DC MOTOR

Indus Institute Of Technology and Engineering

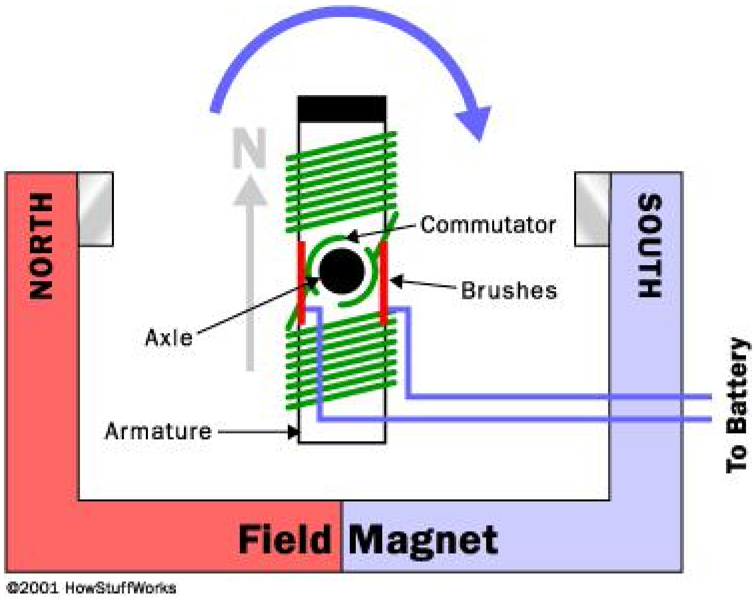
Contents

DC motor principles

A motor is a device which converts an electrical energy into mechanical energy.

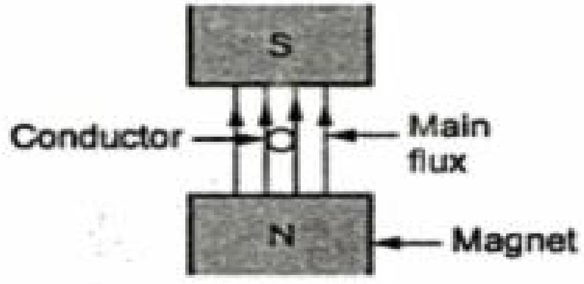
when a current carrying conductor is placed in a magnetic field' it experiences a mechanical force'.

In a practical d.c. motor, field winding produces a required magnetic field while armature conductors play a role of a current carrying conductors and hence armature conductors experience a force.

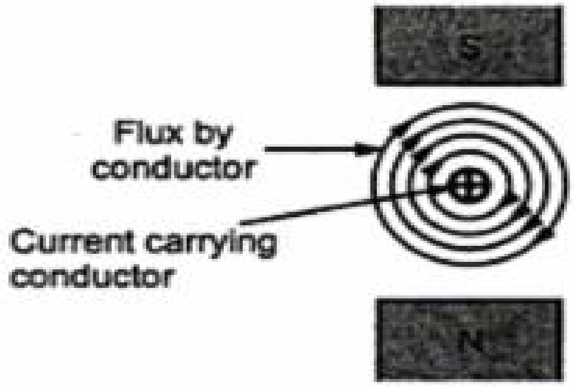


DC motor principles

- As a conductors are placed in the slots which are in the periphery, the individual force experienced by **the conductors acts as a twisting or turning force on the armature which is called a torque.**
- The torque is the product of force and the radius at which this force acts. So overall armature experiences a torque and starts rotating.

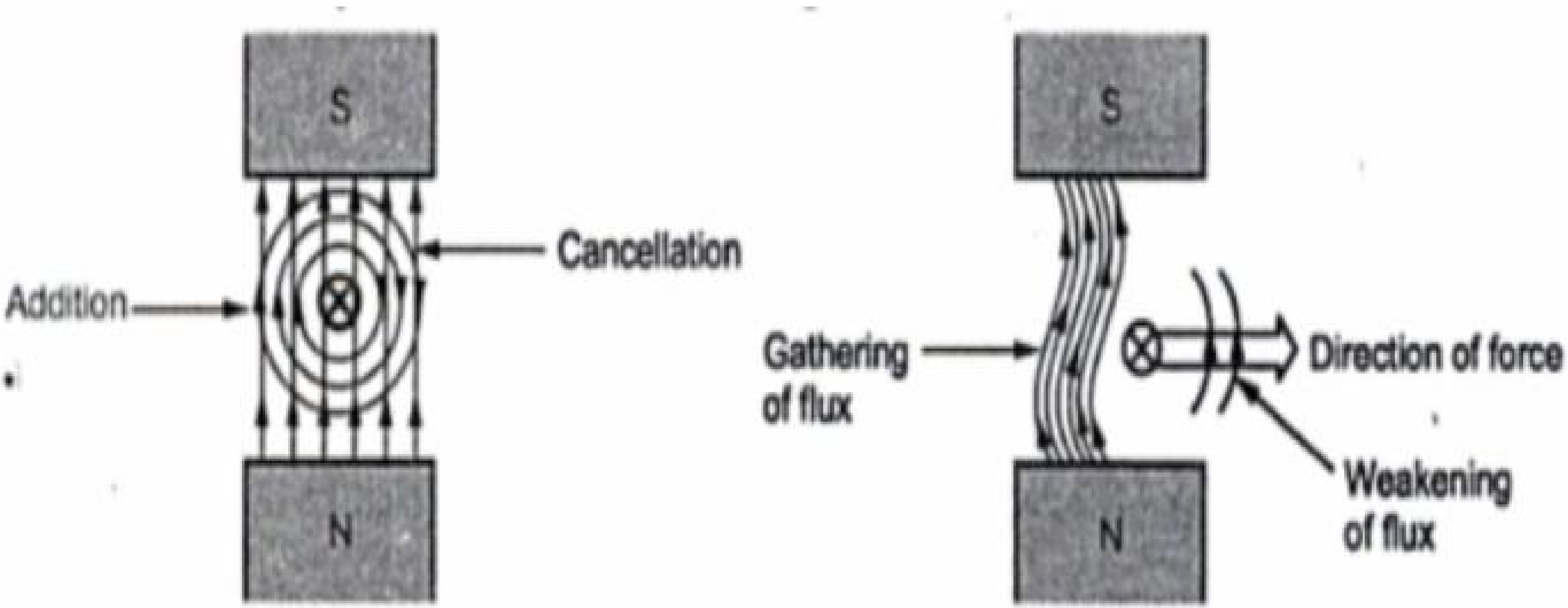


(a) Conductor in a magnetic field



(b) Flux produced by current carrying conductor

DC motor principles



(a) Interaction of two fluxes

(b) Force experienced by the conductor

Direction of Rotation of Motor

- The magnitude of the force experienced by the conductor in a motor is given by,

$$\mathbf{F = B\,l\,I \quad Newton\,(N)}$$

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.

Advantages And Disadvantages

Advantages

- High starting torque,
- Rapid acceleration and deceleration,
- Speed can be easily controlled over wide speed range,
- Used in tough jobs (traction motors, electric trains electric cars),
- Build in wide range of sizes.

Disadvantages

- Needs regular maintenance.
- Cannot be used in explosive area.
- High cost

Back E.M.F

In dc motor the rotating armature will generate an emf as it is rotating under magnetic field, in opposite of the applied voltage and this generated emf in dc motor is called back emf.

$$E_b = \phi ZN \times \left(\frac{P}{60A}\right) \text{volts}$$

Back e.m.f depend upon armature speed.

If speed is high ,E_b is large. hence armature current I_a is small.

If speed is less, E_b is less. hence more current flows which develops motor torque.

Voltage Equation Of The Motor

The voltage V applied across the motor armature has to

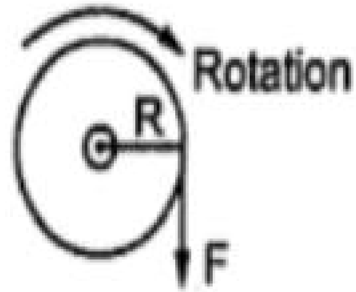
- Overcome the back emf E_b and
- Supply the armature ohmic drop I_aR_a.

$$\mathbf{V = E_b + I_aR_a}$$

This is known as voltage equation of the motor.

Torque

Torque is meant the turning or twisting moment of a force about an axis. It is measured by the product of force and radius at which this force acts.



$$T = F \times r \text{ Newton meter}$$

Work done by force in one revolution

$$= \text{Force} \times \text{Distance} = F \times 2\pi r$$

Power developed $= F \times 2\pi r$ /time for 1 revolution $= F \times 2\pi r /(60/N)$

$$= (F \times r) 2\pi N / 60 \text{ watt}$$

Torque

Now **2πN** = **Angular velocity ω in radian/second and**

$$F \times r = \text{torque}T$$

$$P = \frac{2\text{€}N}{60} \text{´} \quad T$$

or

$$P = \frac{2\text{€}}{60} \text{´} \quad NT$$

P = T x ω watts

Where T = Torque in N – m,

ω = Angular speed in rad/sec.

Armature torque of a Motor

Let T_a 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 E_b I_a,. So if speed of the motor is N r.p.m. then,

Power in armature = Armature torque x ω

∴ $E_b I_a = Ta \times (2\pi N/60)$

but E_b in a motor is given by,

$E_b = (\Phi PNZ) / (60A)$

∴ $(\Phi PNZ / 60A) \times Ia = T_a \times (2\pi N/60)$

Armature torque of a Motor

$$\therefore \quad T_a = \frac{1}{2\pi}\phi I_a \times \frac{PZ}{A}$$

$$T_a = 0.159\,\phi I_a \cdot \frac{PZ}{A} \text{ N-m}$$

Shaft Torque

- The torque which is available for doing useful work is known as shaft torque., it is so called becoz it is available at the shaft.
- Motor output = $Tsh \times 2\pi n\, watts$

$$Tsh = \frac{outputinwatts}{2\pi N / 60}$$

Armature torque of a Motor

- For a series motor is φ is directly proportional to Ia becoz field winding carry full armature current.

‘ Ta ¥ Ia^2

- For shunt motor, φ is practically constant,

Ta ¥ Ia

hence

Major types of dc motors

- Self excited DC motor
  - **Series dc motor**
  - **Shunt dc motor**
  - **Compound dc motor**
- Separately excited DC motor
- Permanent Magnet DC motor

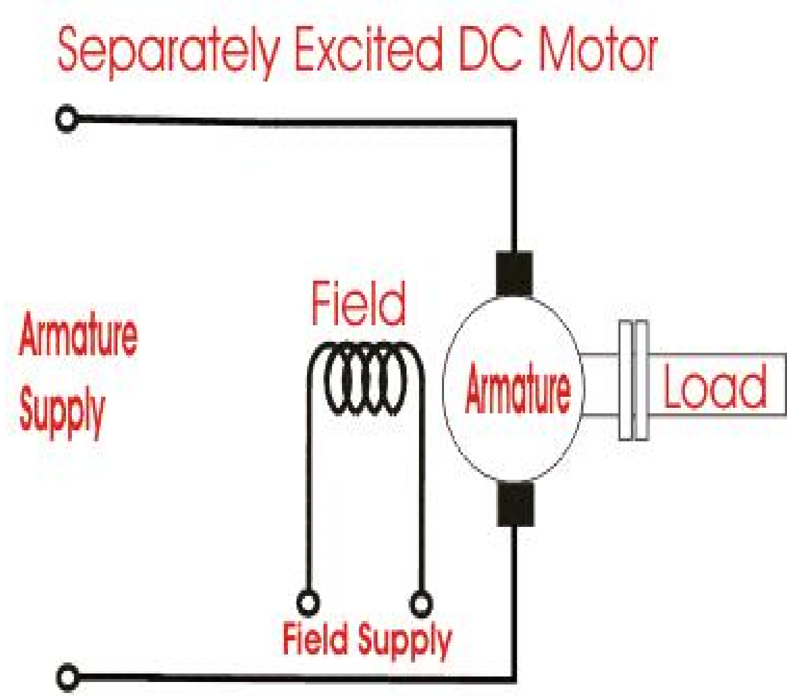
Separately Excited DC Motor

A separately excited DC motor the supply is given separately to the field and armature windings.

From the torque equation of dc motor

$T_g = K_a \varphi I_a$

So the torque in this case can be varied by varying field flux φ, independent of the armature current I_a.



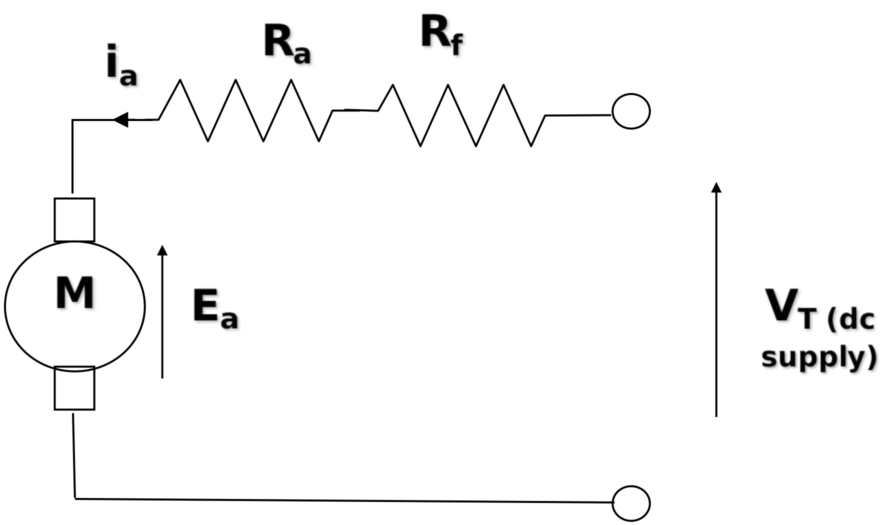
$$V_f = i_f R_f$$

$$V_T = E_a + i_a R_a$$

Series motors

- Series motors connect the field windings in series with the armature.

- Series motors lack good speed regulation, but are well-suited for high-torque loads like power tools and automobile starters because of their high torque production and



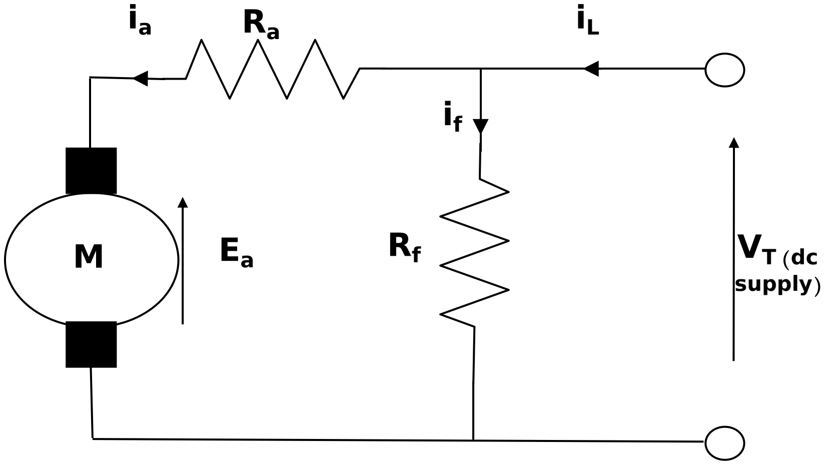
$$V_T = E_a + i_a(R_a + R_f)$$

$$note: i_a = i_L$$

Shunt motors

Shunt motors use high–resistance field windings connected in parallel with the armature.

- Shunt motors easily have armature reaction, a distortion and weakening of the flux generated by the poles that results in commutation problems evidenced by sparking at the brushes.



- Installing additional poles, called interpoles, on the stator between the main poles wired in series with the armature reduces armature reaction.

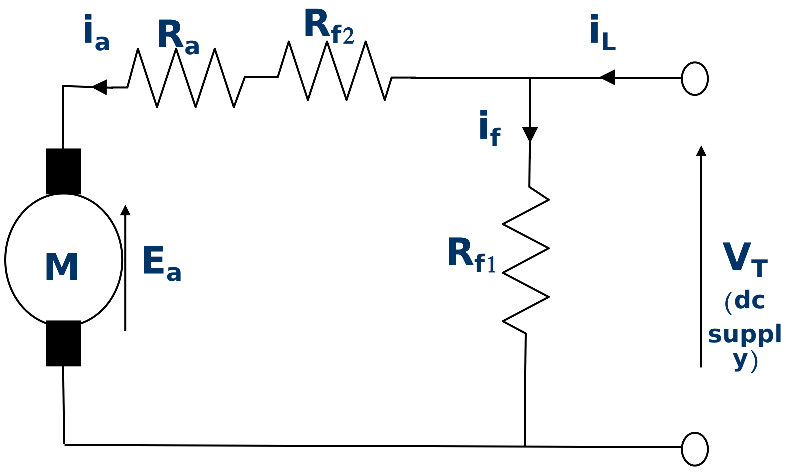
$$note : i_L = i_a + i_f$$

$$V_T = i_f R_f$$

Compound motors

The concept of the series and shunt designs are combined.

$$V_T = E_a + i_a(R_a + R_{f2})$$



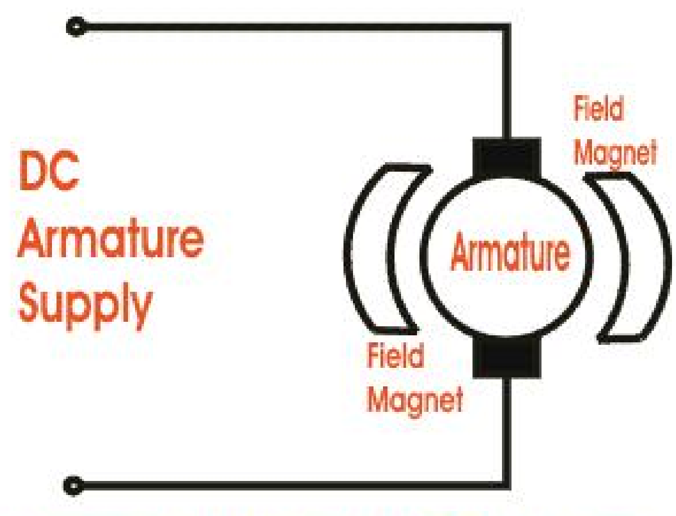
$$note: i_L = i_a + i_f$$

$$V_T = i_f R_{f1}$$

Permanent Magnet DC Motor

The **permanent magnet DC motor** consists of an armature winding as in case of an usual motor, but does not necessarily contain the field windings.

- The construction of these types of DC motor are such that, radially magnetized permanent magnets are mounted on the inner periphery of the stator core to produce the field flux.
- The rotor on the other hand has a conventional dc armature with commutator



Permanent Magnet DC Motor

Permanent Magnet DC Motor

- The torque equation of dc motor is

$$\mathbf{T_g = K_a \, \varphi \, I_a.}$$

- Here φ is always constant, as permanent magnets of required flux density are chosen at the time of construction and can't be changed there after.
- For a permanent magnet dc motor

$$\mathbf{T_g = K_{a1} I_a}$$

- Where $K_{a1} = K_a.\varphi$ which is another constant. In this case the torque of DC Motor can only be changed by controlling armature supply.

Motor Characteristics Curve

Three basic characteristics are

- Torque vs. armature current
- Speed - armature current
- Speed vs. torque

Torque –Armature Current Characteristics

- The torque developed by the armature of dc motor is given by

$$T_a = 0.159 \frac{P \phi I_a Z}{A} Nm$$

P,Z,A are constant for a particular motor.

Hence,

$$T_a \propto \phi I_a$$

$$T_a = K' \phi I_a$$

Speed –Armature Current Characteristics

For a DC motor, the expression for speed is given by

Speed, $$N = K \frac{V - I_a R_a}{\phi}$$

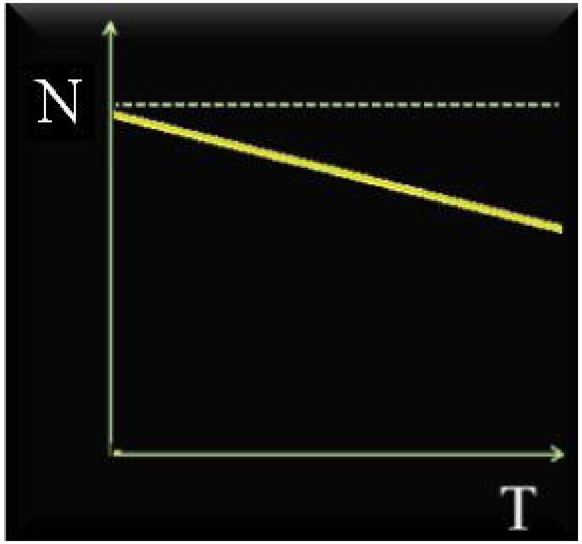
For shunt motor:

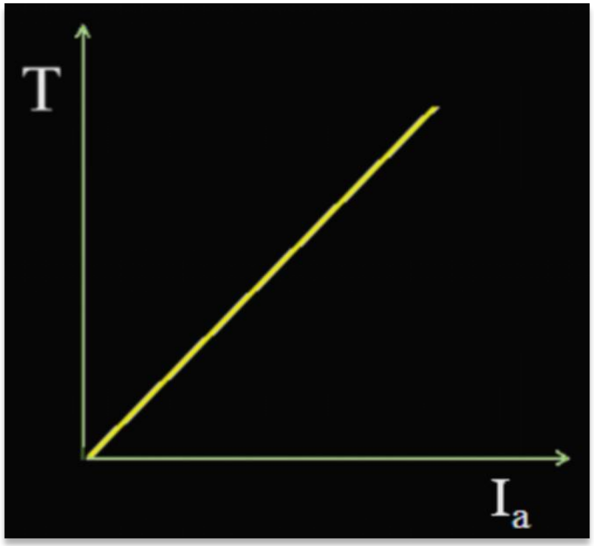
N=K1(V-IaRa)

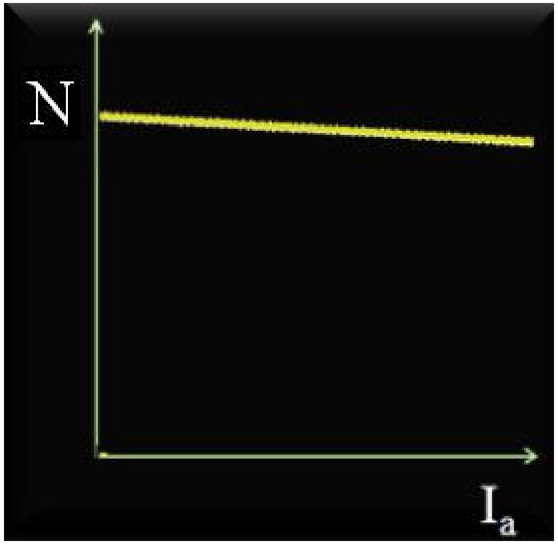
Speed of the motor falls slightly with the armature current

DC Shunt Motor

The following are the three important operating characteristics of DC Shunt Motor:







1. **Speed – Torque characteristics**
2. **Torque – armature current characteristics**
3. **Speed – armature current characterist**

Speed – Torque characteristics of DC Shunt Motor

Three Equations are used to get this characteristics

i) $T = k.\,Ø.I_a$

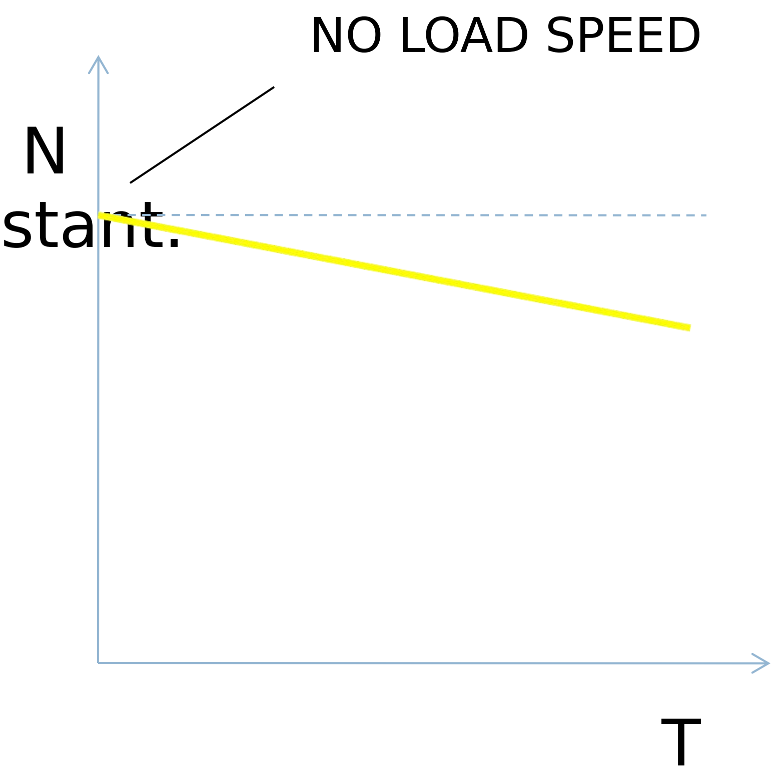
ii) $E_a = k.Ø.N$

iii) $E_a = V – R.\,I_a$

For shunt motor, φ is constant.

$$N = \frac{V - \frac{T}{K.Ø}.R}{K.Ø}$$

$$N = \frac{V}{K.Ø} - \frac{T}{(K.Ø)^2}.R$$



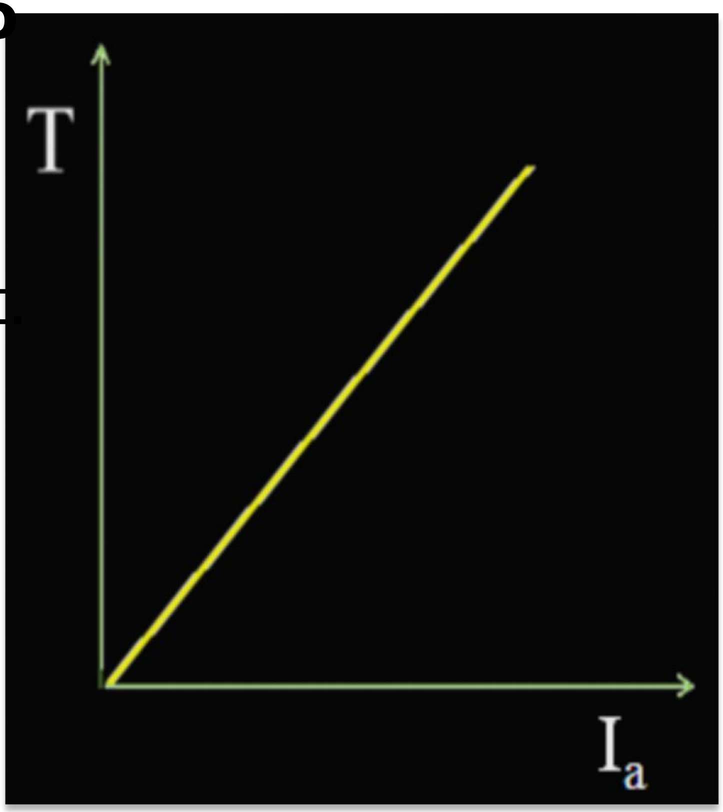
Torque –Armature current characteristic of DC Shunt Motor

Three Equations are used to get this characteristics

i) $T = k.\,Ø.I_a$

For shunt motor, φ is constant.

T proportional to I_{a},



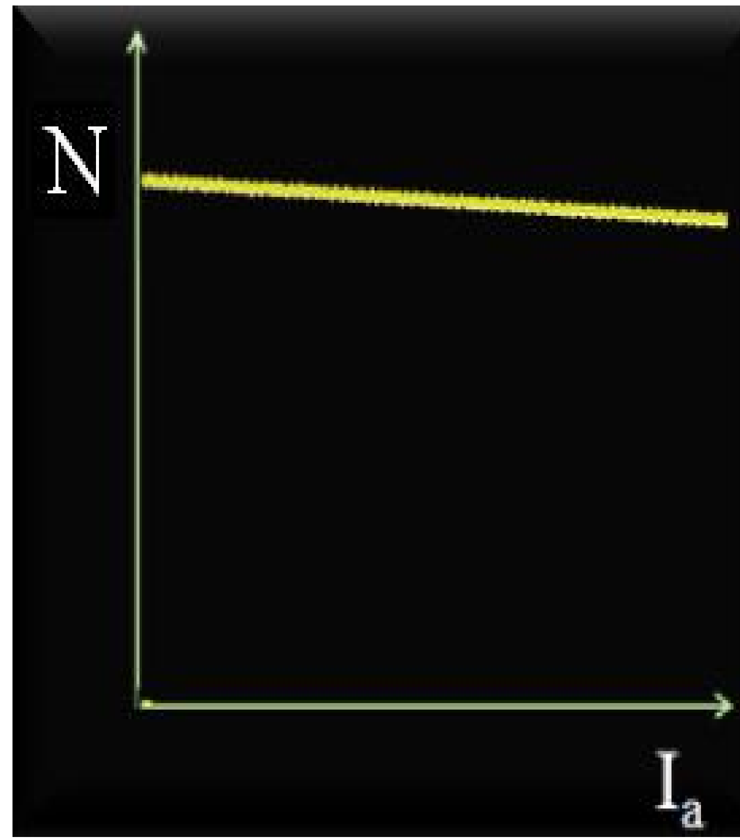
Speed – armature current characteristic of DC Shunt Motor

$E_a = k.Ø.N$

$E_a = V – R.\ I_a$

By using above two equation it can be obtained:

$$N = \frac{V}{kf} - \frac{RI_a}{kf}$$

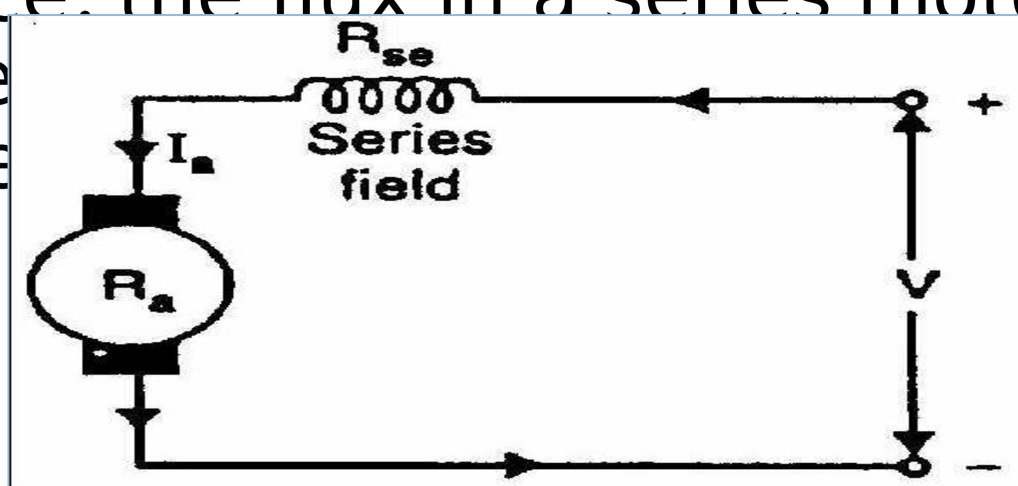


Conclusions

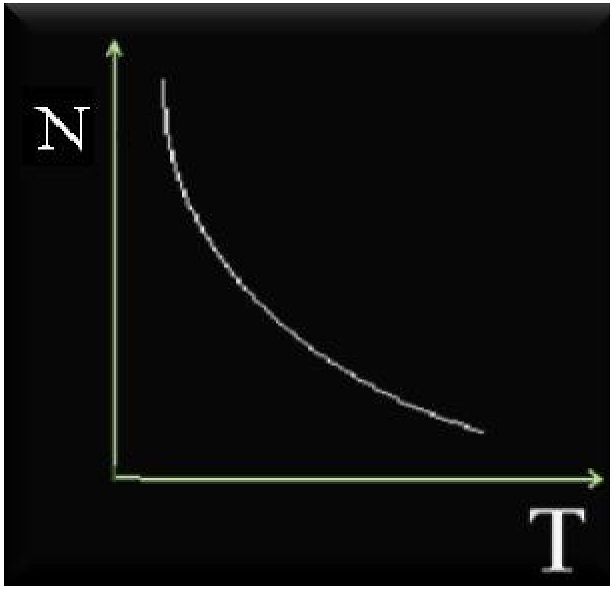
- There is slight change in the speed of a shunt motor from no–load to full load. Hence, it is essentially a constant–speed motor.
- The starting torque is not high because Ta ∞ Ia.

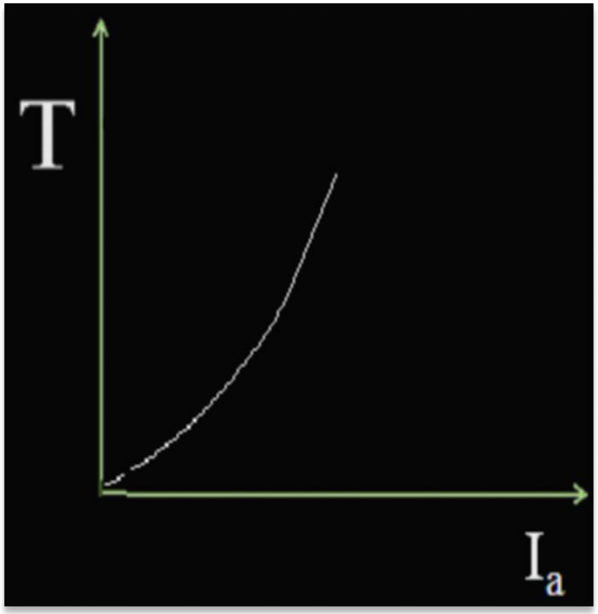
DC Series Motor

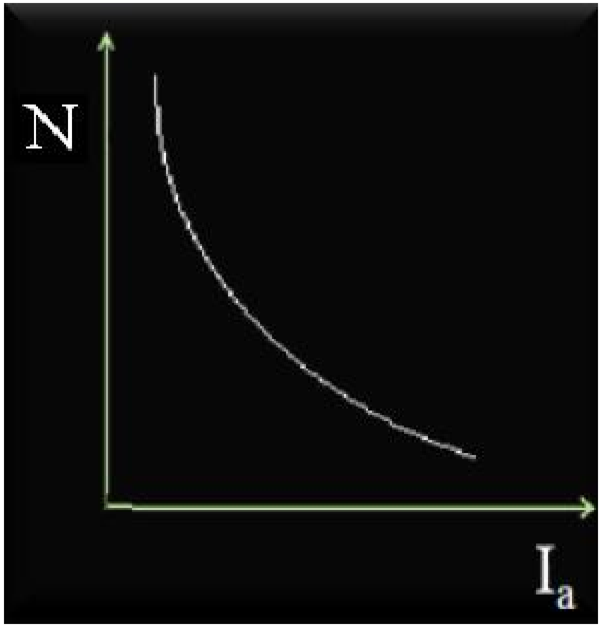
- The current passing through the field winding is the same as that in the armature.
- If the mechanical load on the motor increases, the armature current also increases.
- Hence, the flux in a series motor incre … armature curre …



DC Series Motor







1. **Speed – Torque characteristics**
2. **Torque – armature current characteristics**
3. **Speed – armature current characterist**

Speed – Torque Characteristics of DC Series Motor

Three Equations are used to get this characteristics

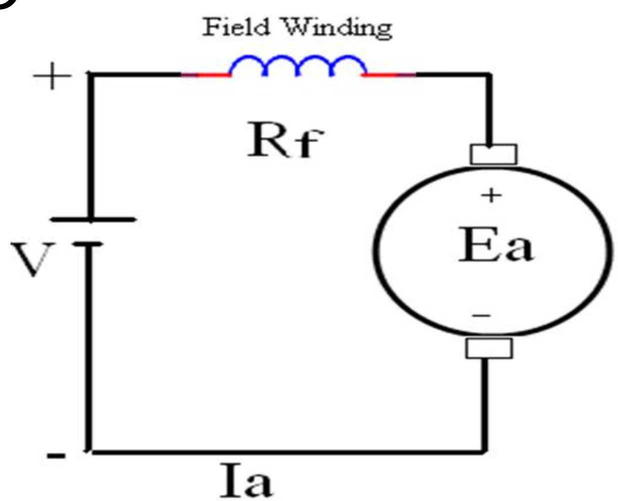
i) $T = k.\, Ø.I_a$

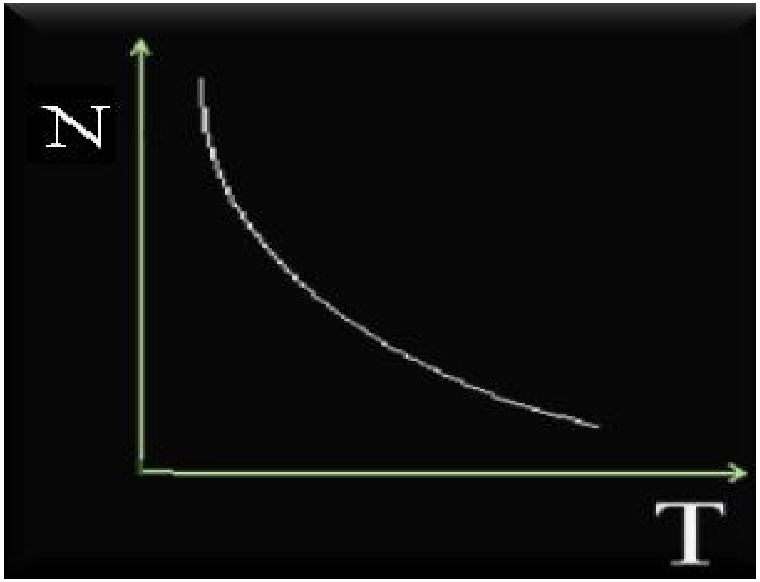
ii) $E_a = k.Ø.\, N$

iii) $E_a = V - R.\, I_a$

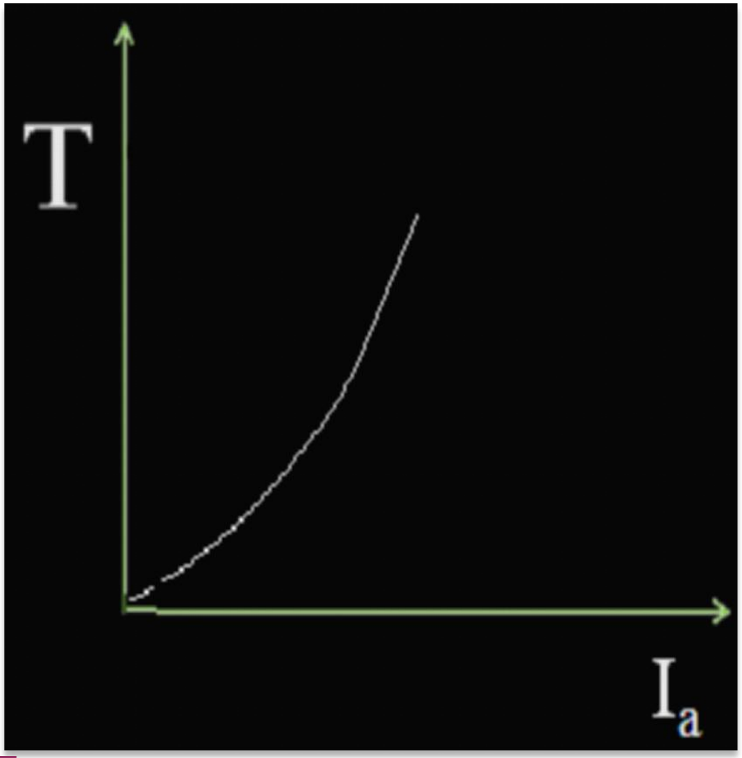
From this circuit:

$I_a = k'\, Ø$





Torque –Armature current characteristic of DC Series Motor



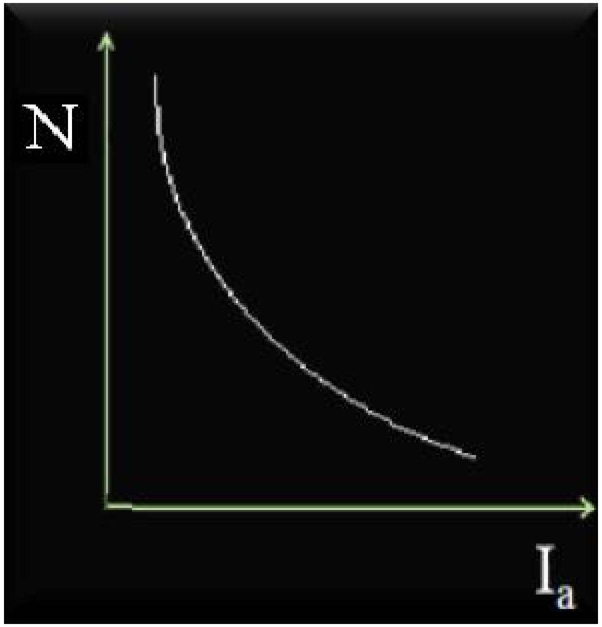
$$t = kf I_a \triangleq t = kI_a^2$$

Speed – armature current characteristic of DC Series Motor

$$kfN = V - I_a R$$

$$N = \frac{V}{kf} - \frac{I_a R}{kf}$$

$$N = \frac{V}{k' I_a} - k'' R$$



From above equation, graph can be obtained.

Conclusions

- It has a high starting torque becaus $T_a \propto \phi I_a$
- It is a variable speed motor i.e., it automatically adjusts the speed as the load changes. Thus if the load decreases, its speed is automatically raised and vice-versa.
- At no-load, the armature current is very small and so is the flux. Hence, the speed rises to an excessive high value .
- This is dangerous for the machine which may be destroyed due to centrifugal forces set up in the rotating parts.
- Therefore, a series motor should never be started on no-load. However, to start a series motor, mechanical load is first put and then the motor is started.

Compound Motors

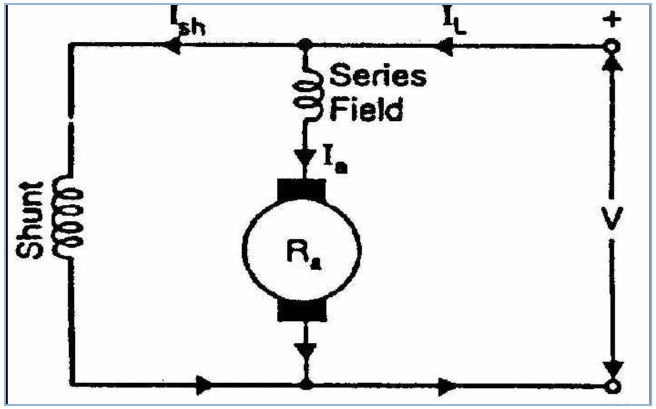
A compound motor has both series field and shunt field. The shunt field is always stronger than the series field. Compound motors are of two types:

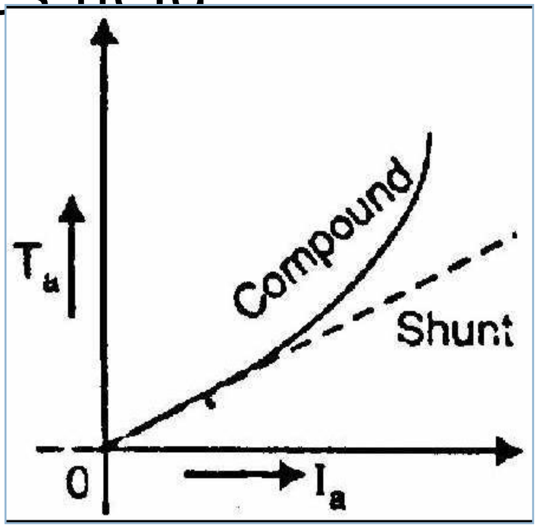
- *Cumulative-compound motors in which series field aids the shunt field.*
- *Differential-compound motors in which series field opposes the shunt* field.

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

Ta/Ia Characteristic

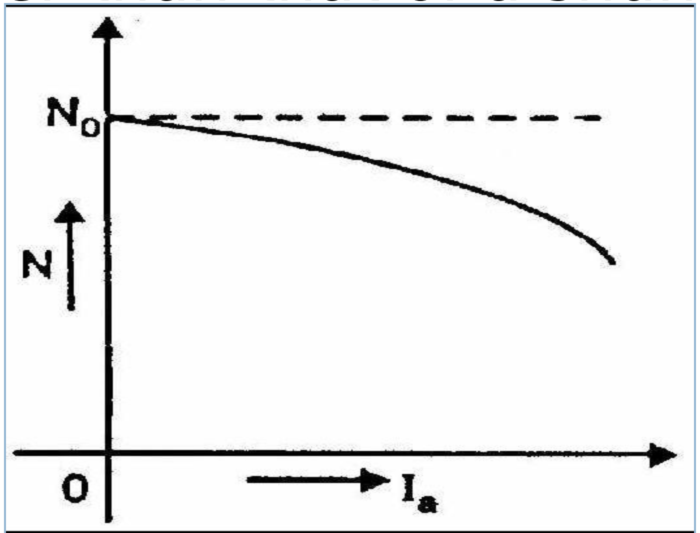
- As the load increases, the series field increases but shunt field strength remains constant. Consequently, total flux is increased and hence the armature torque .
- Torque of a cumulative–compound motor is greater than that of shunt motor for a given armature current due to series field





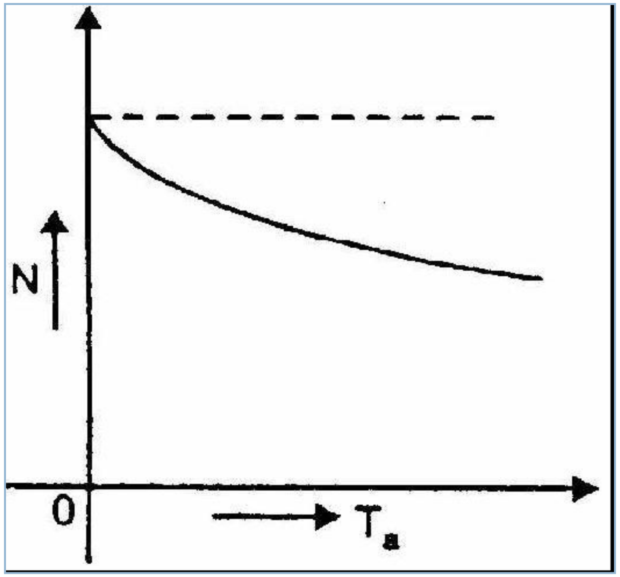
N/Ia Characteristic

- As the lead increases, the flux per pole also increases. Consequently, the speed of the motor tails as the load increases .
- 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.



N/Ta Characteristic

- 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.

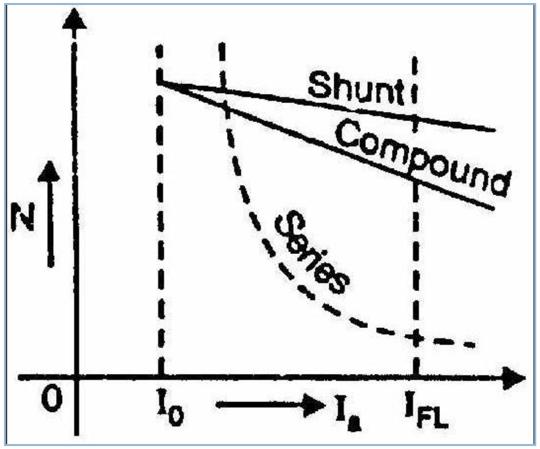


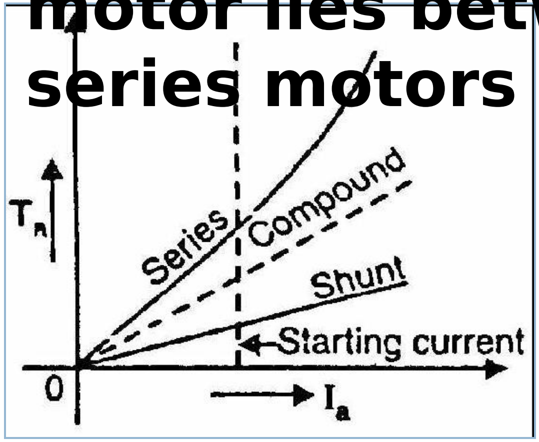
Conclusions

- A cumulative compound motor has characteristics intermediate between series and shunt motors.
- Due to the presence of shunt field, the motor is prevented from running away at no–load.
- Due to the presence of series field, the starting torque is increased.

Comparison of Three Types of Motors

- The speed regulation of a shunt motor is better than that of a series motor. However, speed regulation of a cumulative compound motor lies between shunt and series motors





- For a given armature current, the starting torque of a series motor is more than that of a shunt motor. However, the starting torque of a cumulative compound motor lies between series and shunt motors

Both shunt and cumulative compound motors have definite no–load speed. However, a series motor has dangerously high speed at no–load.

Speed Control for dc motor

- There are three variables that can influence the speed of the motor, V

  I_f } Variables

  R_a

- Thus, there are three methods of controlling the speed of the shunt and separately excited dc motor,

  i. **Armature terminal – voltage speed control**
  ii. **Field speed control**
  iii. **Armature resistance speed control**

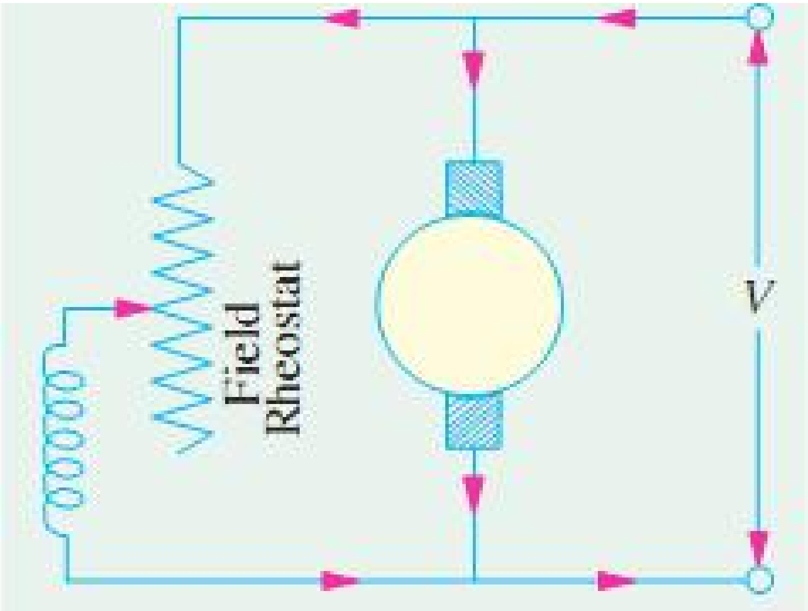
Speed Control Of Shunt Motor

- **Variation of Flux or Flux Control Method**:

By decreasing the flux, the speed can be increased and vice versa.

The flux of a dc motor can be changed by changing Ish with help rheostat.

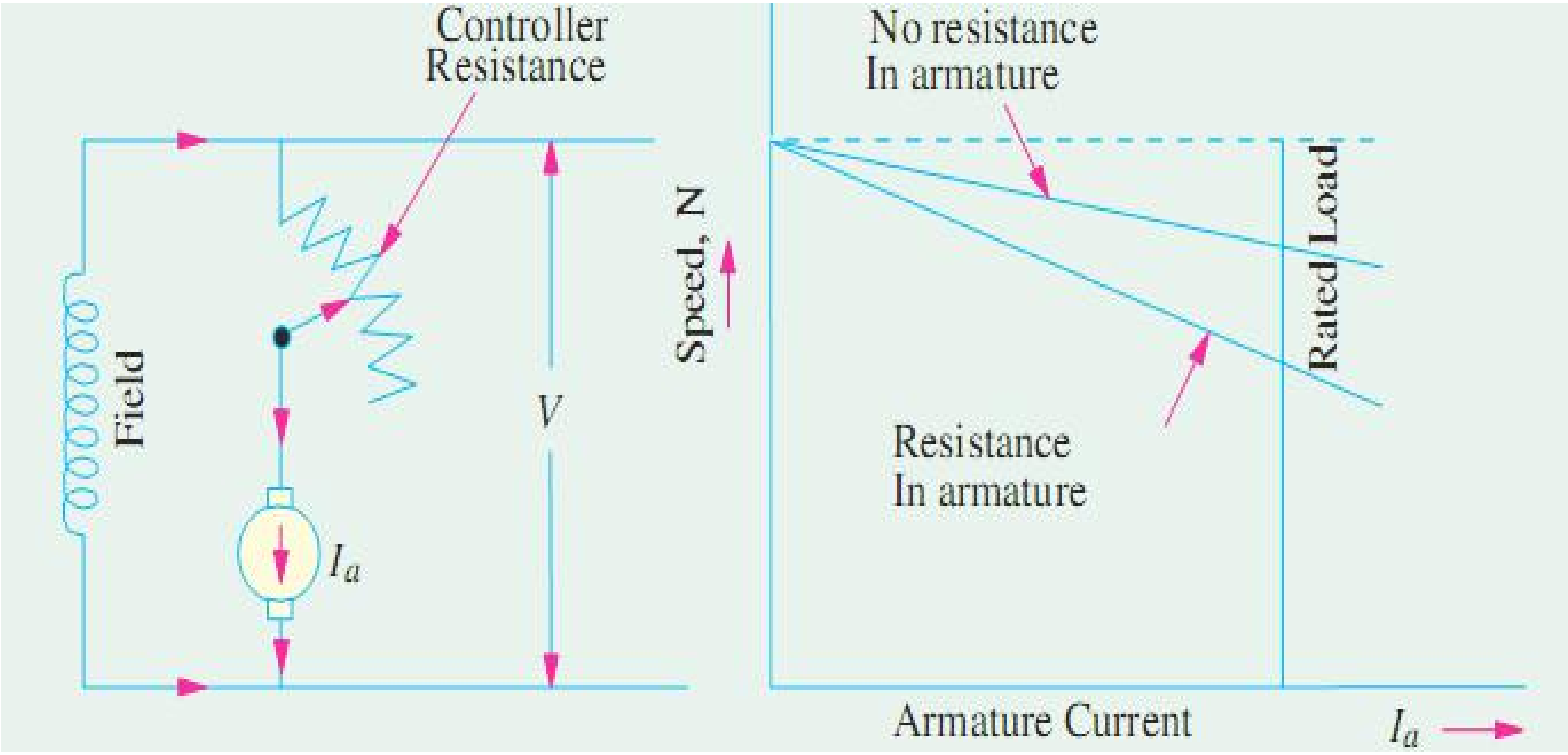
Since Ish is relatively small, shunt field rheostat has to carry only a small current, which means $I^2 R$ loss is small, so that rheostat is small in size.



Armature or Rheostatic Control Method

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

Armature or Rheostatic Control Method



Advantages And Disadvantages

- **Advantages armature resistance speed control:**
  1. Starting and speed control functions may be combined in one rheostat
  2. The speed range begins at zero speed
  3. Simple method
- **Disadvantages armature resistance speed control :**
  1. Introduce more power loss in rheostat
  2. Speed regulation is poor
  3. Low efficiency due to rheostat

Speed Control

Armature terminal – voltage speed control

- Use power electronics controller
  - AC supply Šrectifier
  - DC supply Šchopper
- Supply voltage to the armature is controlled
- Constant speed regulation

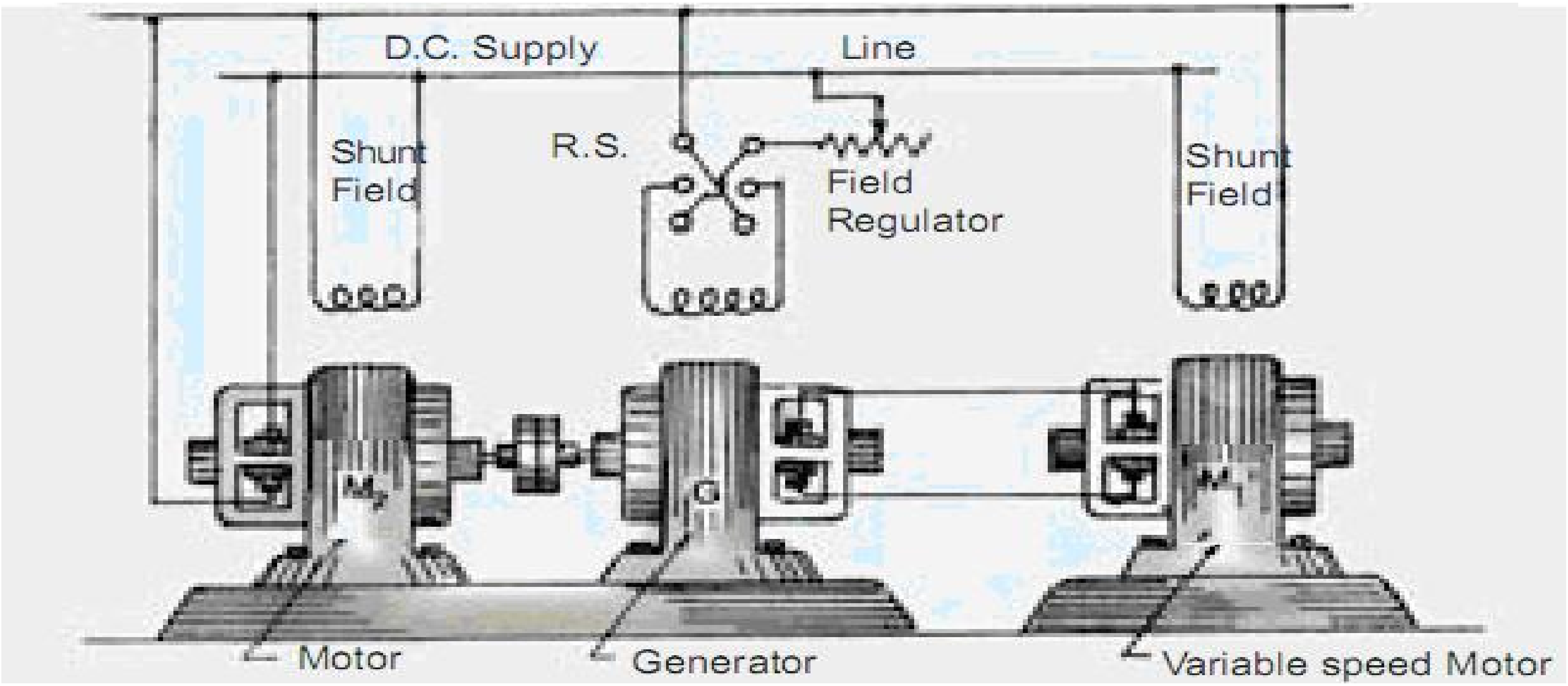
Voltage Control Method

(a) Multiple Voltage Control:

- In this method, the shunt field of the motor is connected permanently to a fixed exciting voltage, but the armature is supplied with different voltages by connecting it across one of the several different voltages.
- The armature speed will be approximately proportional to these different voltages.
- The intermediate speeds can be obtained by adjusting the shunt field regulator.

Ward-Leonard System

This system is used where an unusually wide and very sensitive speed control is required as for electric excavators, elevators and the main drives in steel mills and blooming and paper mills.



Ward-Leonard System

- It is a basic armature control method. This control system is consisting of a dc motor M1 and powered by a DC generator G.
- In this method the speed of the dc motor (M1) is controlled by applying variable voltage across its armature.
- This variable voltage is obtained using a motor-generator set which consists of a motor M2(either ac or dc motor) directly coupled with the generator G.
- It is a very widely used method of speed control of DC motor.

Ward-Leonard System

Advantages of Ward Leonard System

- It is a very smooth speed control system over a very wide range (from zero to normal speed of the motor).
- The motor can run with a uniform acceleration.
- Speed regulation of DC motor in this ward Leonard system is very good.

Disadvantages of Ward Leonard System

- The system is very costly because two extra machines (motor-generator set) are required.
- Overall efficiency of the system is not sufficient especially it is lightly loaded.

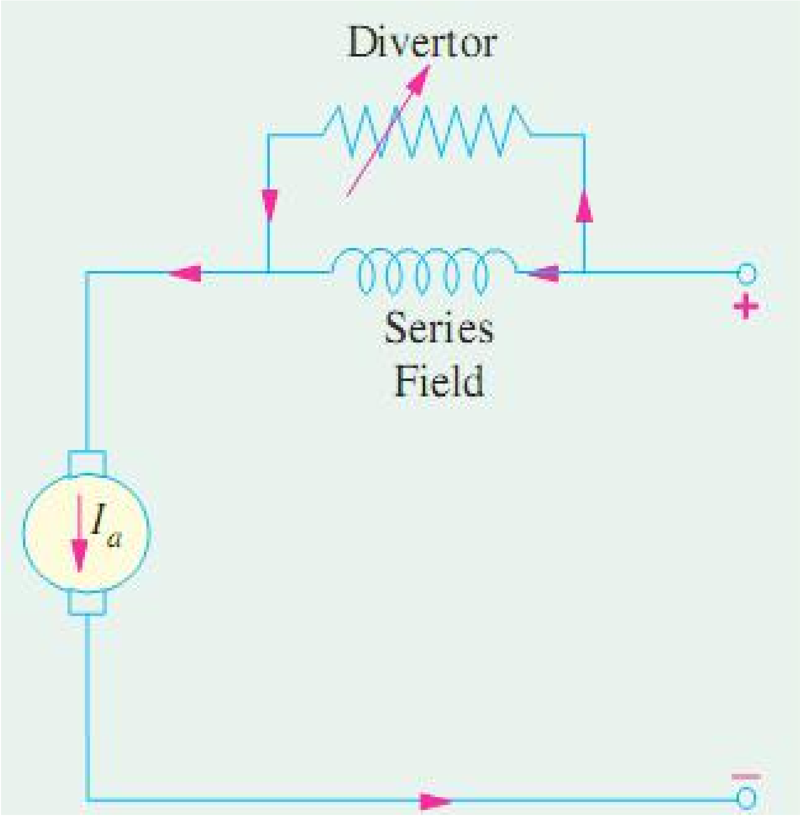
Speed Control of Series Motors

- Flux Control Method: Variations in the flux of a series motor can be brought about in any one of the following ways:
- Field Diverter
- Armature Diverter
- Trapped Field Control

Field Diverters

The series winding are shunted by a variable resistance known as field diverter.

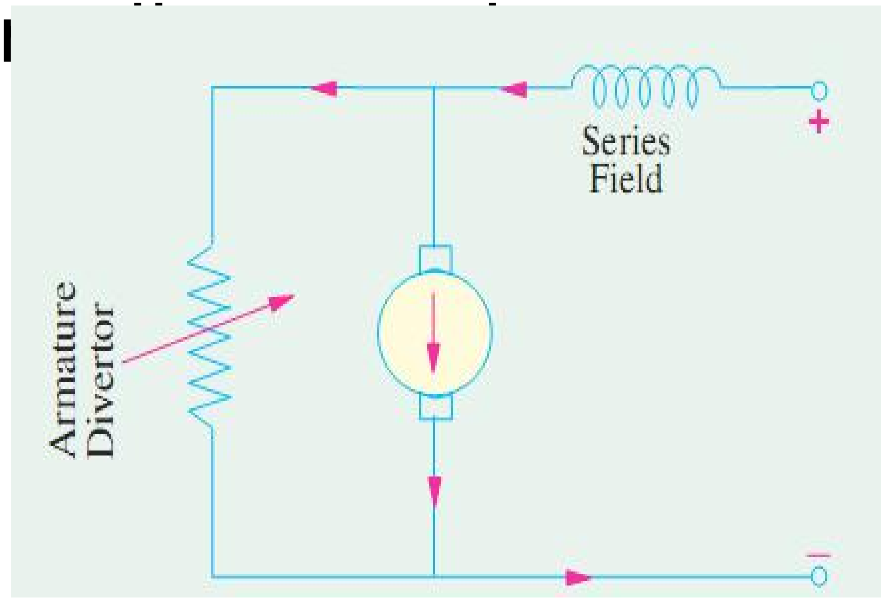
- Any desired amount of current can be passed through the diverter by adjusting its resistance. Hence the flux can be decreased and consequently, the speed of the motor increased.



Armature Diverter

- A diverter across the armature can be used for giving speeds lower than the normal speed.
- For a given constant load torque, if Ia is reduced due to armatur
must increase

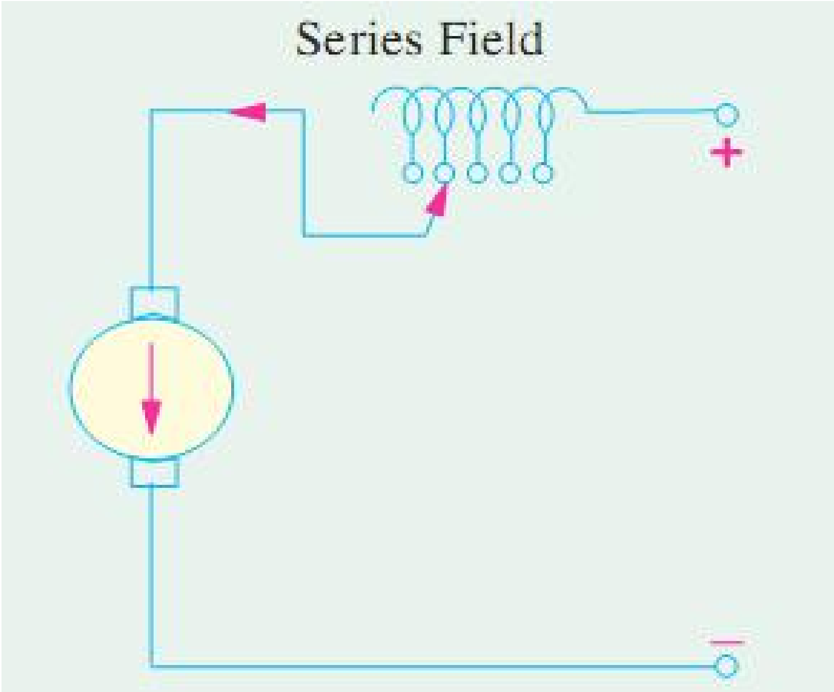
The variation in speed can be controlled by varying the diverter resistance.



Trapped Field Control Field

- This method is often used in electric traction. The number of series filed turns in the circuit can be changed.

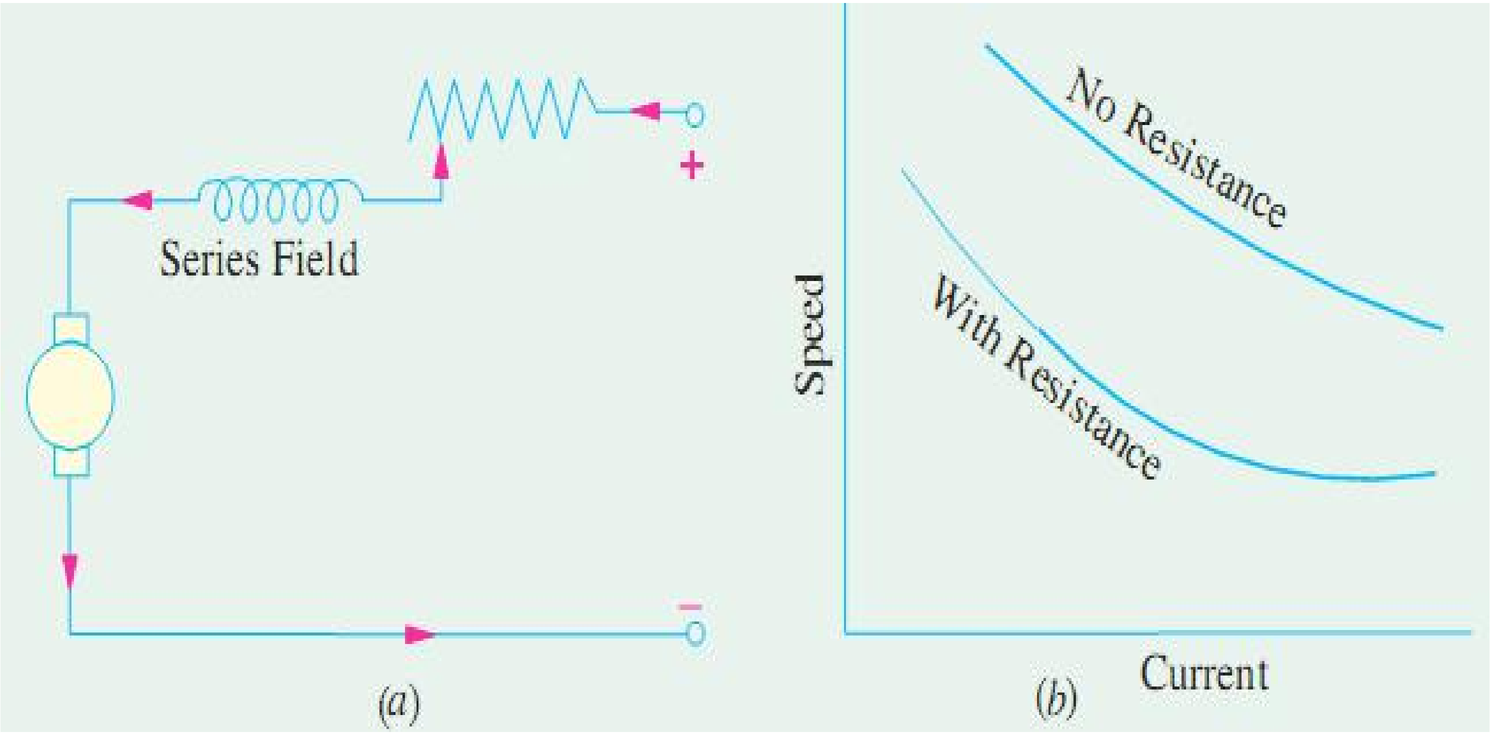
With full field, the motor runs at its minimum speed which can be raised in steps by cutting out some of the series turns.



Variable Resistance in Series with Motor

- By increasing the resistance in series with the armature the voltage applied across the armature terminals can be decreased.
- With reduced voltage across the armature, the speed is reduced.
- However, it will be noted that since full motor current passes through this resistance, there is a considerable loss of power in it.

Variable Resistance in Series with Motor



Losses

Power Losses in dc machines are classified as

Copper Loss: caused by the current flow and occurs in

- Armature winding
- Series field winding
- Commutating pole winding
- Compensating winding
- Shunt field winding and
- Loss due to brush contact resistance

Iron loss : caused by varying magnetization and occur in

- Armature core
- Armature teeth

Losses (con.)

Mechanical Losses : caused by the rotation of the machine and occurs as

- Bearing friction
- Brush friction
- Air friction

Stray load loss

- Increase in iron loss
- Increase in copper loss
- Additional losses due to short ckts, etc.

Copper losses

- These losses are the losses due to armature and field copper windings. Thus **copper losses** consists of Armature copper loss, Field copper loss and loss due to brush contact resistance.
- **Armature copper loss** = $I_a^2 R_a$ (Where I_a is Armature current and R_a is Armature resistance)
- This loss is about 30 to 40% of full load losses.
- **Field copper loss** = $I_f^2 R_f$ (where I_f is field current and R_f is field resistance)

  In case of shunt wounded field, this loss is practically constant.

  Field copper loss is about 20 to 30% of full load

Iron losses (Magnetic losses)

- As iron core of the armature is continuously rotating in a magnetic field, there are some losses taking place in the core. Therefore iron losses are also known as *Core losses.* This loss consists of **Hysteresis loss and Eddy current loss**.

Hysteresis loss

- **Hysteresis loss is due to reversal of magnetization of the armature core. When the core passes under one pair of poles, it undergoes one complete cycle of magnetic reversal.**
- The frequency of magnetic reversal if given by,

$$f = PN/120$$

(where, P = no. of poles and N = Speed in rpm)

- **Hysteresis loss** is given by:

$$W_h = \eta B_{max}^{1.6} f V \text{ (watts)}$$

where, η = Steinmetz hysteresis constant
V = volume of the core in m^3

Eddy current loss

When the armature core rotates in the magnetic field, an emf is also induced in the core (just like it induces in armature conductors), according to the Faraday's law of electromagnetic induction.

- Though this induced emf is small, it causes a large current to flow in the body due to low resistance of the core. This current is known as **eddy current.**
- The power loss due to this current is known as eddy current loss.
- Eddy current loss We is given by

$$W_e = K B^2_{max} f^2 t^2 V^2 \text{ (watts)}$$

Mechanical Losses

- Mechanical losses consists of the losses due to friction in bearings and commutator. Air friction loss of rotating armature also contributes.
- These losses are about 10 to 20% of full load losses.

Starting of DC Motor

- DC motor unlike other types of motor has a very high starting electric current that has the potential of damaging the internal circuit of the armature winding of dc motor if not restricted to some limited value.
- This limitation to the **starting current of dc motor** is brought about by means of the starter.

Effect of Starting Current

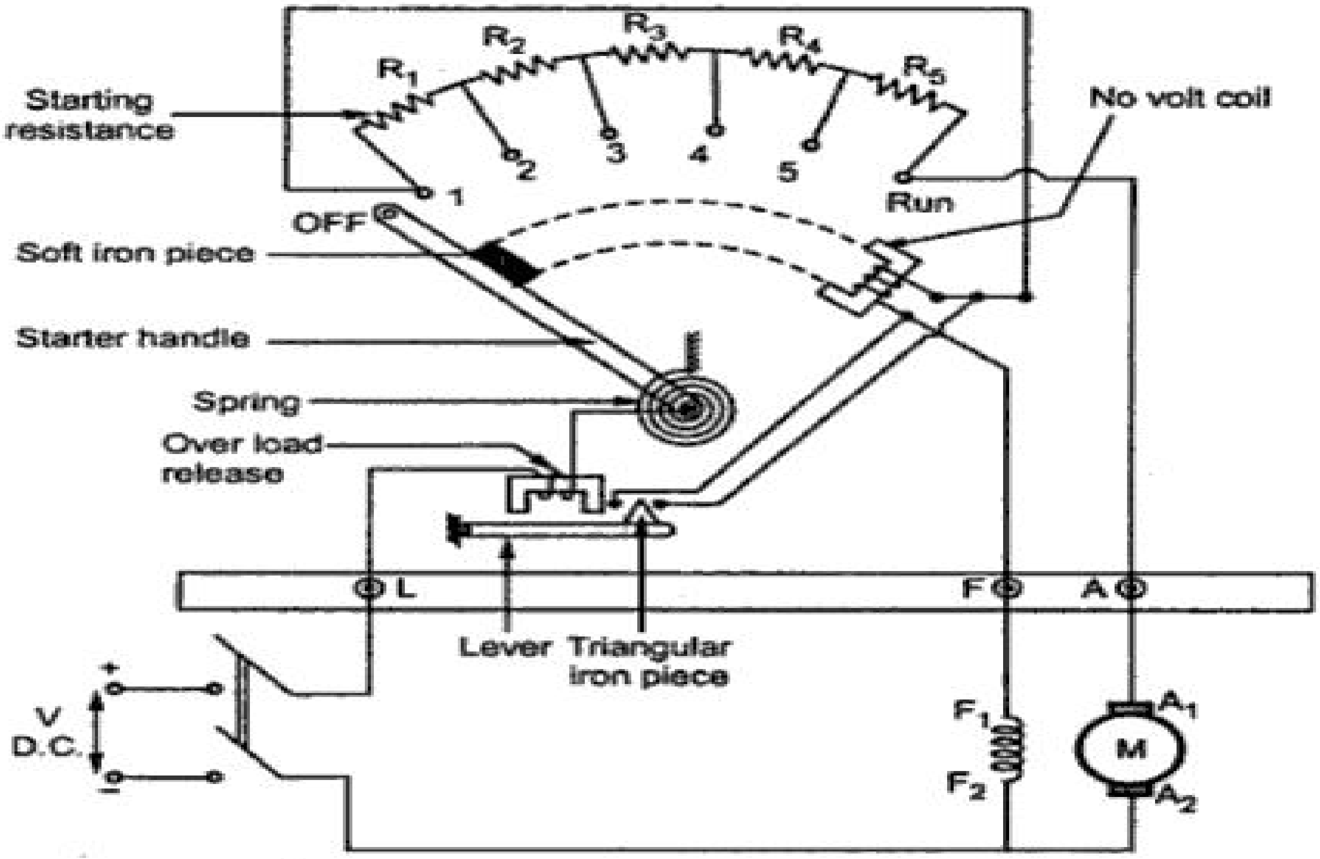
High starting current of dc motor creates two major problems.

- 1) Firstly, current of the order of 400 A has the potential of damaging the internal circuit of the armature winding of dc motor at the very onset.
- 2) Secondly ue equation of dc motor is giv

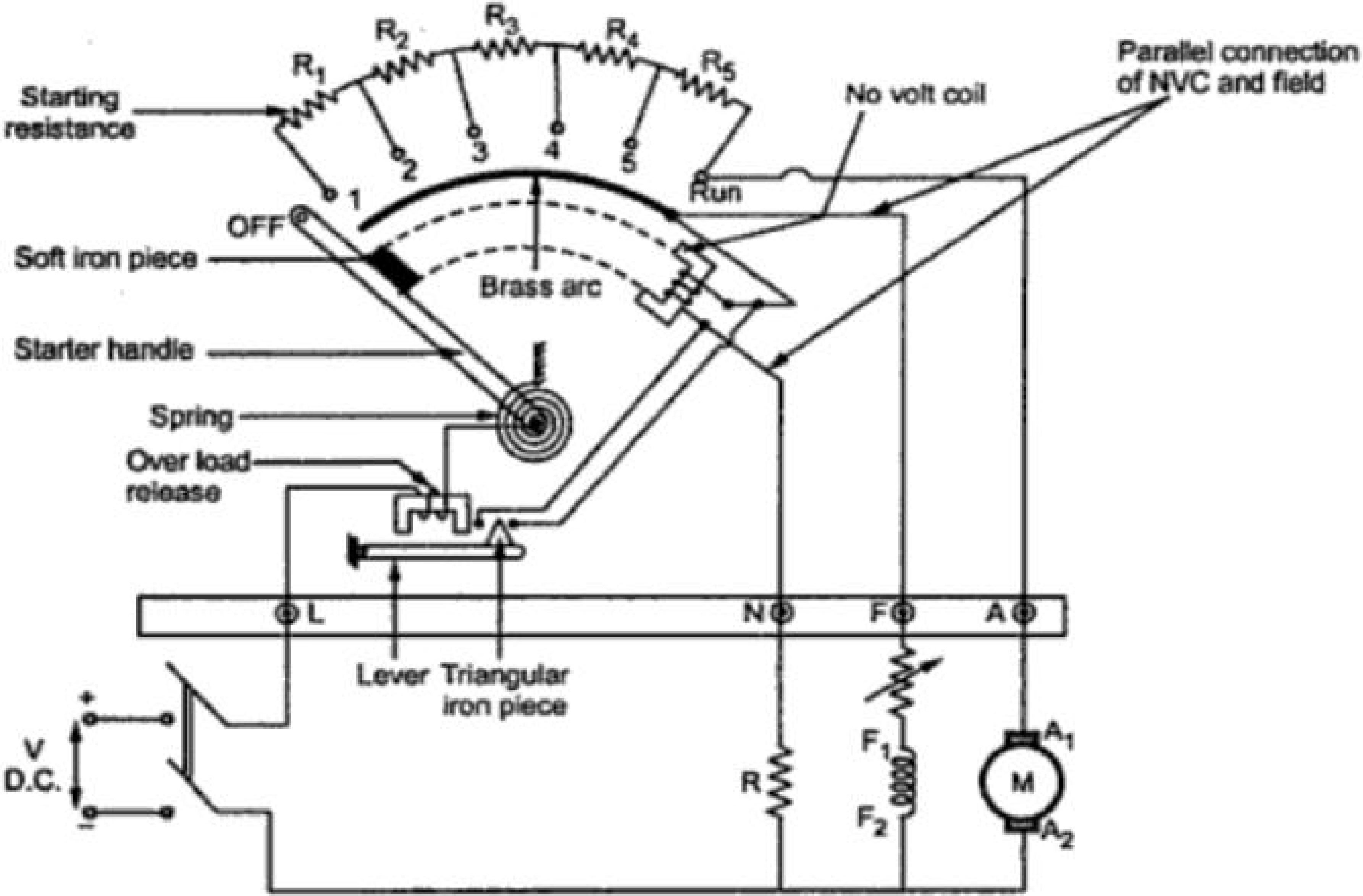
$$Therefore, I_a = \frac{E}{R_a}$$

- Very high electromagnetic **starting torque of DC motor** is produced by virtue of the high starting current, which has the potential of producing huge centrifugal force capable of flying

3 point starter



3 point Starter



4 point Starter