# MODULE- 4

## DC GENERATORS

Any electrical machine that converts mechanical energy to electrical energy is called as Generators. The electrical machine that converts electrical energy to mechanical energy is called as motor. They work on the principle of electromechanical energy conversion. However, the construction of both motors and generators are same, they differ by the principle of operation.

The first DC electrical machine was invented in 1839 in Edinburgh but took 4 decades to be commercialized.

### Construction of DC machine

The construction of the motor parts can be broadly classified into two: stator and rotor. Stator is the stationary part and rotor is rotating. The stator parts include: Base Plate, yoke, field system, lifting eye and terminal box. The rotor parts include: armature. Commutator and brushes is shown in Fig 4.1.



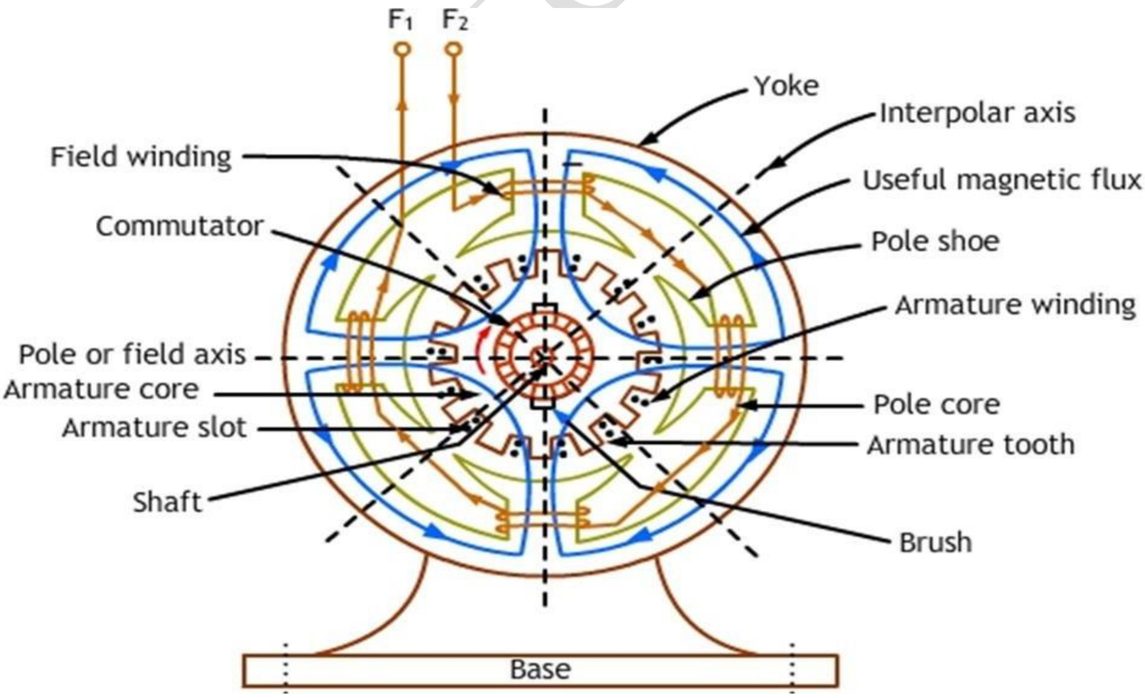



Fig: 4.1. Parts of DC Machine

***Yoke:*** yoke is the outermost part of the machine which is made of either cast iron or cast steel depending on the application. For instance, for small applications such as toys, fans etc, it is made of cast iron. For bigger application such as industrial and generating stations the yoke is made up of cast steel. The outer frame or yoke serves double purpose: (i) It provides mechanical support for the poles and acts as a protecting cover for the whole machine. (ii) It carries the magnetic flux produced by the poles. Base plate is to give the support for the entire system to stand.

***Pole Cores and Pole Shoes:*** The field system consists of pole shoe and pole field. The poles are made up of alloy steel that has high permeability and less hysteresis loss. The coil is wound on the pole which is excited to provide the magnetic field. The poles are tightly reverted to the yoke using nuts and bolts. The pole shoes serve two purposes: (i) They spread out the flux in the air gap and also, being of larger cross-section, reduce the reluctance of the magnetic path. (ii) They support the exciting coils (or field coils) as shown below. There will be small ducts provided along the pole shoe that keeps the air circulation intact.

***Pole Coils:*** The field coils or pole coils, which consist of copper wire or strip, are former-wound for the correct dimension. Then, the former is removed and wound coil is put into place over the core. When current is passed through these coils, they electro magnetize the poles which produce the necessary flux that is cut by revolving armature conductors.

***Armature Core:*** It houses the armature conductors or coils and causes them to rotate and hence cut the magnetic flux of the field magnets. In addition to this, its most important function is to provide a path of very low reluctance to the flux through the armature from a N-pole to a S-pole. It is cylindrical or drum-shaped and is built up of usually circular sheet steel discs or laminations approximately 0.5 mm thick. The slots are either die-cut or punched on the outer periphery of the disc and the keyway is located on the inner diameter as shown. In small machines, the armature stampings are keyed directly to the shaft. Usually, these laminations are perforated for air ducts which permit axial flow of air through the armature for cooling purposes. The purpose of using laminations is to reduce the loss due to eddy currents. Thinner the laminations, greater is the resistance offered to the induced emf, smaller the current and hence lesser the $I^2 R$ loss in the core.

***Armature Windings:*** The armature windings are usually former-wound. These are first wound in the form of flat rectangular coils and are then pulled into their proper shape in a coil puller. Various conductors of the coils are insulated from each other. The conductors are placed in the armature slots which are lined with tough insulatingmaterial. This slot insulation is folded over above the armature conductors placed in the slot and is secured in place by special hard wooden or fiber wedges.

***Commutator:*** The functions of the commutator are to facilitate collection of current from the armature conductors, and to convert the alternating current induced in the armature conductors into unidirectional current in the external load circuit. It is of cylindrical structure and is built up of wedge-shaped segments of high-conductivity hard-drawn or drop forged copper. These segments are insulated from each other by thin layers of mica. The number of segments is equal to the number of armature coils. Each commutator segment is connected to the armature conductor by means of a copper lug or riser. To prevent them from flying out under the action of centrifugal forces, the segments have V-grooves, these grooves being insulated by conical micanite rings.

***Brushes and Bearings:*** The brushes, whose function is to collect current from commutator, are usually made of carbon or graphite and are in the shape of a rectangular block. These brushes are housed in brush-holders, the brush-holder is mounted on a spindle and the brushes can slide in the rectangular box open at both ends. The brushes are made to bear down on the commutator by a spring. A flexible copper pigtail mounted at the top of the brush conveys current from the brushes to the holder. The number of brushes per spindle depends on the magnitude of the current to be collected from the commutator.

Because of their reliability, ball-bearings are frequently employed, though for heavy duties, roller bearings are preferable. The ball and rollers are generally packed in hard oil for quieter operation and for reduced bearing wear, sleeve bearings are used which are lubricated by ring oilers fed from oil reservoir in the bearing bracket.

## Basic principle of operation of D.C machine as a generator

Generator works on the principle of Faraday's laws of electromagnetic induction and the type of emf is dynamically induced emf. When a conductor cuts the magnetic flux lines of flux an emf is induced in the conductor. The magnitude of the emf induced in the conductor is given by:

$$E = Blv\sin\theta$$

Where B: magnetic flux density in wb/m$^2$

$l$ : length of the portion of the conductor in the magnetic field in m

$v$ : velocity of the conductor in m/s

$\theta$ : Angle between direction of movement of the conductor in the magnetic field and the direction of magnetic flux



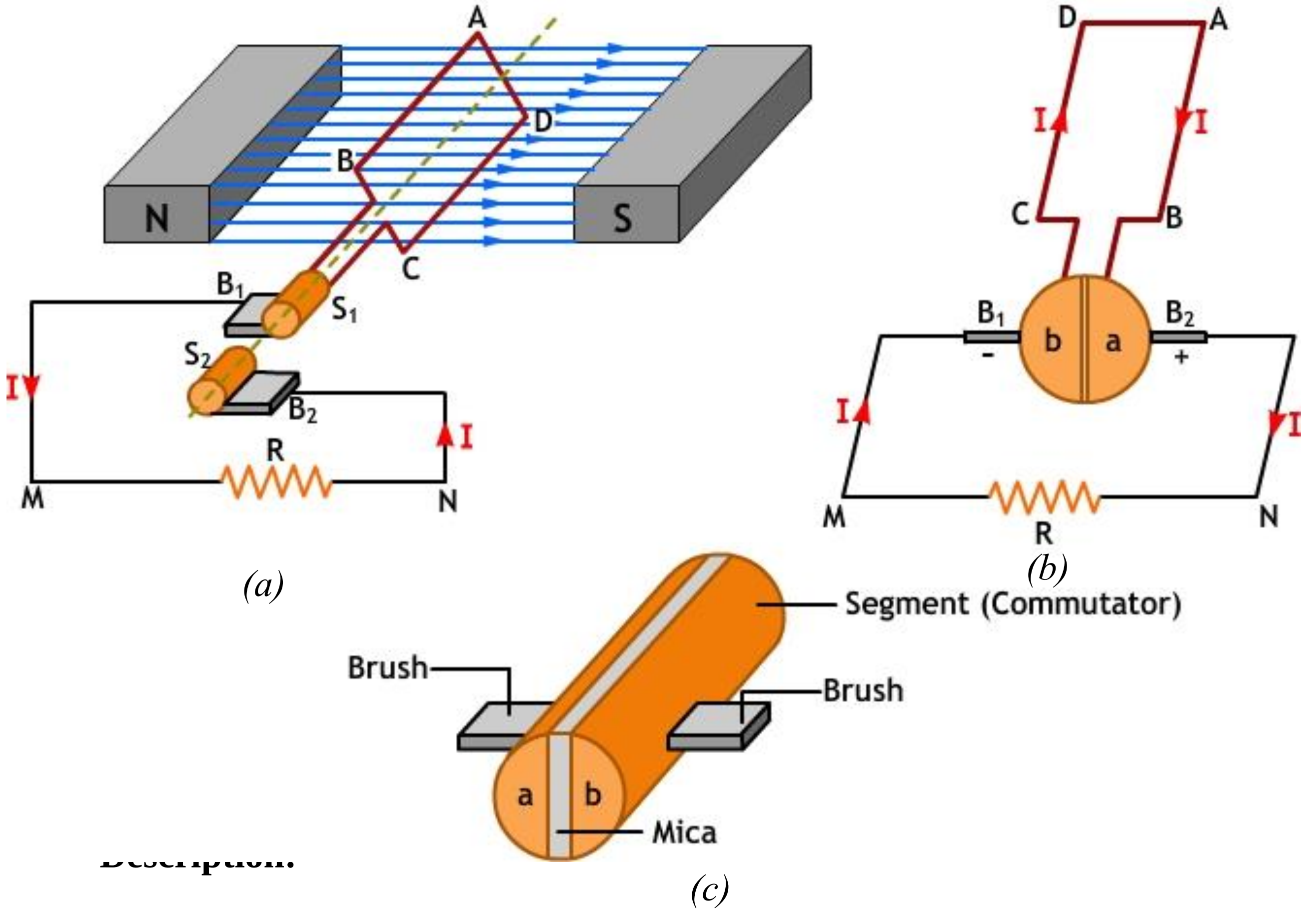



Fig 4.2: Generator working principle

The working principle of a generator can be better understood by simple concept of faradays laws. Consider two conductors AB and CD which are tied together in the back end and to the separate slip rings S1 and S2 in the front end as shown in the Fig 4.2(a). the conductors ABCD as a whole forms one coil. Let the coil be rotated in the counterclockwise direction such that AB rotates under the influence of north pole and CD under south pole and the current flows from M to N through the resistor as shown. Similarly, after rotation of $180^0$ the conductor Cd will be under the influence of north pole and AB under the influence of south pole thus from $180^0$ to $360^0$ rotation the emf induced in the conductor gets reversed and the current flows from N to M through resistor R as shown in Fig 4.2(b). The type of emf generated will be alternating. In view of obtaining DC voltage, split ring can be replaced with slip rings as depicted in Fig 4.2(c). In the split rings there are two segments a and b which are separated by a insulting medium and the brushes are placed on these segments. When AB is under the influence of south pole and CD under north pole the brushes just slide through the split rings to maintain the direction of current flow from M to N only.

**Fleming's right-hand rule (for generators): -** shows the direction of induced emf (current) when a conductor moves in a magnetic field.

The right hand is held with the thumb, first finger and second finger mutually perpendicular to each other (at right angles)

- The Thumb represents the direction of Motion of the conductor
- First finger represents the direction of the Field or Flux. (north to south)
- The Second finger represents the direction of the induced or generated Current (the direction of the induced current or emf will be the direction of conventional current; from positive to negative).

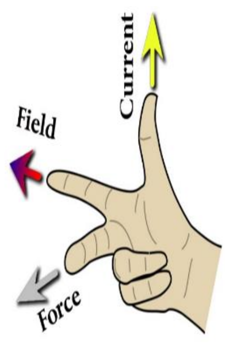



Fig 4.3: Flemings Right hand rule

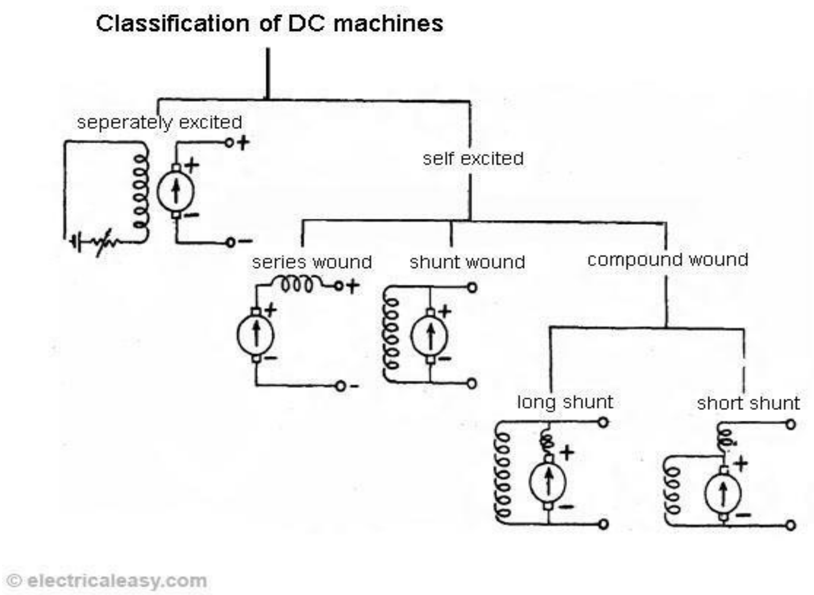
## Classification of Generators: -

Generators are usually classified according to the way in which their fields are excited.

The field windings provide the excitation necessary to set up the magnetic fields in the machine. There are various types of field windings that can be used in the generator or motor circuit.

In addition to the following field winding types, permanent magnet fields are used on some smaller DC products. Generators may be divided in to

(a) Separately-excited generators and
(b) Self-excited generators




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

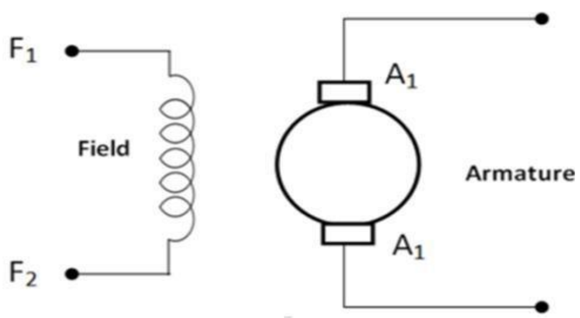



*Fig 4.4: Separately-excited generator*

Armature current $Ia=I_{L\backslash}$

Terminal voltage V=Eg-IaRa volts

Power developed P=EgIa watts

Power delivered to the load $=EgIa-Ia^2Ra=Ia(Eg-IaRa)=VIa$ watt

(b) **Self-excited generators** are those whose field magnets are energized by the current produced by the generators themselves. Due to residual magnetism, there is always present some flux in the poles. When the armature is rotated, some emf and hence some induced current is produced which is partly or fully passed through the field coils thereby strengthening the residual pole flux.

Self-excited generators are classed according to the type of field connection they use.

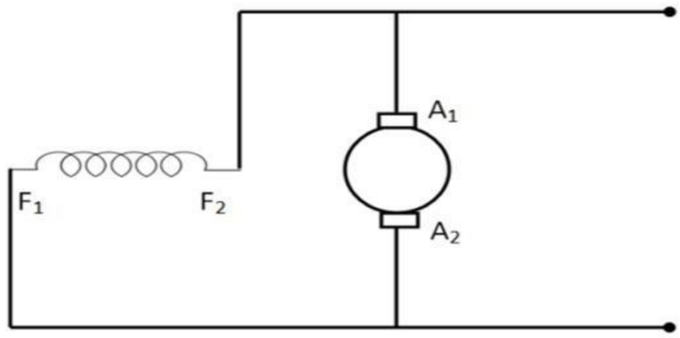



Fig 4.5: Self-excited generators

There are three general types of field connections:

(a) Series-Wound,

(b) Shunt- Wound (parallel),

(c) Compound-wound

Compound-wound generators are further classified as cumulative-compound and differential- compound.

**Series-wound generator: -** In the series-wound generator, shown in Fig 4.6, the field windings are connected in series with the armature. Current that flows in the armature flows through the external circuit and through the field windings. The external circuit connected to the generator is called load circuit.

A series-wound generator uses very low resistance field coils, which consist of a few turns of large diameter wire.

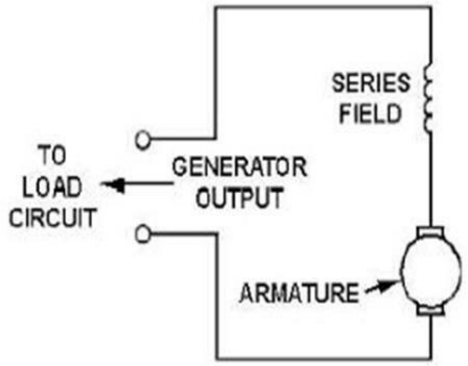



Fig 4.6: Series-wound generator

The voltage output increases as the load circuit starts drawing more current. Under low-load current conditions, the current that flows in the load and through the generator is small. Since small current means that a small magnetic field is set up by the field poles, only a small voltage is induced in the armature. If the resistance of the load decreases, the load current increases. Under this condition, more current flows through the field. This increases the magnetic field and increases the output voltage. A series-wound dc generator has the characteristic that the output voltage varies with load current. This is undesirable in most applications. For this reason, this type of generator is rarely used in everyday practice.

Armature current

$Ia=Ise=I_L=I$ Terminal

voltage $V=Eg-$

$I(Ra+Rse)$ Power

developed $P=EgIa$

Power delivered to the load= $EgIa-I^2(Ra+Rse)=I[Eg-I(Ra+Rse)]=VI$

**Shunt wound: -** In this field winding is connected in parallel with the armature conductors and have the full voltage of the generator applied across them. The field coils consist of many turns of small wire. They are connected in parallel with the load. In other words, they are connected across the output voltage of the armature.

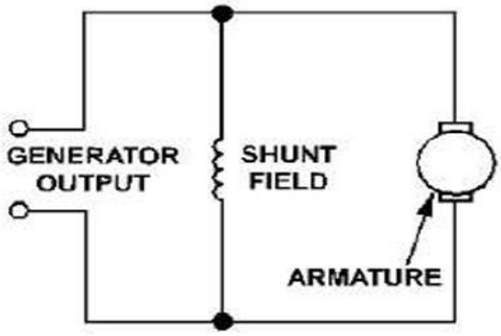



Fig 4.7: Shunt wound

Current in the field windings of a shunt-wound generator is independent of the load current (currents in parallel branches are independent of each other). Since field current, and therefore field strength, is not affected by load current, the output voltage remains more nearly constant than does the output voltage of the series-wound generator.

In actual use, the output voltage in a dc shunt-wound generator varies inversely as load current varies. The output voltage decreases as load current increases because the voltage drop across the armature resistance increases (E = IR).

In a series-wound generator, output voltage varies directly with load current. In the shunt-wound generator, output voltage varies inversely with load current. A combination of the two types can overcome the disadvantages of both. This combination of windings is called the compound- wound dc generator.

- Armature current $I_a=I_L+I_{sh}$
- Shunt field current $I_{sh}=(V/R_{sh})$
- Terminal voltage $V=I_{sh}\ R_{sh}$
- Power delivered $P=E_g\ I_a$
- Power given to the load $=VI_L$

Compound-wound generator: -

Compound-wound generators have a series-field winding in addition to a shunt-field winding, as shown in Fig 4.8. The shunt and series windings are wound on the same pole pieces. They can be either short-shunt or long shunt as shown in Fig 4.8. In a compound generator, the shunt field is stronger than the series field. When series field aids the shunt field, generator is said to be commutatively-compounded. On the other hand if series field opposes the shunt field, the generator is said to be differentially compounded.

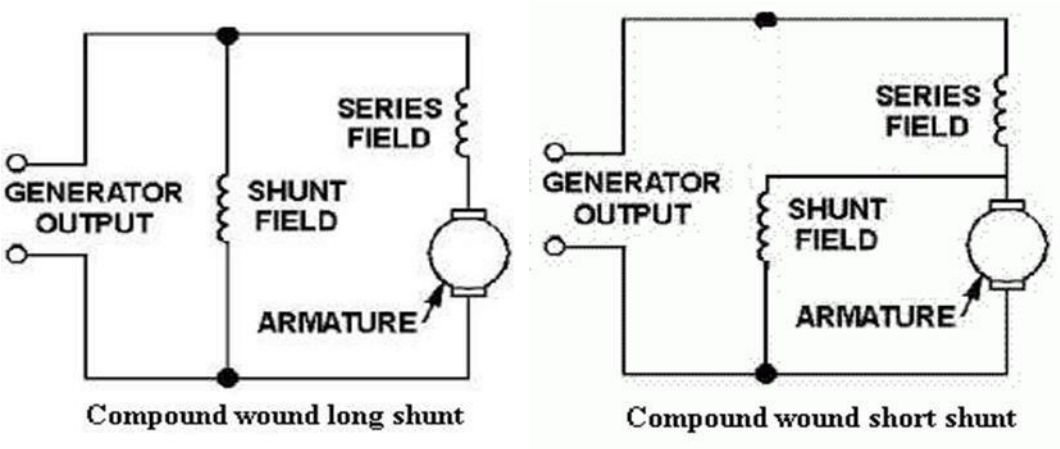



Fig 4.8: Differential and compound generator

In the compound-wound generator when load current increases, the armature voltage decreases just as in the shunt-wound generator. This causes the voltage applied to the shunt-field winding to decrease, which results in a decrease in the magnetic field. This same increase in load current, since it flows through the series winding, causes an increase in the magnetic field produced by that winding.

By proportioning the two fields so that the decrease in the shunt field is just compensated by the increase in the series field, the output voltage remains constant. This is shown in Fig, which shows the voltage characteristics of the series-, shunt-,and compound-wound generators. As you can see, by proportioning the effects of the two fields (series and shunt), a compound-wound generator provides a constant output voltage under varying load conditions. Actual curves are seldom, if ever, as perfect as shown.

Short shunt compound wound generator: -

- Series field current $Ise=I_L$
- Shunt field current $I_{sh}=(V+I_{se} R_{se})/R_{sh}$
- Terminal voltage $V=E_g-I_a Ra-I_{se} R_{se}$
- Power delivered $P=E_g I_g$
- Power given to the load $=VI_L$

Long shunt compound wound generator:-

- Series field current $I_{se}=I_L=I_a=I_{sh}+I_L$
- Shunt field current $I_{sh}=(V/R_{sh})$
- Terminal voltage $V=E_g-I_a(R_a+R_{se})$
- Power delivered $P=E_g I_g$
- Power given to the load $=VI_L$

**E.M.F Equation of DC Generator:**

Let, f = Flux / pole in webers Change in flux d $\phi$ = P $\phi$ webers

Z = Total number armature conductors

= Number of slots x Number of conductors per slot

P = Number of poles

A = Number of parallel paths in the armature.

N = Rotational speed of armature in revolutions per minute (r.p.m)

Time taken to complete one revolution = 60/N sec.

E = e.m.f induced / parallel path in armature.

By Faradays law

$$\text{E.M.F generated per conductor} = \frac{d\phi}{dt} = \frac{\phi PN}{60 \text{ volts}}$$

$$\text{Number of armature conductors per parallel path} = \frac{Z}{A}$$

$$E_g = \text{e.m.f generated per conductor} \times \text{Number of conductors in each parallel path}$$

$$E_g = \left(\frac{\phi PN}{60}\right) \times \frac{Z}{A} \text{ volts} \qquad \ldots\ldots\ldots(i)$$

For a Simplex Wave-Wound Generator

Number of parallel paths A=2

$$E_g = \frac{\phi PN \cdot \left(\frac{Z}{2}\right)}{60} = \frac{\phi ZPN}{120} \text{ volts}$$

For Simplex Lap-Wound Generator:

Number of parallel paths, A = P

Equation (i)

$$E_g = \frac{\phi PN \cdot \left(\frac{Z}{P}\right)}{60} = \frac{\phi ZN}{60} \text{ volts}$$

becomes

# DC MOTOR

Whenever a current carrying conductor is placed in a magnetic field it experiences a force and the force is given by:

$$F = BIl$$

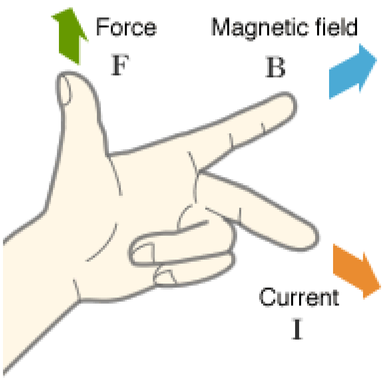
Where F: Force experienced in Newtons

B: Flux Density of magnetic field in $Wb/m^2$

I: current flowing through the conductor in amperes

l: length of the conductors in meters

**By Fleming's left-hand rule: -**It states that "when the thumb, fore finger and middle finger are held mutually perpendicular to each other, with the fore finger in the direction of magnetic field, middle finger in the direction of the current, then the direction of thumb indicates the direction of force experienced by the conductor".




**Types of DC Motors: -**Separately Excited DC Motor: - As the name suggests, in case of a 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 current does not flow through the field windings, the field winding is energized from a separate external source.

From the torque equation of dc motor we know Tg = Ka φ Ia So the torque in this case can be varied by varying field flux φ, independent of the armature current Ia.

**Self-Excited DC Motor:-**In case of self-excited dc motor, the field winding is connected either in series or in parallel or partly in series, partly in parallel to the armature winding, and on this basis its further classified as

(1) DC Shunt Motor

(2) DC Series Motor

(3) DC Compound Motor
  (i) Cumulative Compound Motor
    (a) Long shunt
    (b) Short shunt

(ii) Differential Compound Motor
    (a) Long shunt
    (b) Short shunt

**DC Shunt Motor: -**In this type of motor, the field winding is connected in parallel with armature as shown in Fig4.9 (a). There are as many number of field coils as there are poles. When connected to supply, constant voltage appears across the field windings (as they are connected in parallel with armature). The field current is therefore constant and is independent of the load current.Shunt field winding usually are designed to have large number of turns of fine wire. Its resistance, therefore, is high enough to limit the shunt field current to about 1 to 4 percent of the rated motor current

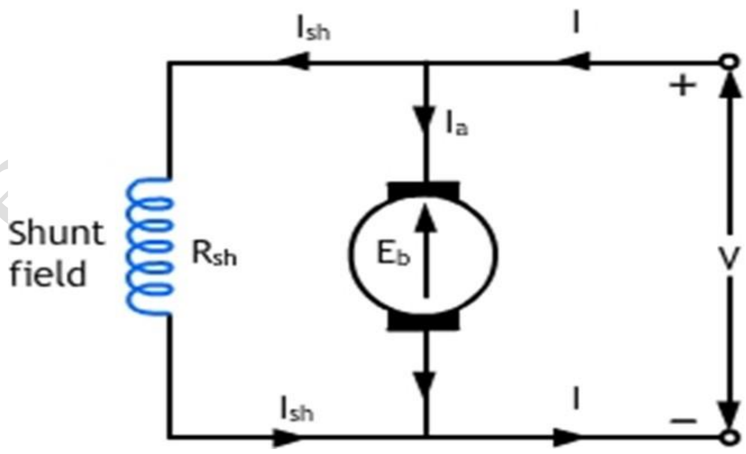



Fig 4.9 DC Shunt Motor

$I_{sh} = V/R_{sh}$ and $I_a = I - I_{sh}$.

where I is the line current

$E_b = V - I_a R_a - B.C.D - A.R.D$

where B.C.D is brush contact drop (1 V/brush, A.R.D is the armature reaction drop

**DC Series Motor: -**A series motor receives its excitation from a winding which is connected in series with the armature and carries load current Fig 4.9.1 dc series motor. As the series field has to carry high load current, it is made of a thick wire and a few turns. As the resistance is low, the voltage drop across the series winding is small.This motor has excellent starting and over-load torque characteristics. The disadvantages are that the motor attains dangerously high speed at no-load. Speed adjustment of the motor is somewhat difficult.

$I_a = I = I_{se}$

$E_b = V - I_a (R_a + R_{se}) - B.C.D - A.R.D.$

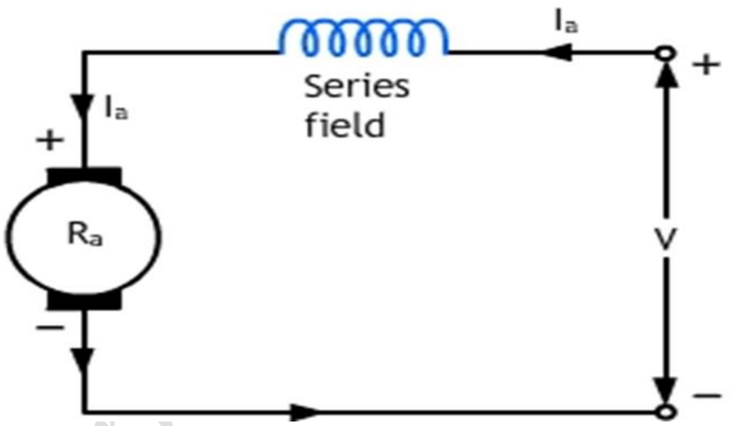



Fig 4.9.1 dc series motor

**DC Compound Motor: -**In compound motors excitation results from combined action of both shunt field winding and series field winding. In the short-shunt connection, which is sometimes used, the shunt field is directly connected in parallel with the armature, in which case, the series field current is the same as the line current. Excitation of a compound motor is a combination of series and shunt excitation. The motor, therefore, has mixed characteristic between that of a series motor and a shunt motor. These motors behaves somewhat better than a shunt motor from the point of view of starting and overload torque; and has definite stable no-load speed like a shunt motor. Speed of this motor is adjustable as easily as that of a shunt motor. It's speed, however, tends to change as much as 25 percent between full-load and no-load due to the effect of series winding.

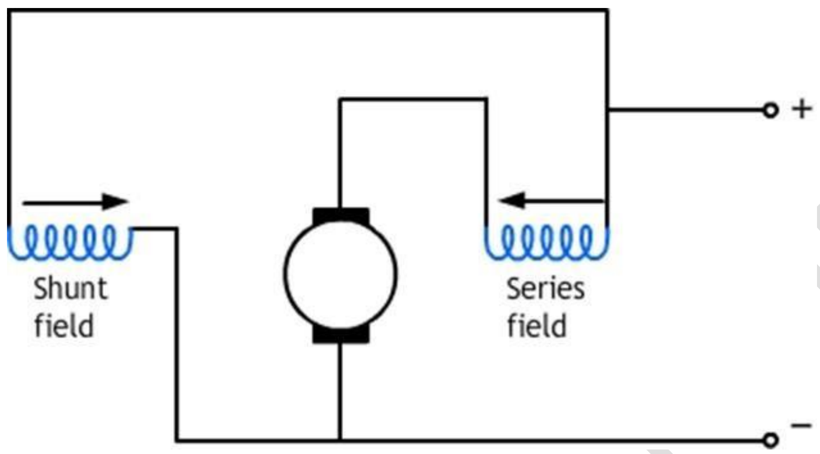



Fig 4.10 Differential compound motor

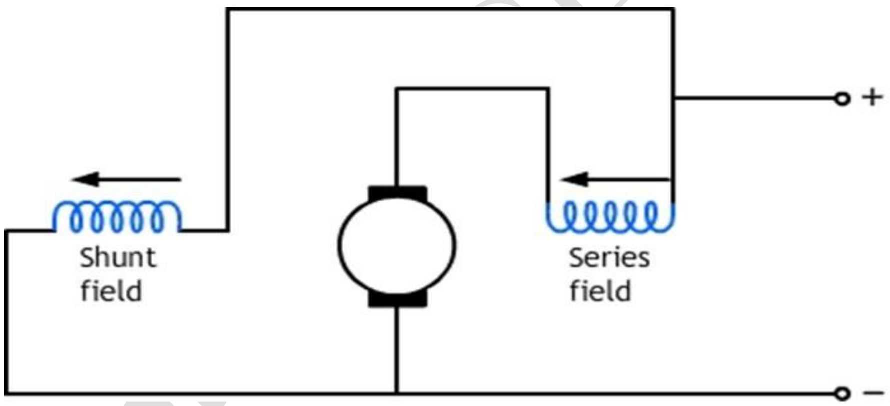



Fig 4.11 Cumulative compound motor

**Back EMF ($E_b$):**When the voltage V is applied to the motor, current $I_a$ will flow through the armature and $I_{sh}$ will flow through the field of the motor which will set the flux causing EMF. The EMF developed in the armature opposes the applied voltage and hence it is called the back e.m.f ($E_b$).The applied voltage V has to drive current through the armature conductors against the opposition of the back E.M.F and hence work has to be done. It is in the form of mechanical power developed by the armature. The armature current Ia is given by eq (1)

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

**Significance of Back EMF**: Back EMF is a must in a motor which helps to regulate the armature current and also the real cause for the production of torque.

$$V = E_b + I_a R_a$$

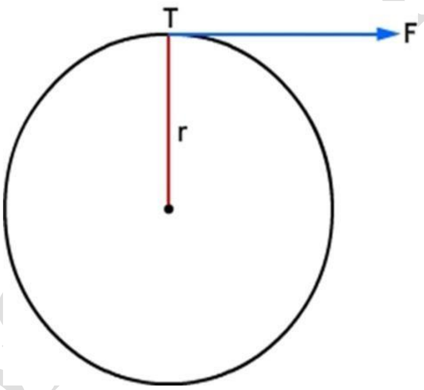
Expression for the back Emf is given by **E=V-IaRa,**

$$\text{and } E_b = \frac{\phi Z N . \left(\frac{P}{A}\right)}{60} \text{ volts}$$

Where E is the back emf, V is the applied emf, Ia is the armature current and Ra is the armature circuit resistance. And also, **E= PZNΦ/60A** volts, from the machine parameters.

## Torque Equation: -

Torque is the turning moment about its axis. It is also equal to Force x Distance




Consider the armature of the DC Motor of radius r and let F be the force acting tangential to its surface as shown in Fig .

Therefore, Torque = $T_a$ = F x r in Newton meter ------------------------ (1)

The work done by this force F in one revolution

W = F x distance covered in revolution

W = F x $2\pi$r watt second.

The power developed by the armature = work done in one second.

= F x r x $2\pi$ N / 60 where N = No of revolutions / minute

= ($2\pi$N / 60) x $T_a$ watts

But power developed in the armature =$E_b$ $I_a$

$$\text{Therefore } E_b I_a = \left(\frac{2\pi N}{60}\right) \times T_a$$

$$\left(\frac{\phi Z N}{60}\right)\left(\frac{P}{A}\right) \times I_a = \left(\frac{2\pi N}{60}\right) \times T_a \left(\because E_b = \frac{\phi Z N}{60}\frac{P}{A}\right)$$

$$\text{Therefore, } T_a = \left(\frac{1}{2\pi}\right)\phi Z I_a \cdot \frac{P}{A} \text{ Newton meter}$$

$$= 0.159\,\phi Z I_a \cdot \frac{P}{A} \text{ Newton meter}$$

The actual torque or shaft torque (torque available at the shaft) or Useful torque =

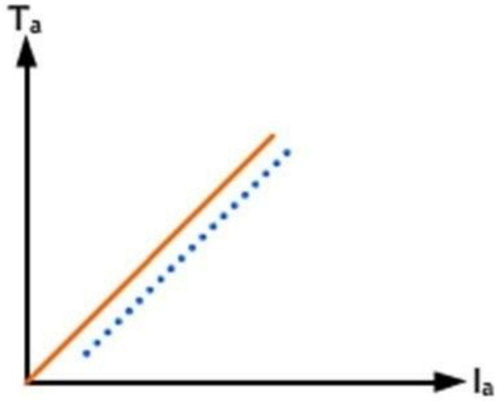
$T_{sh} = T_a - T_L$ where $T_{sh}$ = shaft torque

$T_a$ = armature torque
$T_L$ = lost torque due to iron losses and mechanical

losses Output = $2\pi N T_{sh}/60$

$T_{sh}$ = output x 60 / $2\pi N$
If output is in Horse Power,
$T_{sh}$ = output in H.P x 735.5/($2\pi N$/60) N-M

Characteristics of DC Shunt Motor:

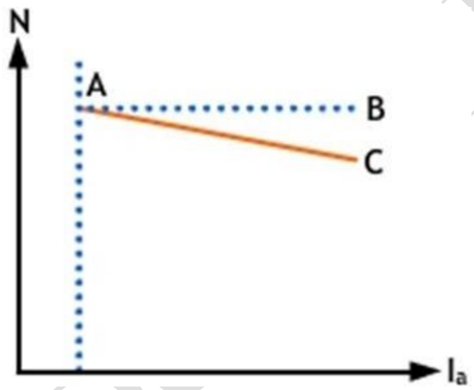



**(a) Ta/Ia characteristics (electrical characteristics):-** As assumed that flux ϕ is constant in the shunt machine

Ta∝Ia

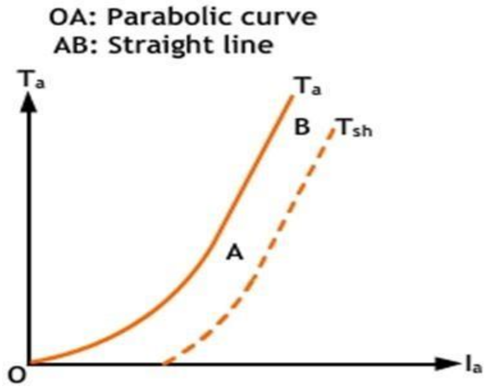
This implies that the characteristic is a straight line. Larger armature current is required to start a heavy load. Therefore, a shunt motor should not be started on heavy load.

**(b)** N/Ia characteristics: -




N∝ ($E_b$/ϕ), As ϕ is assumed to be constant, N∝$E_b$. As $E_b$is also practically constant, the speed is constant.

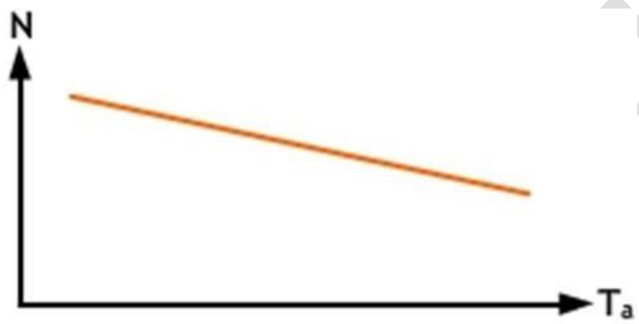
However, to be accurate both $E_b$ and ϕ decrease with increasing load. But $E_b$ decreases somewhat more than ϕ so that there is some decrease in speed, the drop ranging from 5 to 15 % of full load, depending on certain other conditions. The actual speed curve will be somewhat dropping as shown by line AC.




The characteristic does not have a point of zero armature current, because a small current is necessary to maintain the rotation of motor at no-load.

As there is no change in the speed of shunt motor, during the transition from no load to full load, it may be connected to loads which can be suddenly disconnected without fear of excessive speeding.

(c) N/Ta characteristics or mechanical characteristics:-



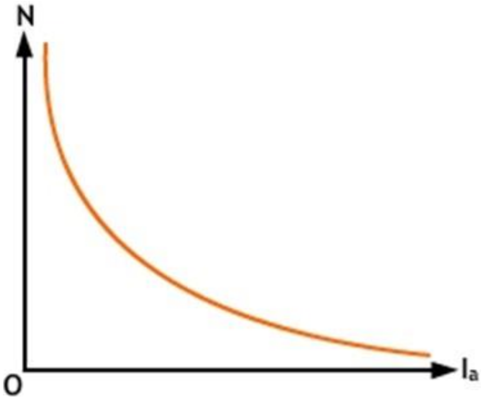

The values of N and $T_a$ for various armature currents $I_a$ is shown. The speed falls as the load torque increases.The $N/T_a$ characteristic is of great importance in determining which type of motor is best suited to drive a given load.

## Characteristics of series motor

**(a) Torque vs. armature current characteristic**

Since T $\alpha$ $I_a{}^2$ in the linear zone and T$\alpha$ $I_a$ in the saturation zone, the T vs. $I_a$ characteristic is as shown in Fig. At light loads, $I_a$ and hence $\phi$ is small, but as $I_a$ increases, $T_a$ increases as the square of the current in a parabolic manner till the point of saturation A is reached. After saturation $\phi$ is practically independent of $I_a$, hence $T_a$ $\alpha$ $I_a$ and so that the characteristic becomes straight line.

**(b)** Speed vs. armature current

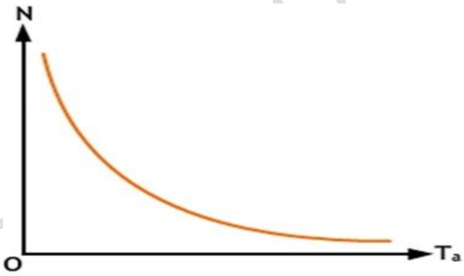



The changes in speed can be determined from the formula

$$N \alpha \ (E_b/\phi)$$

variation of $E_b$ for different load currents is negligible that $E_b$ may be treated as a constant. If $I_a$ is increased, flux $\phi$ too increases. So speed is inversely proportional to the armature current.When there is heavy load $I_a$ is large. But when the load and consequently $I_a$ decreases to a low value, the speed becomes dangerously high. Hence, a series motor should invariably be started with some mechanical load on it, to prevent excessive speed and damage due to heavy centrifugal forces produced.

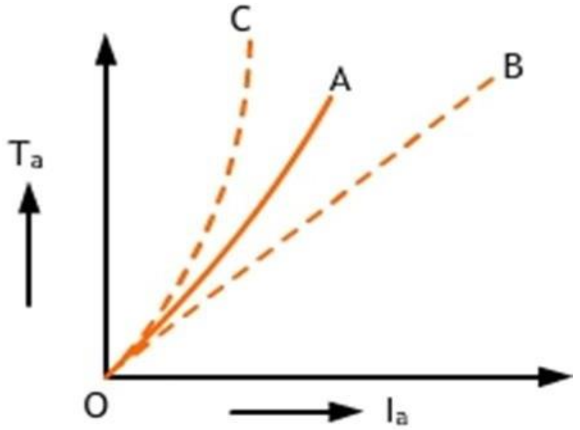
**(c)** Speed vs. Torque characteristic




The speed vs torque characteristic of a series motor is shown. From the curve, it is apparent that the series motor develops a high torque at low speed and vice versa. This is because an increase in torque requires an increase in armature current, which is also the field current. The result is that the flux is strengthened and hence speed drops. Similarly, at low torque, the motor speed is high.

Characteristics of DC Compound Motor:

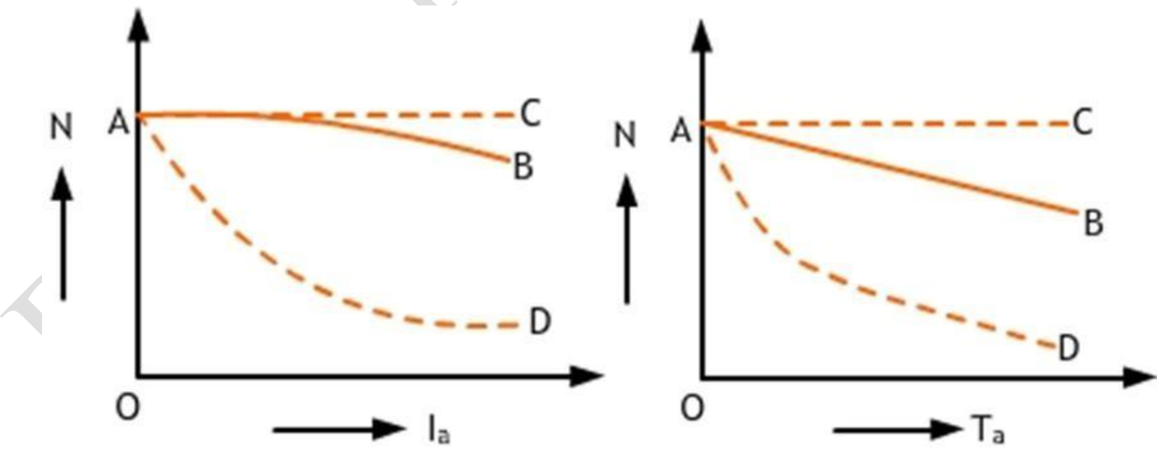
In the cumulative compound motor as Ia increases, flux Φse increases but the shunt field current Ish and ϕsh remain constant and total flux increases




$T_a \propto \phi I_a$

Fig(A)

As the armature current is increased, the series flux increases, thus increasing the total flux of the motor. As a result of this, the torque is increased. The increase of torque $T_a$ with armature current is shown by a $T_a/I_a$ characteristic curve OA. This increase of Ta with $I_a$ is greater than what it is in the case of shunt motor (dotted curve OB) less than what it is in the case of series motor develops a high torque with sudden increase in load.




We have just discussed that, with the increase of $I_a$, the series flux and hence total flux increases. This leads to decrease in motor speed, starting from a particular value given by the point A at no- load. The variation of N with $I_a$ is given by the characteristic AB in Fig (B).

Again, the decrease in speed is greater than what it would be in the case of a shunt motor (given by the dotted curve AC), but less than what it would be in the case of a series motor.As series excitation assists shunt excitation, the $N/T_a$ characteristic curve AB will lie between that of a shunt motor(dotted line AC) and of a series motor(dotted line AD)

Applications of DC Motors:

**(1) DC Shunt Motor:** When constant speed is required DC shunt motors are used.

Example: Lathes, Centrifugal pumps, fans, drilling machines. etc.

**(2) DC Series Motor:** For high starting torque we prefer DC series motor. Example: Electric traction, electric locomotive, cranes, hoists, conveyors etc.

**(3) DC Compound Motor:** When we require constant speed and high starting torque Cumulative compound motors are preferred. Example: shears, punches, coal cutting machine, elevators, conveyors, printing presses etc. Differential compound motors have no practical applications (being unstable).

## Problems

1) A 6 pole lap wound dc generator has 51 slots, each slot has 18 conductors. The useful flux per pole is 35 mwb. Find the generated emf in the armature, if it is driven at a speed of 750 rpm.

Given: P = 6

A = P (lap wound)

Number of slots = 51

Conductors/slot = 18

Total No. of conductors = 51* 18 = Z

$\phi$= 35mwb; N =
750 rpm, emf
generated

$$= \frac{\phi ZN}{60}\left(\frac{P}{A}\right) \text{volts} = \frac{\left(35\times10^{-3}\right)\times\left(51\times18\right)\times750\times6}{60\times6}$$

= 401.6 volts.

2) An 8 pole d.c. generator has 650 armature conductors. The flux per pole is 20 mWb. Find the value of emf generated when the armature is wave wound and is rotating at a speed of 1200 rpm. What must be speed at which the armature is to be driven to generate the same emf, if the armature is lap wound.

generate the same emf, if the armature is
lap wound. Given: P = 8;
A = 2 (wave wound)
No. of conductors = 650
$\phi$ = 20 mWb; N = 1200 rpm,
emf generated

$$= \frac{\phi ZNP}{60A} \text{volts} = \frac{\left(20\times10^{-3}\right)\times\left(650\right)\times1200\times8}{60\times2} = 1040 \text{ volts}$$

To find the speed of armature, when it is lap wound,

$$N = \frac{E_g\times60A}{\phi ZP} = \frac{\left(1040\right)\times60\times8}{\left(20\times10^{-3}\right)\times\left(650\right)\times8} = 4800 \text{ rpm}$$

3) A d.c series motor is running with a speed 800 rpm while taking a current of 20 A from the supply. If the load is changed such that the current drawn by the motor is increased to 50A, calculate the speed of the motor on new load. The armature and series field winding resistances are 0.2 ohm and 0.3 ohm respectively. Assume that the flux produced is proportional to the current. Assume the supply voltage as 250 V.

For load 1, $N_1$ = 800 rpm, $I_1 = I_{a1}$ = 20 A
For load 2, $I_1 = I_{a2}$ = 50

A

$E_{b1}$ = 240 V ......................... ($E_{b1} = V - I_{a1}(R_a + R_{se})$)

$E_{b2}$ = 225 V ......................... ($E_{b2} = V - I_{a2}(R_a + R_{se})$)

$$\frac{N_2}{N_1} = \left(\frac{E_{b2}}{E_{b1}}\right) \times \left(\frac{I_{a1}}{I_{a2}}\right)$$

$N_2$ = 300 rpm

4) The armature current of a series motor is 60 A when on full load. If the load is adjusted so that this current decreases to 40 A, find the new torque expressed as a percentage of full load torque. The flux for a current of 40 A is 70% of that when the current is 60 A.

$T \propto \phi Ia$,

i) Full load torque = $T_{fl} = \phi \times 60$

ii) $T_{40} = 0.7\ \phi \times 40$

$T_{fl}/\ T_{40} = 60\ \phi/$

$(0.7\ \phi \times 40)\ T_{40} =$

$0.4667\ T_{fl}$

Torque at 40 A is 46.67% of full load torque

5) A 4 pole 250 V d.c. shunt motor has a back emf of 240.8 V and takes a current of 20 A. Calculate the power developed. Take the resistance of the field winding as 250 ohms.

P = 4
V = 250 V
$E_b$= 240.8 V
$I_L$=20A
$R_{sh}$= 250 ohms
$R_{sh}$= 250 ohms
Power developed = $E_b I_a$
$Ia = I_L - I_{sh}$ and
$I_{sh} = V/R_{sh}$
Ish = 250/250 =1 A
Ia = 20 – 1 = 19 A
Power developed =240.8 x 19 = 4572.8 W.

6) A 230 V dc series motor takes 12 A and runs at 800 rpm. At what speed will it run, when 10 ohm resistance is connected in series with the armature the motor taking the same current at the same supply voltage. Take Ra and Rse of the motor as 0.5 ohm each.

V = 230 V
IL = Ia = Ise = 12 A
Ra = Rse = 0.5 ohms
$E_{b1} = V - I_{se}R_{se} - IaRa$.
= 230 - 12 x 0.5 - 12 x 0.5 = 218.
When 10-ohm resistance is connected in series with the armature, then
$E_{b2} = V - Ise\ (Rse + Ra + 10)$
= 230 - 12(0.5 + 10 + 0.5) = 98 V.
Let $N_2$ be the corresponding speed then
$E_{b2}/E_{b1}=(N2/N1) \times (f1/f2)$
Since $f_1 = f_2$
$N_2 = (E_{b2}/E_{b1}) \times N_1$
$N_2$ = 98 x 800/218 =359.6 rpm.

## Exercise problems

A 4 pole DC shunt motor takes 22A from 220V supply. The armature and the field resistances are 0.5 Ω and 100Ω respectively. The armature is lap connected with 300 conductors. If the flux per pole is 20mWb, calculate the speed and gross torque.

**1.** A 20kW, 200V dc shunt motor has armature and field resistances of 0.05 ohm and 100 ohm respectively. Calculate the total power developed by the armature when it delivers full output power

**2.** A DC series motor connected to a connected to a 440V supply runs at 600rpm when taking a current of 50A. Calculate the value of resistor which when inserted in series with the motor will reduce the speed to 400rpm, the gross torque being then half its previous value. Resistance of motor is 0.2Ω. Assume the flux to be proportional to the field current.

**3.** . A D.C series motor running with a speed of 1000rpm, while taking a current of 22amp from the supply. If the load is changed such that the current drawn by the motor is increased to 55amp, calculate the speed of the motor on new load. The armature and series winding resistances are 0.3ohm and 0.4ohm respectively. Assume supply voltage as 250V.

**4.** A 200V, 4 pole, lap wound dc shunt motor has 600 conductors on its armature. The resistance of the armature winding is 0.5Ω and shunt field winding is 200Ω. The motor takes a current of 21A, the flux per pole is 30mWb, find the speed and gross torque developed in the motor