Basic Electrical Technology
[ELE 1051]

L26 – Transformers & DC Motors

Contents

Introduction

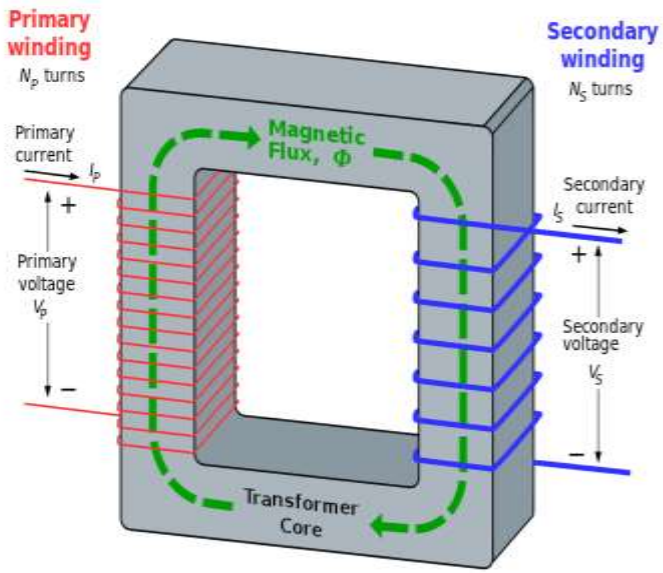
Static device with AC excitation

Transfers energy between two or more magnetically coupled circuits without change in frequency.

Principle of operation: *Electromagnetic Induction*

Electric circuits are linked by a common ferromagnetic core

Ferromagnetic core ensures *maximum* magnetic flux linkage



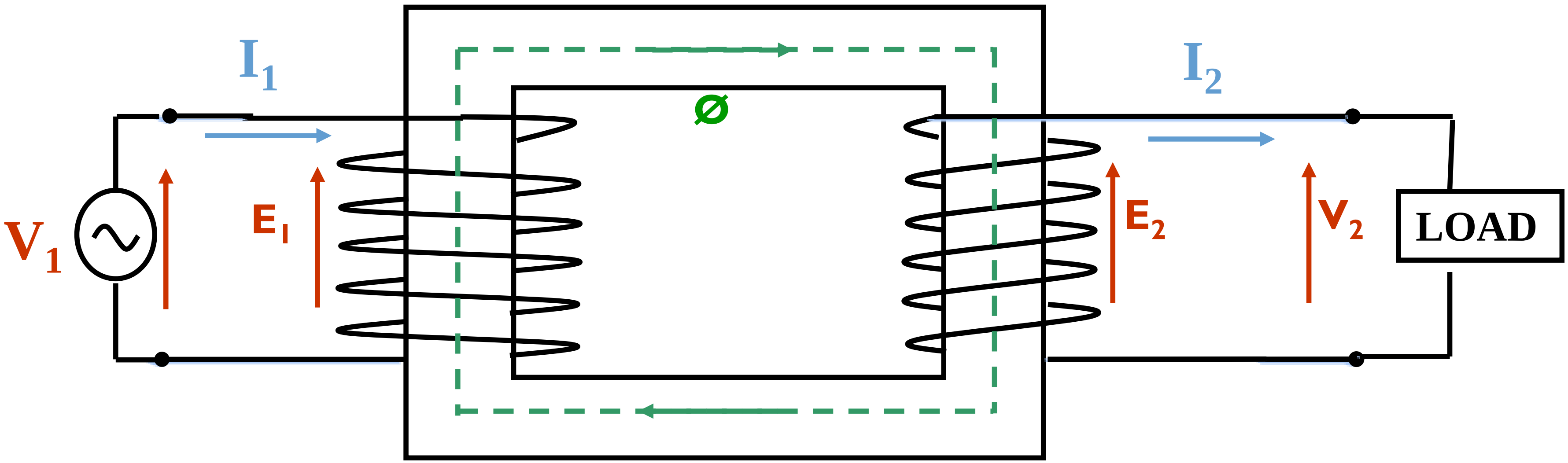
Applications:

- Electric power systems
- Power transmission, distribution networks
- Electronic circuits
- Electric traction

Types

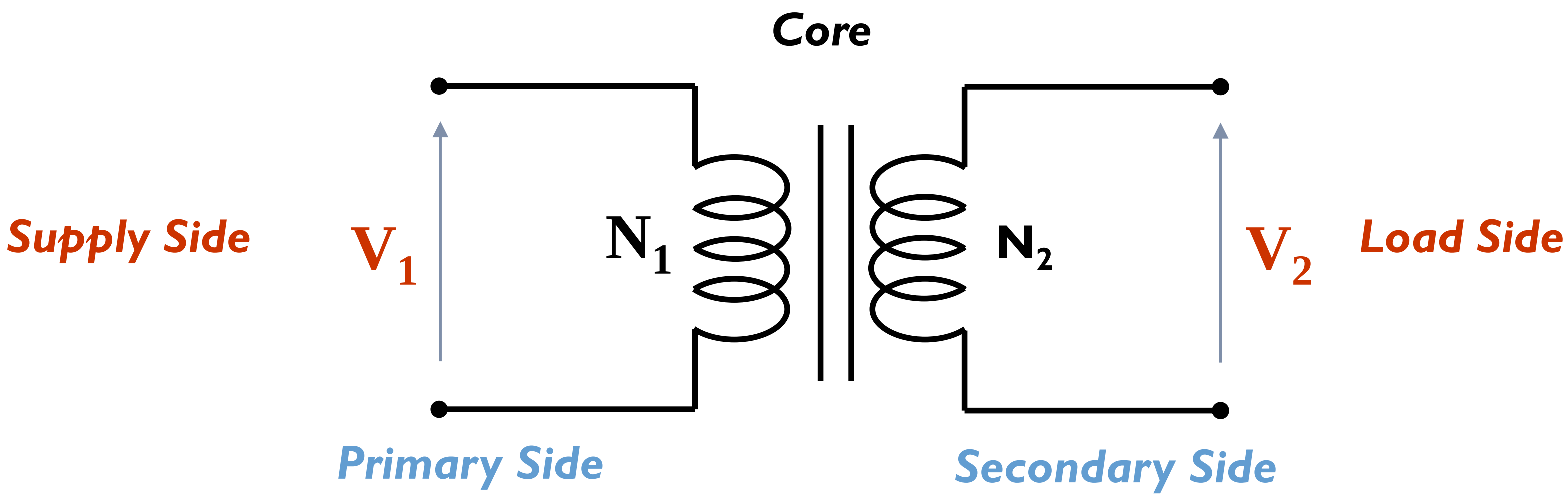
Based on Construction	***Based on Function***	***Based on Windings***
Core Type	Step Up	Single Winding
Shell Type	Step Down	2 or 3 Windings

Operation of Transformer



- Magnetic Core : Flux path
- Flux Linkages : Primary & Secondary
- Induced Emf :
  - Primary – Self Induced Emf
  - Secondary – Mutually Induced Emf

Representation



N_1 = Number of turns on primary
N_2 = Number of turns on secondary

Emf Equation of Transformer

$$\boldsymbol{Core\ flux}, \emptyset = \emptyset_m Sin\omega t$$

$$\boldsymbol{Induced\ Emf}, e = -N\frac{d\emptyset}{dt} = N\omega\emptyset_m Sin(\omega t - 90°)$$

$$e = E_m Sin(\omega t - 90°)$$

$$\boldsymbol{where}, E_m = N\omega\emptyset_m \rightarrow Maximum\ value\ of\ self\ induced\ emf$$

$$\boldsymbol{RMS\ value\ of\ self\ induced\ emf}, E = \frac{E_m}{\sqrt{2}} = \frac{N\omega\emptyset_m}{\sqrt{2}} = \frac{2\pi f N\emptyset_m}{\sqrt{2}}$$

$$\boldsymbol{Primary\ Induced\ Emf}, E_1 = 4.44\ N_1 f\emptyset_m$$
$$\boldsymbol{Secondary\ Induced\ Emf}, E_2 = 4.44\ N_2 f\emptyset_m$$

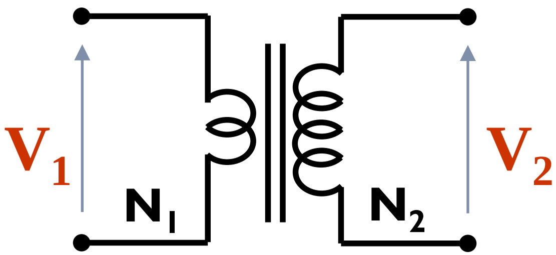
Emf Equation of Ideal Transformer…

$$\frac{V_1}{V_2} \cong \frac{E_1}{E_2} = \frac{I_2}{I_1} = \frac{N_1}{N_2} = a = Turns\ Ratio$$

$where, V_1 \& V_2\ are\ the\ terminal\ voltages,$

$E_1 \& \ E_1 are\ the\ induced\ RMS\ voltages,$

$N_2 > N_1$: Step Up

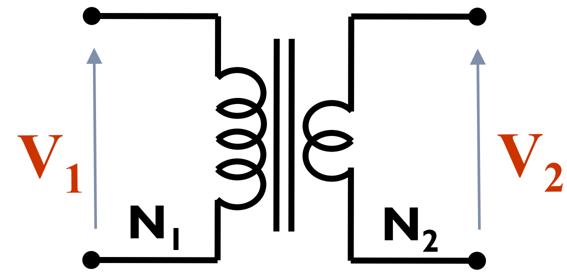


$E_2 > E_1$

$V_2 > V_1$

$I_1 > I_2$

$N_2 < N_1$: Step down

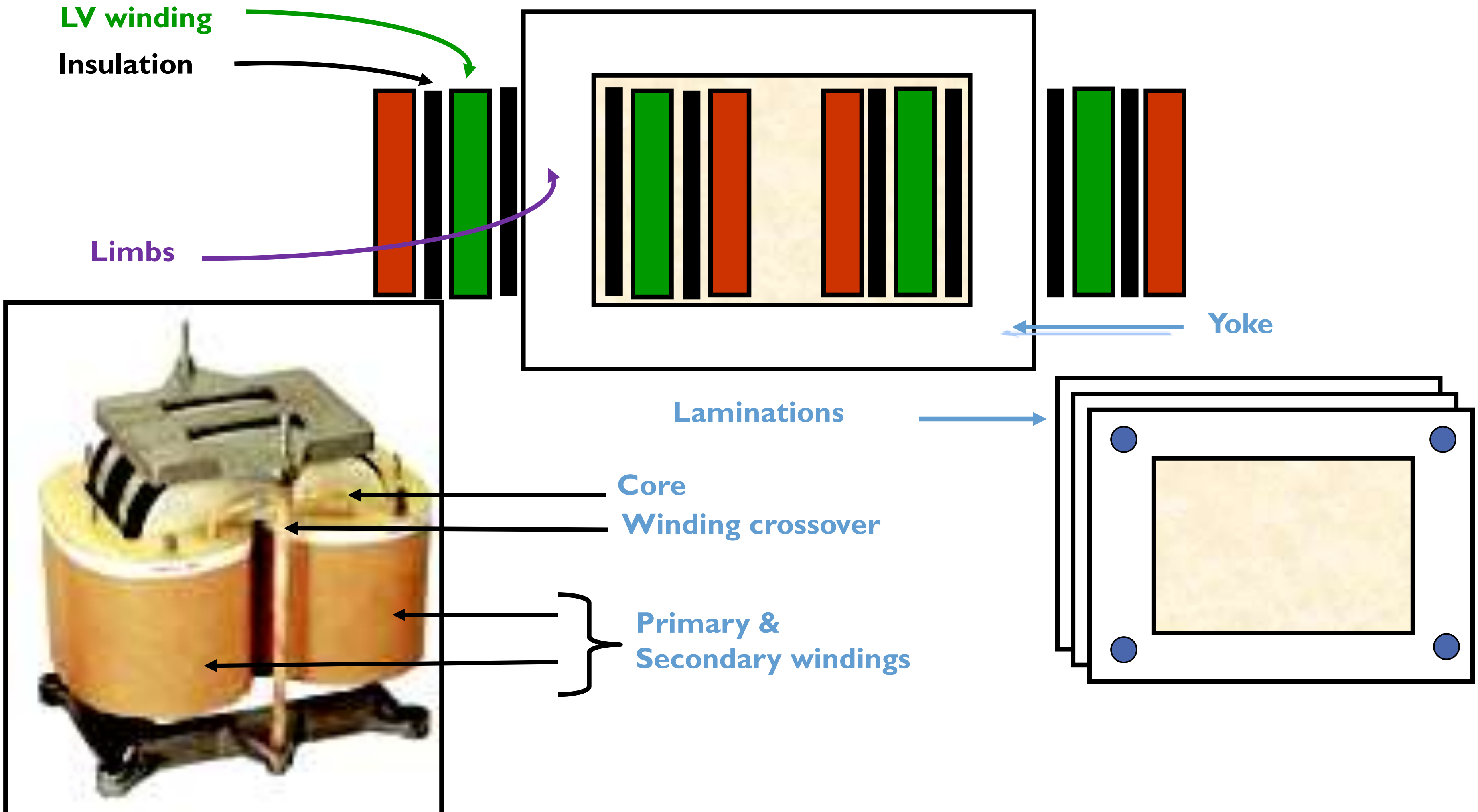


$E_2 < E_1$

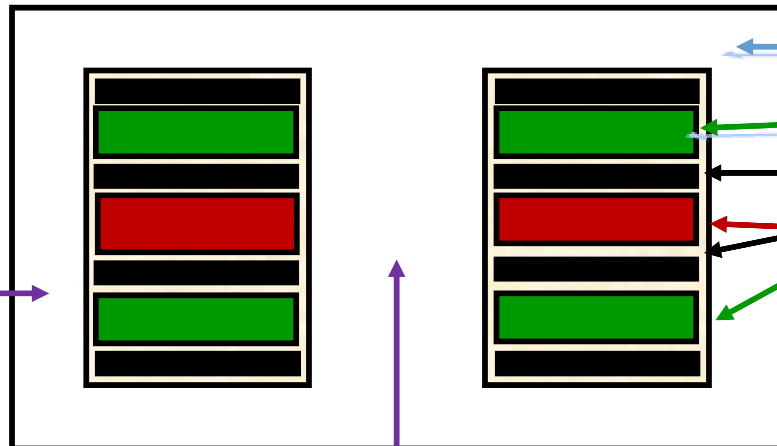
$V_2 < V_1$

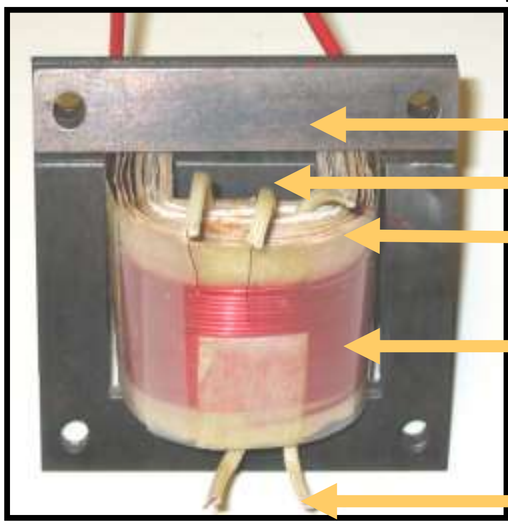
$I_1 < I_2$

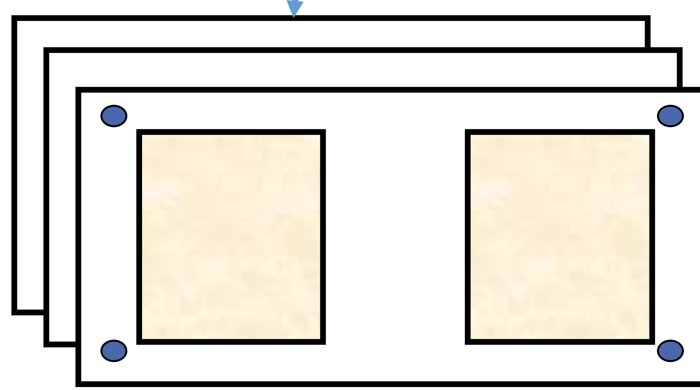
Construction- *Core Type*



Construction- *Shell Type*







Losses & Efficiency

Core Loss

- Hysteresis Loss
- Eddy Current Loss

◦ Depends on flux which is constant hence the loss is constant

◦ Minimized using high graded core material and lamination

Copper Loss

- Winding Resistance (in primary and secondary)

◦ Current (or Load) dependent, hence variable loss

Total Loss = Core Loss + Copper Loss

Efficiency: Very high 97% to 99% (since it is a static device)

Auto Transformer

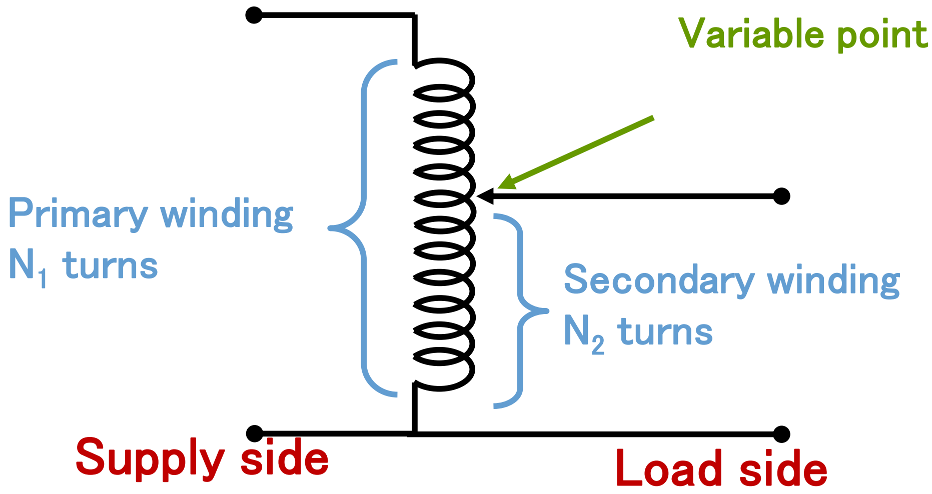
One winding transformer

- Part of winding common to primary & secondary circuits

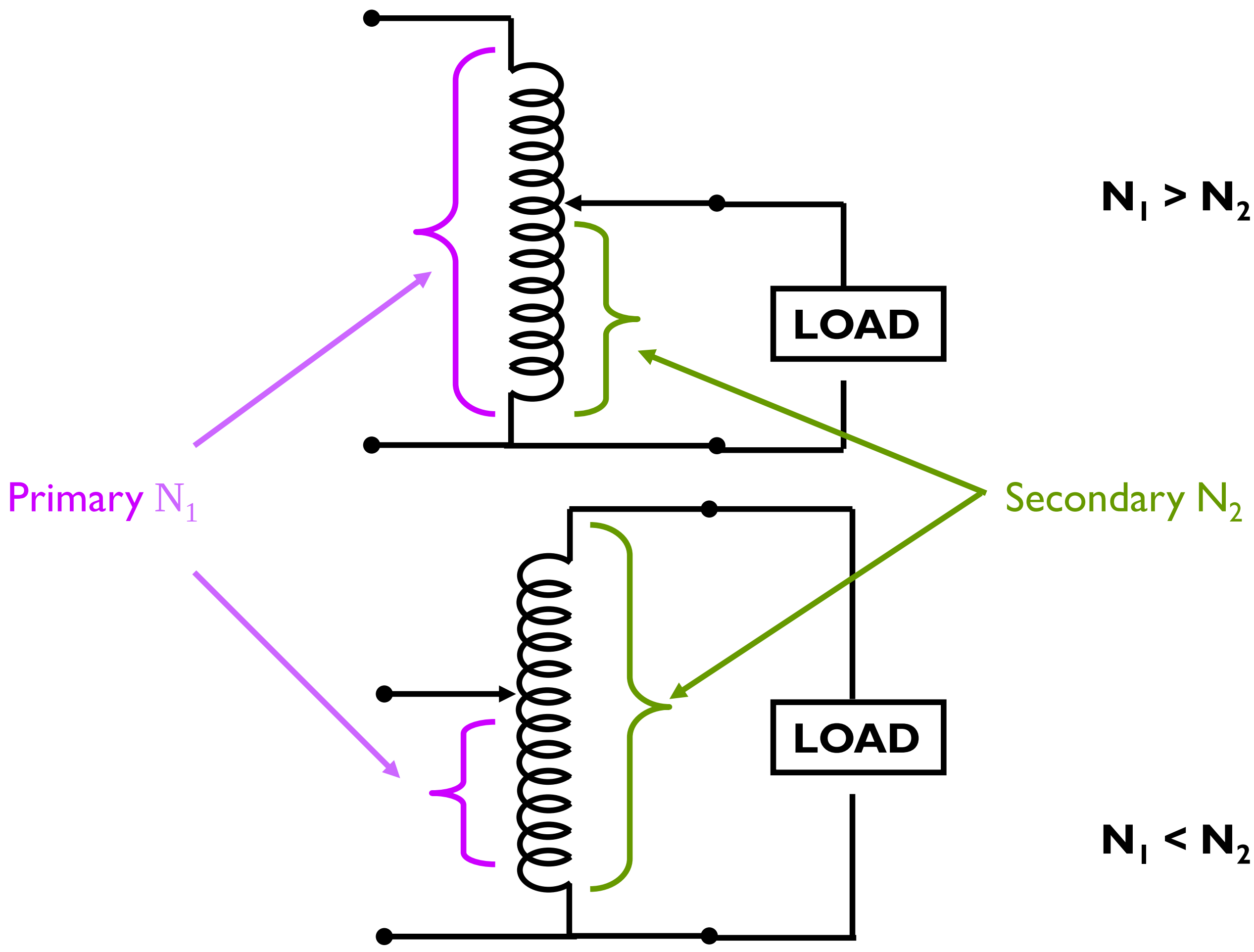
One winding wound over the entire core

Secondary winding can be varied using variable point

Used in power applications to interconnect systems operating at different voltage classes, for example 138 kV to 66 kV for transmission



Auto Transformer- Types



$N_1 > N_2$: Step Down type

$N_1 < N_2$: Step Up type

3 Phase Transformer

3 primary coils & 3 secondary coils.

Possible connections of primary & secondary windings

- *star/star*
- *star/delta*
- *delta/delta*
- *delta/star*

3 single-phase transformers of similar ratings can be connected to form a 3 phase transformer

Application

Power Transformer: Used in electric transmission network

Distribution Transformer: Used in electric distribution networks

Instrument Transformers (PT & CT): Used for high voltage & current measurement

Isolation Transformer: 1:1 transformers used in circuits to provide electrical isolation.

Constant Voltage Transformer: Used as voltage regulators

High frequency Transformer: Transformers designed for operating with high frequency – ferrite core

Introduction to Electric machines

Electric motors may be broadly classified as

- D.C motors
- Induction motors
- Synchronous motors

The last two categories of motors operate on alternating current.

Both ac and dc motors work with the Law of electro magnetic induction and Law of electromagnetic interaction such as Faraday's law, Lenz's law, Ampere's law, Biot-Savart's law etc…

DC Motors

Introduction

- DC motors have excellent dynamic performance & speed control characteristics when compared with its AC counter parts.

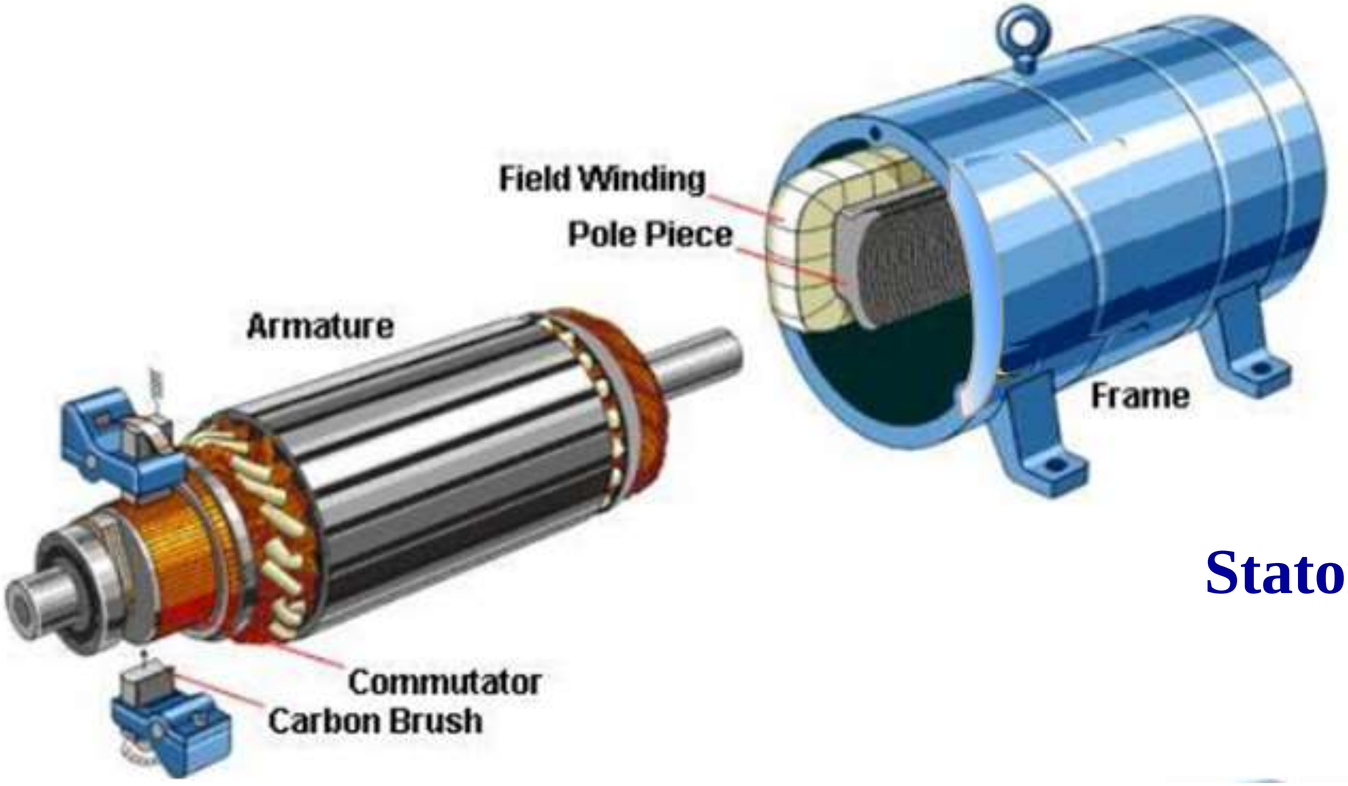
- DC Motors are classified as Shunt, Series, Compound, Separately excited etc… based on how the field system is connected with armature system.

- The most preferred drive motors for Traction and sophisticated control requirement.

- With the advancement of Power Electronics, AC motor performance also matches with that of DC motors

- Many DC motors are getting replaced by AC motors with enhanced control features because of the ease in maintenance and power r supply requirements.

Construction



Stator

Rotor

Construction

Major parts are the stator and the rotor with an air gap in between.

- **Stator** : houses the field winding
- **Rotor** : carries the armature winding

Stator consists of

- Yoke(or frame)
- Poles
- Brushes, brush holders and end covers

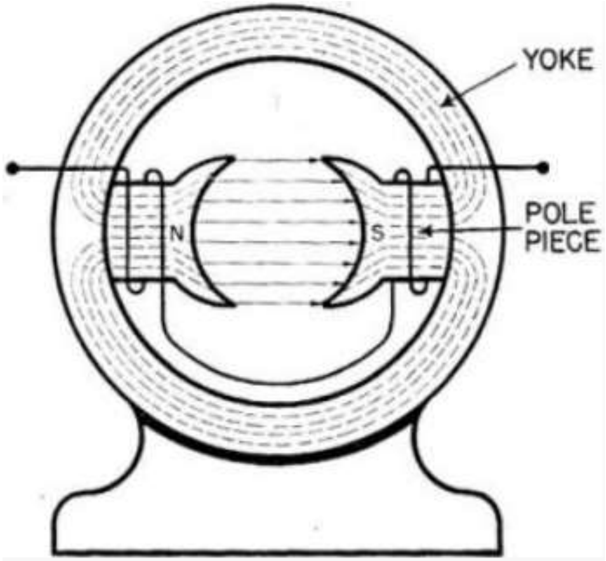
Rotor consists of

- Armature
- Commutator

Construction

Yoke

- Outer shell housing all the parts
- Two end covers supporting the bearings
- Cast steel is used as a material



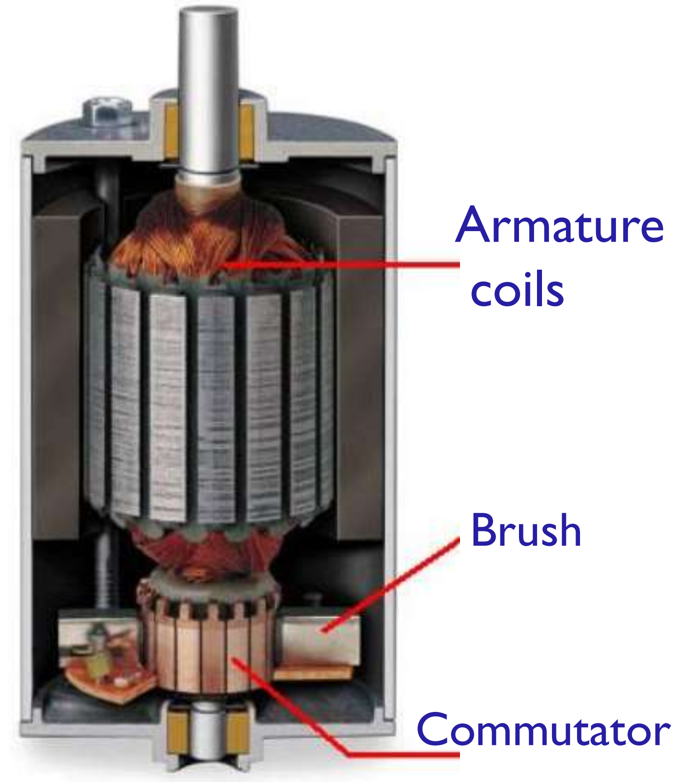
Main Poles

- The field coils are wound
- When excited with dc , produce alternate North and South poles

Construction

Armature

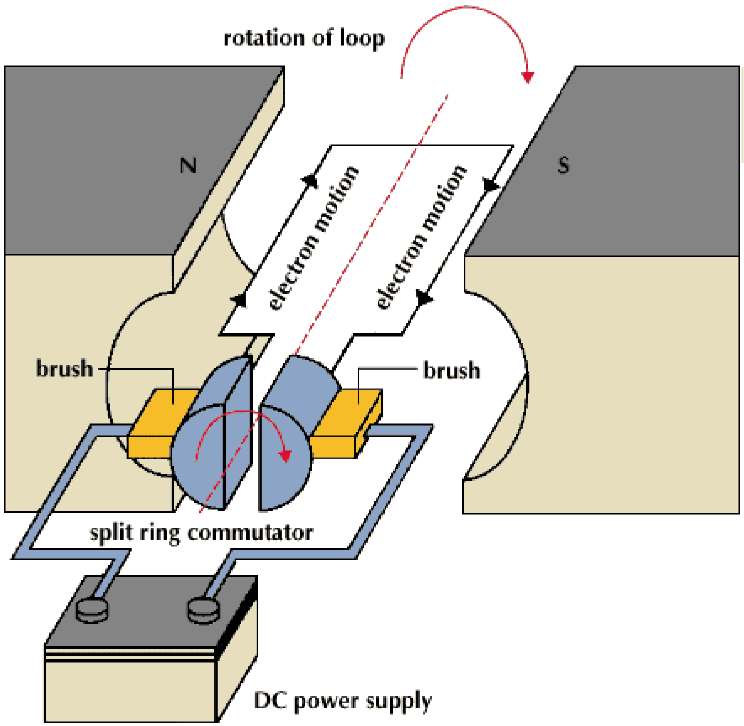
- Rotating part of the DC machine.
- Core is slotted to receive the armature winding.

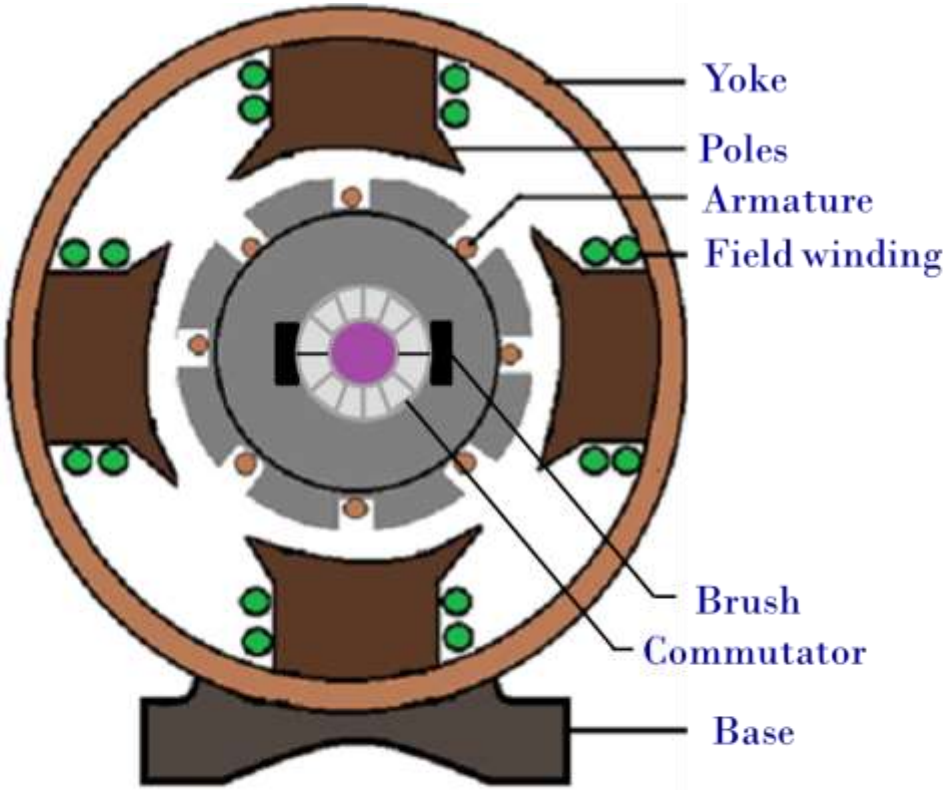


Commutator

- Mechanical Rectifier which rectifies AC to DC
- Carbon Brushes rest on the surface of the commutator.
- The brush holders provide slots for the brushes to be placed

Working Principle





Working Principle

- Current carrying armature conductors placed in the magnetic field experience a force which rotates the armature.

- Induced emf in armature conductor regulates the current drawn to match with the connected load.

- The motor continues to operate in an equilibrium with motor torque balancing load torque and the tractive effort.

$$V = E_b + I_a R_a$$

$$N \propto \frac{E_b}{\emptyset}$$

$$T \propto I_a \times \emptyset$$

V = Voltage applied(Volts)
Eb = Induced Back e.m.f(Volts)
Ia = Armature current(Amperes)
Ra = Armature resistance(ohms)
N = Speed of the motor(r.p.m)
T = Torque developed(Nm)
Ø = Flux (Webers)

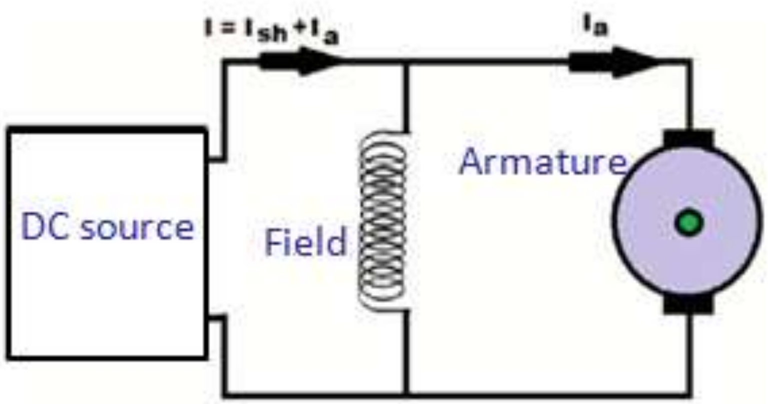
Types of DC Motors

- **Shunt-Wound.**
- **Series-Wound.**
- **Compound-Wound.**
- **Separately excited DC motor.**

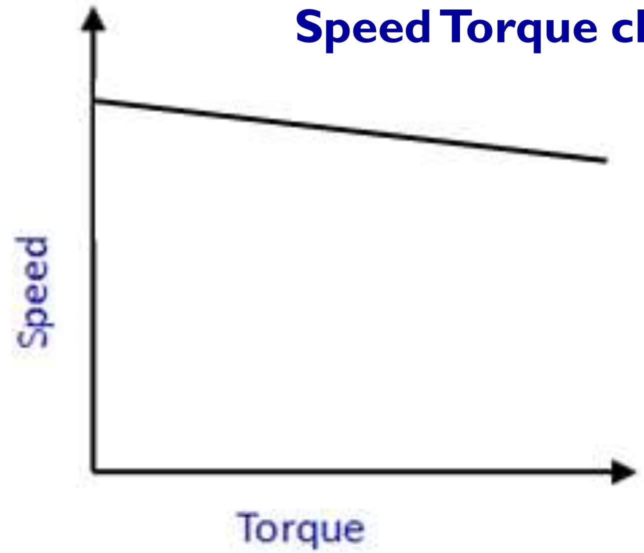
Types of DC Motors

DC Shunt Motor

- Torque proportional to armature current.
- Currents in the field and armature are independent of one another.
- As a result, these motors have excellent speed control.



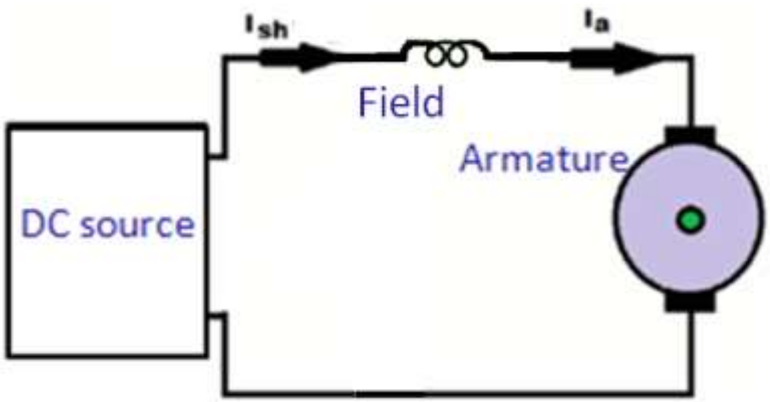
Speed Torque characteristics

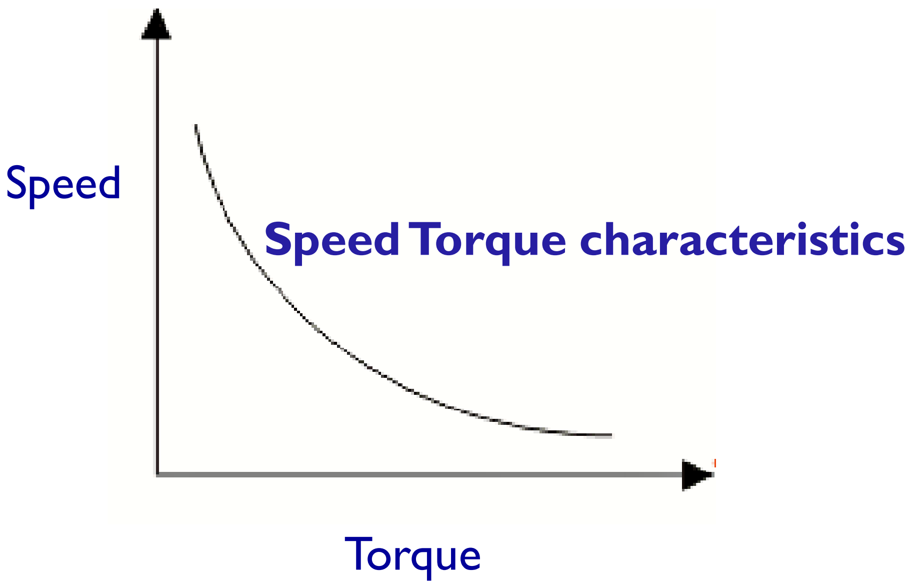


Types of DC Motors

DC Series Motor

- Field and armature currents are equal
- Torque is proportional to the square of the armature current
- Starting torque quite high and its gets regulated automatically as speed increases.
- Most preferred for Traction.

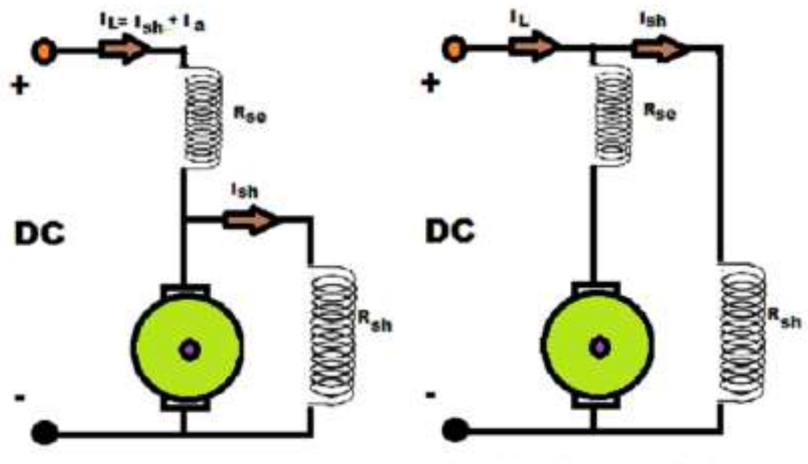


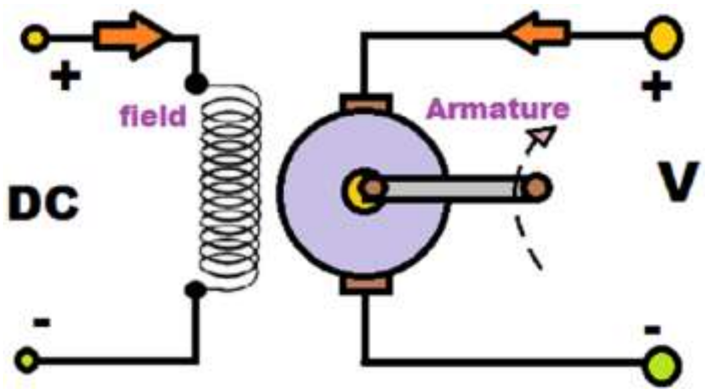


Types of DC Motors

DC compound motor

Seperately excited DC motor





Applications

- D.C. shunt motor is used for drive requiring moderate torques.

- D.C. series motor: Electric traction, high speed tools

- D.C. compound motor :Rolling mills and other loads requiring large momentary torques

Summary

- D.C Motors can be shunt wound , series wound , compound wound or separately excited .
  - For a d.c motor

$$V = E_b + I_a R_a$$

$$N \propto \frac{E_b}{\emptyset} \qquad T \propto I \times \emptyset$$