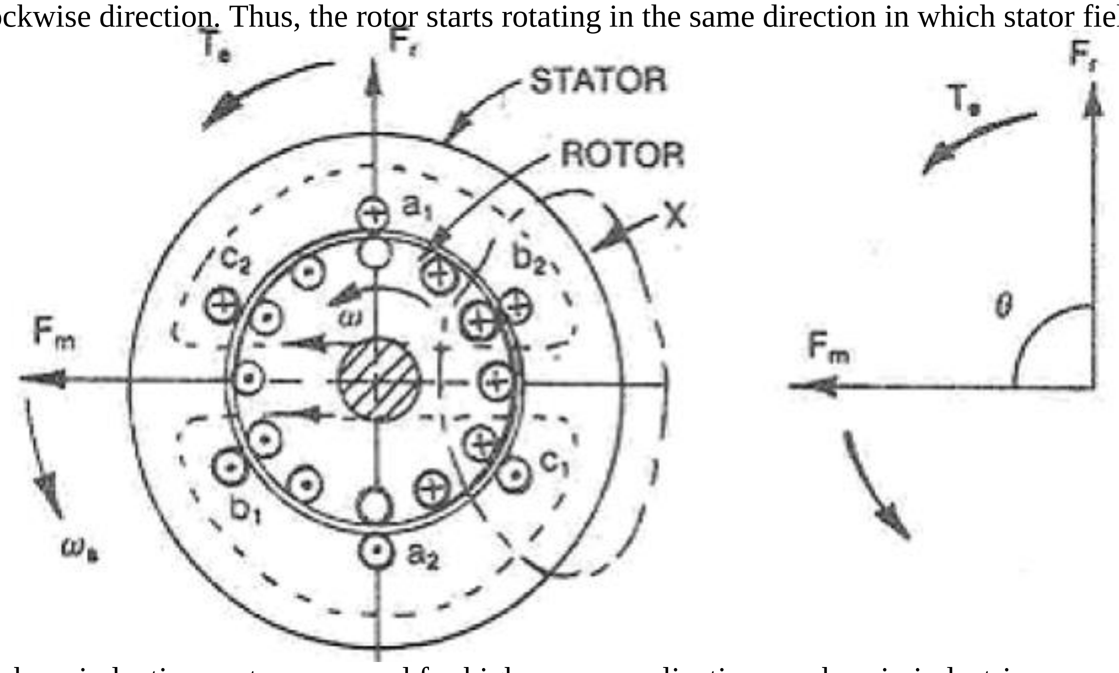
Applications: Due to their relatively simple construction, availability in variety of designs, and characteristics and promoted by economics as well as meeting the special requirements, single-phase induction motors are widely used, particularly where fractional horse power range is less than 2 H.P. For example motors in 1/8 to 3/4 H.P. ranges are used in fans, refrigerators, washing machines, blowers, centrifugal pumps, 1/30 to 1/20 H.P. range, are used in toys, hair dryers, vending machines, etc.

Single-phase motors are used in most homes, offices and rural areas.

- ✓ **3ϕ Induction Motor**

Operation of a 3- phase induction motor: When the 3- phase supply is given to the stator of a 3- phase wound induction motor, a rotating field is set-up in the stator. At any instant the magnetic field set up by the stator is shown in fig. An arrowhead F_m marks the direction of resultant field. Let this field be rotating in an anti- clockwise direction at an angular speed of w_s radians per second ie. Synchronous speed. The stationary rotor conductors cut the revolving field and due to electromagnetic induction an emf is induced in the rotor conductors. As the rotor conductors are short circuited, current flows through them in the direction as marked in the fig. Rotor current carrying conductors set up a resultant field F_r.

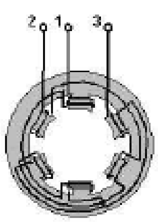
This tries to come in line with the stator main field F_m. Due to this an electromagnetic T_e is developed in the anticlockwise direction. Thus, the rotor starts rotating in the same direction in which stator field is revolving.



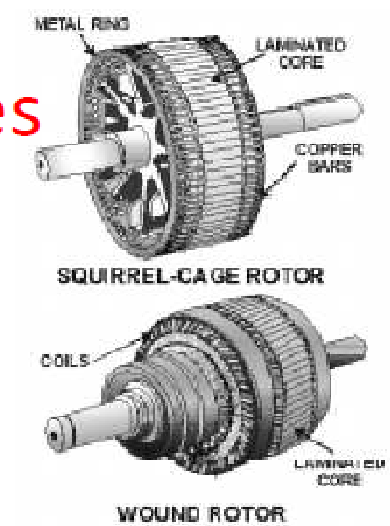
Three phase induction motors are used for high power applications such as in industries.

✓ **Rotors used in AC Machine**

Squirrel cage rotor	phase wound rotor
Almost constant speed but decreases slightly with increased load.	Speed decreases more rapidly than squirrel cage motor.
Starting torque is somewhat less, but running torque is good.	Starting torque is about three times the full load torque. Running torque is also good.
Starting current is about 5-6 times the full load current.	Starting current is about 2 times the full load current.
Speed control is done by changing poles.	Speed control is done by changing external resistance of rotor circuit.
Power factor is about 0.7 to 0.8.	Power factor is about 0.8 to 0.9.
Cost of fabrication is low.	Cost of fabrication is high.
Maintenance cost is very low.	Maintenance cost is high (because of extra resistance).
Application- lathes, drills, printing machines, blowers.	Applications – lifts, cranes, where high starting torque is needed.

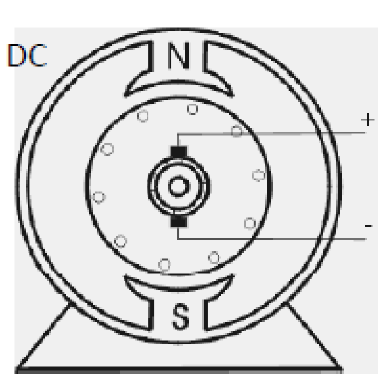


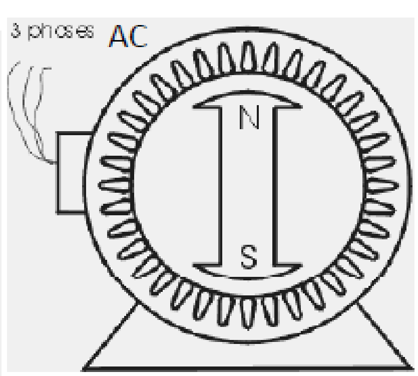
Synchronous Machines

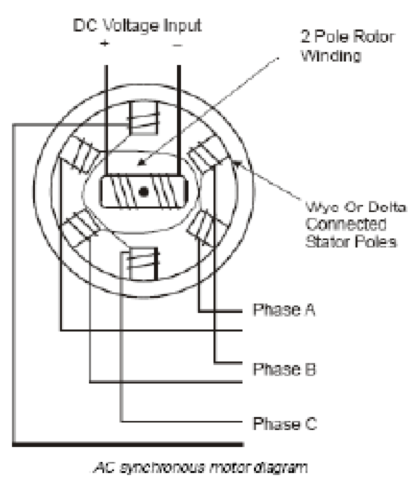


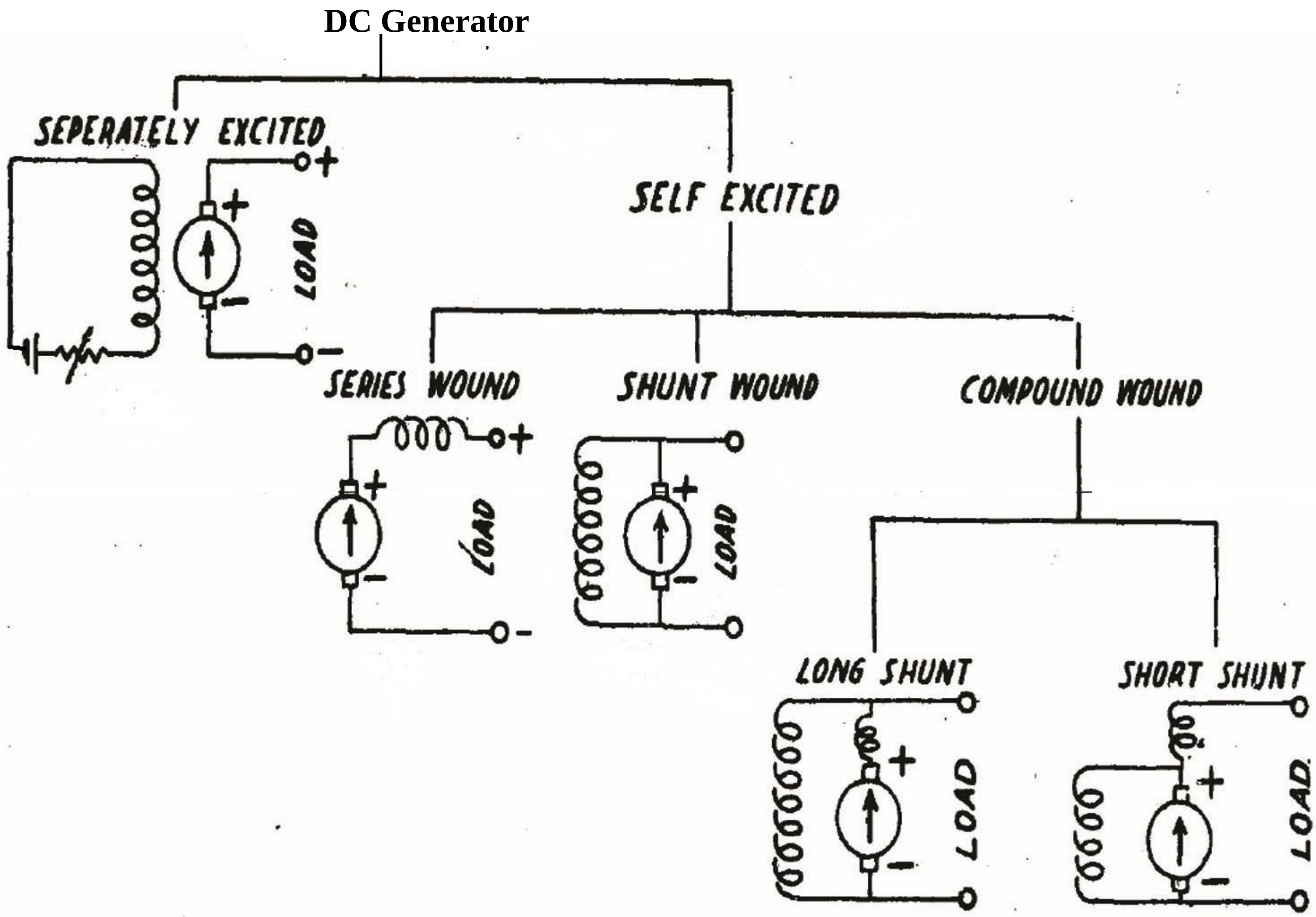
THREE-PHASE ROTATING FIELDS require three pairs of windings 120° apart, energized by voltages that also have a 120-degree phase displacement.

SYNCHRONOUS MOTORS are specifically designed to maintain constant speed, with the rotor synchronous to the rotating field. Synchronous motors require modification (such as squirrel-cage windings) to be self-starting.



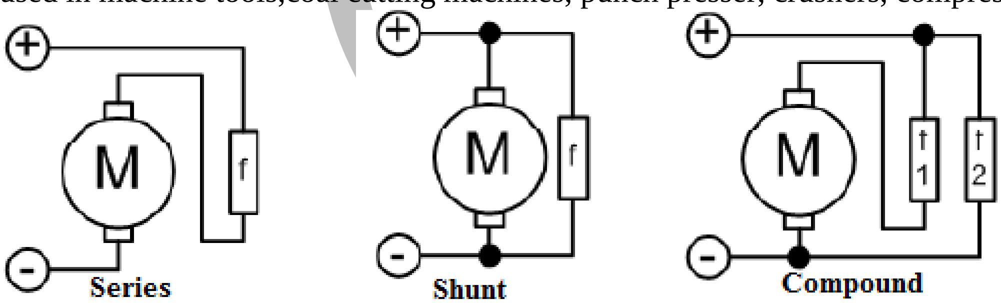






✓ Types of D.C. Motors:

Series – wound motor possesses the field winding of a few turns of heavy conductor, connected in series with the armature, i.e. load current flows through both the field and armature. With increasing load, the speed decreases. Consequently, at no-load, the speed of the motor is very high. Hence, series-wound motor should never be used without load. Such motors are used in cranes, pumps, trains, trolleys, etc. due to its very high starting torque.
Shunt – wound motor possesses the field winding of large number of turns, and high resistance, which is connected in parallel with the armature. Its staring torque is about 2.5 to 3 times greater than the full-torque. By using shunt regulator the variations of speed of the motor can be achieved. It runs practically at constant speed at almost all loads. Such motors are used in lathes, drills, printing press and for driving pumps.
Compound – wound motor has series as well shunt windings. Depending upon the type of field connections, a compound motor can be one in which series field assists the shunt field windings. With heavy starting loads, the torque increases. As the load increases, the speed decreases, and vice-versa, similar to series motor. However, when the load is suddenly decreased, the shunt prevents the motor from speeding beyond safe limits.Such motors are used in machine tools,coal cutting machines, punch presser, crushers, compressor, etc.



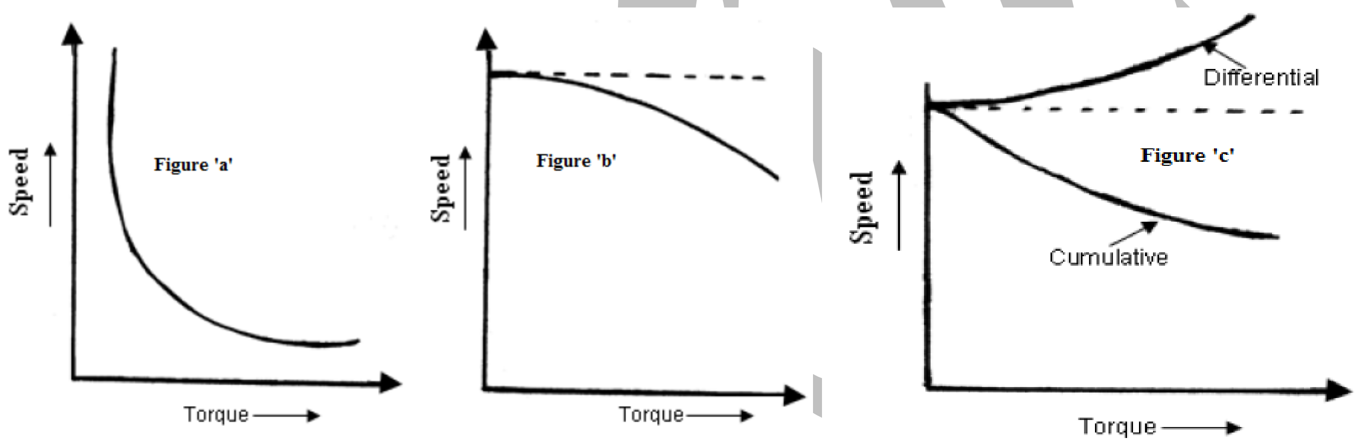
Where ' f ' is field / stator coil

- **Speed–torque characteristics**

Series Motor: Since a series motor develops a high initial torque at low speeds; and a low torque at high speed, so speed-torque characteristic of a series motor is hyperbola. High initial torque at low speeds enables even a small series motor to start a heavy load. However when starting friction is overcome the motor begins to accelerate, counter emf increases, current and torque decreases correspondingly as the motor speeds up. Fig. (a)

Shunt Motor: The speed – torque characteristics is similar to speed-armature current characteristics. The flux is independent of load and remains constant. As the back emf is also practically constant, speed is a constant. But strictly speaking both back emf and flux decrease with increasing load. However the back emf decreases slightly more than flux so that on the whole there some decrease in speed. Hence, the torque curve is slightly drooping. Fig. (b)

Compound motors: Speed –Torque characteristic depends on the type of compound motor. In a cumulative compound motor Fig.(c), the series excitation helps the shunt excitation. So, its speed- torque characteristic lies between that of shunt- motor and series motor. In a differential compound motor Fig.(g)the torque increases very slightly with speed.



<u>Numerical analysis</u>

Q.5) A shunt generator work at 450 A , at 230 V. Resistance of shunt field and armature are 50Ω & 0.03Ω respectively. Calcualte the generated emf ?

Ans. 243.50 V

Q.6) A long shunt compound generator deliver a load current of 50 A at 500 volt and has armature , series field and shunt field resistance of 0.05 Ω , 0.03 Ω , & 250 Ω respectively . Armature current allow 1V contact drop per brush. Calculate the generated voltage ?

Ans. 506.16 V

Q.7) A short shunt compound generator deliver a load current of 30 A at 220 V and has armature, series field and shunt field resistance of 0.05 Ω , 0.30Ω and 200Ω respectively. Armature current allow 1V contact drop per brush. Calculate the induced emf & the armature current?

Ans. 232.55 V & 31.1A

Q.8) A 4 pole DC shunt generator with a wave wound armature having 390 conductors has to supply a load of 500 lamps each of 100 Watt at 250 V. Allowing 10 V for the voltage drop in the connecting leads between the generator and the load and the brush drop of 2 V. The flux per pole is 30 m Wb and armature resistance & shunt resistance are respectively 0.05 Ω & 65 Ω. Calculate generated emf and the speed at which the generator should be driven.

Ans. 272.2 V & 698rpm

Q.9) A 4 pole DC motor has a wave wound armature with 594 conductors. The armature current is 40 A and flux per pole is 7.5 mWb . Calculate the H.P of motor when running at 1440 rpm?

Ans. 56.72Nm , 11.63 HP

Q.10) A 6 pole lap wound shunt motor has 500 conductors in the armature. The resistance of the armature path is 0.05 Ω. The resistance of shunt field is 25 Ω. Flux per pole is 2×10^{-2}. Find the speed of the motor when it takes 120A from a d.c. mains of 100 V supply ?

Ans. 565.2 rpm