D.C. Machines:

Syllabus: Working principle of D.C.Machine as a generator and a motor. Types, constructional features and Types of armature windings. Emf equation of generator, relation between induced Emf and terminal voltage with an enumeration of brush contact drop and drop due to armature reaction. Operation of D.C. motor, back Emf and its significance, torque equation. Types of D.C. motors, characteristics and applications. Necessity of a starter for D.C. motor.

Introduction:

- The converters which are used to continuously translate an electrical input to a mechanical output or vice versa are called as DC machines.
- If the conversion is from mechanical to electrical energy then it is called ad DC Generator and if the conversion is from electrical to mechanical energy then it is called as DC Motor.

Working principle of D.C.Machine as a generator and a motor:

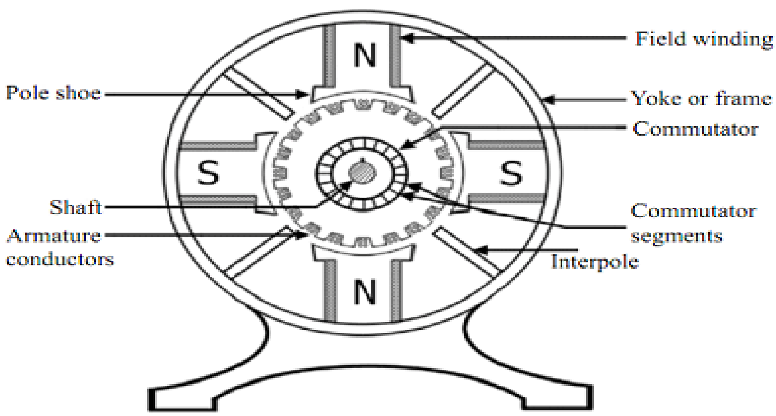
Working principle of D.C.Machine as a generator:

- Whenever a coil is rotated in a magnetic field an Emf will be induced in this coil and is given by **e=B*l*v*Sinθ** volts/coil side where, B=The flux density in Tesla, l=the active length of the coil side in meters v=the velocity with which the coil is moved in meters/sec and θ is the angle between the direction of the flux and the direction of rotation of the coil side.
- The direction of the induced voltage can be ascertained by applying **Fleming's right hand rule.**

Working principle of D.C.Machine as a motor:

- Whenever a current coil is placed under a magnetic field the coil experiences a mechanical force, and is given by **F= B*I*l*Sinθ** Newton/coil side where, I is the current through the coil.
- Applying **Fleming's left hand rule**, we note torque T_e will be produced in the counter clockwise direction causing the rotor to move in the same direction.

Construction of DC Machine:



Salient parts of a D.C.Machine are:

(i)Field system (poles)

(ii)Coil arrangement (armature)

(iii)Commutator

(iv)Brushes

(v)Yoke

Yoke:

i) It serves the purpose of outermost cover of the D.C. machine. So that the insulating materials get protected from harmful atmospheric elements like moisture, dust and various gases like SO_2, acidic fumes etc.

ii) It provides mechanical support to the poles.

iii) It forms a part of the magnetic circuit. It provides a path of low reluctance for magnetic flux.

Poles:

Each pole is divided into two parts a) pole core and b) pole shoe

- Pole core basically carries a field winding which is necessary to produce the flux.
- It directs the flux produced through air gap to armature core, to the next pole.
- Pole shoe enlarges the area of armature core to come across the flux, which is necessary to produce larger induced emf. to achieve this, pole shoe has given a particular shape

Field winding [F1-F2]:

- The field winding is wound on the pole core with a definite direction.
- To carry current due to which pole core on which the winding placed behave as an electromagnet, producing necessary flux. As it helps in producing the magnetic field i.e. exciting the pole as electromagnet it is called Field winding or Exciting winding.

Armature:

- It is further divided into two parts

  namely,

  I) Armature core and

  II) Armature winding
- Armature core is cylindrical in shape mounted on the shaft. It consists of slots on its periphery and the air ducts to permit the air flow through armature which serves cooling purpose.

Commutator:

- The basic nature of Emf induced in the armature conductors is alternating.
- This needs rectifications in case of D.C. generator which is possible by device called commutator.

Brushes and brush gear:

- To collect current from commutator and make it available to the stationary external circuit.
- Ball bearings are usually used as they are more reliable.
- For heavy duty machines, roller bearings are preferred.

Types of D.C. Armature Windings

Lap Winding	Wave Winding
In this winding all the pole groups of the coils generating emf in the same direction at any instant of time are connected in parallel by the brushes.	In this winding all the coils carrying current in the same direction are connected in series i.e., coils carrying current in one direction are connected in one series circuit and coils carrying current in opposite direction are connected in other series circuit.
2. Lap winding is also known as parallel windings.	2. Wave winding is also known as series winding.
3. The number of parallel path is equal to the number of poles i.e., A = P.	3. The number of parallel paths is always equal to 2 i.e., A = 2.
4. The number of brush required by this winding is always equal to the number of poles.	4. The number of brushes required by this winding is always equal to 2.
5. The machine using lap winding requires equalizer rings for obtaining better commutation.	5. The machine using wave winding does require dummy coils to provide the mechanical balance for the armature.
6. Lap windings are used for low voltage and high current machines.	6. Wave windings are used for high voltage and low current machines.

Emf Equation of DC Generator:

For one revolution of the conductor,
Let, Φ = Flux produced by each pole in weber (Wb) and
P = number of poles in the DC generator. Therefore,
Total flux produced by all the poles $= \phi \times P$

Time taken to complete one revolution $= \frac{60}{N}$
Where, N = speed of the armature conductor in rpm.

Now, according to Faraday's law of induction, the induced emf of the armature conductor is denoted by "e" which is equal to rate of cutting the flux. Therefore,

$$e = \frac{d\phi}{dt} \quad and \ e = \frac{total\ flux}{time\ take}$$

Induced emf of one conductor is Induced emf of one conductor is

$$e = \frac{\phi P}{\frac{60}{N}} = \phi P \frac{N}{60}$$

Let us suppose there are Z total numbers of conductor in a generator, and arranged in such a manner that all parallel paths are always in series.
Here, Z = total numbers of conductor A = number of parallel paths
Then, Z/A = number of conductors connected in series
We know that induced Emf in each path is same across the line
Therefore, Induced Emf of DC generator E = Emf of one conductor × number of conductor connected in series.

Induced Emf of DC generator is

$$e = \phi P \frac{N}{60} X \frac{Z}{A} \ volts$$

Simple wave wound generator Numbers of parallel paths are only 2 = A Therefore,

Induced Emf for wave type of winding generator is

$$\frac{\phi PN}{60} X \frac{Z}{2} = \frac{\phi ZPN}{120} \ volts$$

Simple lap-wound generator Here, number of parallel paths is equal to number of conductors in one path i.e. P = A Therefore,

Induced **Emf** for lap-wound generator is

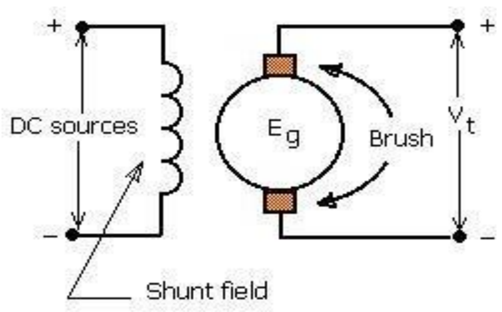
$$E_g = \frac{\phi ZN}{60} X \frac{P}{A} \ volt$$

Types of DC Generators

- It is characterized by the manner in which field excitation is provided.
- In general the method employed to connect field and armature winding has classify into two groups.

Separately Excited Generators:

In separately excited dc machines, the field winding is supplied from a separate power source. That means the field winding is electrically separated from the armature circuit.



Self Excited Field Generators:

- This type of generator has produced a magnetic field by itself without DC sources from an external.
- The electromotive force that produced by generator at armature winding is supply to a field winding (shunt field) instead of DC source from outside of the generator.
- Therefore, field winding is necessary connected to the armature winding.

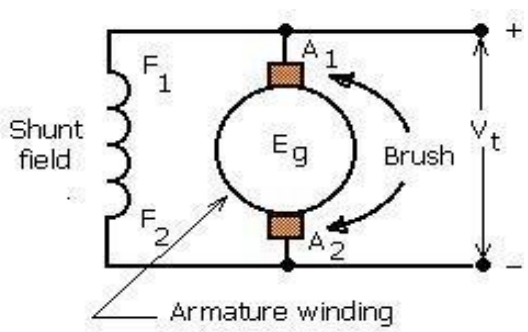
  They may be further classified as: a) DC Shunt generator

  b) DC Series generator

  c) DC Compound generator.

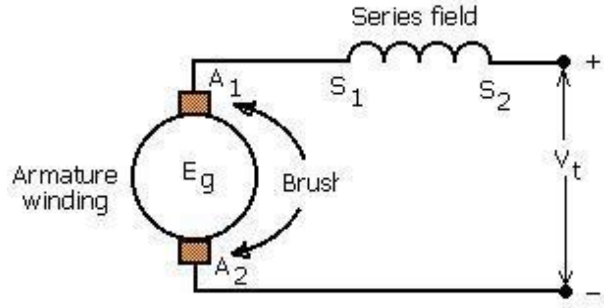
a) **Shunt generator:**

- This generator, shunt field winding and armature winding are connected in parallel through commutator and carbon brush.



b) **Series generator:**

- The field winding and armature winding is connected in series.
- There is different from shunt motor due to field winding is directly connected to the electric applications (load).
- Therefore, field winding conductor must be sized enough to carry the load current consumption and the basic circuit



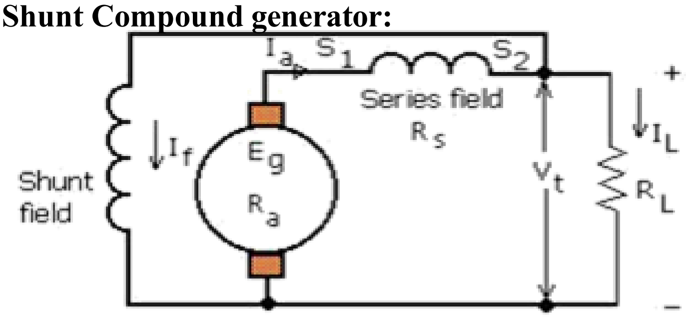
c) Compound generator :

- The compound generator has provided with magnetic field in combine with excitation of shunt and series field winding, the shunt field has many turns of fine wire and caries of a small current, while the series field winding provided with a few turns of heavy wire since it is in series with an armature winding and caries the load current.
- There are two types of Compound generators such as

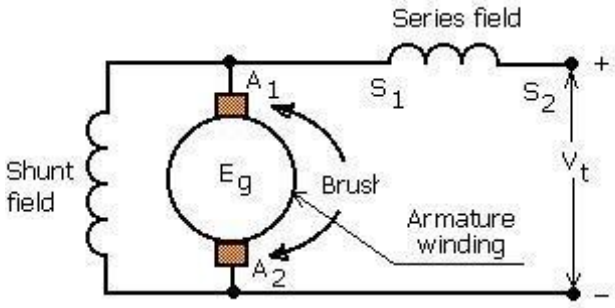
(i) Long shunt Compound Generator

(ii) Short Shunt Compound Generator

Long Shunt Compound generator:



Short Shunt Compound Generator:



DC Motors:

Operation of a DC motor:

- When a DC machine is loaded as a motor, the rotor conductors carry current.
- These conductors lie in the magnetic field of the air gap.
- Thus, each conductor experiences a force.
- The conductors lie near the surface of the rotor at a common radius from its centre
- Hence, a torque is produced around the circumference of the rotor, and the rotor starts rotating.

Back Emf and its Significance:

- 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 an emf is induced in them.
- The induced emf acts in opposite direction to the applied voltage V(Lenz's law) and is known as back emf.
- Back EMF always acts to reduce the changing magnetic field through the coils. It does so by generating a voltage which opposes the supply voltage, thus reducing the current.

Significance:

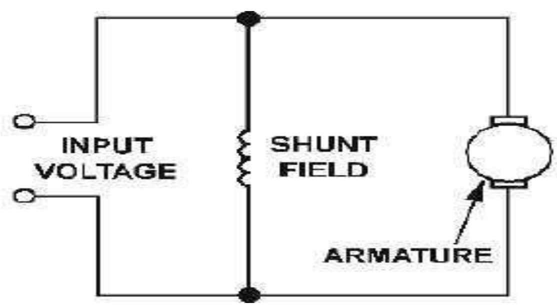
- The presence of back emf. makes the d.c. motor a self-regulating machine i.e., it makes the motor to draw as much armature current as is just sufficient to develop the torque required by the load.
- Back emf in a D.C. motor regulates the flow of armature current i.e., it automatically changes the armature current to meet the load requirement.

Types of DC Motors:

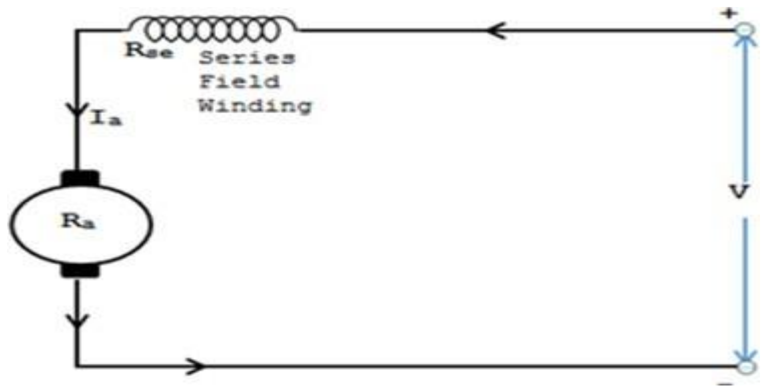
Motors are classified into 3 types: a) DC Shunt motor.
b) DC Series motor.
c) DC Compound motor.

a) DC Shunt motor:

- In shunt wound motor the field winding is connected in parallel with armature.
- The current through the shunt field winding is not the same as the armature current.



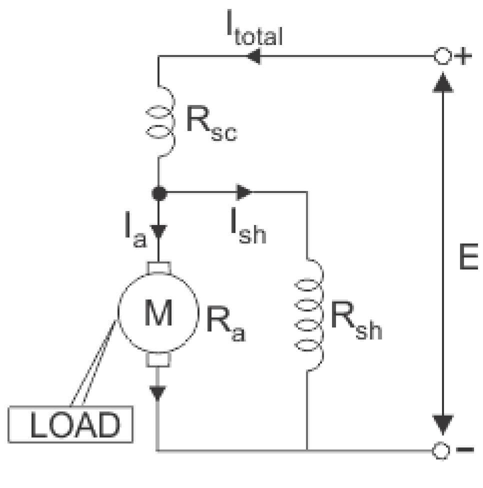
b) DC Series motor:



- In series wound motor the field winding is connected in series with the armature.
- Therefore, series field winding carries the armature current.

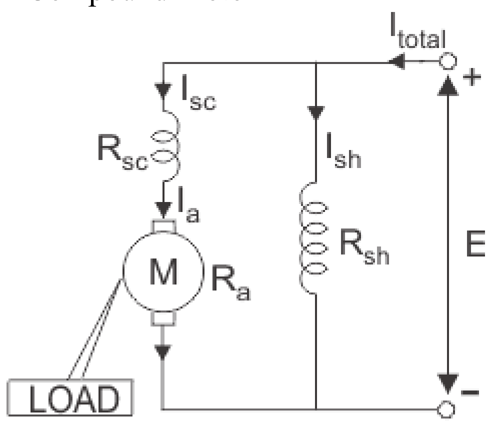
c) DC Compound motor:

- Compound wound motor 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 :
  1) Short-shunt connection Compound Motor



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

2) Long shunt connection Compound Motor



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

Torque equation of a DC Motor:

$$V = E_b + I_a R_a \quad \ldots\ldots..(1)$$

Multiplying the equation (1) by I_a we get

$$VI_a = E_b I_a + I_a^2 R_a \quad \ldots\ldots..(2)$$

Where,

VI_a is the electrical power input to the armature.

$I^2{}_a R_a$ is the copper loss in the armature.

We know that,**Total electrical power supplied to the armature = Mechanical power developed by the armature + losses due to armature resistance**

Now, the mechanical power developed by the armature is Pm.

$$P_m = F_b I_a \ldots\ldots.(3)$$

Also, the mechanical power rotating armature can be given regarding torque T and speed n.

$$P_m = \omega T = 2\pi\, nT \quad \ldots\ldots(4)$$

Where n is in revolution per seconds (rps) and T is in Newton-Meter.

Hence,

$$2\pi\, nT = E_b I_a \quad \text{or}$$

$$T = \frac{E_b I_a}{2\pi n}$$

But,

$$E_b = \frac{\varphi ZNP}{60\ A}$$

Where N is the speed in revolution per minute (rpm) and

$$n = \frac{N}{60}$$

Where, n is the speed in (rps).

Therefore,

$$E_b = \frac{\varphi ZnP}{A}$$

So, the torque equation is given as

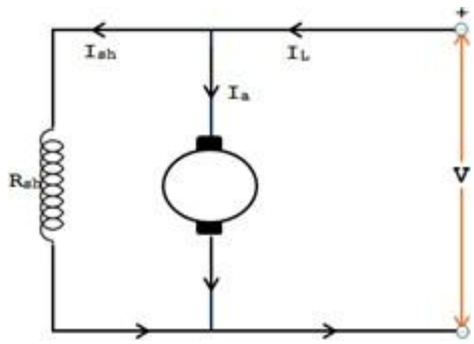
$$T = \frac{\varphi ZP}{2\pi A} \,.\, I_a$$

Characteristics of DC Motors:

The three important characteristic curves are

1. Torque V_s Armature current characteristic (T_a/I_a)
2. Speed V_s Armature current characteristic (N/I_a)
3. Speed V_s Torque characteristic (N/T_a)

DC Shunt Motor Characteristics:

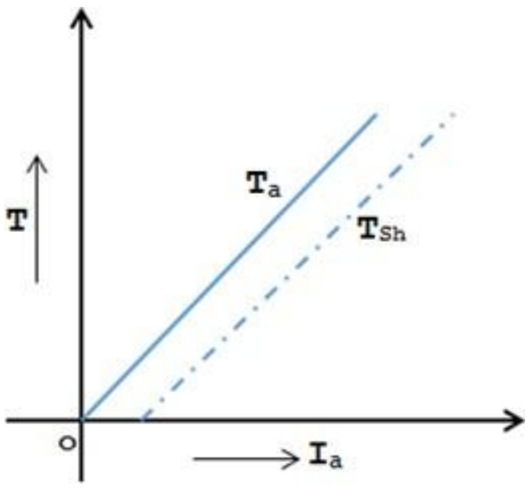


In this circuit the field winding is directly connected to the source voltage, so the field current Ish and the flux in a shunt motor are constant.

Torque V_s Armature current characteristic (T_a/I_a):

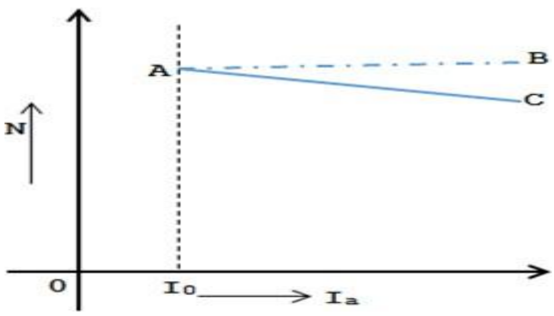
We know that in a DC Motor Ta α ΦIa.

In this the flux Φ is continuous by ignoring the armature reaction, since the motor is working from a continual source voltage

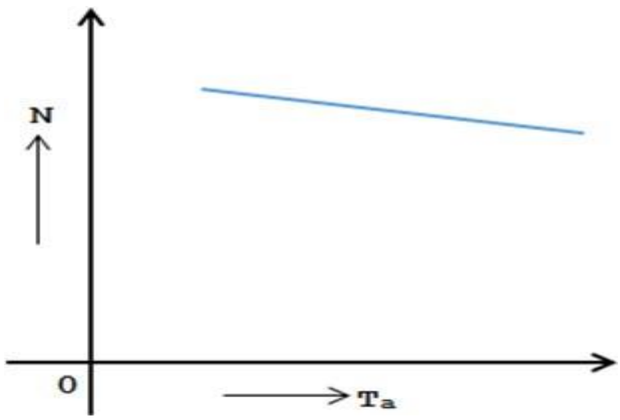


Speed V_s Armature current characteristic (N/I_a):

- At normal condition the back EMF Eb and Flux Φ both are constant in a DC Shunt motor.
- Hence the armature current differs and the speed of a DC Shunt motor will continue constant which is shown in the fig (dotted Line AB).
- Whenever the shunt motor load is increased Eb=V-IaRa and flux reduces as a result drop in the armature resistance and armature reaction.
- On the other hand, back EMF reduces marginally more than that the speed of the shunt motor decreases to some extent with load.

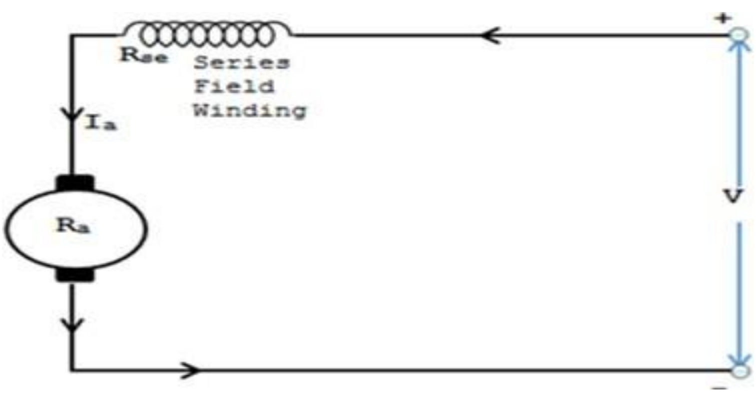


Speed V_s Torque characteristic (N/T_a):

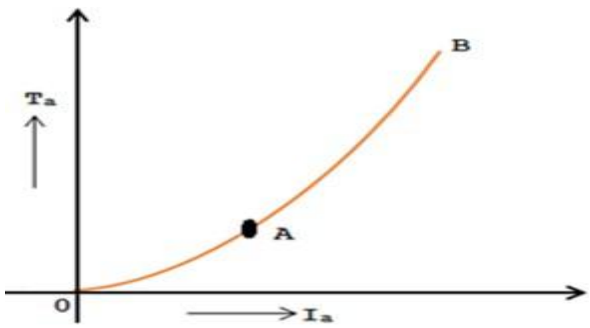


- The speed reduces when the load torque increases.

DC Series Motor:



Torque V_s Armature current characteristic (T_a/I_a):

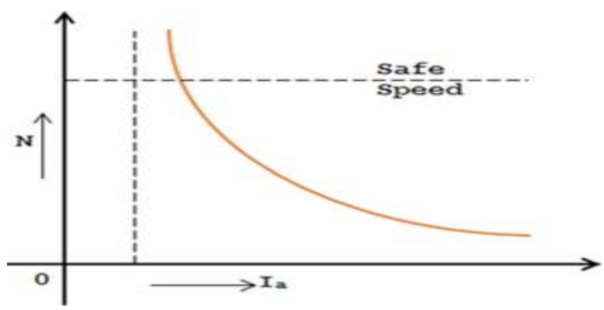


We know that Ta ∝ ΦIa

- Up to Magnetic Saturation Φ ∝ Ia, the armature torque Ta is directly proportional to square of the armature current (i.e.. Ta ∝ I2a).
- If armature current is doubled over, then armature torque is almost increasing fourfold

- Thus the armature torque vs. armature current curve up to magnetic saturation is a parabola, which is shown in the characteristic curve OA.
- On the other hand once the magnetic saturation is reached, the Ta is directly proportional to the Ia.
- As a result the armature torque vs. armature current magnetic saturation characteristic is a straight line, which is shown in the curve AB.

Speed V_s Armature current characteristic (N/I_a):



The Series Motor Speed N is known as N α (E_b/Φ).

We know that back EMF E_b = V-Ia (Ra+Rse).

As soon as the Ia increases, the back EMF E_b reduced due to drop in Ia (Ra+Rse) even though the flux increased. Still, Ia (Ra+Rse) is less in usual circumstance and might be vomited. Therefore, N α (1/ Φ).

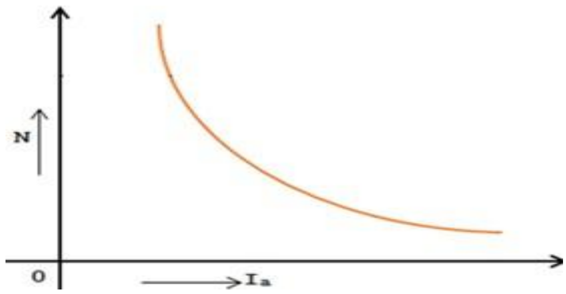
The speed vs. armature current characteristic follows the hyperbolic curve up to magnetic saturation {α (1/ Φ)}.

In series motor the current flows in the field winding and the armature are same.

The armature current will increases whenever the mechanical load of the motor increase.

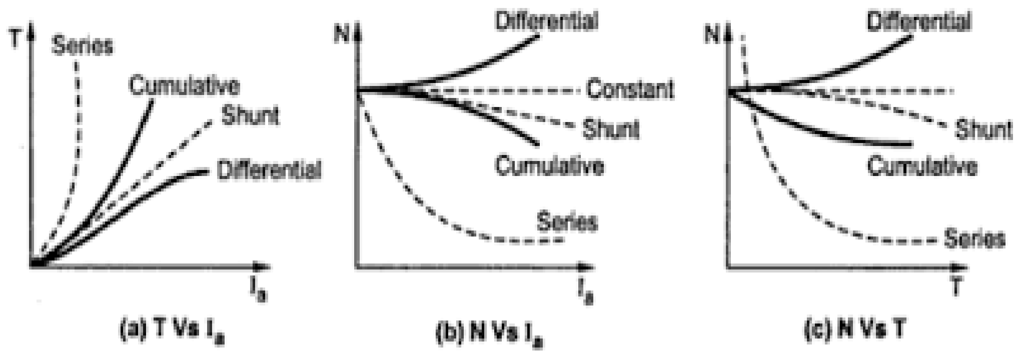
As a result the flux will increase in the series motor when the armature current increases and vice versa.

Speed V_s Torque characteristic (N/T_a):



- From this curve it is evident that the series motor runs at low speed when it develops high torque and vice versa. .
- This is due to the increase in armature torque need to increase the armature current and also the field current.
- As a result flux gets strengthened and drops the speed of the motor. If the speed gets increased the torque must be low.

Characteristic of Compound motor:



Necessity of a Starter:

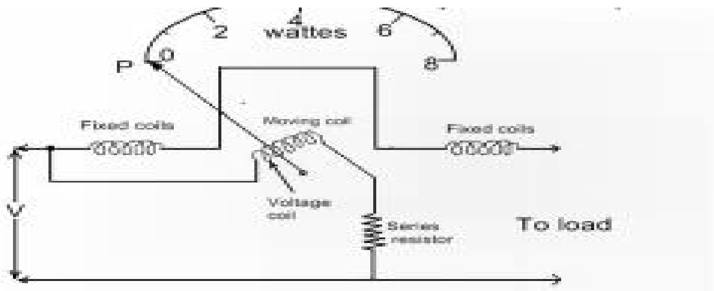
- In a D.C motor whose armature is stationary is switched directly to its supply voltage, it is likely that the **fuses protecting** the motor will **burn out** because the armature resistance is small, frequently being less than one ohm.
- Thus, **additional resistance** must be added to the armature circuit at the instant of closing the switch to start the motor.

- Back Emf create critical role in governing the operation of dc motor. Back emf is generated as the motor armature start to rotate in presence of magnetic field and it is counter to the supply voltage.
- The back emf at the starting is zero and develops as the motor gradually speed up.
- We know that general emf equation **E=E**b+**I**a**R**a.
- At starting E_b=0 so **I**a=E/Ra, which indicates that current will be dangerously high at starting (As Armature resistance Ra is small).Hence it is necessary to use starter to limit the starting current to allowable lower value.

II. Measuring *Instruments*:

Syllabus: Construction and Principle of operation of dynamometer type wattmeter and single phase induction type energy meter.

Electrodynamometer Type Wattmeter:



Dynamometer type Wattmeter

Construction:

It consists of the following parts:

Moving coil - Moving coil moves the pointer with the help of spring control instrument In electrodynamometer type wattmeter, moving coil works as pressure coil. Hence moving coil is connected across the voltage and thus the current flowing through this coil is always proportional to the voltage.

Fixed coil - The fixed coil is divided into two equal parts and these are connected in series with the load, therefore the load current will flow through these coils. Now the reason is very obvious of using two fixed coils instead of one, so that it can be constructed to carry considerable amount of electric current. These coils are called the current coils of electrodynamometer type wattmeter. Earlier these fixed coils are designed to carry the current of about 100 amperes but now the modern wattmeter are designed to carry current of about 20 amperes in order to save power.

Control system - Out of two controlling systems i.e. gravity control and spring control, only spring controlled systems are used in these types of wattmeter. Gravity controlled system cannot be employed because they will contain appreciable amount of errors.

Damping system - Air friction damping is used, as eddy current damping will distort the weak operating magnetic field and thus it may lead to error.

Scale - There is uniform scale is used in these types of instrument as moving coil moves linearly over a range of 40 degrees to 50 degrees on either sides.

Working:

Let

v=supply voltage

i=load current and

R=resistance of the moving coil circuit

Current through fixed coils, $i_f = i$
Current through the moving coil, $i_m = v/R$
Deflecting torque,

$$T_d \propto (i_f * i_m) \propto \frac{iv}{R}$$

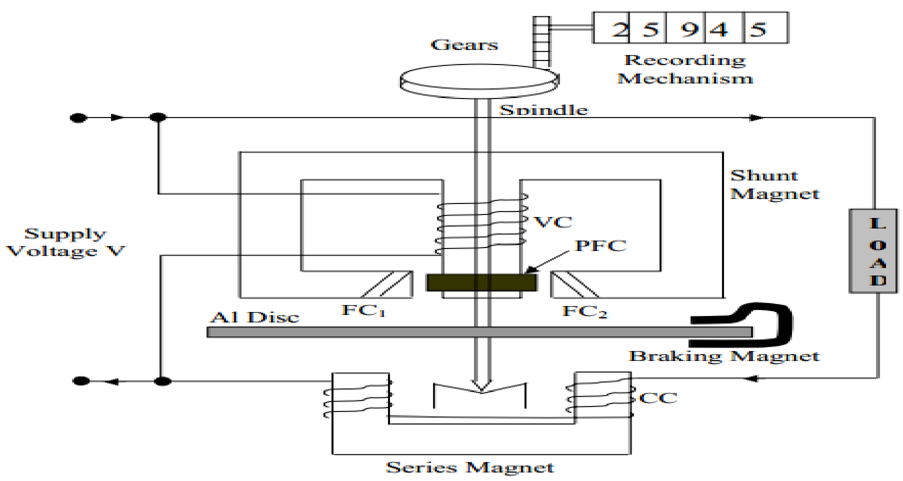
For a DC circuit the deflecting torque is thus proportional to the power.

For any circuit with fluctuating torque, the instantaneous torque is proportional to instantaneous power. In this case due to inertia of moving parts, the deflection will be proportional to the average power. For sinusoidal alternating quantities the average power is V.I.cos**ϕ**, where

V= RMS value of voltage I = RMS value of current, and **ϕ**= phase angle between V and I

Hence an electrodynamometer instrument, when connected as shown in figure, indicates the power, irrespective of the fact it is connected in an AC or DC circuit.

Single Phase Induction Type Energy Meter:



Construction:

- It consists of a pressure coil made of thin copper wire of many turns (also called shunt magnet); a current coil made of thick copper wire of one or two turns (also called series magnet), an aluminium disc mounted on spindle
- A braking magnet is arranged on a disc to control its movement and to stop the movement under no load.
- A phase difference of 90^0 is set between current coil and pressure coil with the help of copper shaded rings.

Working:

- This instrument works on the principle of induction that when both the shunt and series coils are energized by ac, there will be tow alternative fluxes are in the shunt coil and one in the series coil these time varying fluxes are cut by a stationary disc.
- Inducing currents in the disc.
- These currents interacts with the fluxes and results in a torque.
- The disc rotates in a particular direction and the number and speed of rotations depends on the energy consumed by the load.

Numerical:

1. A 4 pole d.c shunt motor takes 22A from 220V supply. The armature & the field resistances are 0.5Ω & 100Ω respectively. The armature is lap connected with 300 conductors. If the flux/pole is 20mWb, calculate the speed & gross torque.
2. A d.c series motor is running with a speed of 1000rpm, while taking current of 22A from the supply. If the load is changed such that the current drawn by the motor is increased to 55A, calculate the speed of the motor on new load. The armature & series winding resistances are 0.3Ω & 0.4Ω. assume supply voltage is 250V
3. A 4 pole, 1500 rpm d.c generator has a lap wound armature having 24 slots with 10 conductors/slot. If the flux/pole is 0.04Wb, calculate the Emf generated in the armature. What would be the generated Emf if the winding is converted as wave?
4. The current drawn from the mains by a 220V d.c shunt motor is 4A on no load. The resistance field & armature windings are 110 ohms & 0.2 ohms respectively. If the line current on full load is 40A at a speed of 1500 rpm, find the no load speed.
5. A 200V, 4 pole, lap wound, d.c shunt motor has 800 conductors on its armature. The resistance of armature winding is 0.5 ohm & that of shunt field winding is 200 ohm. The motor takes a current of 21A, the flux/pole is 30mWb. Find the speed & gross torque developed in the motor
6. An 8 pole, lap connected armature has 40 slots with 12 conductors/slot, generates a voltage of 500V. Determine the speed at which it is running if the flux/pole is 50mWb.

7. An 8 pole generator has 500 armature conductors and has a useful flux/pole of 0,065 Wb. What will be the Emf generated if it is lap connected & runs at 1000 rpm? What must be the speed at which it is to be driven to produce the same emf if it is wave wound?
8. A 4 pole generator with wave wound armature has 51 slots each having 24 conductors. The flux/pole is 0.01 Wb. At what speed the armature rotates to give an induced Emf of 220V? What will the voltage of the winding in lap & the armature rotates at the same speed.
9. A d.c shunt motor takes an armature current of 110a at 480V. The armature resistance is 0.2 ohm. The machine has 6 poles & armature is lap connected with 864 conductors. The flux/pole is 0.05 Wb. Calculate the speed, the torque developed in armature.
10. A 4 pole DC shunt motor takes 22.5 A from 250V supply Ra =0.5ohms, R_{sh}=125ohms, the armature is wave wound with 300 conductors. If the flux per pole is 0.02Wb, calculate speed, torque and power developed.
11. 200V lap wound DC shunt motor has 800 conductors on its armature, the resistance of the armature winding is 0.5ohms and that of field winding is 200ohms, the motor takes a current of 21A, the flux per pole is 30mWb. Find the speed and torque developed by the motors.
12. 200V lap wound DC shunt motor has 800 conductors on its armature, the resistance of the armature winding is 0.5ohms and that of field winding is 200ohms, the motor takes a current of 21A, the flux per pole is 30mWb. Find the speed and torque developed by the motors.
13. A 30 KW, 300 V DC shunt generator has armature and field resistance of 0.05ohms and 100 ohm respectively. Calculate the total power developed by armature when it delivers full output power.
14. A DC shunt motor takes an armature current of 110A at 480V. The armature resistance is 0.2 ohms, The machines has 6 poles, and armature is lap connected with 864 conductors. The flux per pole is 0.05 Wb, calculate speed and torque developed by the armature.
15. The emf generated in the armature of a shunt generator is 625 V, when delivering its full load current of 400A to the external circuit. The field current is 6 A and the armature resistance is 0.06 ohms. What is the terminal voltage?
16. 220 V series motor is taking a current of 40A, resistance of armature 0.5 ohms, resistance of series field is 0.25 ohms. Calculate voltage at the brushes, back Emf, power wasted in armature, and power wasted in series field.