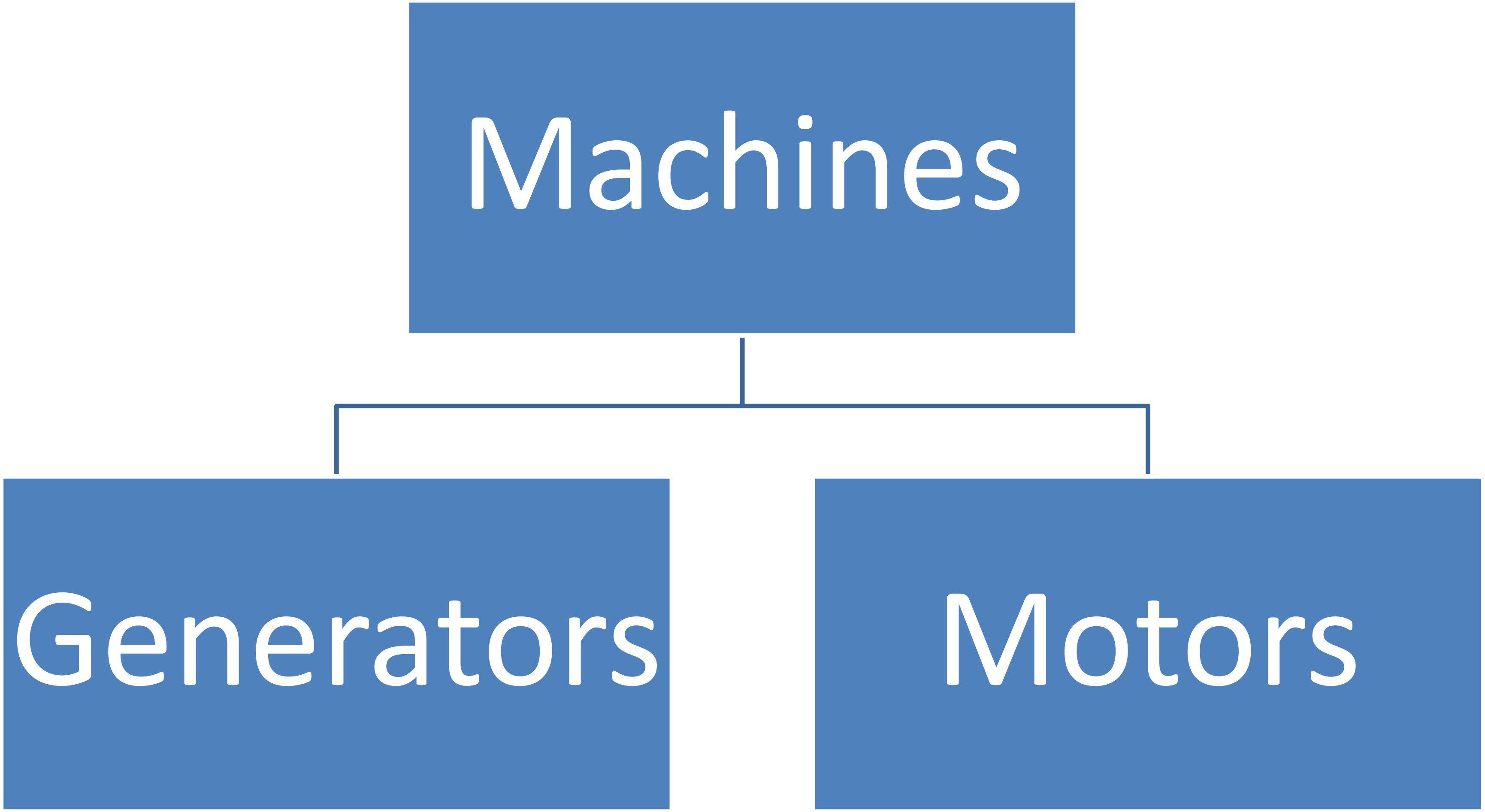
IQRA National University
Peshawar
Department of Electrical Engineering

Electrical Machines

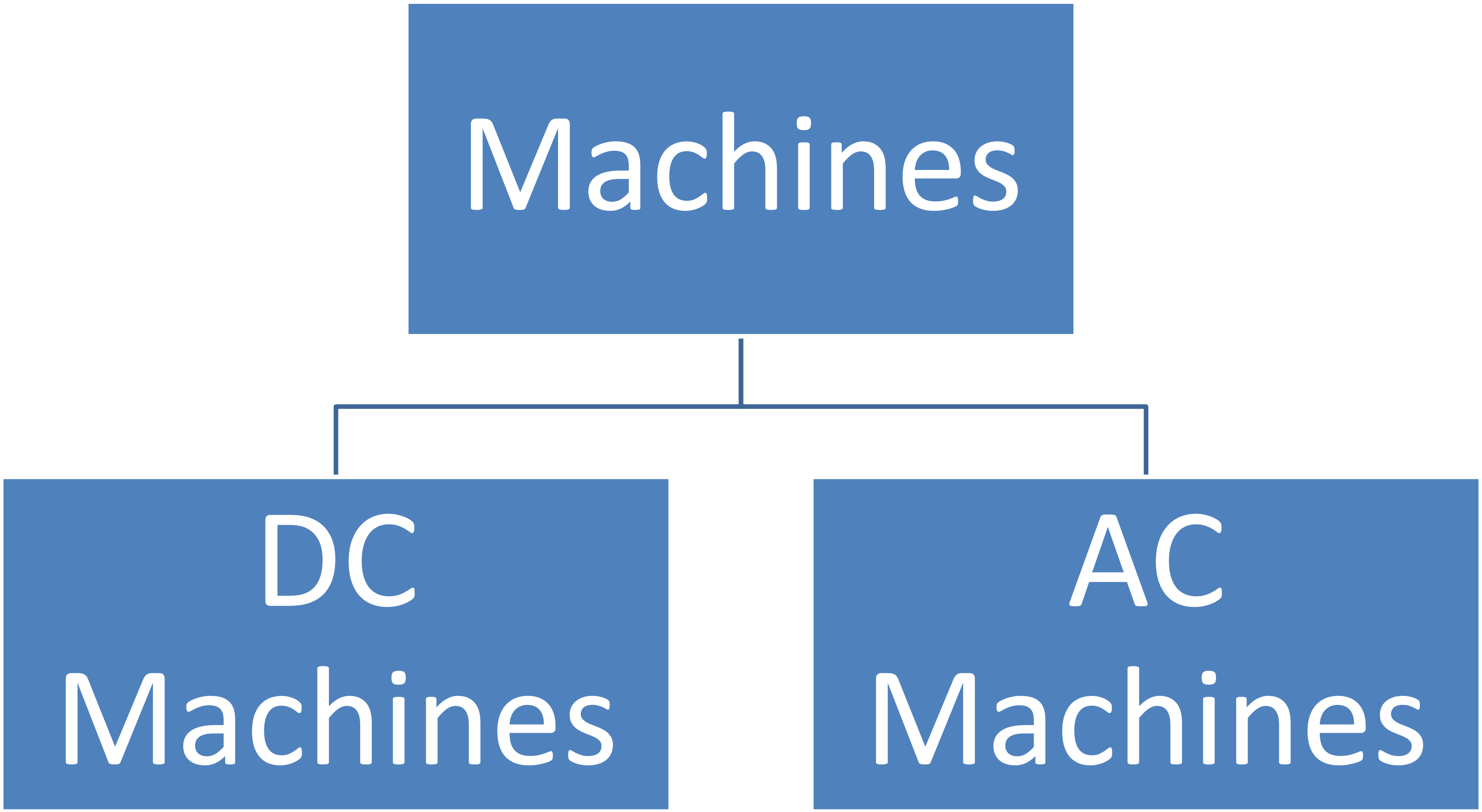
DC Machines

Engr. Sanaullah Ahmad
Lecturer
Electrical Engineering Department
INU Peshawar.

Electrical Machines



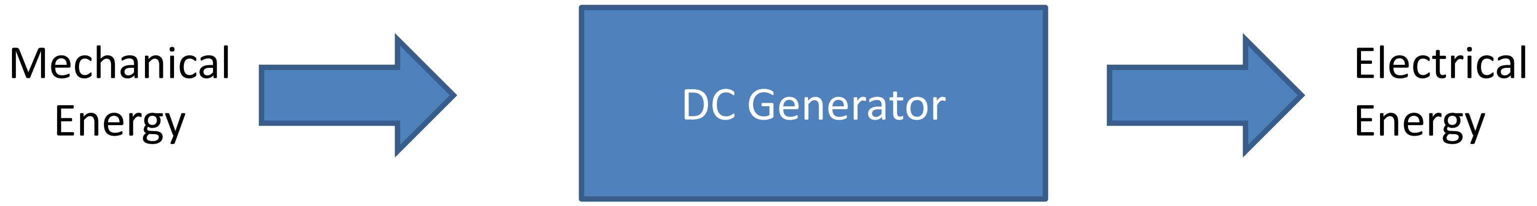
Types of Machines



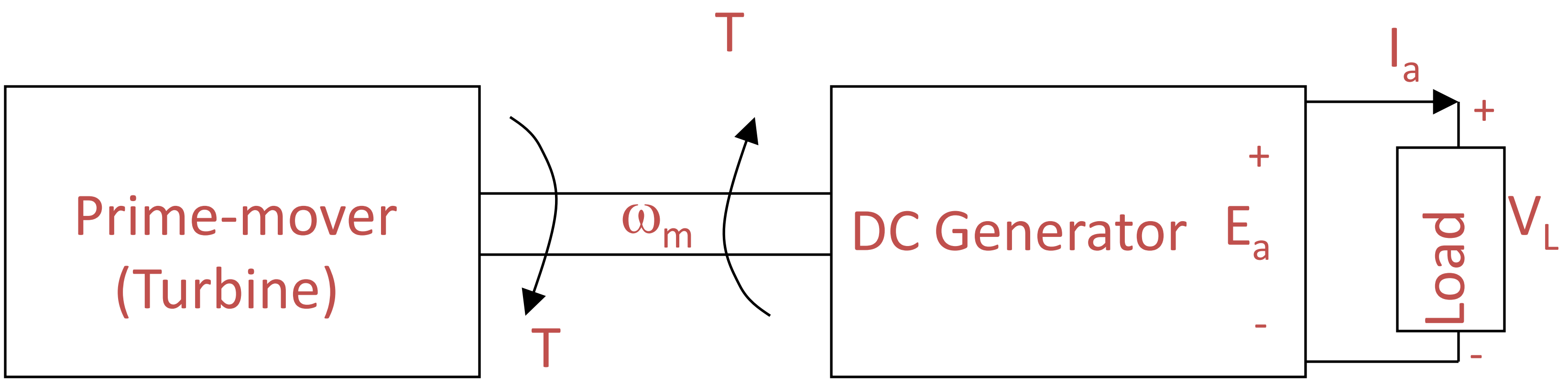
DC Machines

- Direct Current Machines
  - DC Generator
  - DC Motors

  - DC Generators
    - Machine which convert Mechanical energy into DC electrical energy.

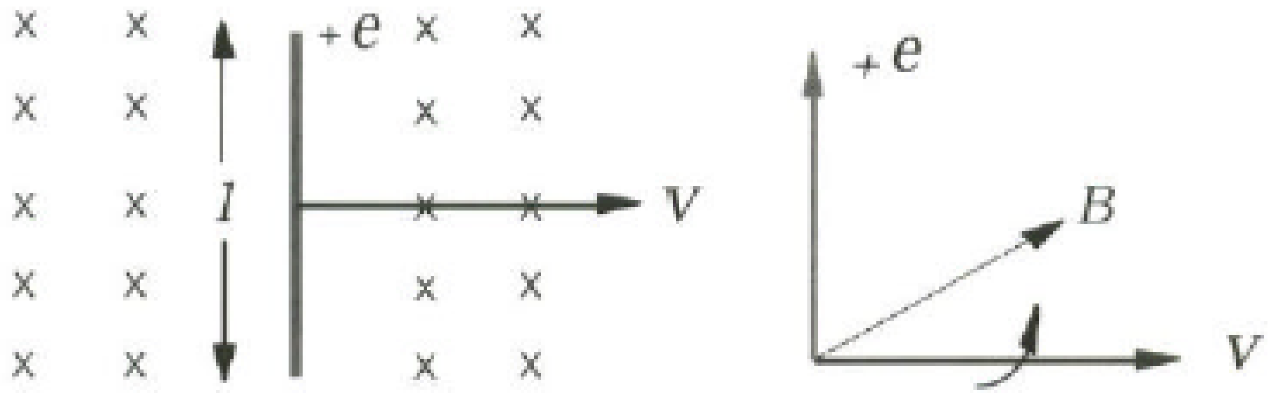


Arrangement



Principle

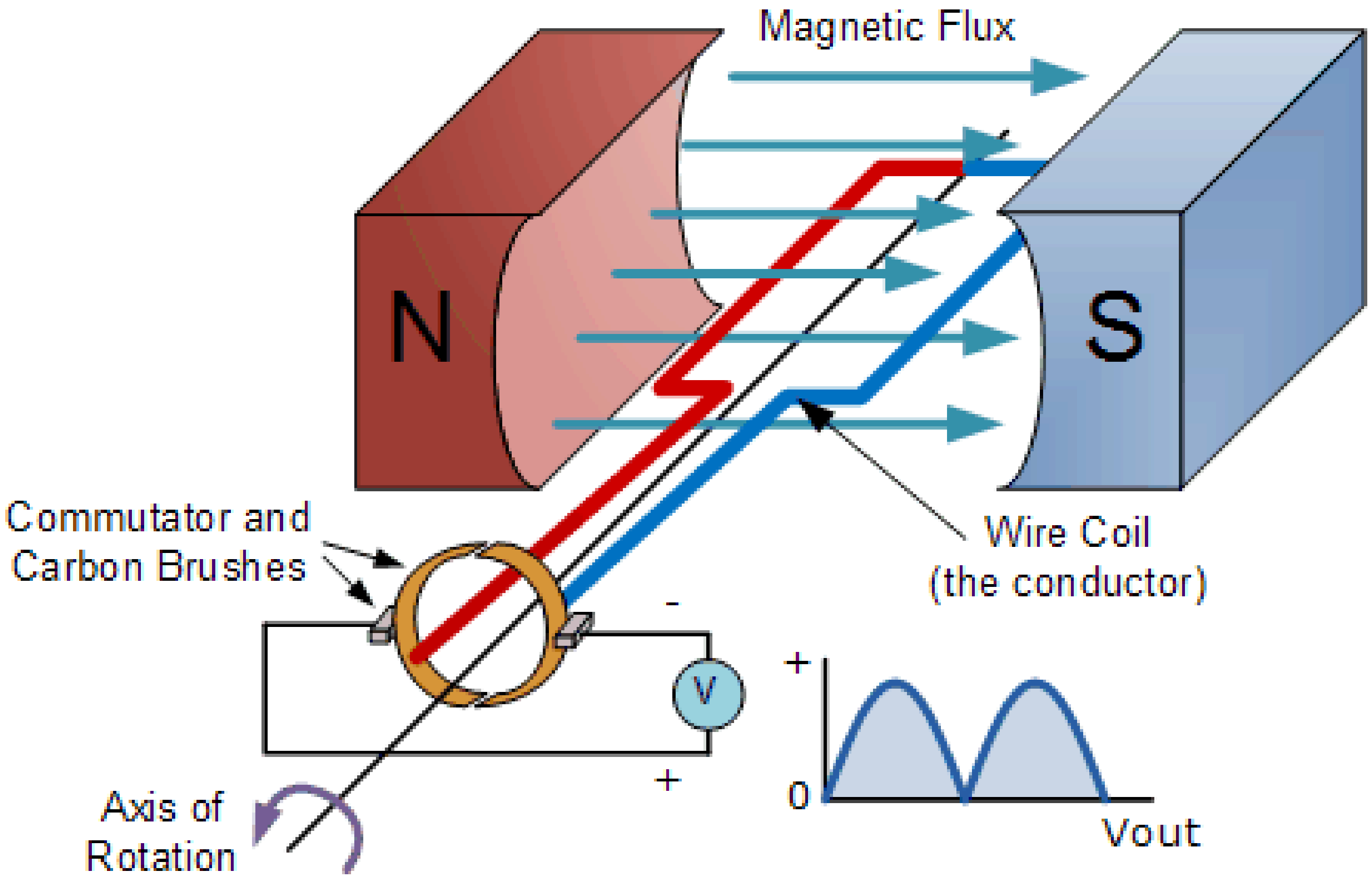
- Based on same fundamental principle of Faraday law of electromagnetic induction.
- According to this law, when a Conductor moves in a magnetic field it cuts magnetic lines of force, due to which an emf is induced in the conductor.
- Hence the most basic two essential parts of a generator are :
  - Magnetic Field
  - Conductor which moves inside magnetic field



e=*Blv*, where *B*, *v* and *e* are mutually perpendicular. The polarity of the induced voltage can be determined from the right hand screw rule. Turn the vector *v* towards the vector *B*. If a right hand screw is turned in the same way the motion of the screw will indicate the direction of positive polarity of the induced voltage *e*.

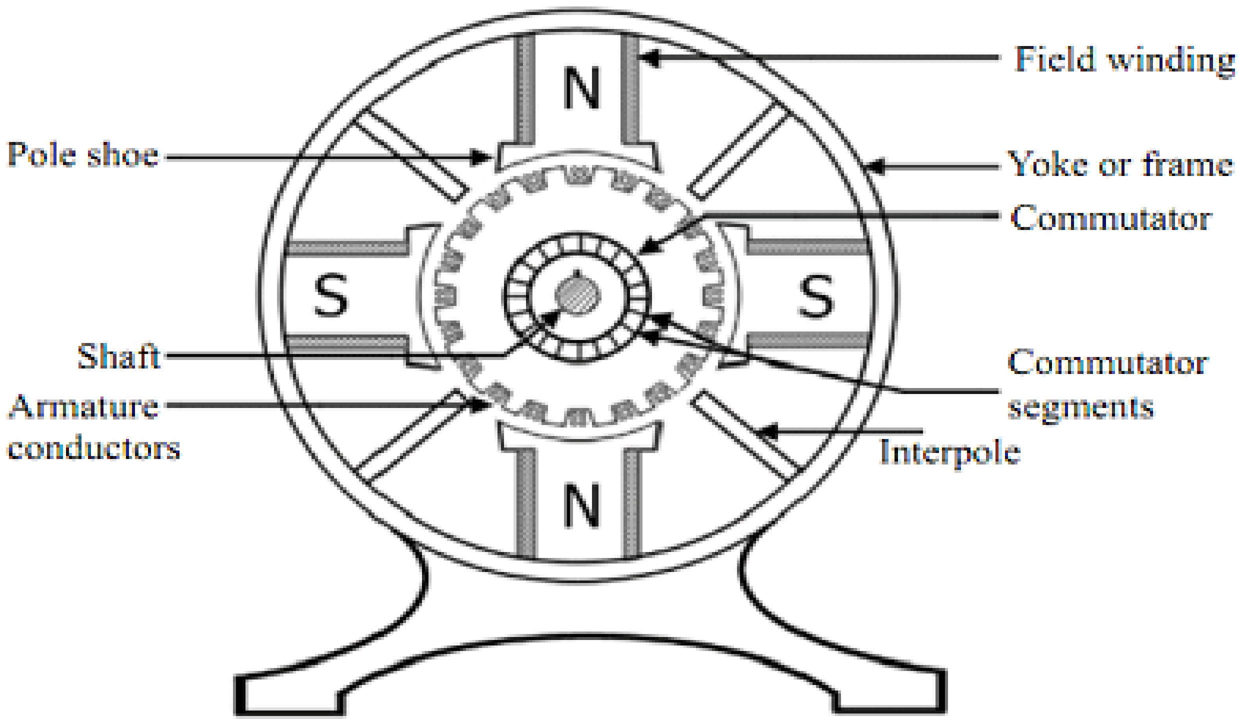
e= Blv sin@

Working



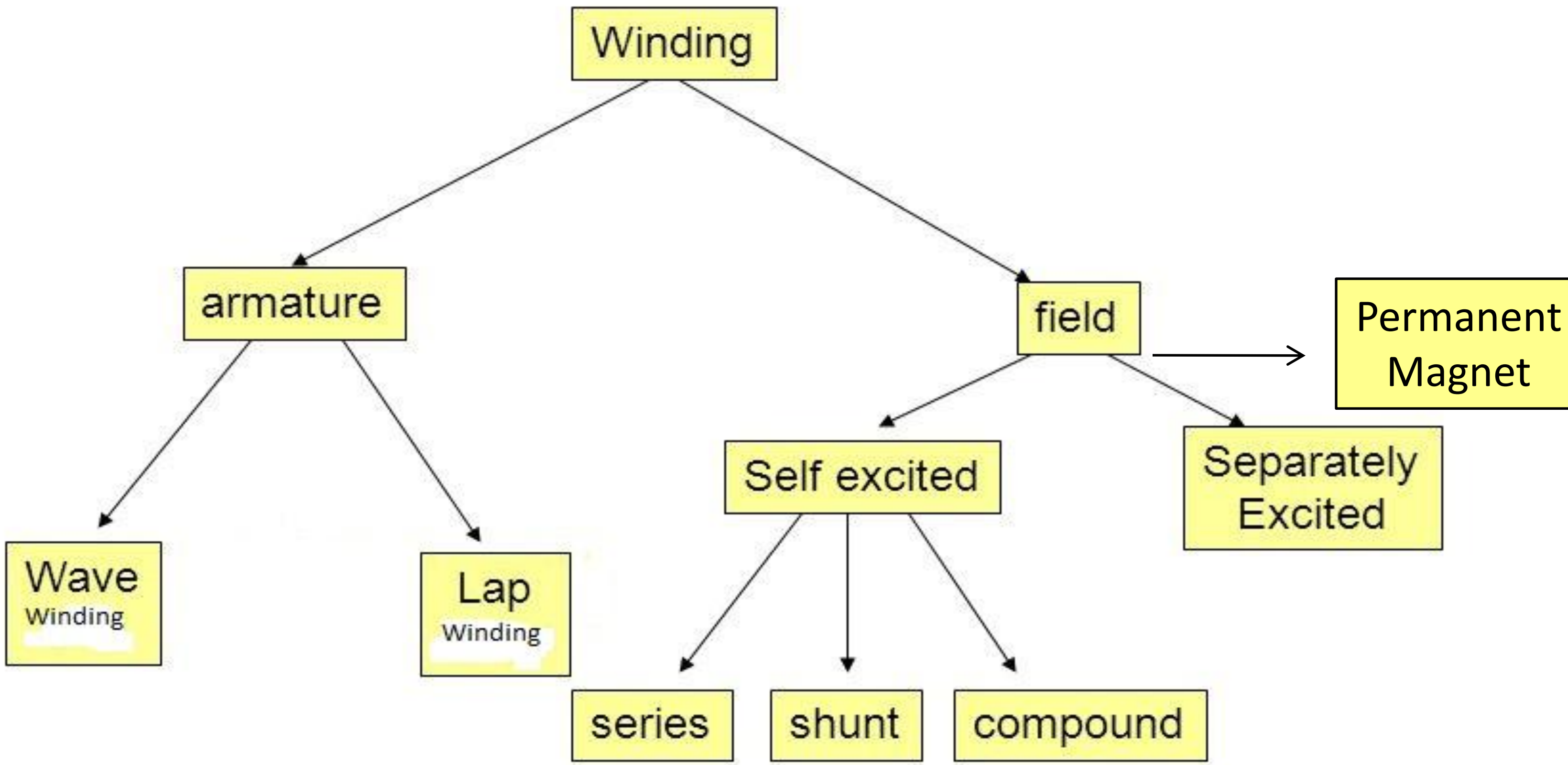
Magnetic Flux
N
S
Commutator and
Carbon Brushes
Wire Coil
(the conductor)
V
-
+
+
0
Vout
Axis of
Rotation

Construction



- **Field System**
- **Armature Core**
- **Armature Winding**
- **Commutator**
- **Brunches**

MACHINE WINDINGS OVERVIEW



Armature Winding

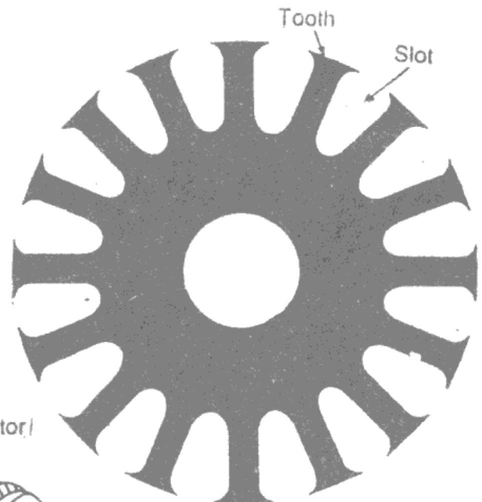


fig.(d)

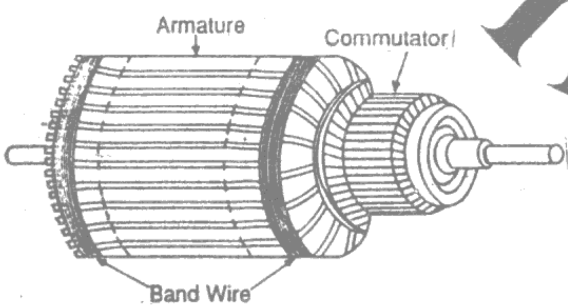


fig.(c)

Laminated Core

Coil

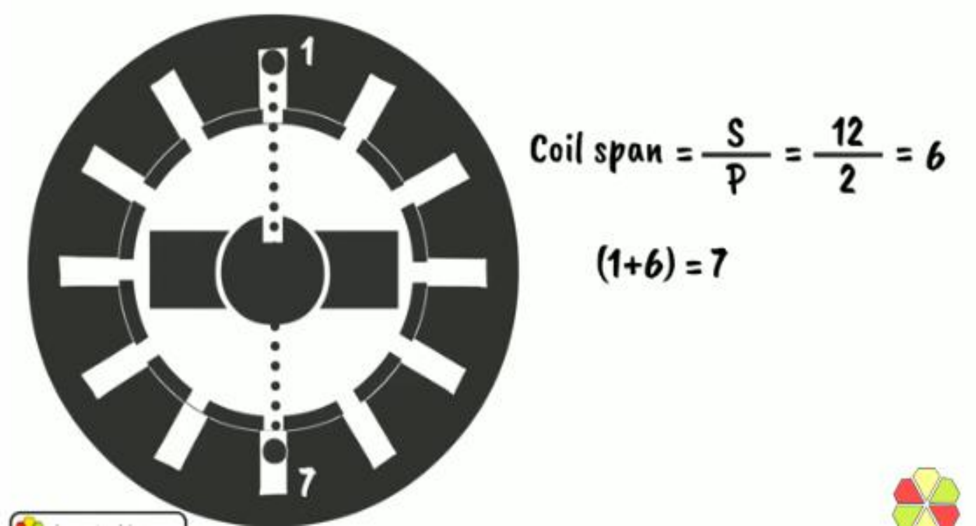
- Coil of dc machine is made up of one turn or multi turns of the Conductor.
- If the coil is made up of single turn or single loop of conductor, it is called single turn coil.
- If the coil is made up of more than one turn of conductor, it is referred as multi turn coil.

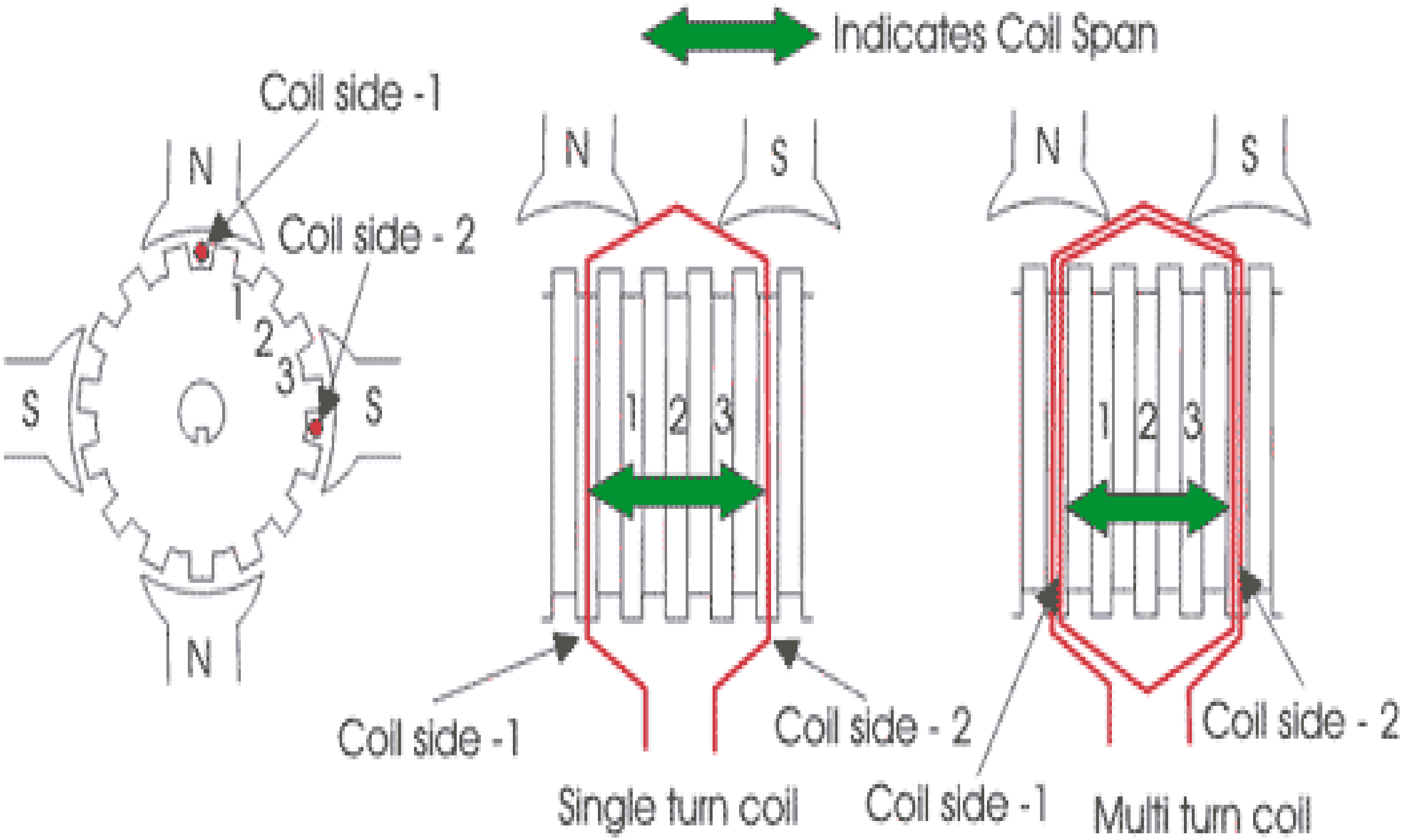
Pole Pitch

- Distance between adjacent poles.
- Measured interms of armature slots
- If 4 poles and 16 slots in armature
- 16/4 = 4 slots per pole

Coil Span

- **Coil span** is defined as distance between two sides of a coil, measured in terms of number of armature slots between them.
- If one side of coil is placed at slot 1 and other at slot 7 the coil span will be 6.
- Slots/Poles = 12/2= 6





Indicates Coil Span
Coil side -1
Coil side - 2
N
S
S
N
1
2
3
N
S
1 2 3
Coil side -1
Coil side - 2
Single turn coil
N
S
1 2 3
Coil side -1
Coil side - 2
Multi turn coil

Full pitch Coil

- If the coil span is equal to the pole pitch, then the **armature winding** is said to be full pitched Coil
- And Winding is known as full pitch winding.
- **Pole Pitch = Coil Span**

Short pitch coil

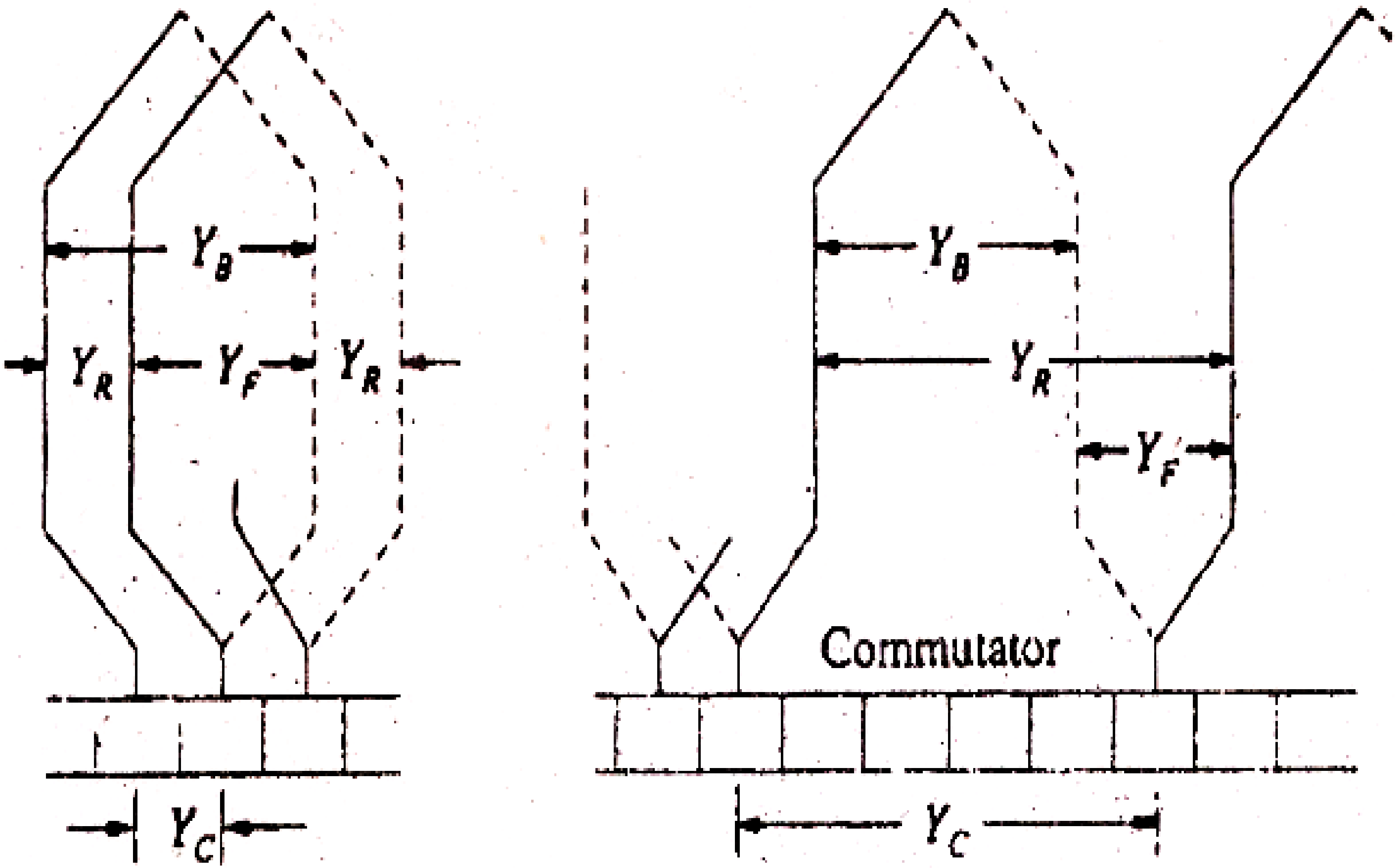
- If the coil span is less then one pole pitch then it is called short pitch coil
- and complete winding is called short winding or frictional winding.

- **Commutator Pitch(Yc)**

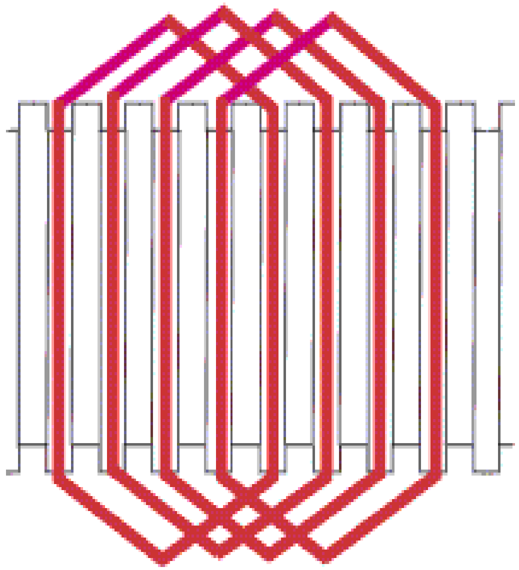
  Number of Commutator segments spanned by each coil ,

  If One side of coil is connected to slot 1 and other to slot 8 the Commutator pitch will be 8-1 = 7 , so Yc = 7

- **Back Pitch (Y_b)**
- **Front Pitch (Y_f)**
- **Resultant Pitch (Yr)**

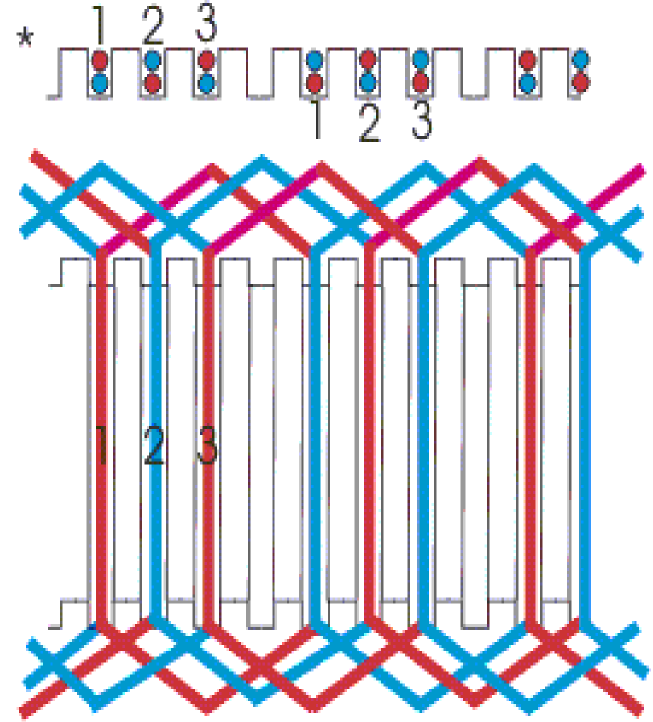

Y_B
Y_R
Y_F
Y_R
Y_C
Y_B
Y_R
Y_F
Commutator
Y_C

Single and Multi Layer Winding



Multi turn Single Layer Winding

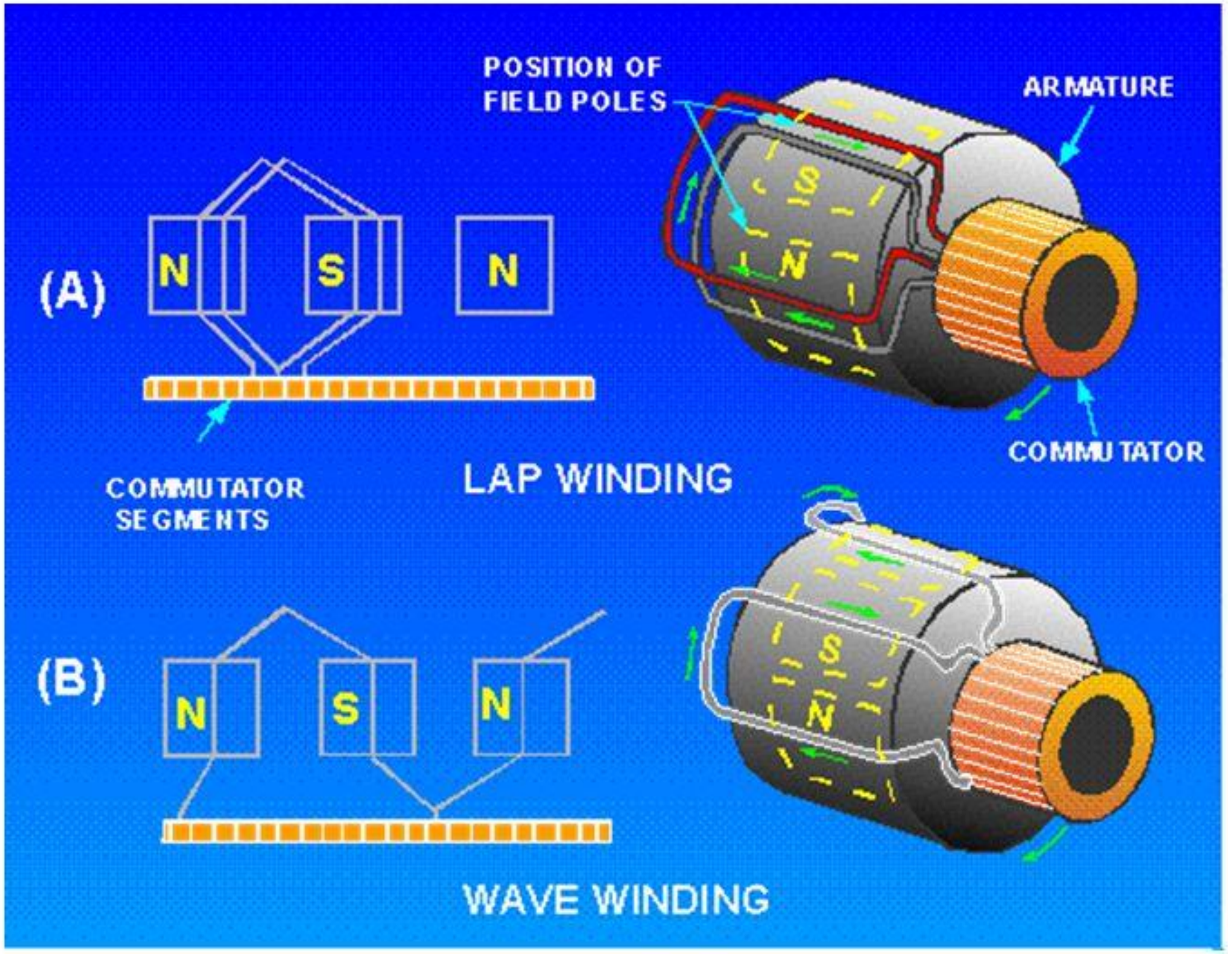
Cross sections of coil sides in slots



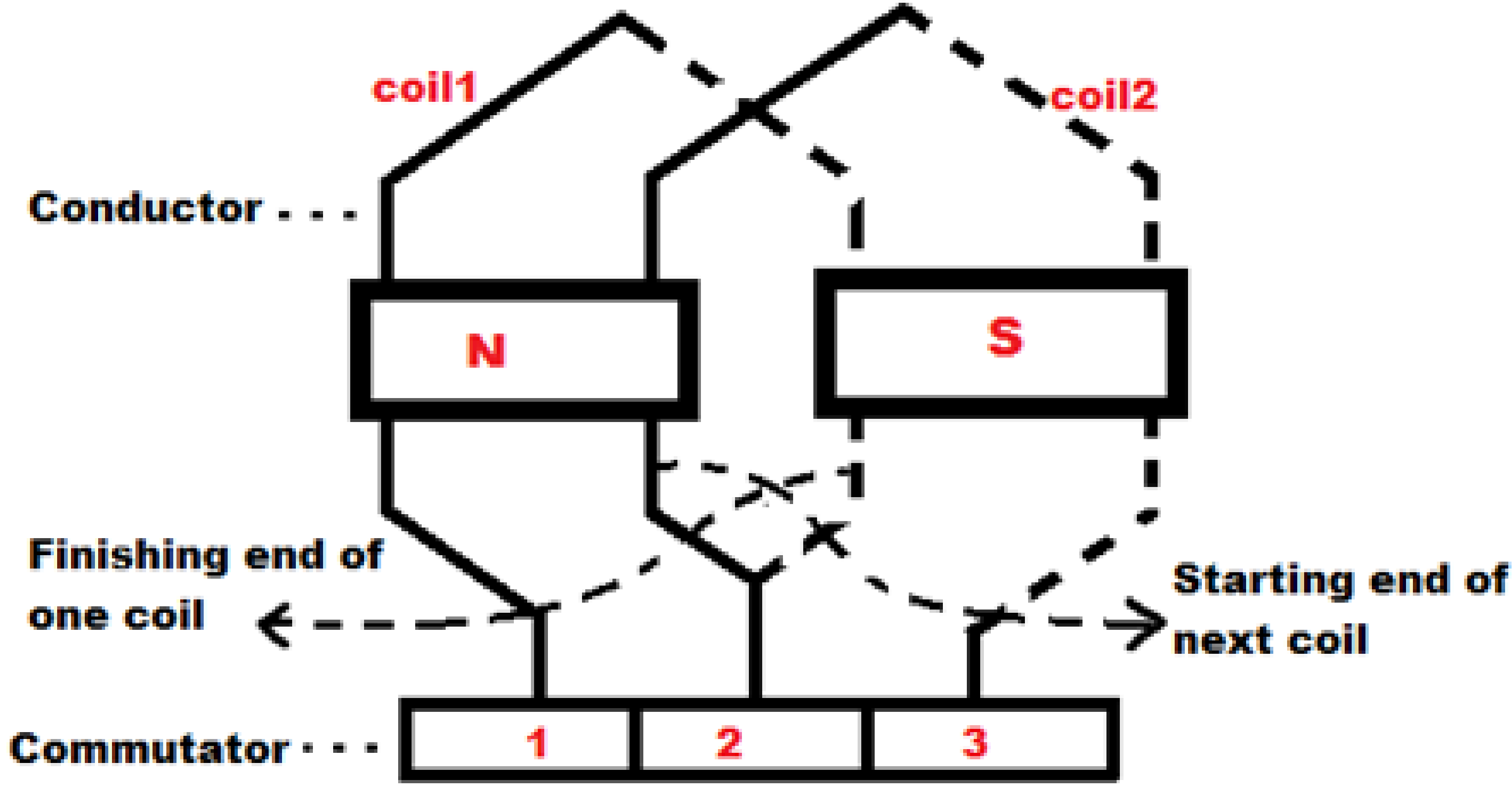
Multi turn Double Layer Winding

[*In Double layer winding, 1,2,3 are marked to only three coils among many]

LAP WINDING & WAVE WINDING

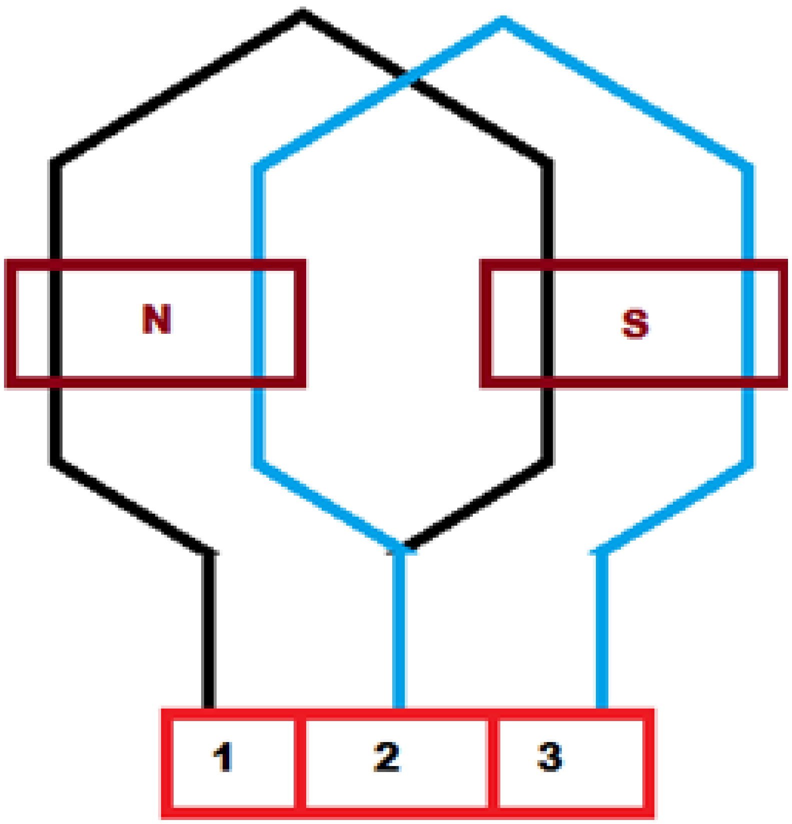


Lap Winding

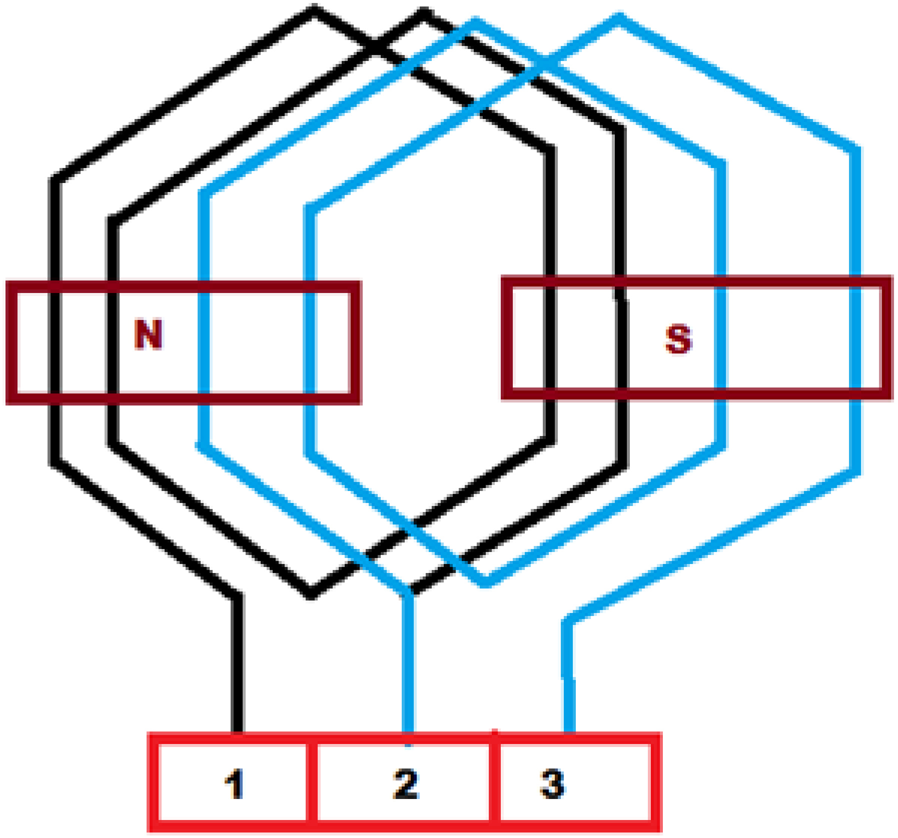


LAP winding

Lap Winding Types

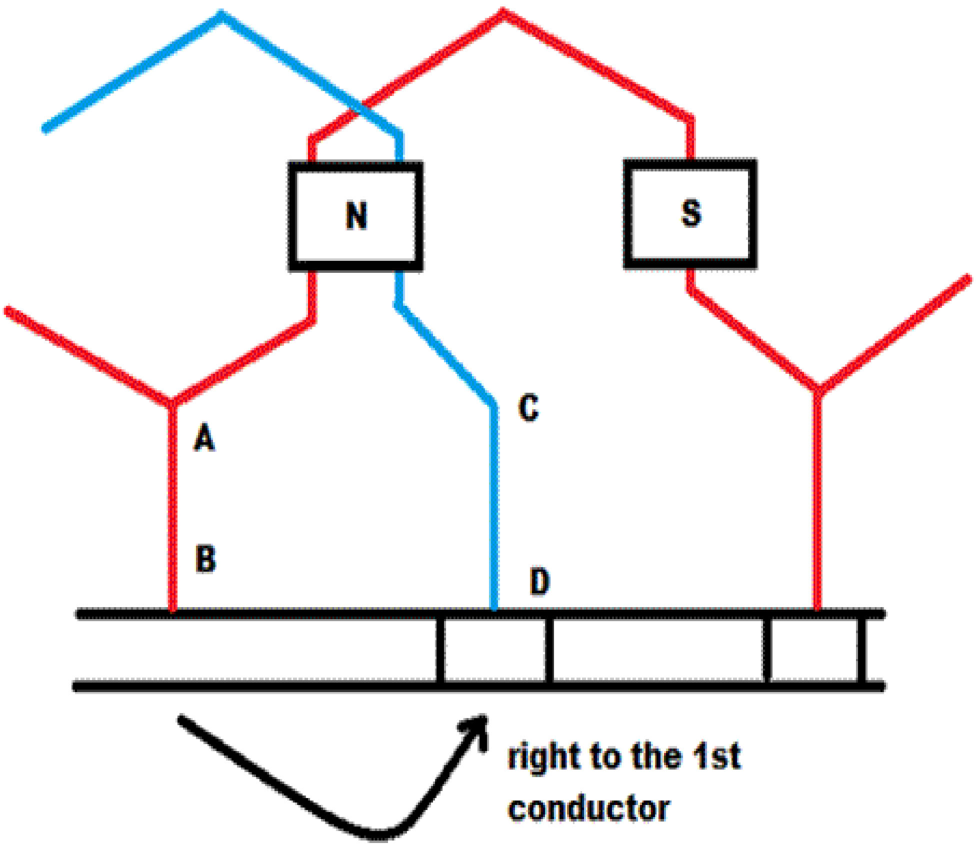


Simplex lap winding

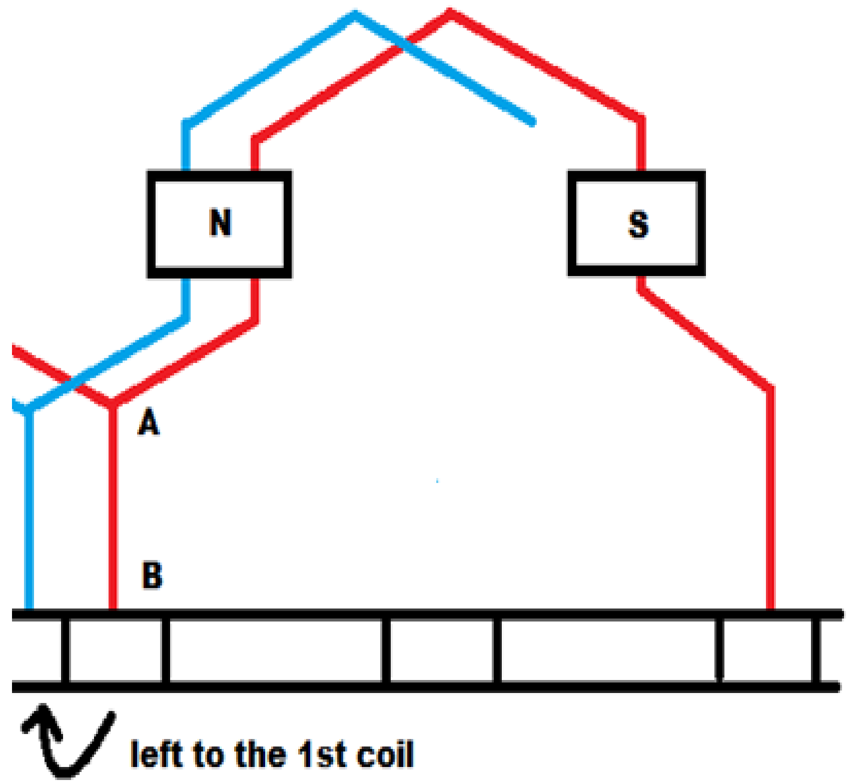


Duplex lap winding

Wave Winding Types

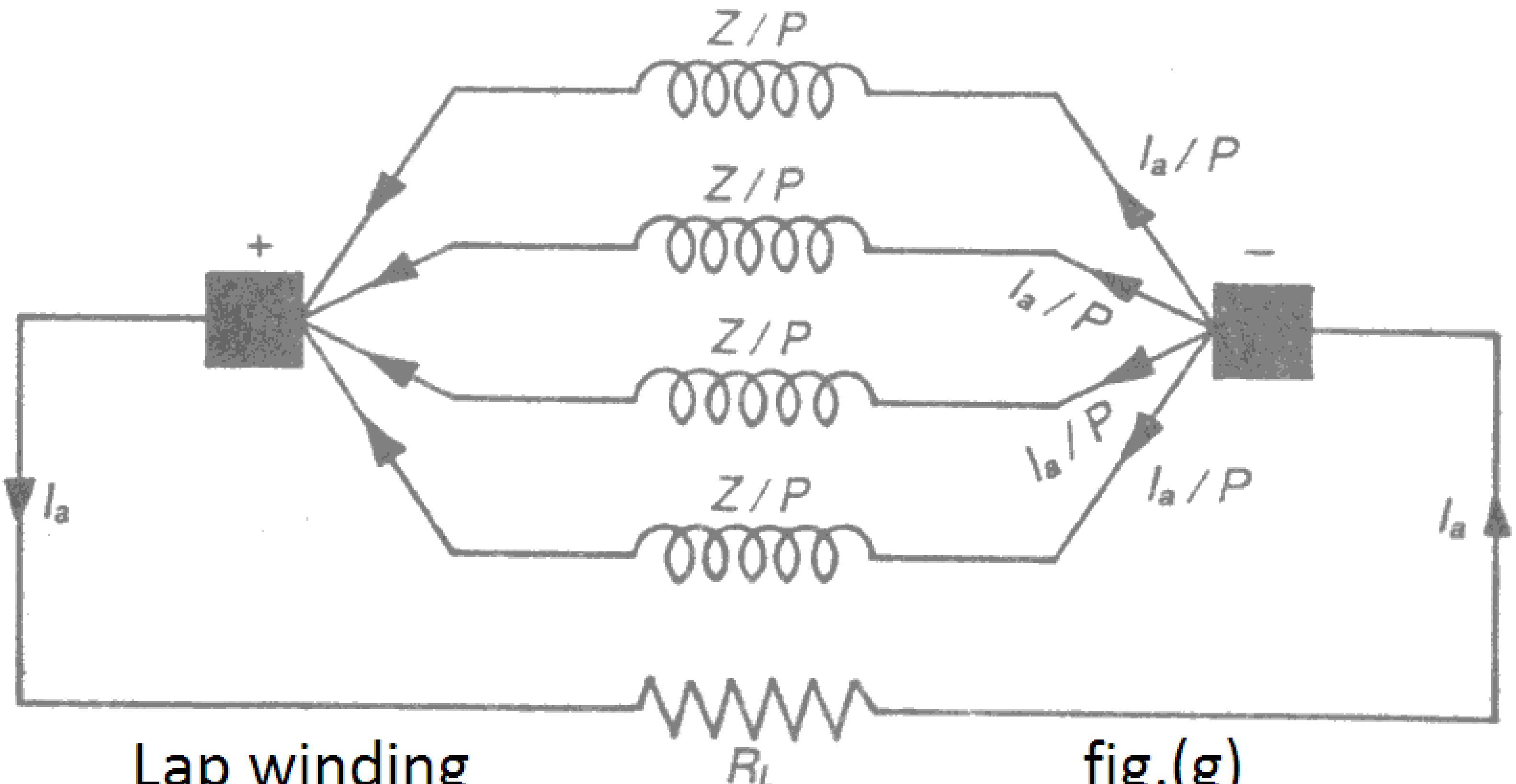


progressive wave winding



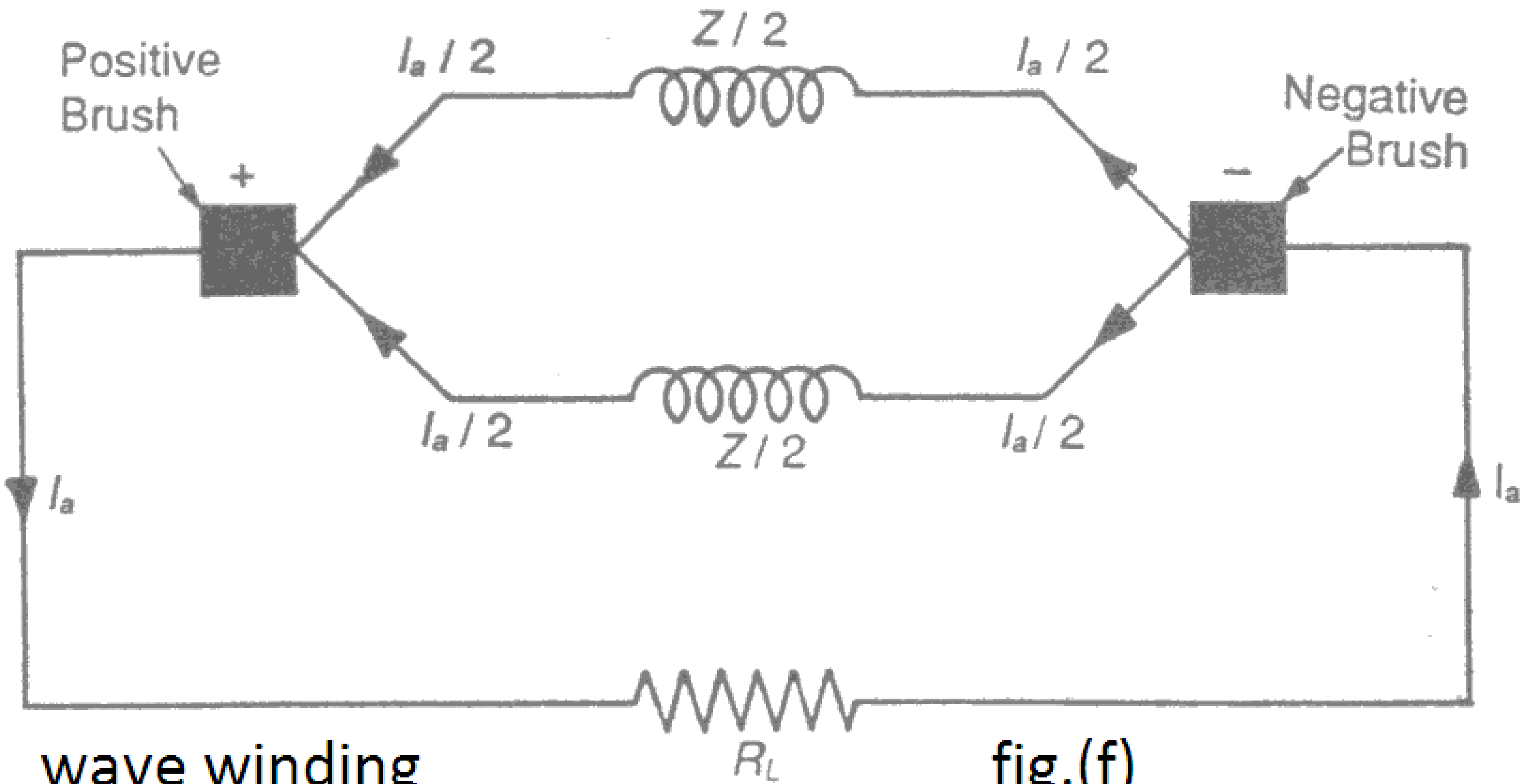
Retrogressive winding

Lap Winding
Parallel Paths= No of Poles



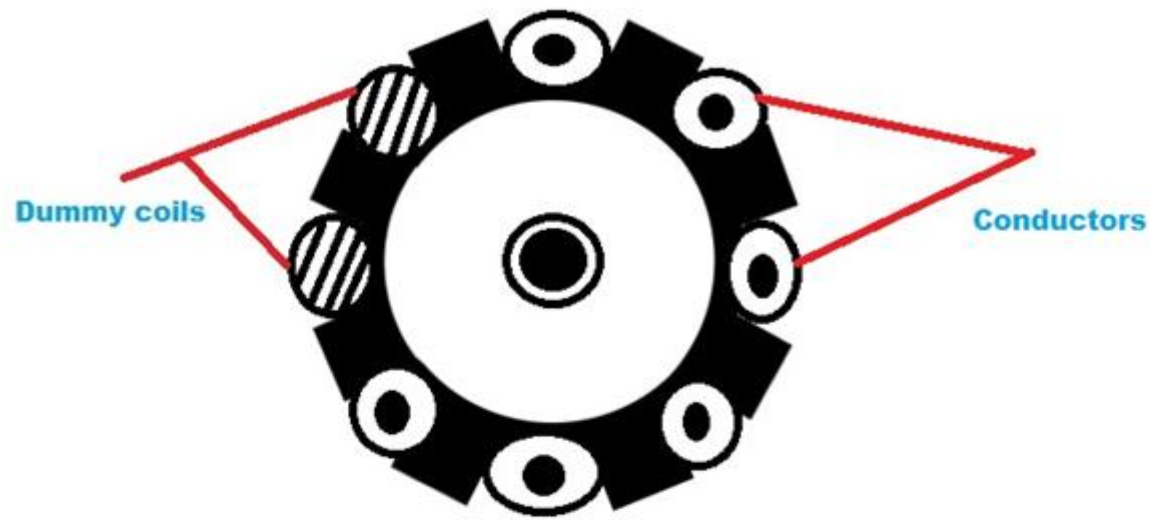
Lap winding fig.(g)

Wave Winding
Parallel Paths = 2



wave winding fig.(f)

Dummy Coil



Basis For Comparison	Lap Winding	Wave Winding
Definition	The coil is lap back to the succeeding coil.	The coil of the winding form the wave shape.
Connection	The end of the armature coil is connected to an adjacent segment on the commutators.	The end of the armature coil is connected to commutator segments some distance apart.
Parallel Path	The numbers of parallel path are equal to the total of number poles.	The number of parallel paths is equal to two.
Other Name	Parallel Winding or Mulitiple Winding	Two-circuit or Series Winding.
EMF	Less	More
Number of Brushes	Equal to the number of parallel paths.	Two
Types	Simplex and Duplex lap winding.	Progressive and Retrogressive wave winding
Efficiency	Less	High
Additional Coil	Equalizer Ring	Dummy coil
Winding Cost	High (because more conductor is required)	Low
Uses	In low voltage, high current machines.	In high voltage, low current machines.

Difference Between Lap Winding and Wave Winding

- Definition
- Connection
- Parallel Paths
- EMF Induced
- No of Brushes
- Types
- Efficiency
- Additional Coils
- Cost
- Voltage & current

EMF Equation of DC Generator

For one revolution of the conductor,

Let,

Φ = Flux produced by each pole in weber (Wb)

P = number of poles in the DC generator.

N = speed of the armature conductor in rpm.

Z = total numbers of conductor

A = number of parallel paths

Z/A = number of conductors connected in series

therefore, Total flux produced by all the poles

$$= \phi \times P$$

And, Time taken to complete one revolution

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

Faraday's law of induction, the induced emf of the armature conductor is

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

Induced emf of one conductor is

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

E = emf of one conductor × number of conductor connected in series.

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

Wave wound Numbers of parallel paths are only 2 = A

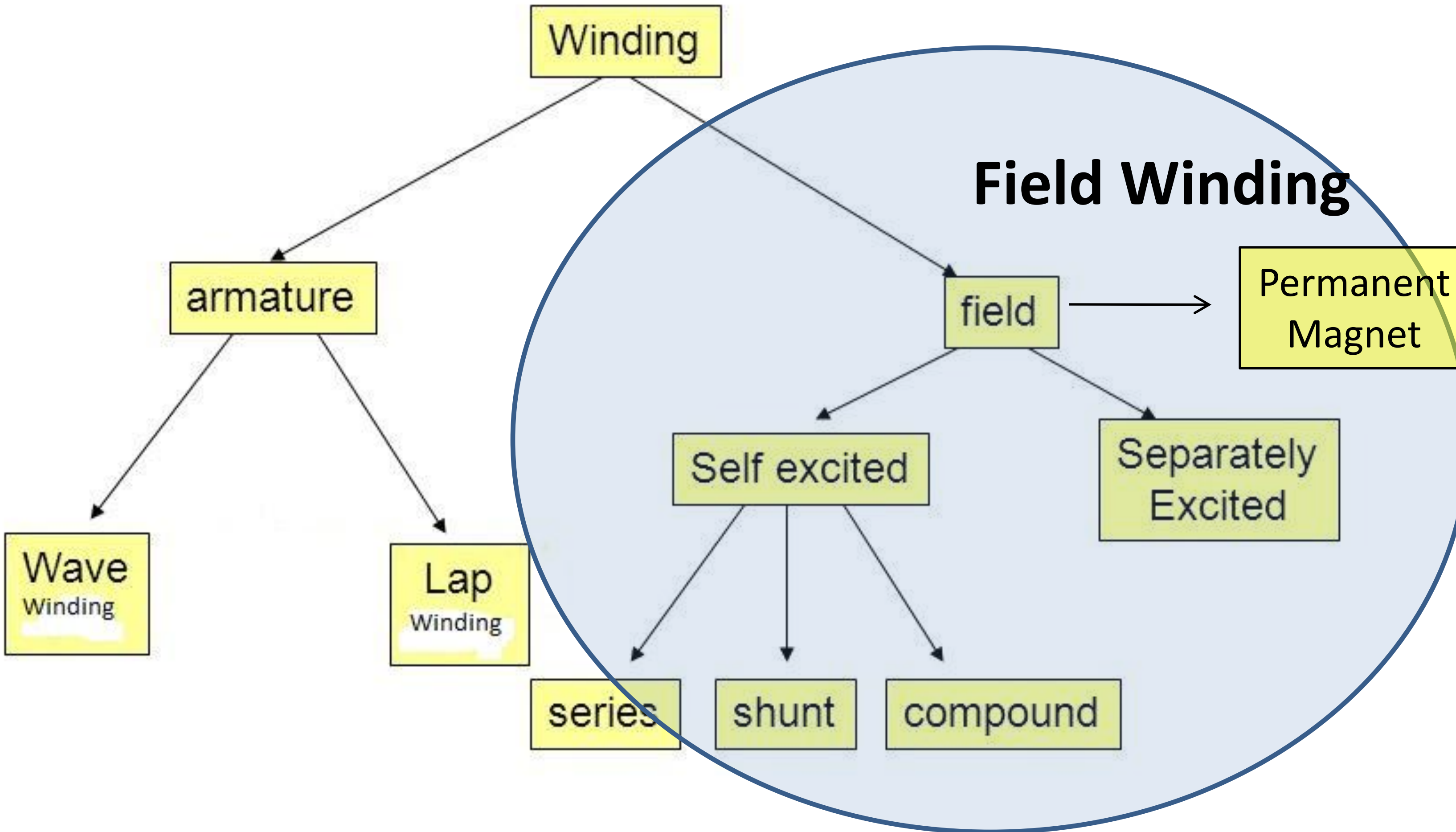
$$\frac{\phi PN}{60} X \frac{Z}{2} = \frac{\phi ZPN}{120} \ volts$$

For Lap number of parallel paths is equal to number of poles one P = A

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

Examples

MACHINE WINDINGS OVERVIEW

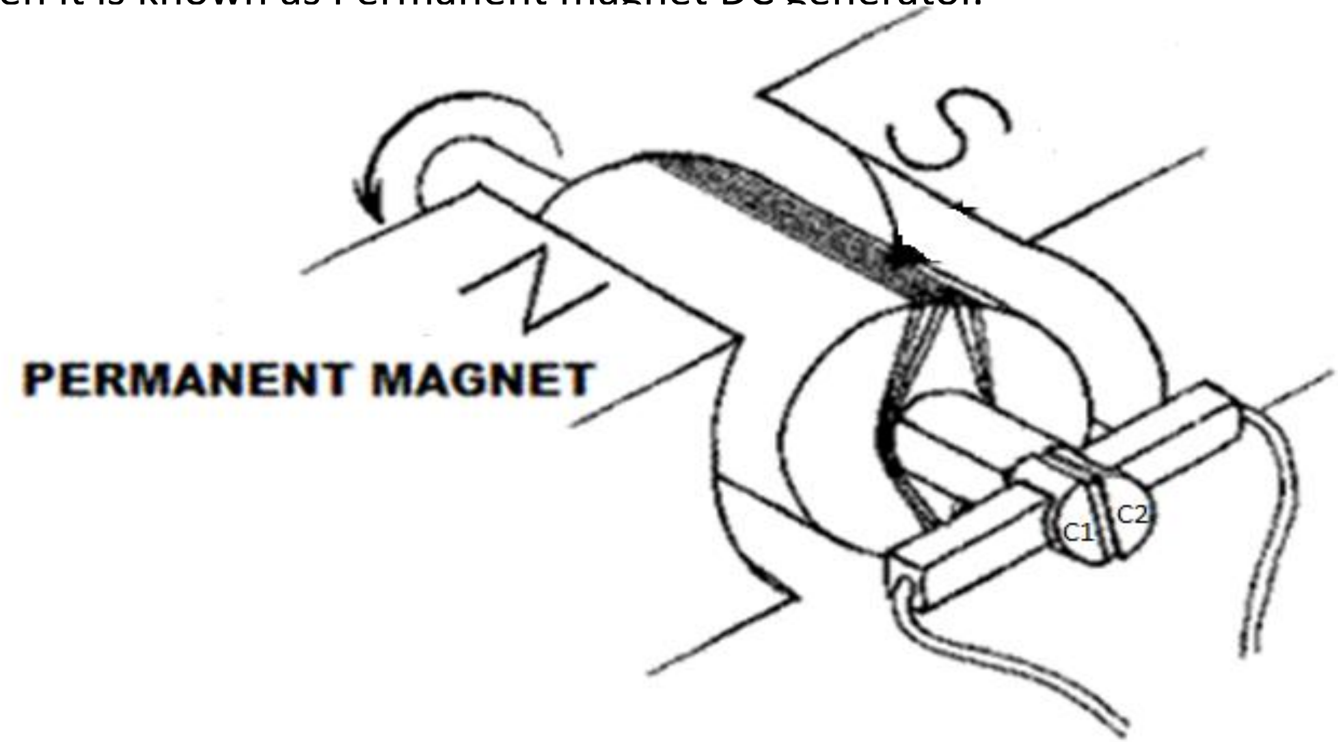


Types of DC Generators

- Generally DC generators are classified according to their field windings:
- There are three methods of excitation:
  1. Permanent magnet DC generators.
  2. Field coils excited by some external source – Separately excited DC generators.
  3. Field coils excited by the generator itself – Self excited DC generators.

Permanent magnet DC generators.

Flux in the magnetic circuit is established by the help of permanent magnets then it is known as Permanent magnet DC generator.

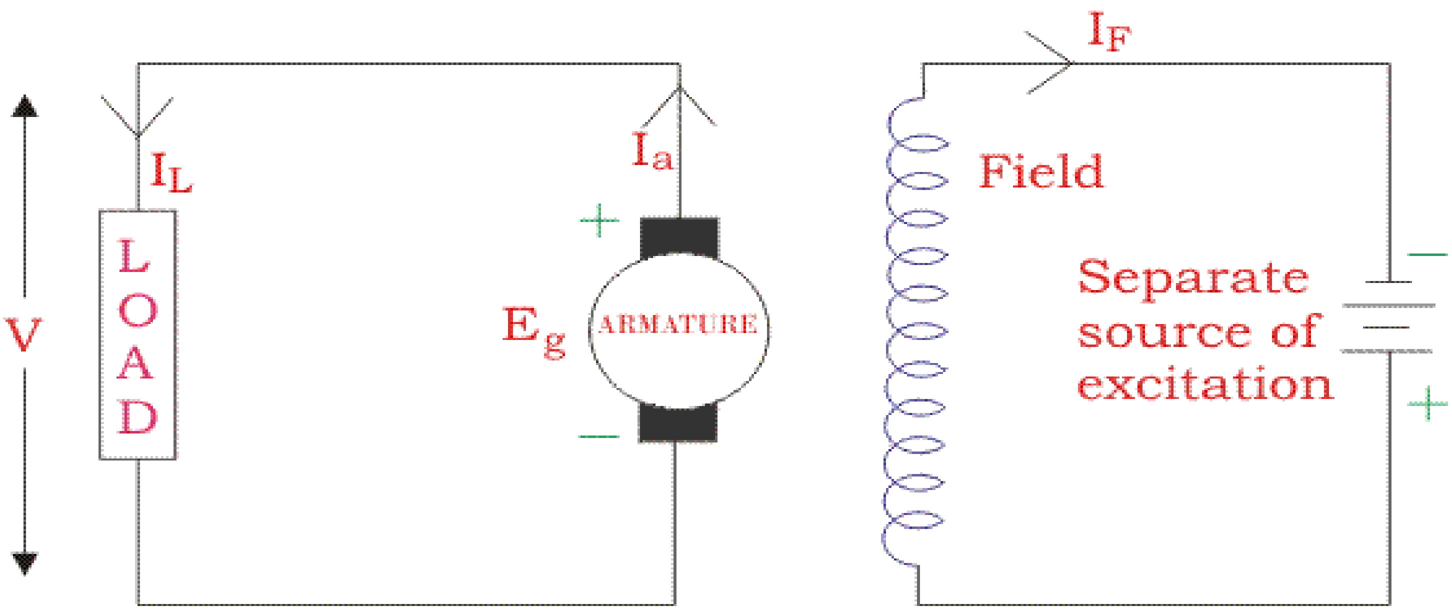


PERMANENT MAGNET DC GENERATOR

This **type of DC generators** generates very low power. So, they are rarely found in industrial applications. They are normally used in small applications like in motor cycles etc.

Separately Excited DC Generator

- These are the generators whose field magnets are energized by some external dc source such as battery.



Separately Excited DC Generator

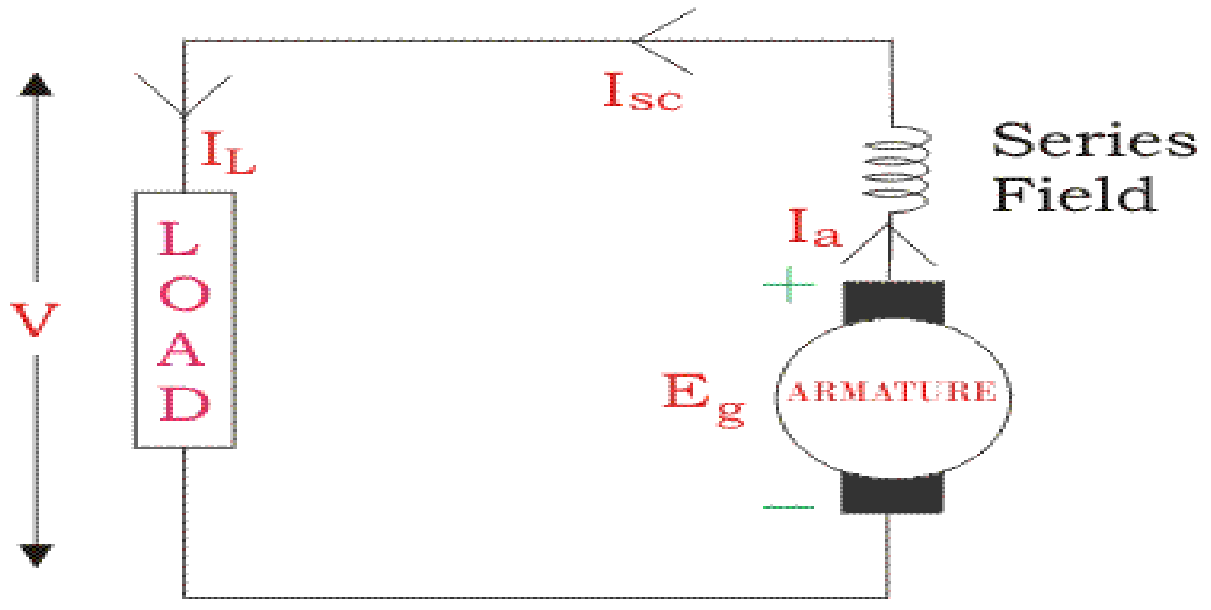
I_a = Armature current
I_L = Load current
V = Terminal voltage
E_g = Generated emf

Self-excited DC Generators

- These are the generators whose field magnets are energized by the current supplied by themselves.
- In these type of machines field coils are internally connected with the armature windings.
- Due to residual magnetism some flux is always present in the poles.
- When the armature is rotated some emf is induced. Hence some induced current is produced.
- Self Excited DC Generators may be classified as…
    1. Series wound generators
    2. Shunt wound generators
    3. Compound wound generators

Series Wound Generator

- In series wound or series self excited DC generators the field windings are connected in series with armature conductors as shown in figure below



Series Wound Generator

Then, $I_a = I_{sc} = I_L = I$ (say)

Voltage across the load, $V = E_g - I(I_a \times R_a)$

Power generated, $P_g = E_g \times I$

Power delivered to the load, $P_L = V \times I$

Whole current flows through the field coils as well as the load. As series field winding carries full load current it is designed with relatively few turns of thick wire.

The electrical resistance of series field winding is therefore very low (nearly 0.5Ω).

R_{sc} = Series winding resistance

I_{sc} = Current flowing through the series field

R_a = Armature resistance

I_a = Armature current

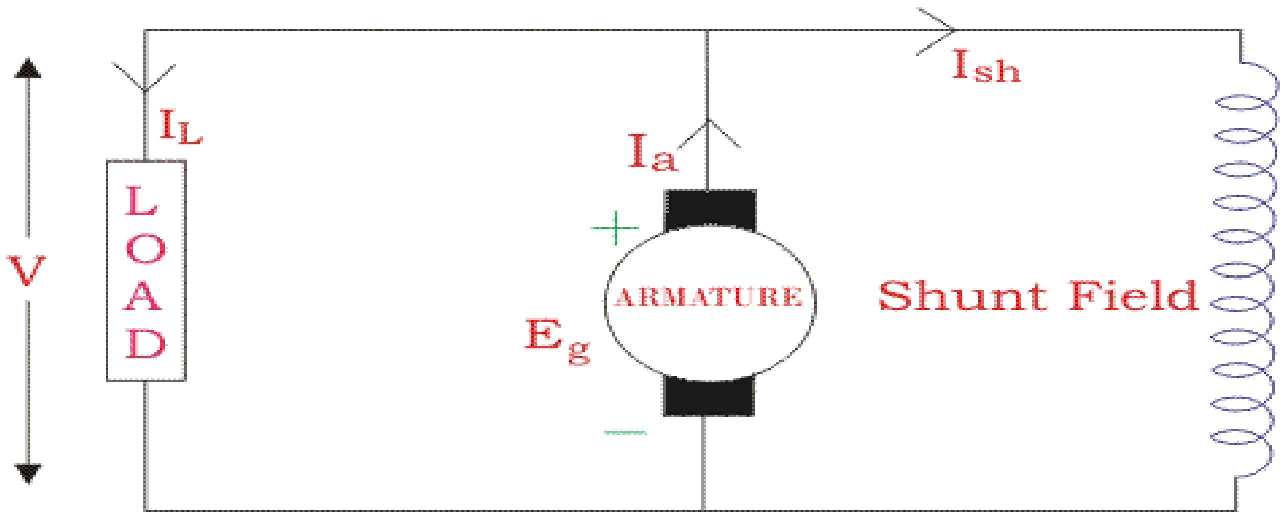
I_L = Load current

V = Terminal voltage

E_g = Generated emf

Shunt Wound DC Generators

- In shunt wound or self excited shunt DC generators the field windings are connected in parallel with armature conductors as shown in figure below.
- In shunt wound generators the voltage in the field winding is same as the voltage across the terminal.



Shunt Wound Generator

Shunt field current, $I_{sh} = V/R_{sh}$

Voltage across the load, $V = E_g - I_a R_a$

Power generated, $P_g = E_g \times I_a$

Power delivered to the load, $P_L = V \times I_L$

- Here armature current I_a is dividing in two parts, one is shunt field current I_{sh} and another is load current I_L.
- So, $I_a = I_{sh} + I_L$
- The effective power across the load will be maximum when I_L will be maximum.
- So, it is required to keep shunt field current as small as possible
- For this purpose the resistance of the shunt field winding generally kept high.

Compound Wound DC Generator

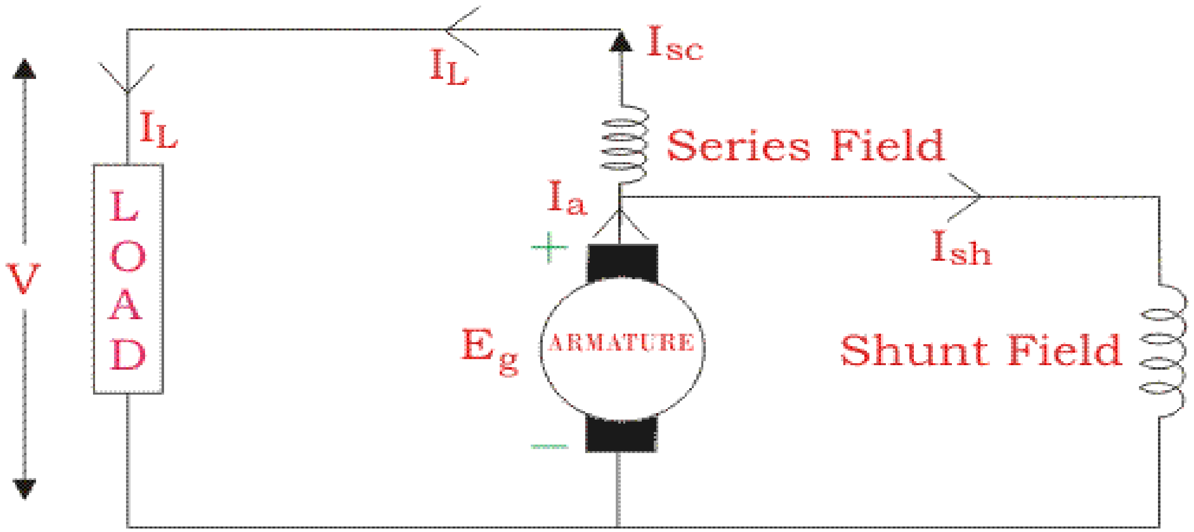
- In Compound wound DC generator or self excited DC generators have both series field winding and shunt field winding.
- One winding is placed in series with the armature and the other is placed in parallel with the armature.
- In series wound generators the output voltage is directly proportional with load current.
- In shunt wound generators, output voltage is inversely proportional with load current.
- A combination of these two types of generators can overcome the disadvantages of both. This combination of windings is called compound wound DC generator.

Types of Compound DC Generators

- Short Shunt DC Compound Generator.
- Long Shunt DC Compound Generator.

Short Shunt DC Compound Generator.

- The generators in which only shunt field winding is in parallel with the armature winding as shown in figure.



Short Shunt Compound Wound Generator

Series field current, $I_{sc} = I_L$

Shunt field current, $I_{sh} = (V+I_{sc} R_{sc})/R_{sh}$

Armature current, $I_a = I_{sh} + I_L$

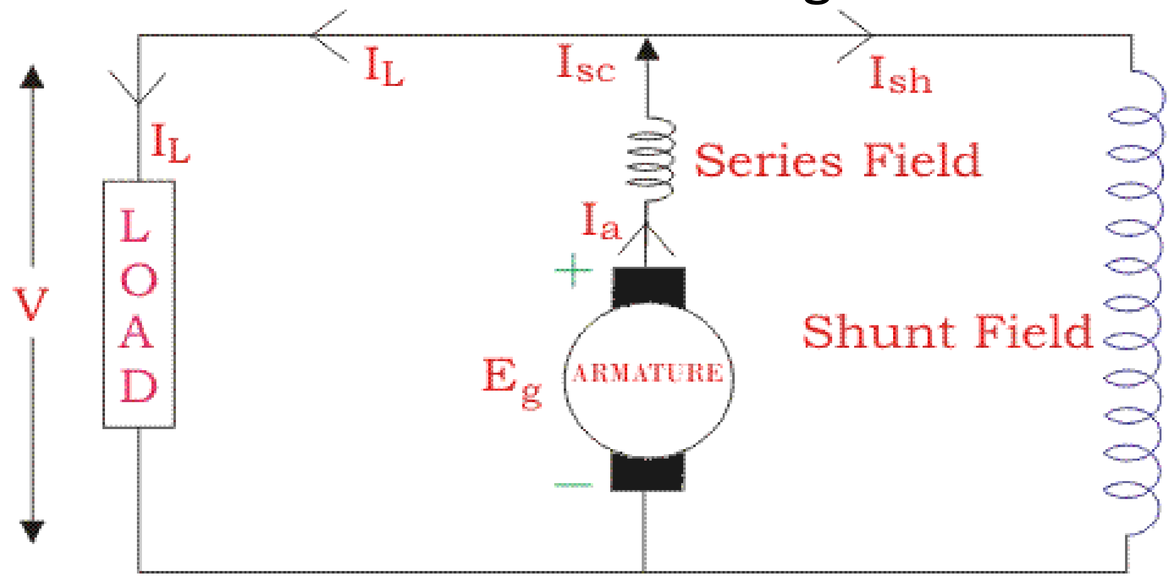
Voltage across the load, $V = E_g - I_a R_a - I_{sc} R_{sc}$

Power generated, $P_g = E_g \times I_a$

Power delivered to the load, $P_L = V \times I_L$

Long Shunt DC Compound Generator.

- The generators in which shunt field winding is in parallel with both series field and armature winding as shown in figure.



Long Shunt Compound Wound Generator

Shunt field current, $I_{sh}=V/R_{sh}$

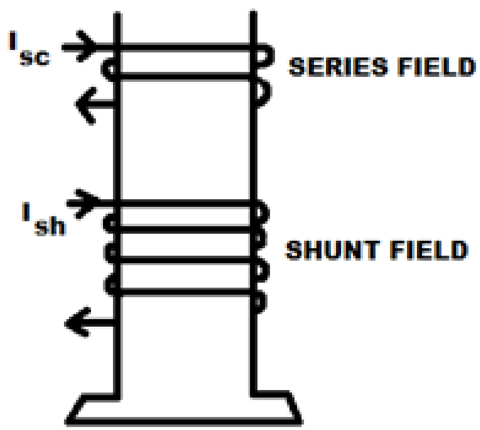
Armature current, $I_a=$ series field current, $I_{sc}= I_L+I_{sh}$

Voltage across the load, $V=E_g-I_a R_a-I_{sc} R_{sc}=E_g-I_a (R_a+R_{sc})$ $[\therefore I_a=I_{cs}]$

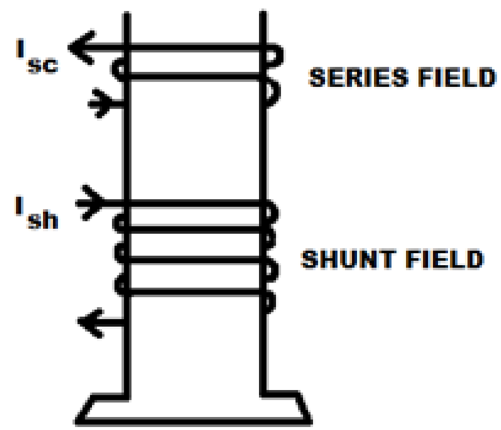
Power generated, $P_g= E_g \times I_a$

Power delivered to the load, $P_L=V \times I_L$

- In a compound wound generator, the shunt field is stronger than the series field. When the series field assists the shunt field, generator is said to be commutatively compound wound.
- On the other hand if series field opposes the shunt field, the generator is said to be differentially compound wound.



CUMULATIVE COMPOUNDING



DIFFERENTIAL COMPOUNDING

Armature Reaction

If a load is connected to the terminals of the dc machine, a current will flow in its armature windings. This current flow will produce a magnetic field of its own, which will distort the original magnetic field from the machine's field poles. This distortion of the magnetic flux in a machine as the load is increased is called the armature reaction.

Examples

DC Motors

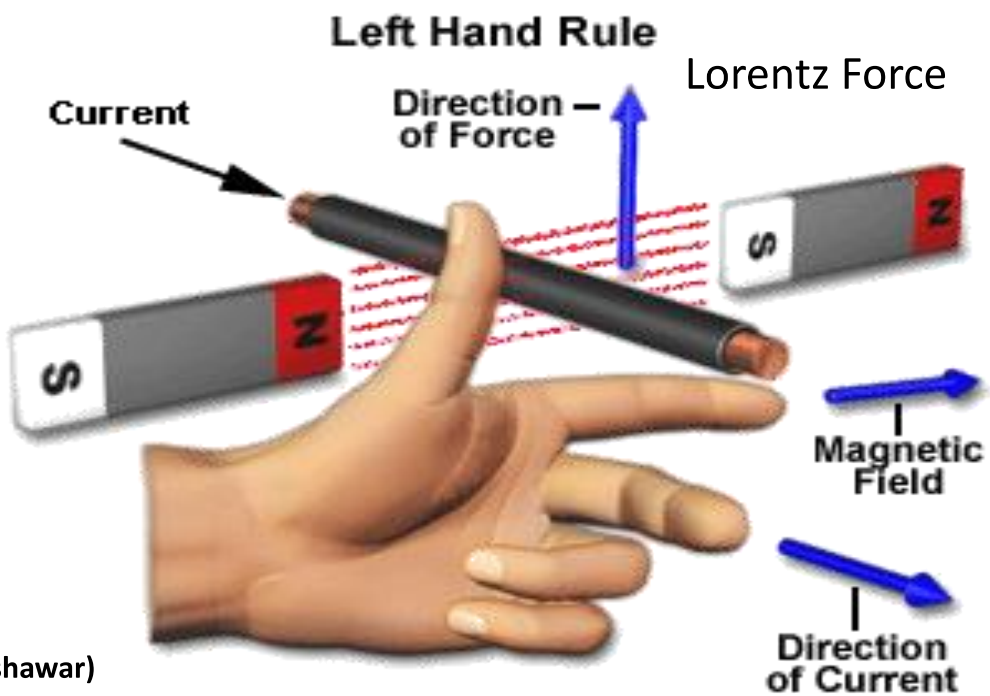
Principle

- Device that converts DC electrical energy to a mechanical energy.

- Direct current motor works on the principal, when a current carrying conductor is placed in a magnetic filed, it experiences a torque and has a tendency to move.

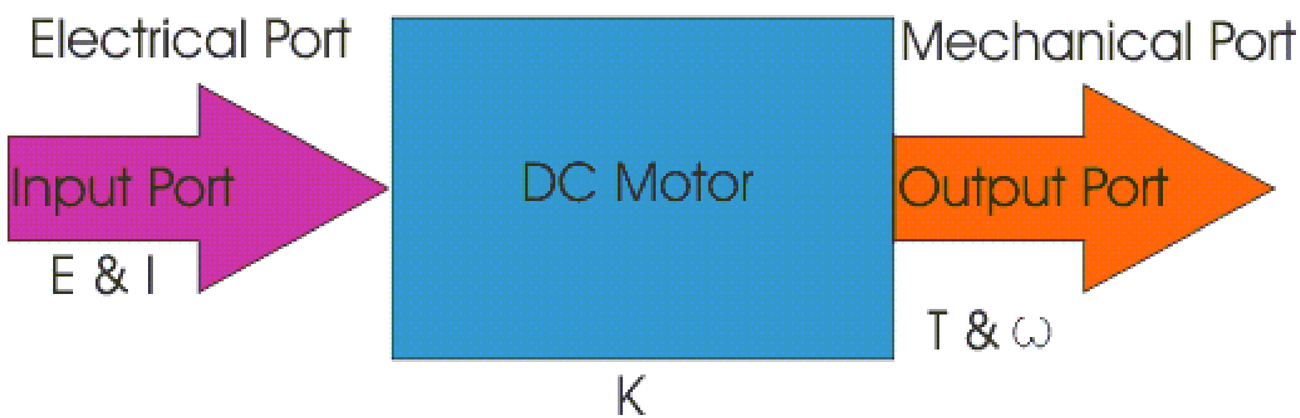
- If the direction of current in the wire is reversed, the direction of rotation also reverses. When magnetic field and electric field interact they produce a mechanical force, and based on that the working principle of DC motor is established.

Lorentz Force

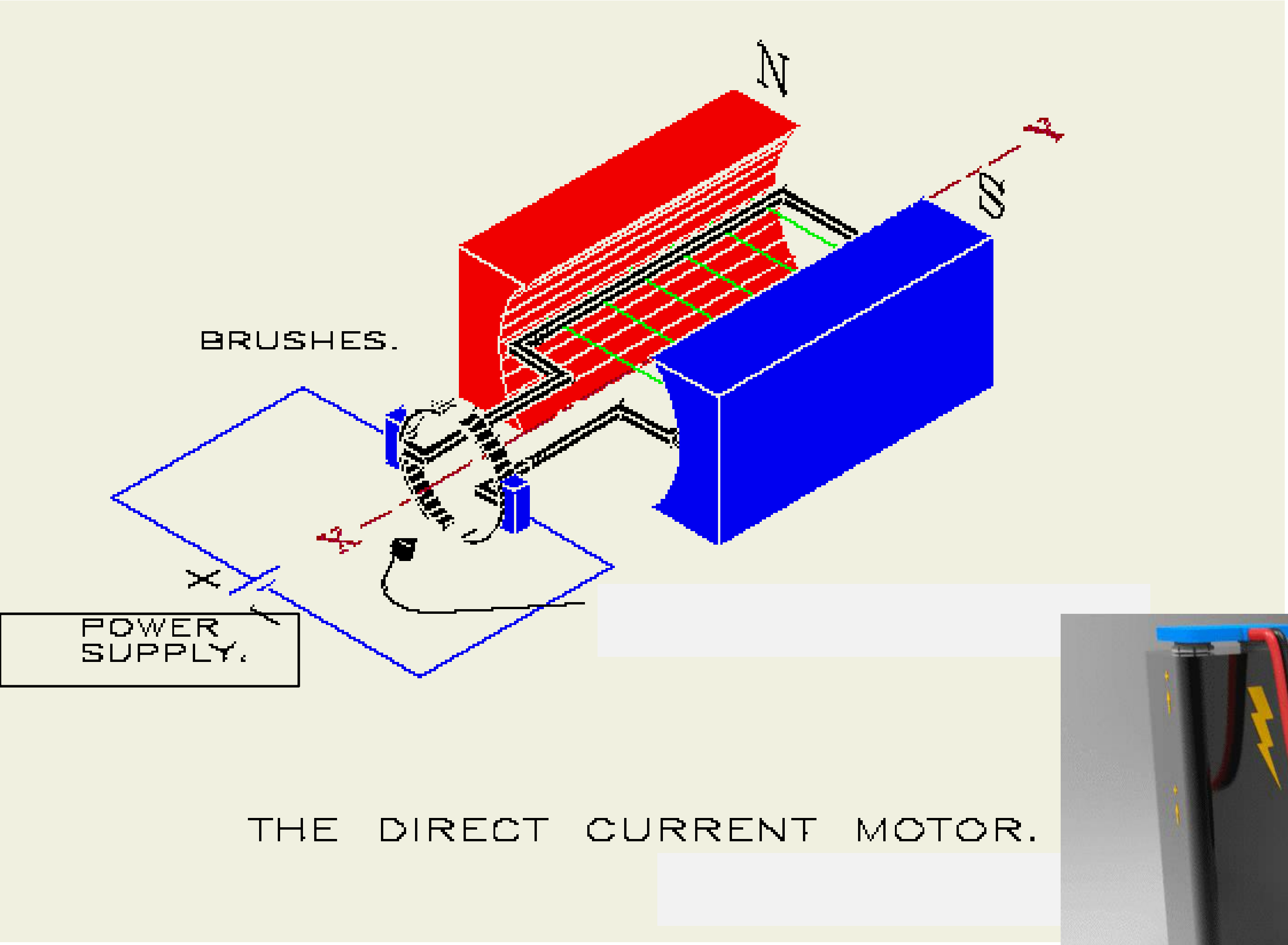


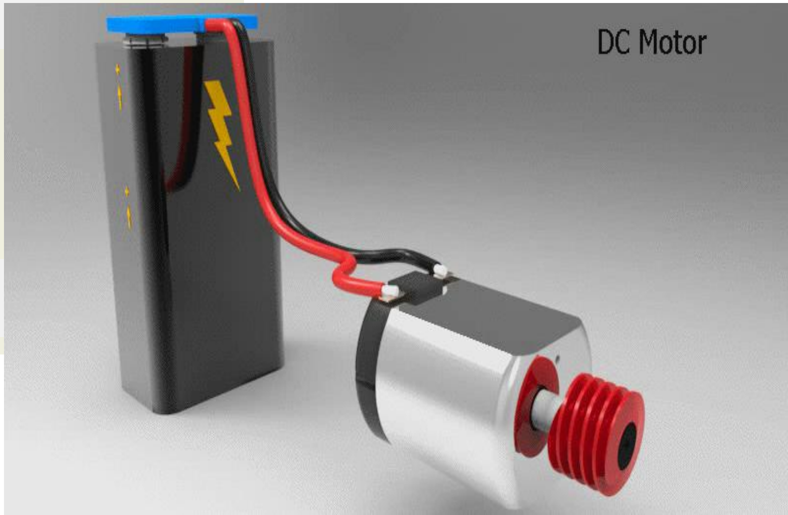
Construction

- Structurally and construction wise a direct current motor is exactly similar to a DC Generator but electrically it is just the opposite.
- Here we unlike a generator we supply electrical energy to the input port and derive mechanical energy from the output port. We can represent it by the block diagram shown below.

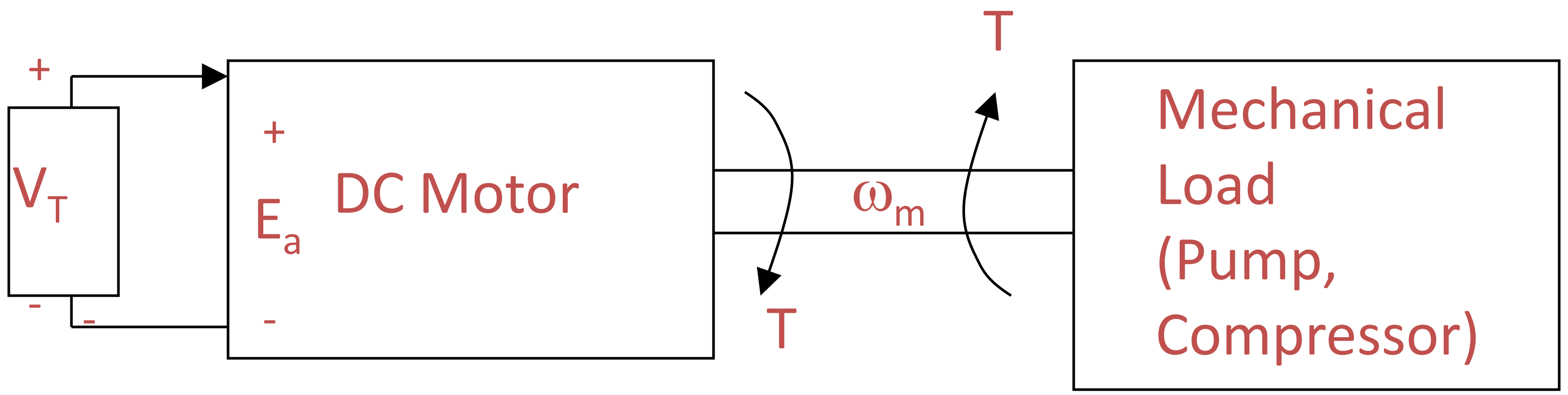


Working





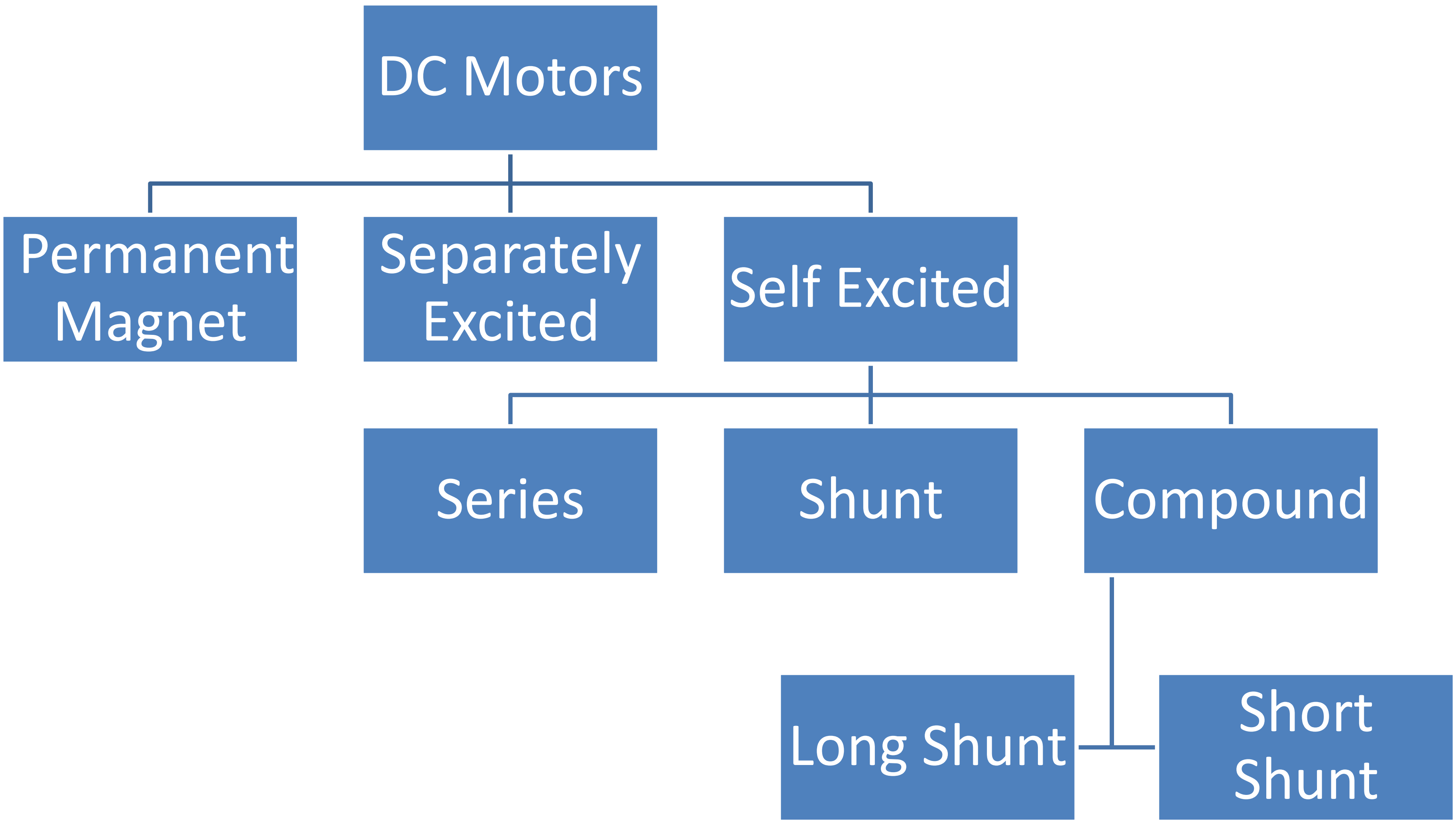
Arrangment



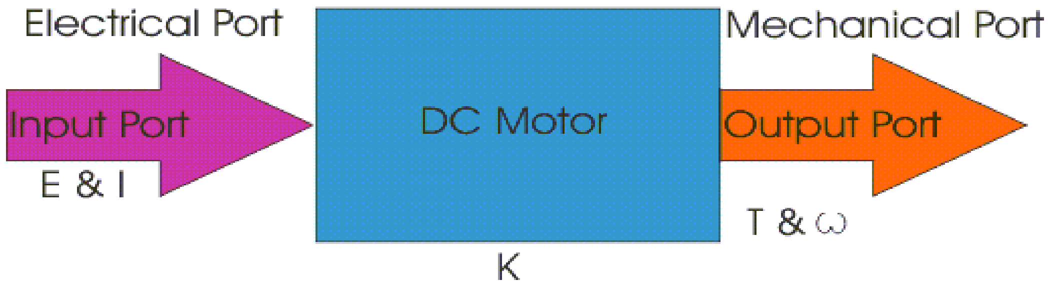
Applications

- The direct current motors has a lot of application in today’s field of engineering and technology.
- Starting from an electric shaver to parts of automobiles, in all small or medium sized motoring applications DC motors come handy.
- And because of its wide range of application different functional types of DC motor are available in the market for specific requirements.

Types of DC Motors



Detailed Description of a DC Motor

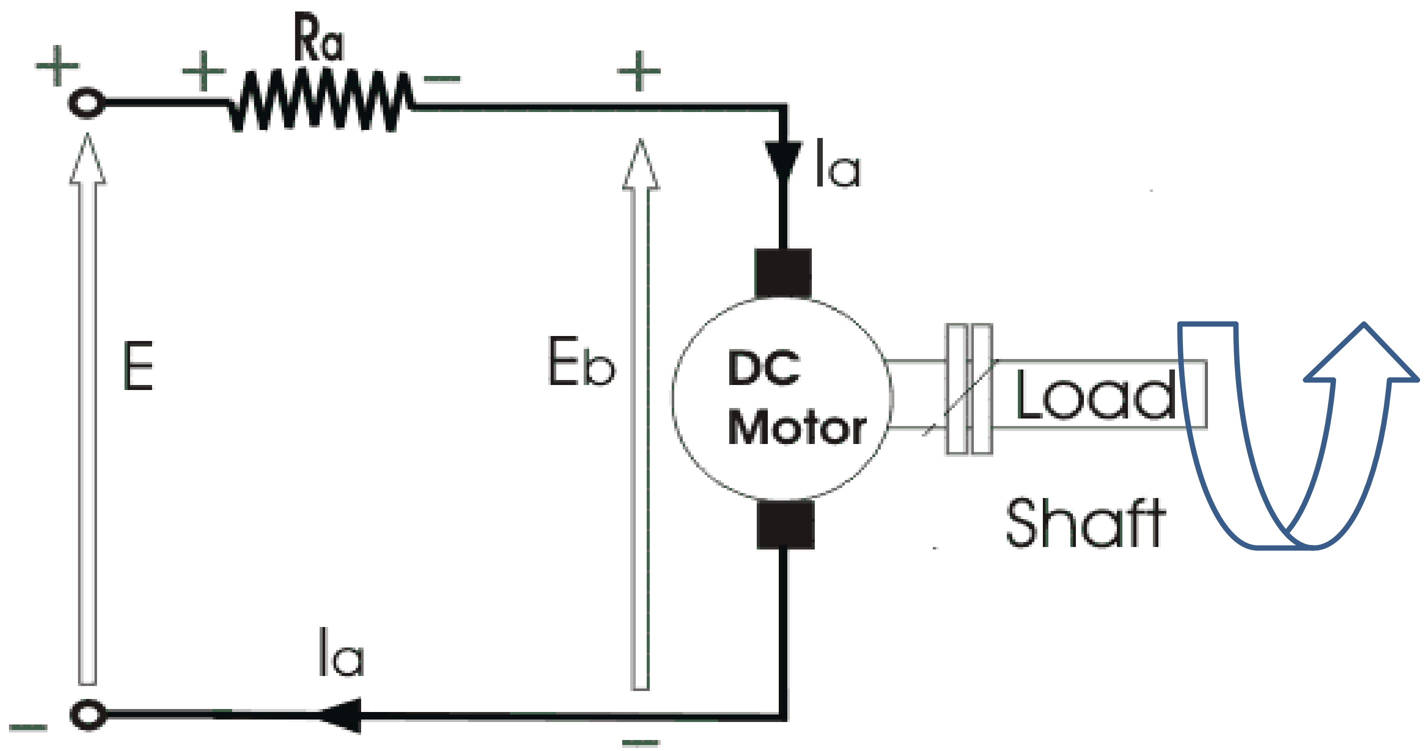


$$T = KI \ and \ E = K\omega$$

- Voltage E and current I is given to the electrical port or the input port and we derive the mechanical output i.e. torque T and speed ω from the mechanical port or output port.
- The input and output port variables of the direct current motor are related by the parameter K.
- we can well understand that motor is just the opposite phenomena of a DC generator, and we can derive both motoring and generating operation from the same machine by simply reversing the ports.

Back EMF "Eb"

Applied Voltage



- Electric current which flows through the rotor armature via brushes, in presence of the magnetic field, produces a torque T_g.
- Due to this torque T_g the dc motor armature rotates.
- As the armature conductors are carrying currents and the armature rotates inside the stator magnetic field, it also produces an emf E_b in the manner very similar to that of a generator.
- The generated Emf E_b is directed opposite to the supplied voltage and is known as the back Emf, as it counters the forward voltage.
- represented by :

$$E_b = \frac{P.\varphi.Z.N}{60.A}$$

- If Speed is reduces by application of load, Eb also decreases thus voltage difference between applied voltage E and Back emf Eb increases
- E- Eb
- Due to increased voltage difference Armature current (Ia) increases as Ia increases Torque also increases and hence speed also increases
- By KVL $$I_a = \frac{E - E_b}{R_a}$$
- Now at starting ,speed ω = 0 so at starting E_b = 0. $$I_a = \frac{E}{R_a}.$$
- If R_a is small, motor has a very high starting current in the absence of back Emf.
- As motor continues to rotate, the back Emf starts being generated and gradually the current decreases as the motor picks up speed.

Torque & Armature Current Relationship

Pe= Pm

Pe= Electrical Power

Pm = Mechanical Power

Pe= Ea Ia as (Ea= Eb + IaRa) KVL

Pe= (Eb+IaRa)Ia

Pe= Eb Ia + ~~Ia2Ra~~ (as dissipate in form of heat)

Pe= Eb Ia

Now

Pm= Tg W :: Tg (Troque in N.M) and W (angular speed in rad/sec)

1 radian = 1/ 2∏ : : In RPM = N * 2∏/60 = rad/sec

Pm = Tg N 2∏/60

Pm = Pe

Tg N 2∏/60 = Eb Ia

$$E_b = \frac{P.\varphi.Z.N}{60.A}$$

$$T = \frac{P.Z.\varphi.I_a}{2.\pi.A}$$

Hence Tg is directly propositional to Ia

Power Developed in a DC Machine

Neglecting Losses

<u>Input mechanical power to DC Generator</u>

$= T\,\omega_m = K_a \Phi I_a \omega_m = E_a\, I_a$

= *Output electric power to load*

<u>Input electrical power to DC Motor</u>

$= E_a\, I_a = K_a \Phi\, \omega_m\, I_a = T_d\, \omega_m$

= *Output mechanical power* to load

Examples

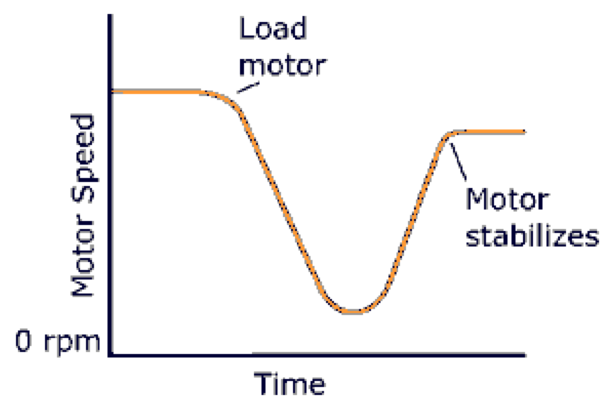
DC Shunt Motor Characteristics

- In DC shunt motor, the field windings are exposed to the entire terminal voltage as they are connected in parallel to the armature winding.
- Self regulation of speed on application of load.
- On loading the shaft initially speed decreases but after some time again come to starting speed.
- Speed reduces Eb also reduce which will increase applied voltage thus Ia increases $T_g = K_a \phi I_a$
- Ia increases Torque also increases so speed is increased thus Shunt DC motor is constant speed motor.

$$E_b = k_a \phi \omega$$

$$E = k_a \phi \omega + I_a R_a$$

$$\therefore \omega = \frac{E - I_a R_a}{k_a \varphi}$$



No Load to Loaded Condition

The shunt wound DC motor is a constant speed motor, as the speed does not vary here with the variation of mechanical load on the output.(Self regulation)

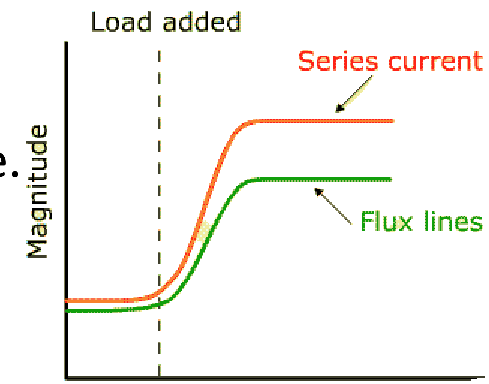
DC Series Motor Characteristics

- The entire armature current flows through the field winding as its connected in series to the armature winding.
- Field winding are thicker in diameter for less resistance.
- Due to which it produces high field and generate large torque.

$$I_{se} \propto \phi$$

- But since here Ise = Ia = Itotal

$$\phi \propto I_{se} \propto I_a$$



- DC series motor has very poor speed regulation. When load is added to shaft the speed is changed this motor incapable of speed regulation so when speed N is reduced Eb is also reduced thus Eb decreases applied voltage increases so field current also increases.
- More increase in Field current will make the motor run beyond controllable speed and thus motor runs away.

And for this particular reason the motor becomes extremely essential as starter motors for most industrial applications dealing in heavy mechanical load like huge cranes or large metal chunks etc. These are operated for less time as high series current may burn the motor.

DC Compound Motor Characteristics

- The compound excitation characteristic in a DC motor can be obtained by combining the operational characteristic of both the shunt and series motors.
- The field windings connected both in series and in parallel to the armature winding.
- Two Types of DC Compound Motors
  - **Cumulative Compound DC Motor**
  - **Differential Compound DC Motor**

Cumulative DC Compound Motors:

shunt field flux assists the main field flux, produced by the main field connected in series to the armature winding then its called cumulative compound DC motor.

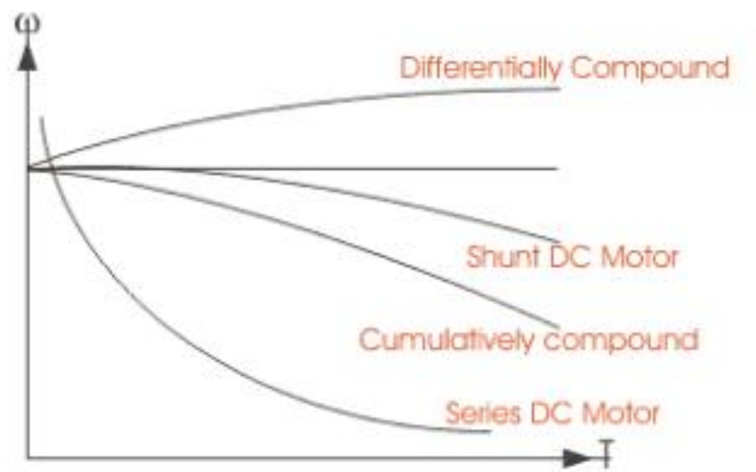
$$\phi_{total} = \phi_{series} + \phi_{shunt}$$

Differential DC Compound Motors:

The arrangement of shunt and series winding is such that the field flux produced by the shunt field winding diminishes the effect of flux by the main series field winding.

$$\phi_{total} = \phi_{series} - \phi_{shunt}$$

- So the compound wound DC motor reaches a compromise in terms of both this features and has a good combination of proper speed regulation and high starting toque.



Speed Control Methods of DC Motors

Speed Control Methods of DC Motors

- Speed control is intentional change in speed of motor.
- It is different from concept of speed regulation where there is natural change in speed due to loading and unloading of shaft.
- Speed change is done manually or by automatically control devices.

- EMF equation :

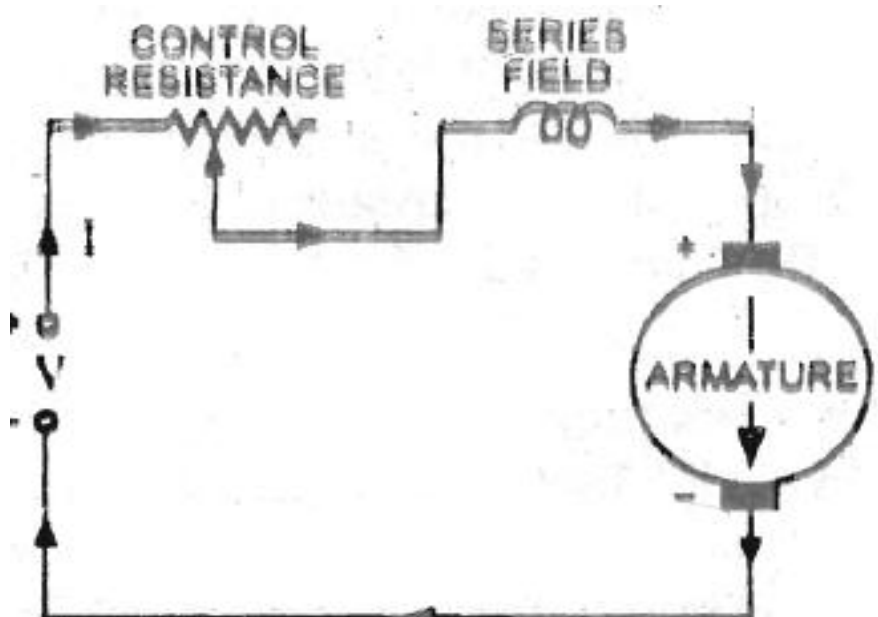
  $E_b = {}^{P\text{Ø}NZ}/_{60A}$

- $N = {}^{E_b 60A}/_{P\text{Ø}Z}$
- but, for a DC motor A, P and Z are constants
- Therefore, $N \propto K\, {}^{E_b}/_{\text{Ø}}$ (where, K=constant)
- So $Eb = V - I_a R_a$
- $N \propto V - I_a R_a / \text{Ø}$
- This shows the speed of a dc motor is directly proportional to the **Voltage applied** , **Armature Current** and **Armature Resistance** and inversely proportional to the **flux per pole**.

Speed Control of DC Series Motor

- Armature Resistance Control Method:

Here the controlling resistance is connected directly in series with the supply of the motor as shown

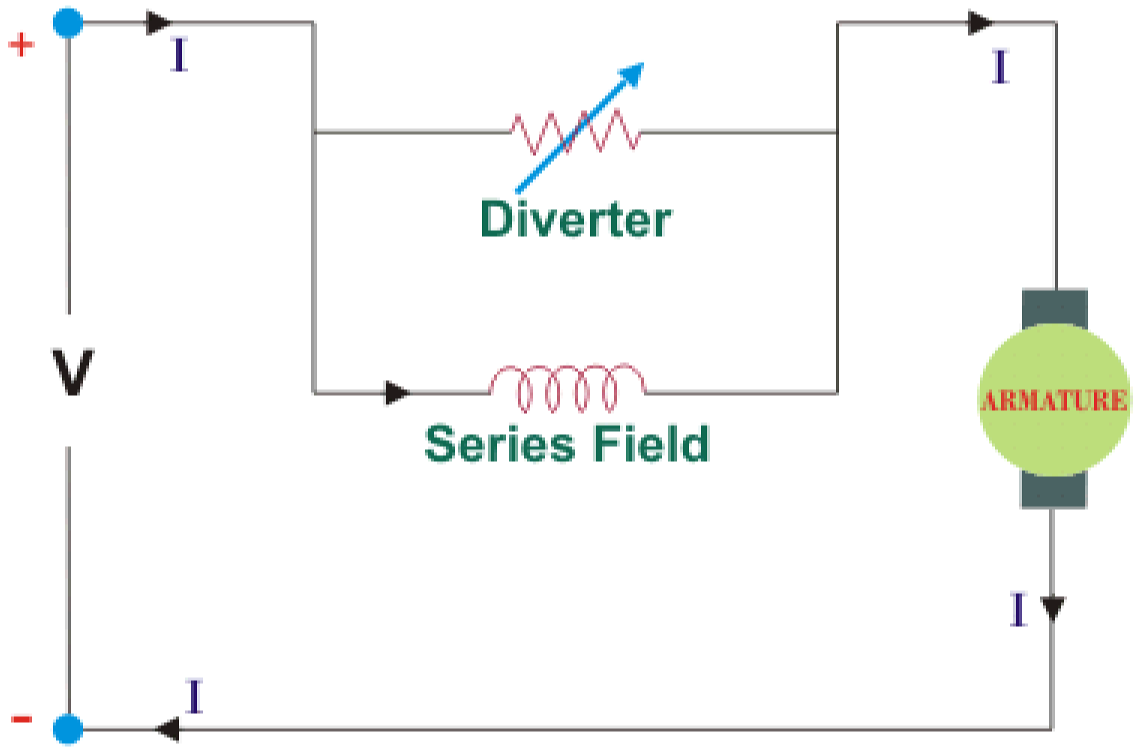


This reduces the voltage available across the armature and hence the speed falls. By changing the value of variable resistance.

This method of speed control is most economical for constant torque.

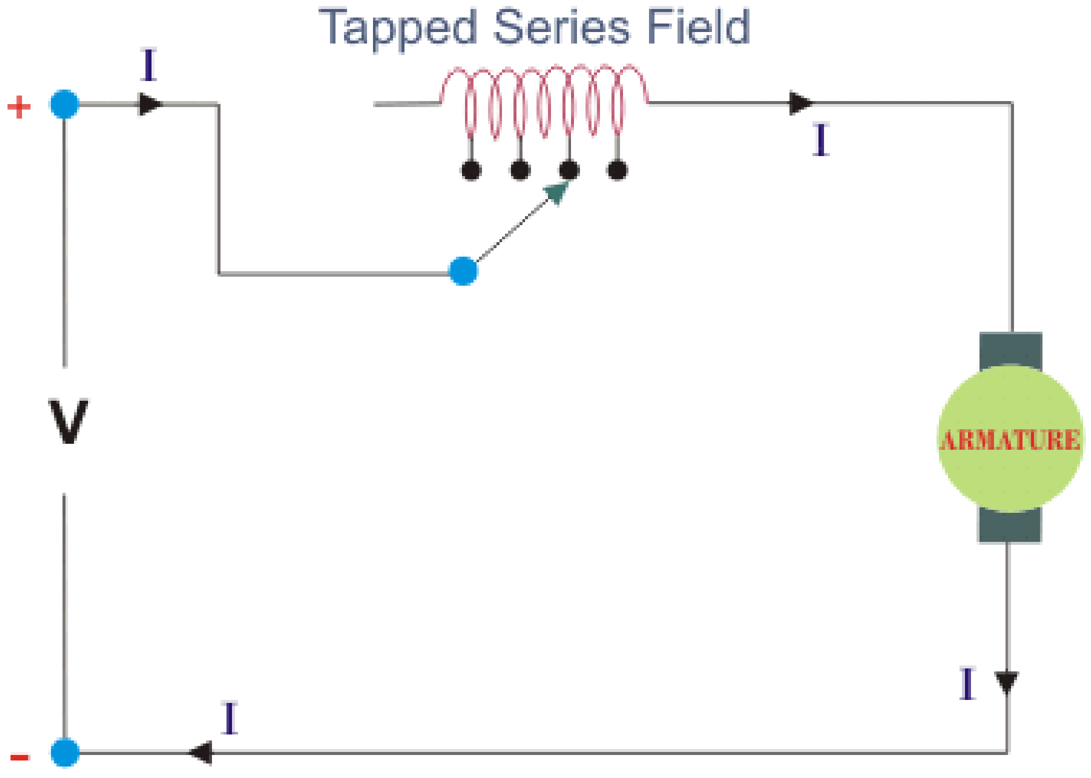
Field Diverter Method

- This method uses a diverter. Here the field flux can be reduced by shunting a portion of motor Current around the series field. Lesser the diverter resistance less is the field current, less flux therefore more speed.



Tapped Field Control

- This is another method of increasing the speed by reducing the flux and it is done by lowering number of turns of field winding through which current flows.



Speed Control of DC Shunt Motor

Speed of a shunt motor can be changed by :

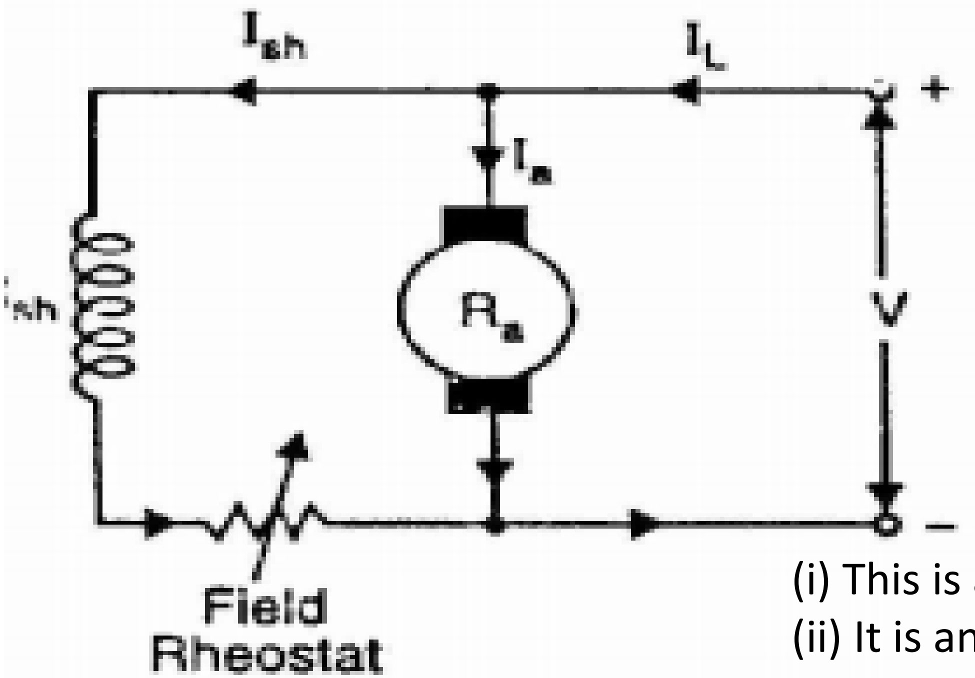
1. Flux control method.

2. Armature control method.

3. Ward Leonard System (Voltage control method).

Flux control method.

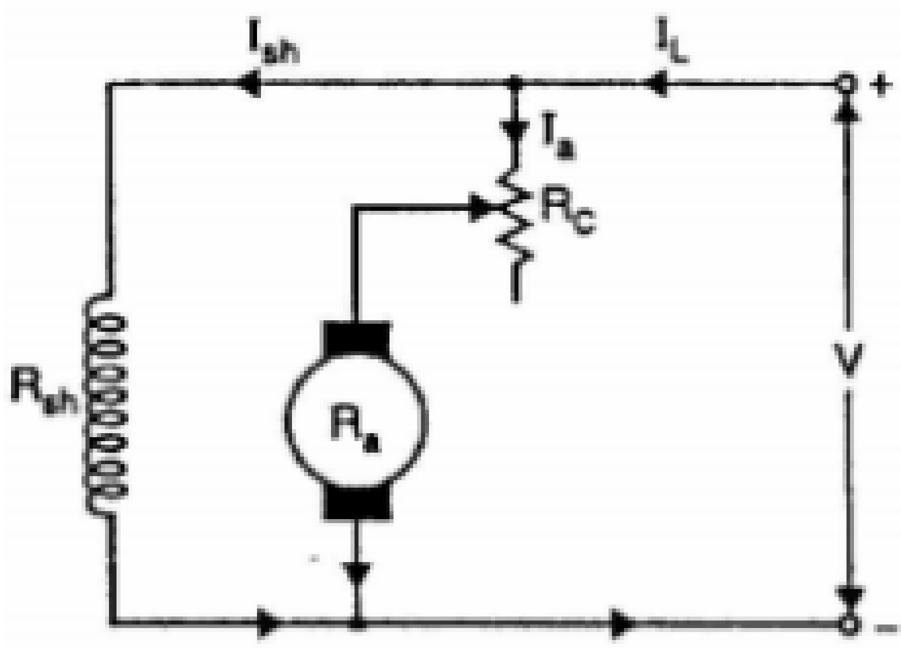
- In this method, a variable resistance (known as shunt field rheostat) is placed in series with shunt field winding as shown:
- An increase in controlling resistances reduces the field current with a reduction in flux and an increase in speed.



(i) This is an easy and convenient method.
(ii) It is an inexpensive method since very little power is wasted in the shunt field rheostat due to relatively small value of Ish.

Armature control method.

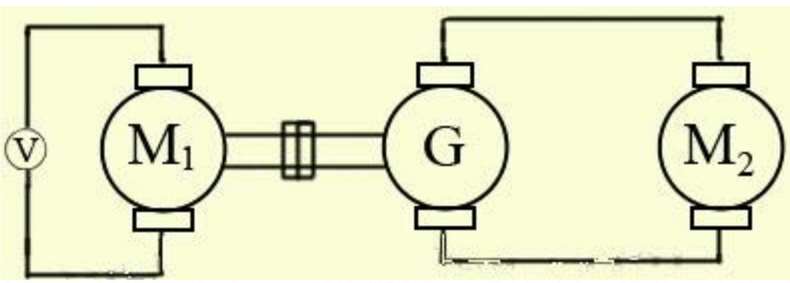
- This is done by inserting a variable resistance RC (known as controller resistance) in series with the armature as shown :
- The Flux remains constant while armature current is changed produces change in speed.

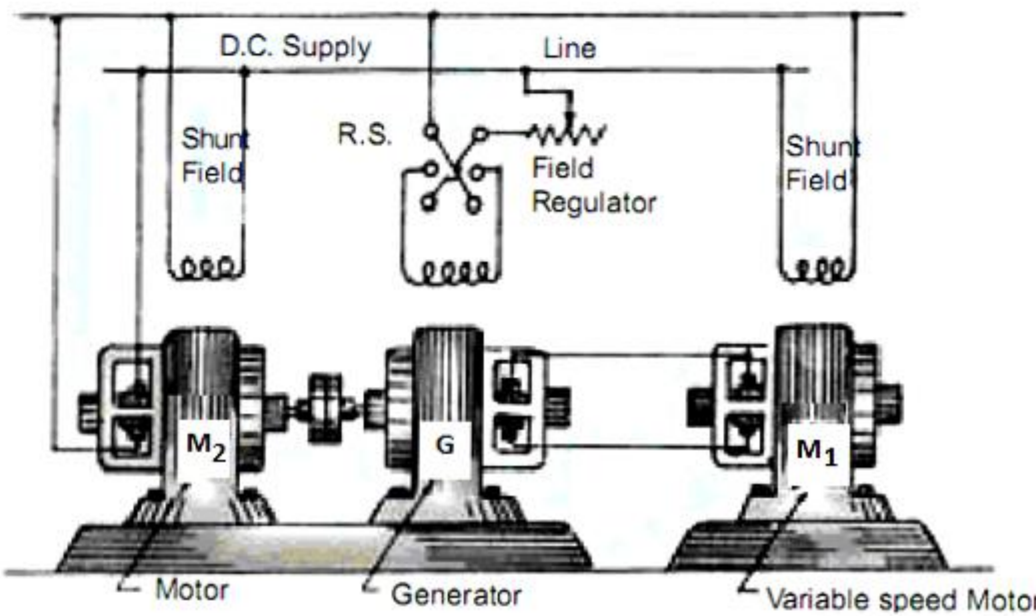


Large amount of power is wasted in the controller resistance since it carries full armature current Ia.

Ward Leonard System (Voltage control method).

- This system is used where very sensitive speed control of motor is required (e.g electric excavators, elevators etc.).





The speed of the motor can be adjusted through a wide range without resistance losses which results in high efficiency.

Types of Braking in a DC Motor

Braking in a DC Motor

- There are various techniques used to stop a DC Motors or to bring it to rest as we cut off the supply.
- Braking is done Mechanically and aswel as Electrically.
- Our focus will be on Electrical braking that is done by voltage and current action.

Electrical Braking Types

- **Regenerative Braking**
- **Dynamic Braking**
- **Plugging**

Regenerative Braking

- The motor produces back emf E_b which is greater than the supply voltage V, which reverses the direction of the motor armature current. The motor begins to operate as an electric generator.
- This type of braking is possible when the driven load forces the motor to run at a speed higher than its no-load speed with a constant excitation.

Dynamic Braking

- Rheostatic braking.
- DC motor is disconnected from the supply and a braking resistor R_b is immediately connected across the armature.
- Motor will now work as a generator, and produces the braking torque.
- So the kinetic energy stored in the rotating parts of the motor is converted into electrical energy.

Plugging

- The armature terminals or supply polarity of a DC separately excited motors or DC shunt motors when running are reversed.
- Thus, the armature current is reversed and a high braking torque is produced.
- It is used in elevators, printing press etc.

.END.