Module 3 : DC Machines

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Lecturer in Electronics Engineering

CO3 : Illustrate the principle and operations of DC machines

Module Outcomes	Description	Duration	Cognitive Level
M3.01 :	Explain the principle and operation of a DC generator	3	nderstanding
M3.02 :	Explain the principle and operation of a DC motor	2	Understanding
M3.03 :	Illustrate the use of starter in DC Motors	3	Understanding
M3.04 :	Compare different DC motors	2	Understanding

Contents:

DC Machines

Working principle of DC generator - different types of DC generators - emf equation of a DC generator - armature reaction - no load characteristics - types.

DC motors - working principle of DC motor - significance of back emf in DC motor - starters - Types of starters -necessity of starter in DC motor - 3 point starter – comparison of DC motors with characteristics and speed

Generators

- The Device which Converts the Mechanical Energy into Electrical Energy is called Generator

- **There are Two types of Generators**

1. **D.C Generator:-** The Generator which converts the Mechanical Energy into D.C Form of Electrical Energy is called D.C Generator
2. **A.C Generator:-** The Generator which converts the Mechanical Energy into A.C Form of Electrical Energy is called A.C Generator

- **Both of the Generator Works on the Principle of Faraday's Law of Electromagnetic Induction.**

DC Generator

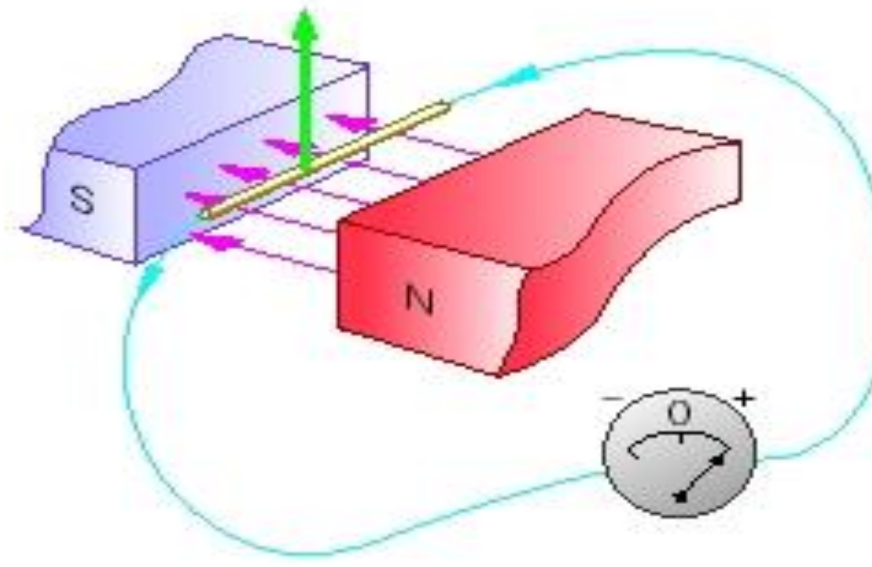
- A **DC generator** or **direct current generator** is one kind of electrical machine (Electromechanical device), and the main function of this machine is to convert mechanical energy into **DC**(**direct current**) electricity.

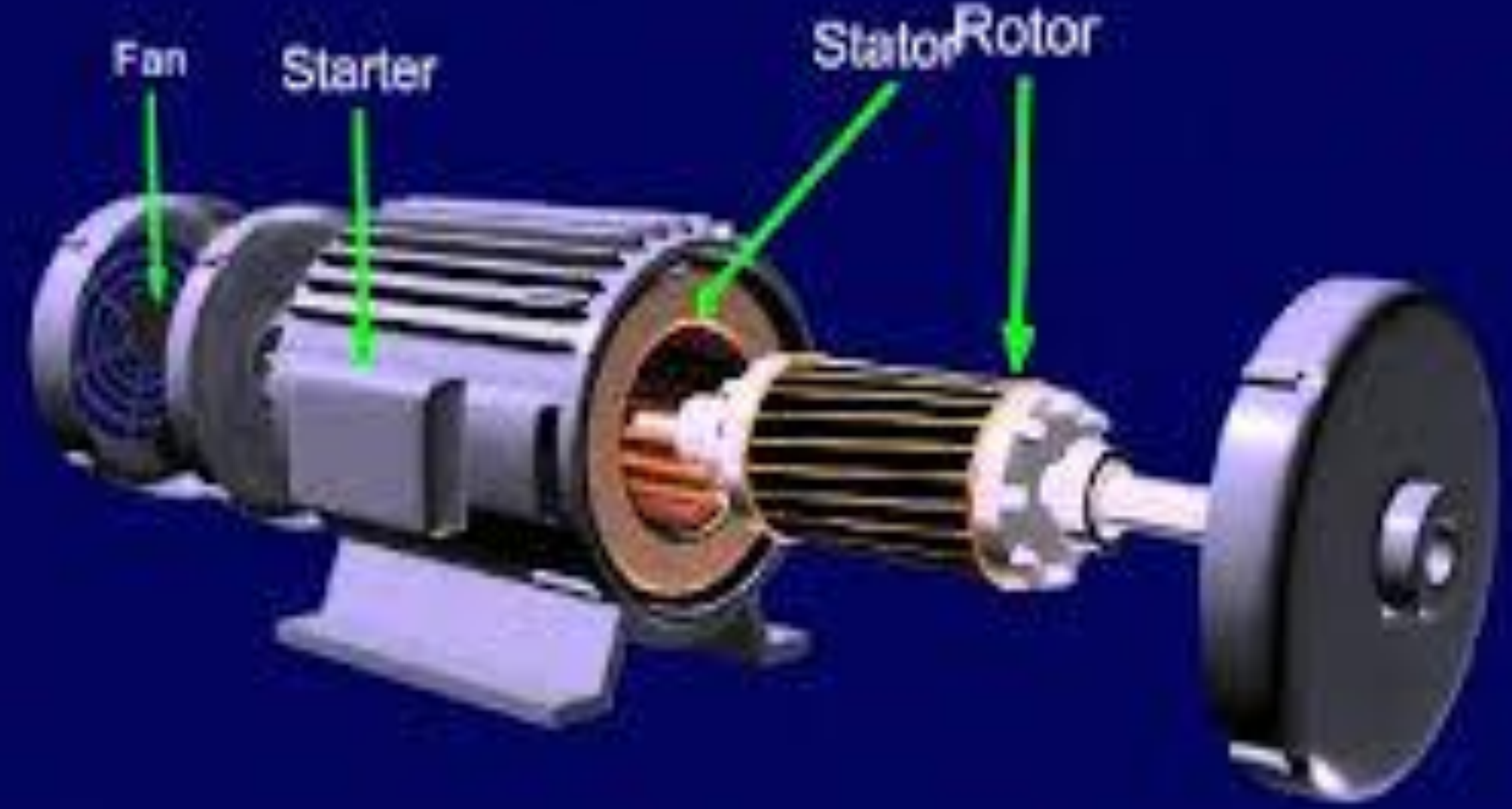
- The energy alteration process uses the principle of energetically induced electromotive force.

DC Generator cont…

Three requirements are essential

1. Conductors
2. Magnetic field
3. Mechanical energy




Fan
Starter
Stator
Rotor

DC Generator - Working principle

- A generator works on the principles of Faraday’s law of electromagnetic induction

- Whenever a conductor is moved in the magnetic field , an emf is induced and the magnitude of the induced emf is directly proportional to the rate of change of flux linkage.

- This emf causes a current flow if the conductor circuit is closed .

Faradays laws

First Law :

Whenever the magnetic flux linked with a circuit changes, an e.m.f. is always induced in it.

or

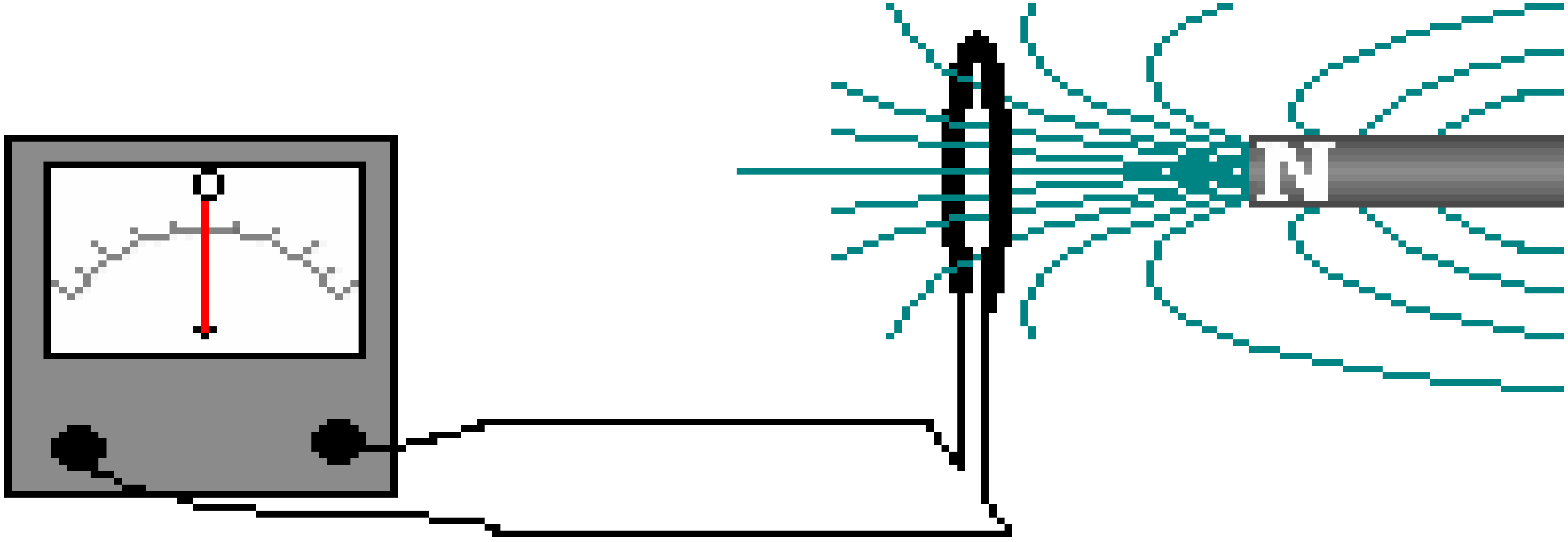
Whenever a conductor cuts magnetic flux, an e.m.f. is induced in that conductor.

Second Law :

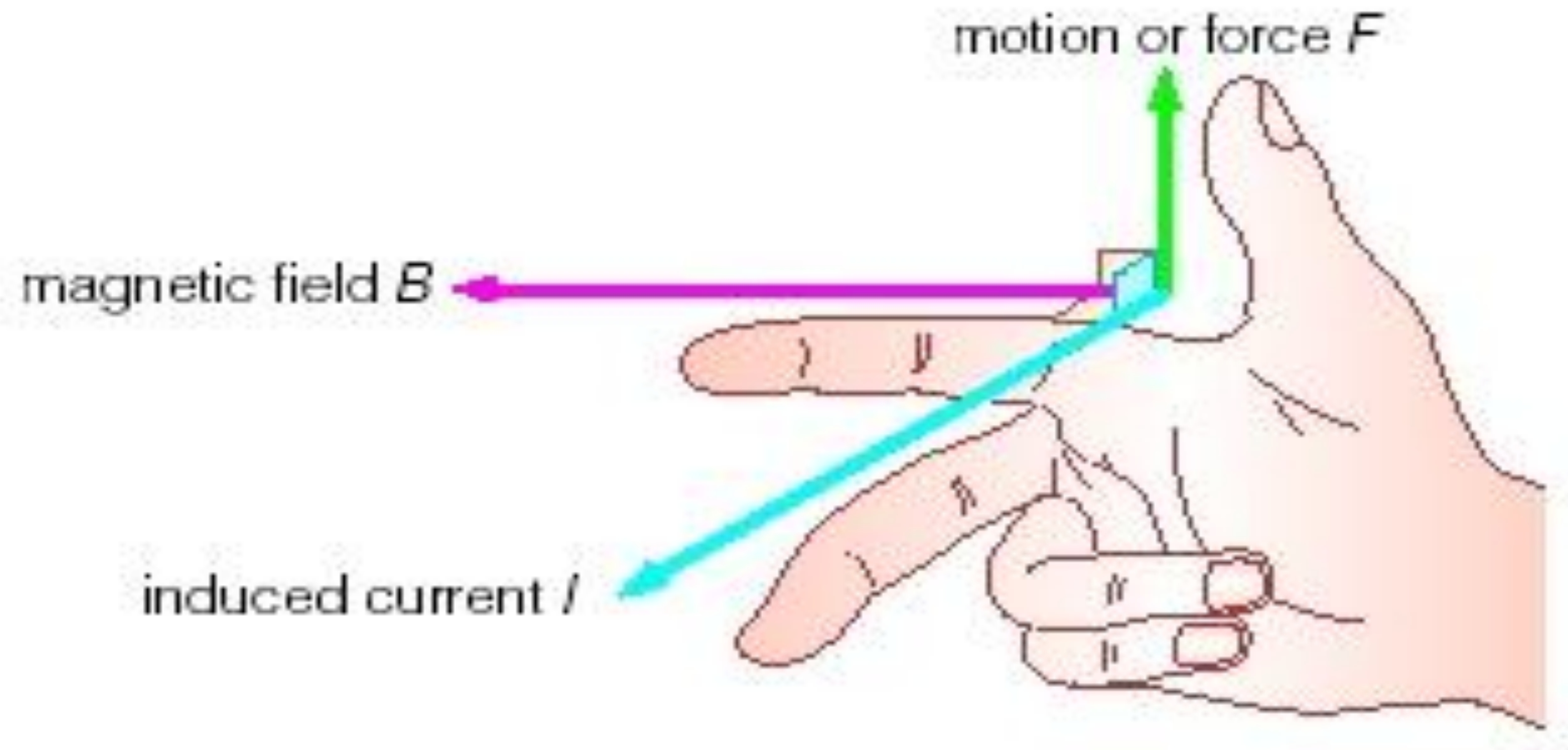
The magnitude of the induced e.m.f. is equal to the rate of change of flux linkages.

Faradays Law of Electromagnetic Induction

A changing magnetic flux through a loop or loops of wire induces an electromotive force (voltage) in each loop.



Fleming's Right hand rule



Fleming's Right hand rule

- **_Used to determine the direction of emf induced in a conductor**

- The middle finger , the fore finger and thumb of the right hand are kept at right angles to one another.
- The fore finger represent the direction of magnetic field
- .The thumb represent the direction of motion of the conductor
- The middle finger will indicate the direction of the inducted emf
- This rule is used in DC Generators

Basic requirements to be satisfied for generation of E.M.F

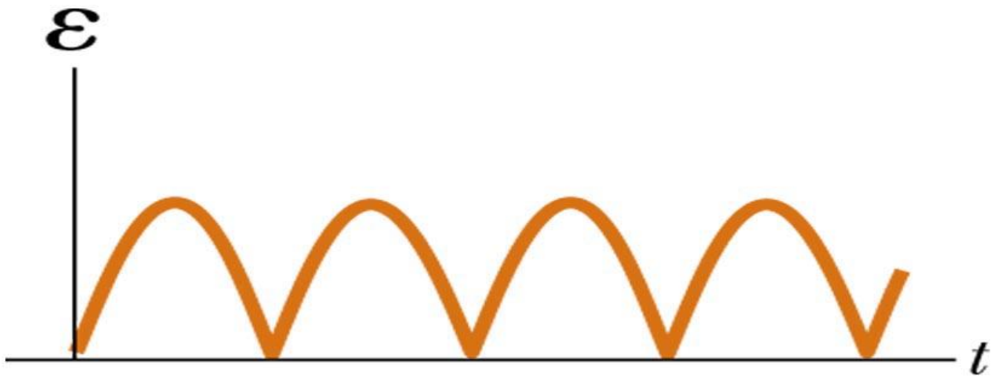
1.A uniform Magnetic field

2.A System of conductors

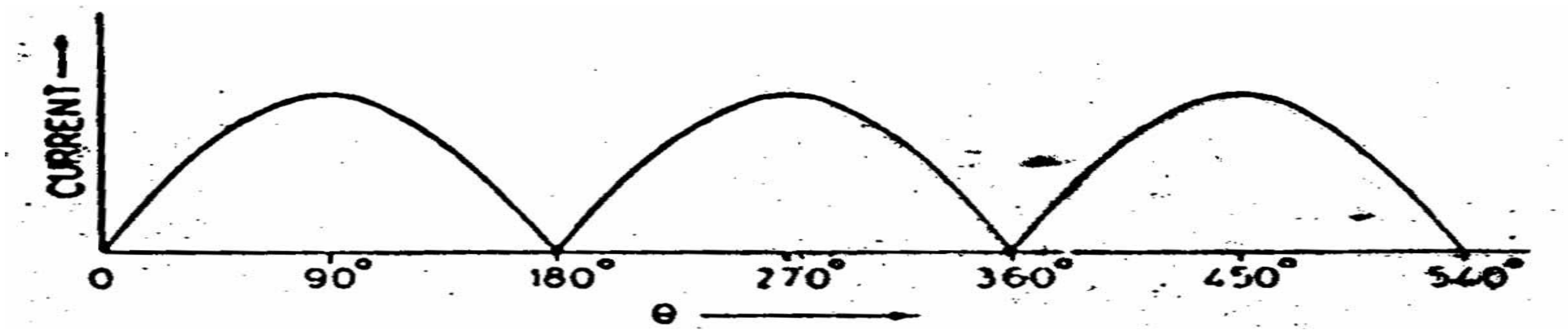
3.Relative motion between the magnetic field and conductors

DC Generators - Output

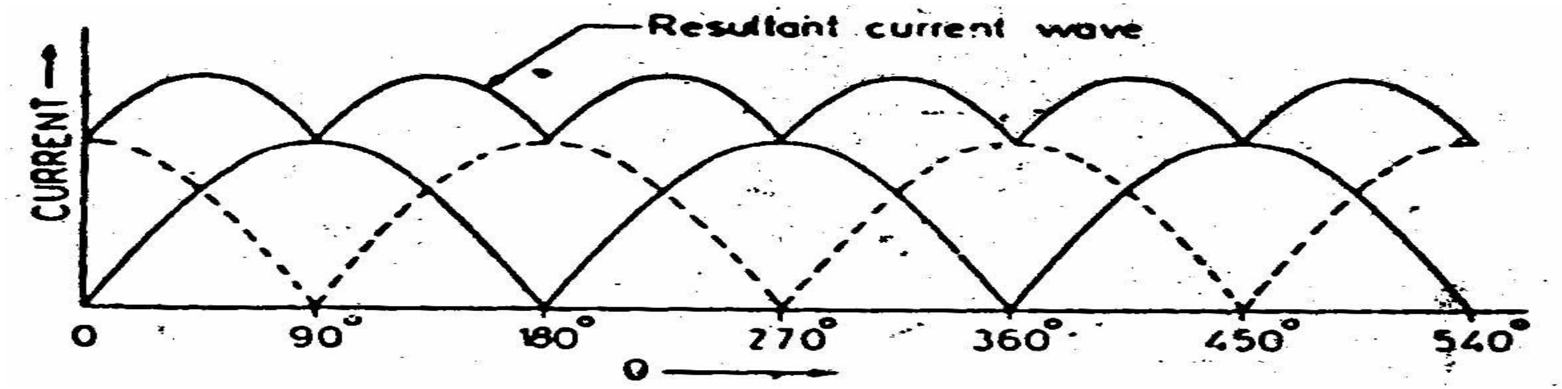
- The output voltage always has the same polarity
- The current is a pulsating current
- To produce a steady current, many loops and commutators around the axis of rotation are used
  - The multiple outputs are superimposed and the output is almost free of fluctuations



(b)

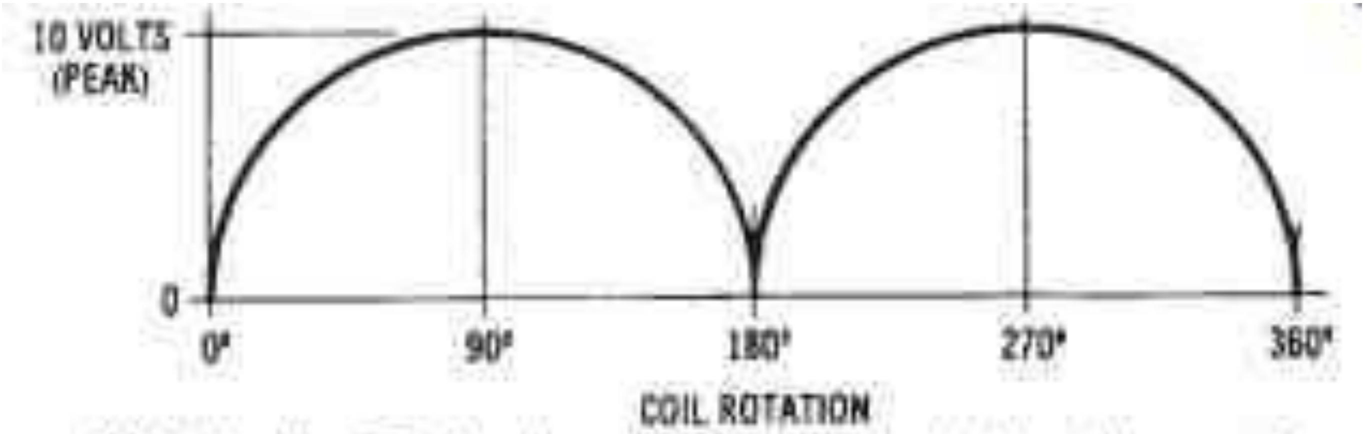


Unidirectional current wave shape

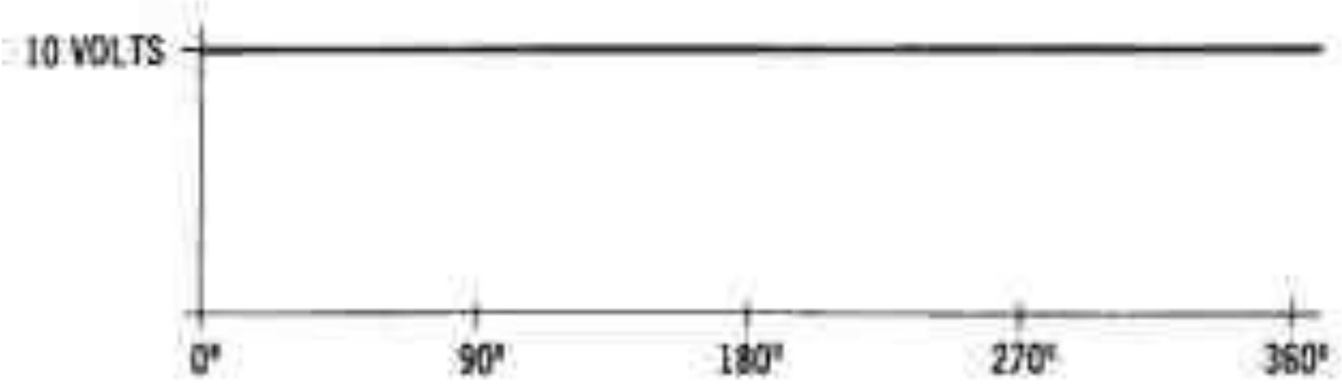


Resultant current wave shape when number of conductors used result current wave shape

DC Generator Waveform



(A) Pulsating DC developed by a simple single-coil generator.



(B) Pure DC developed by a more complex generator using many turns of wire and many commutator segments.

Types of DC Generator

1. Permanent Magnet type DC Generator – Not for normal use
2. Electromagnet type DC Generator

   These are generally classified according to their method of excitation .

- Separately excited DC generator
- Self excited D C generator

Further classification of Self exited DC Generator

- Series wound generator
- Shunt wound generator
- Compound wound generator
  - Short shunt & Long shunt

    Cumulatively compound

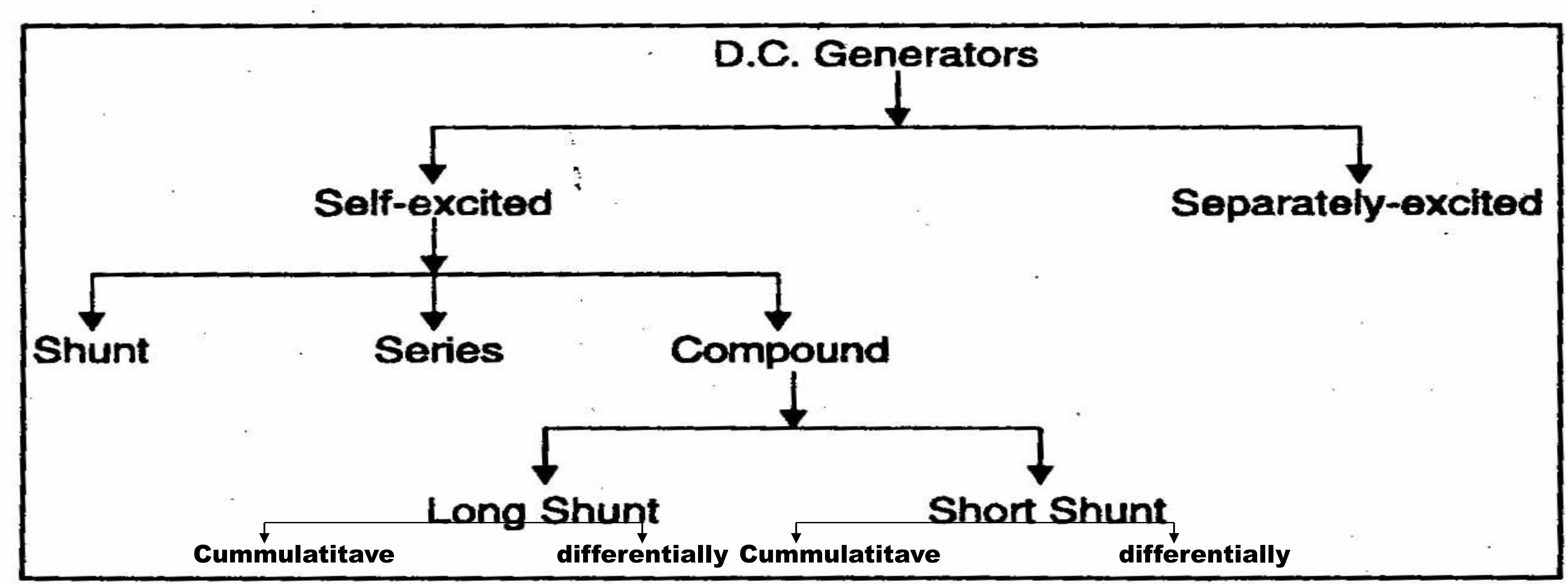
    &

    Differentially compound

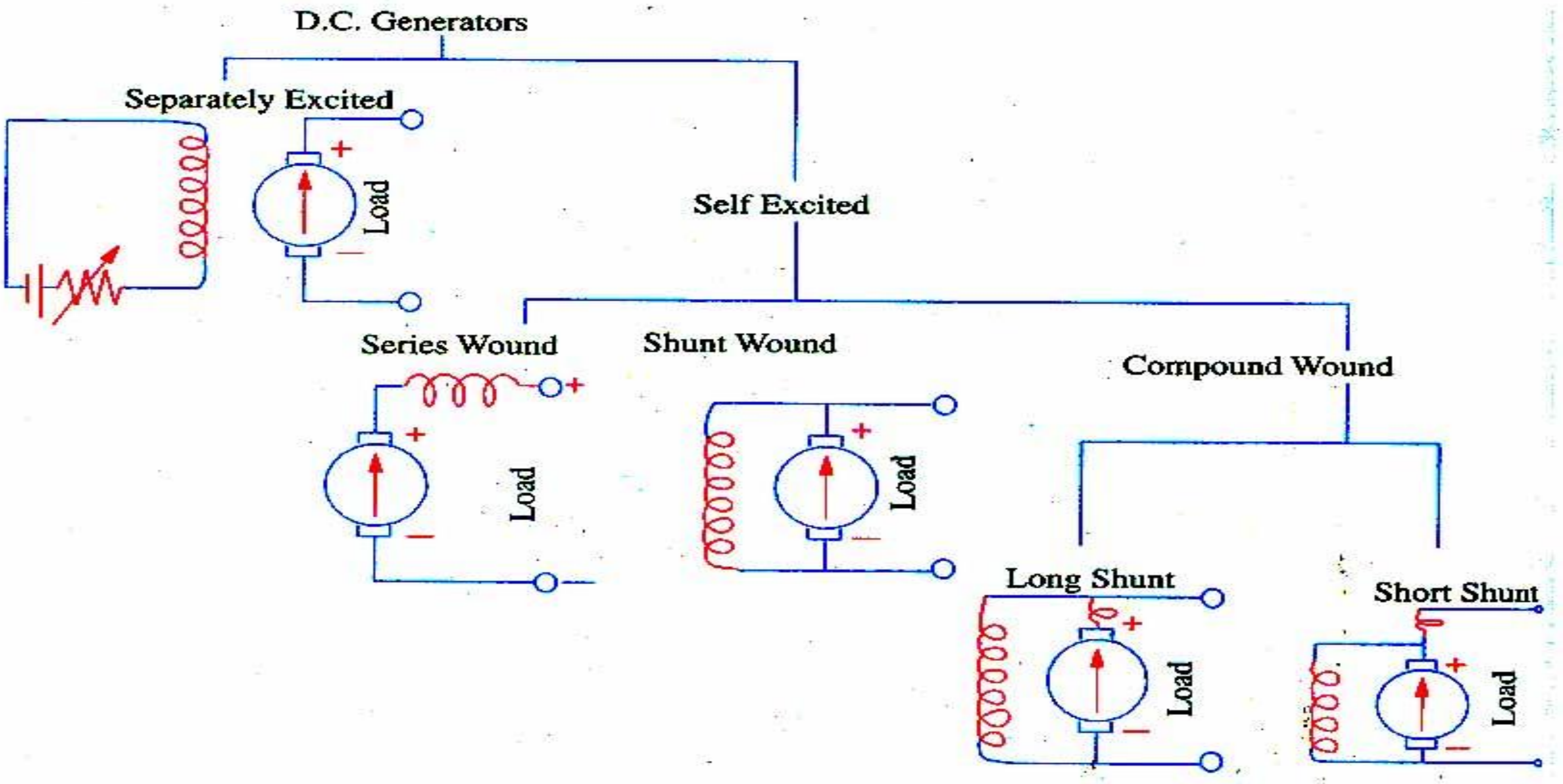
Generators

D.C Generators

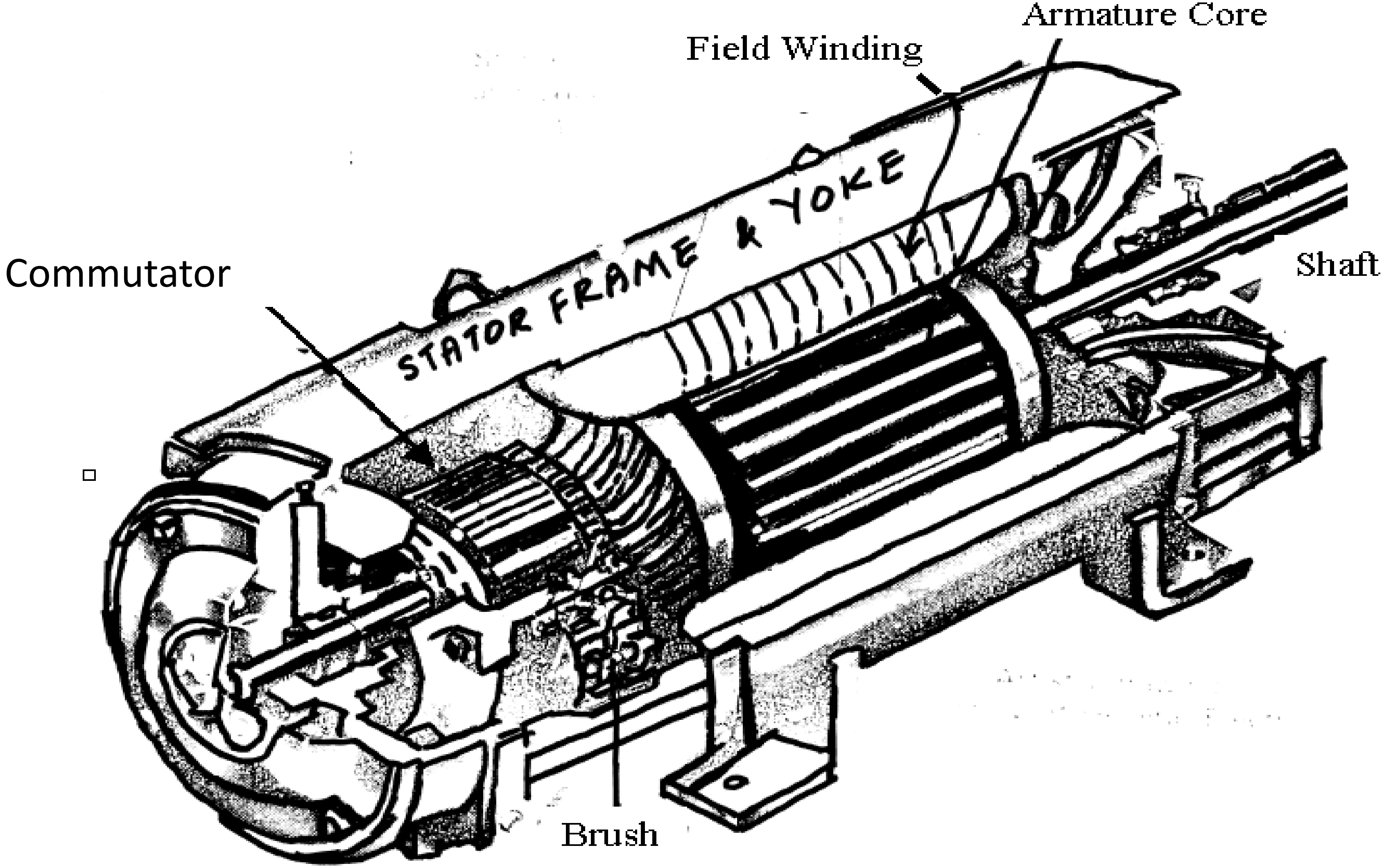
A.C Generators
(Alternators)



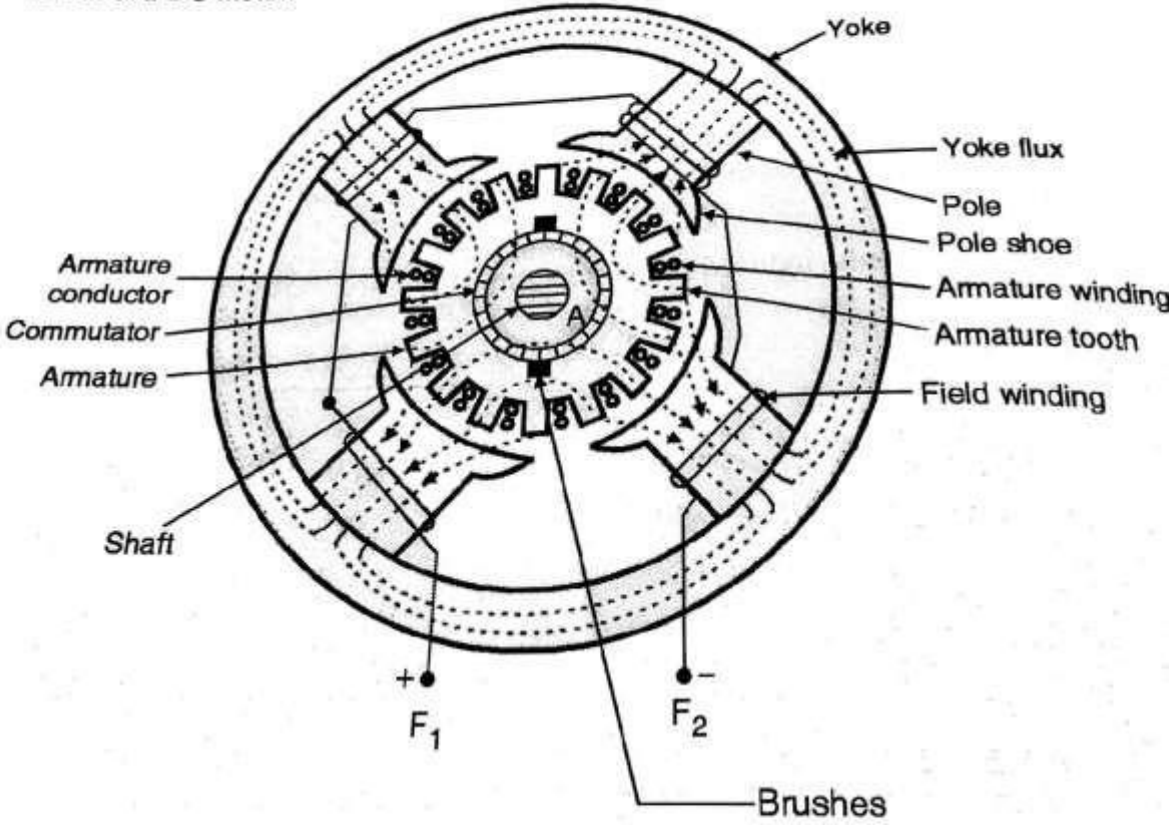
Clasifications of Generators



DC Generator



CONSTRUCTION



- **Important Parts of D.C Generator**

1. **YOKE**
2. **POLES**
3. **FIELD WINDING**
4. **ARMATURE**
5. **COMMUTATOR,BRUSHES and GEAR**
6. **BEARINGS**

Field system

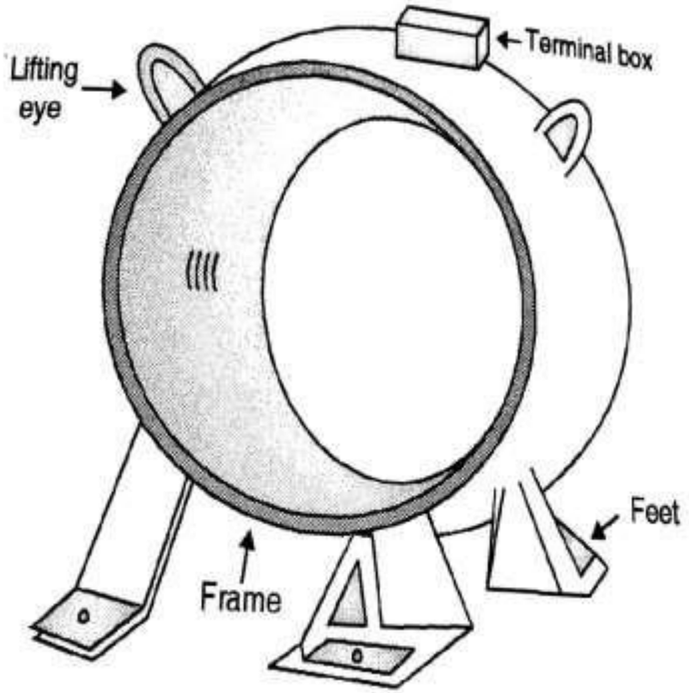
- It is for uniform magnetic field within which the armature rotates.
- Electromagnets are preferred in comparison with permanent magnets

They are cheap , smaller in size , produce greater magnetic effect and Field strength can be varied

Field system consists of the following parts

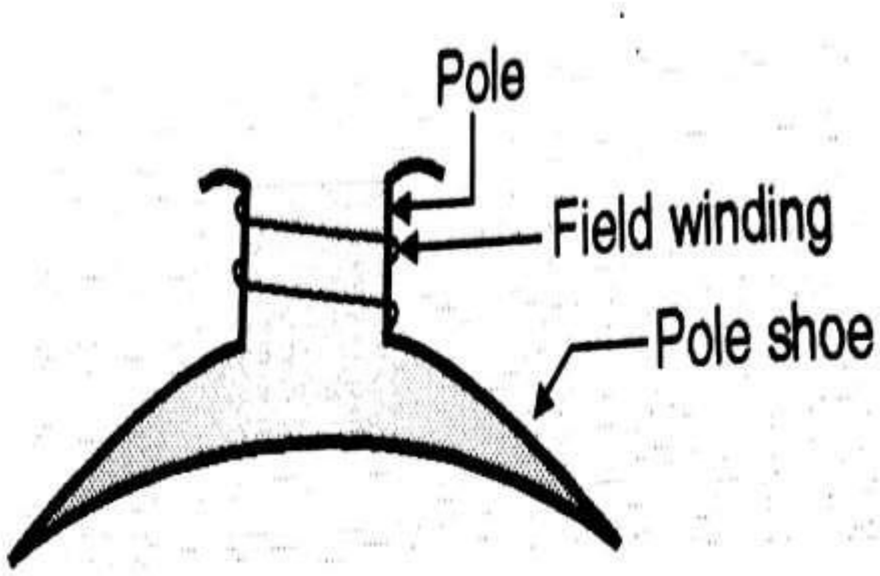
- Yoke
- Pole cores
- Pole shoes
- Field coils

YOKE



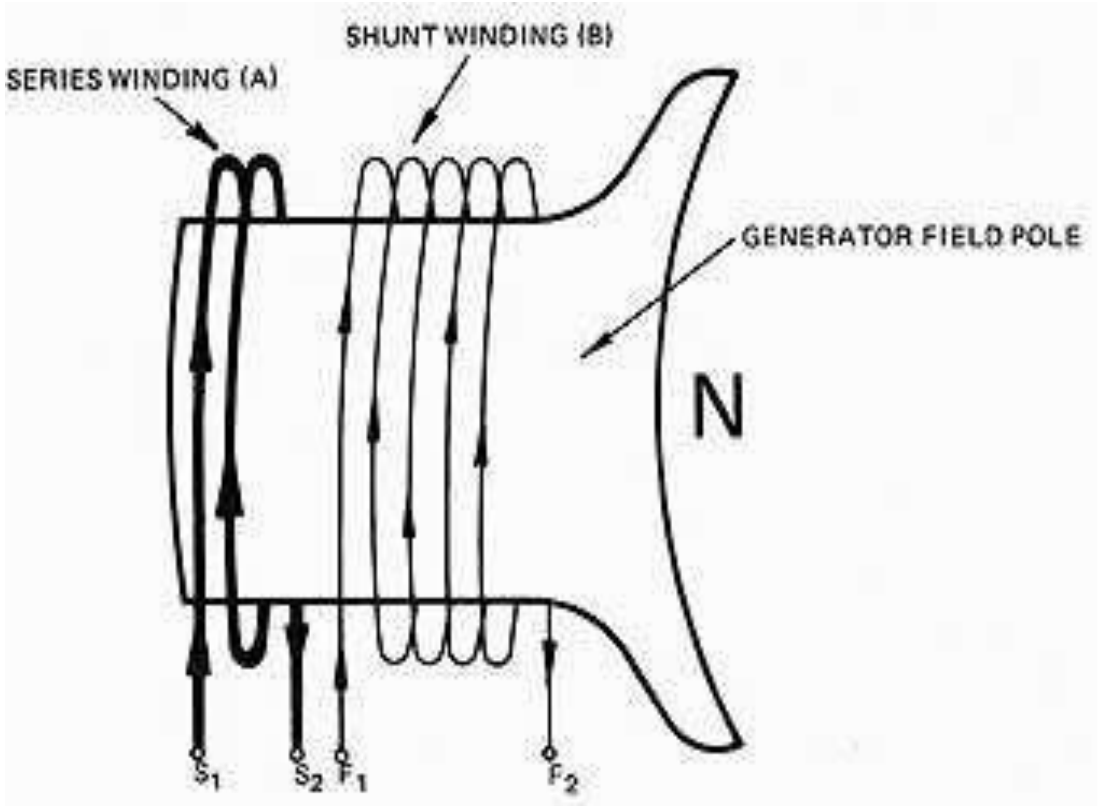
- **Yoke is also called as frame. It provides protection to the rotating and other parts of the machine from moisture, dust etc.**
- **Yoke is an iron body which provides the path for flux**
- **It provides the mechanical support for the poles.**
- **Materials used for yoke are cast iron, silicon steel, cast steel, rolled steel etc.**

POLE



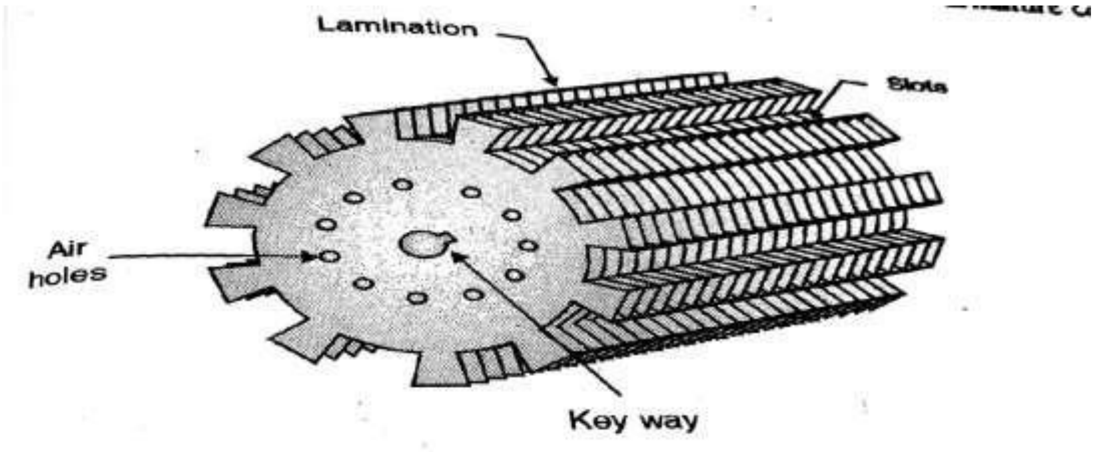
- Pole produce the magnetic flux when the field winding is excited.
- Materials used for Pole is cast steel or cast iron.
- Pole is a Part on Which **Field Winding** is Wound Over.

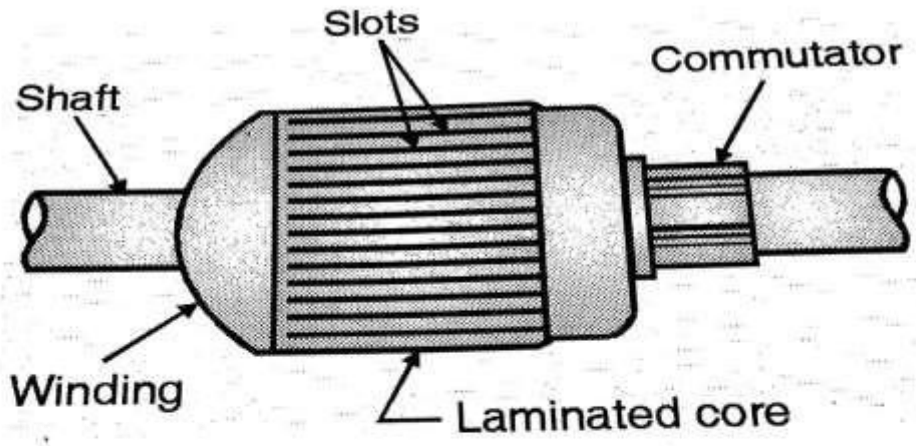
FIELD WINDING



- The field winding is also called as exciting winding.
- Current is passed through the field winding in a specific direction ,to magnetize the pole.
- The metal is used for the field conductor is copper.

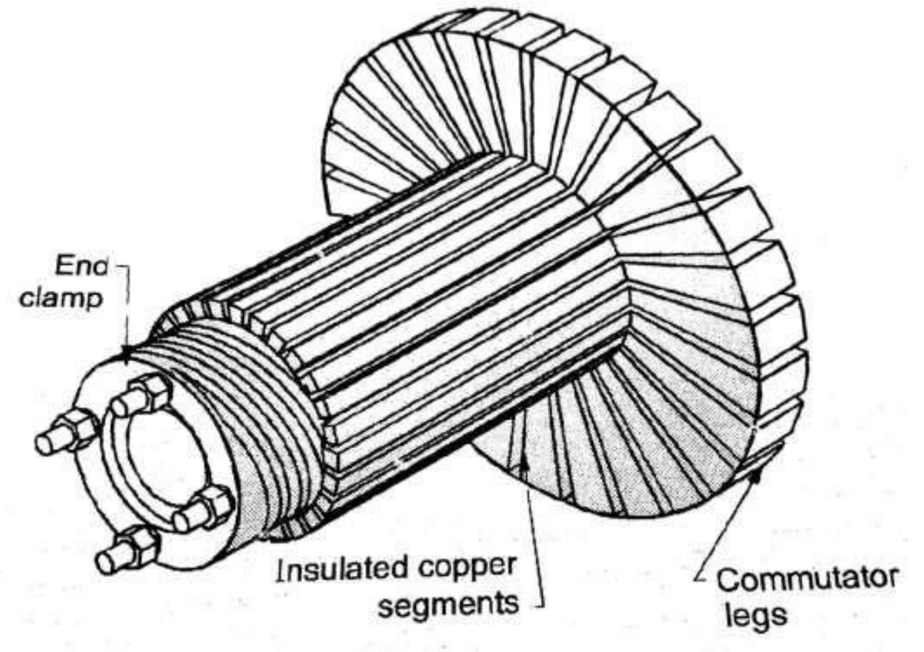
ARMATURE CORE





- All these slots are parallel to the shaft axis.
- Armature conductor are placed in these slots.
- Armature core provides a low reluctance path to the flux produced by the field winding.
- Cast steel or cast iron are used for the armature core.

Commutator

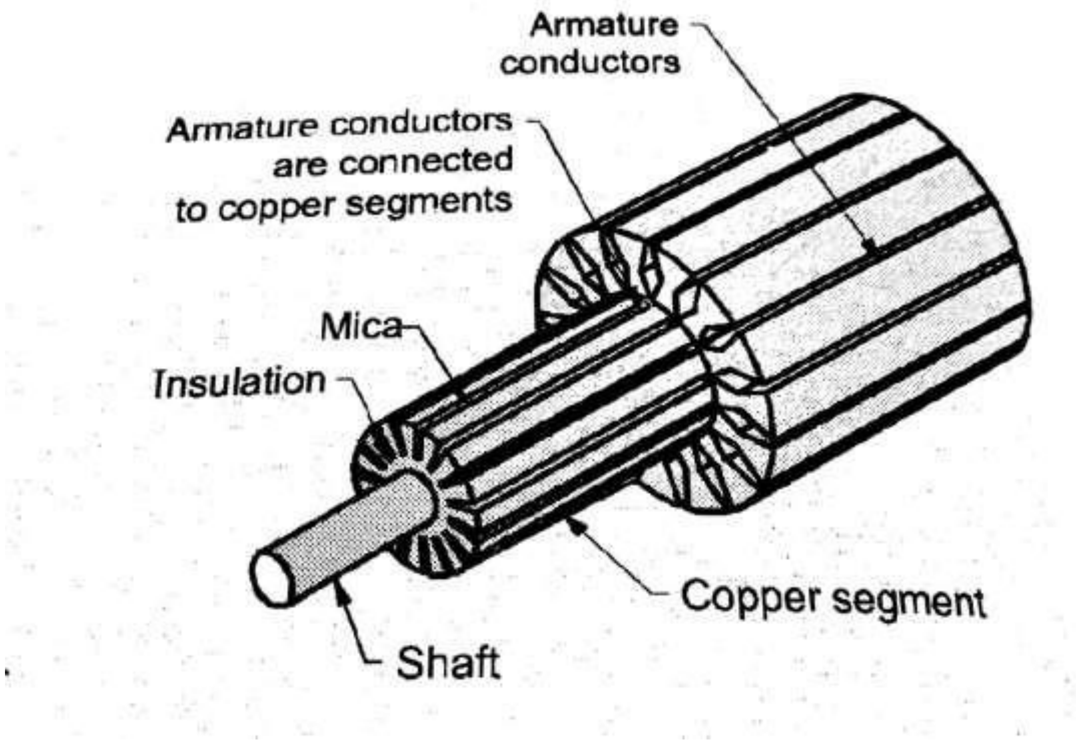


- Connect with external circuit
- Converts AC into unidirectional current
- Cylindrical in shape
- Made of wedge shaped copper segments
- Segments are insulated from each other
- Each commutator segment is connected to armature conductors by means of a cu strip called riser.
- No of segments equal to no of coils

Carbon brush

- Carbon brushes are used in DC machines because they are soft materials
- It does not generate spikes when they contact commutator
- To deliver the current thro armature
- Carbon is used for brushes because it has negative temperature coefficient of resistance
- Self lubricating , takes its shape , improving area of contact

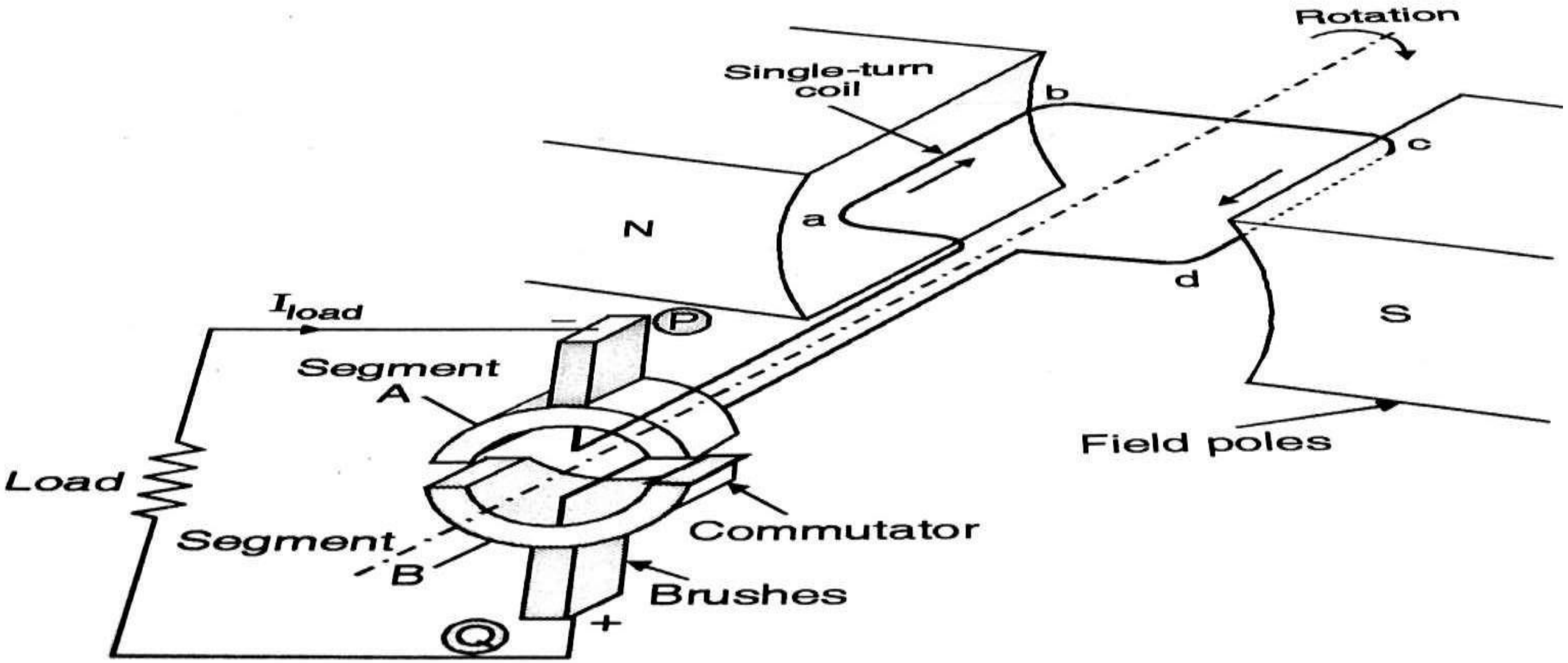
ROTOR



- The Rotor is the moving part of a D.C. generator.

- The rotor rotates because the wires and magnetic field of the motor are arranged so that a torque is developed about the rotor's axis.

WORKING of DC GENERATOR



- **The Coil can Rotate in Clockwise or Anticlockwise Direction.**
- **The Commutator Brush is Connected to the Coil.**
- **Commutator is Divided into Two Parts A and B.**

- **The Coil is Suspended between the Field Poles.**
- **The Coil is Given the Mechanical Energy which Results in the Rotation of it.**
- **As the Commutator Segments A&B is Connected with Conducting Coil ab and cd Respectively they Rotate Together.**
- **Due to Which the Flux is Produced Resulting in the Generation of Electric Current.**

- **As the Commutator has the Property of Converting the Bidirectional Emf(AC) into Unidirectional Emf (DC) .**
- **The DC Current is Generated by the DC Generator.**
- **Which can Directly Used by Connecting the Output across the Load or it Can be stored inatteries and Can be used Later on.**

EMF Equation of a DC Generator

As the armature rotates, a voltage is generated in its coils. In the case of a generator, the emf of rotation is called the **Generated emf** or **Armature emf** and is denoted as Er = Eg.

In the case of a motor, the emf of rotation is known as **Back emf** or **Counter emf** and represented as Er = Eb.The expression for emf is same for both the operations. I.e., for Generator as well as for Motor

EMF equation contd...

Let,

P – Number of poles of the machine
ϕ – Flux per pole in Weber.
Z – Total number of armature conductors.
N – Speed of armature in revolution per minute (r.p.m).
A – Number of parallel paths in the armature winding.

Flux cut by 1 conductor
in 1 revolution = **P * φ**

Time taken to complete one revolution is given as

t = **N/60**

Flux cut by 1 conductor in 60 sec = **P φ N /60**

Therefore, the average induced e.m.f in one conductor
will be = **PφN/60**

he number of conductors connected in series in each parallel path **= Z/A.**

Therefore, the average induced e.m.f across each parallel path or the armature terminals is given by the equation shown below.

$$E_g = \mathbf{P\varphi NZ/60A}$$

$$E_g = \mathbf{K\varphi\ ,\ \ K = PNZ/60A}$$

Thus, it is clear that the induced emf is directly proportional to the speed and flux per pole. The polarity of induced emf depends upon the direction of the magnetic field and the direction of rotation. If either of the two is reverse the polarity changes, but if two are reversed the polarity remains unchanged.

This induced emf is a fundamental phenomenon for all the DC Machines whether they are working as a generator or motor.
If the machine, DC Machine is working as a Generator, the induced emf is given by the equation shown below.

$$\mathbf{Eg = P\varphi NZ/60A}$$

Where $\mathbf{E_g}$ is the **Generated Emf**
If the machine, DC Machine is working as a Motor, the induced emf is given by the equation shown below.

$$\mathbf{Eb = P\varphi NZ/60A}$$

In a motor, the induced emf is called **Back Emf (E_b)** because it acts opposite to the supply voltage.

Armature Reaction

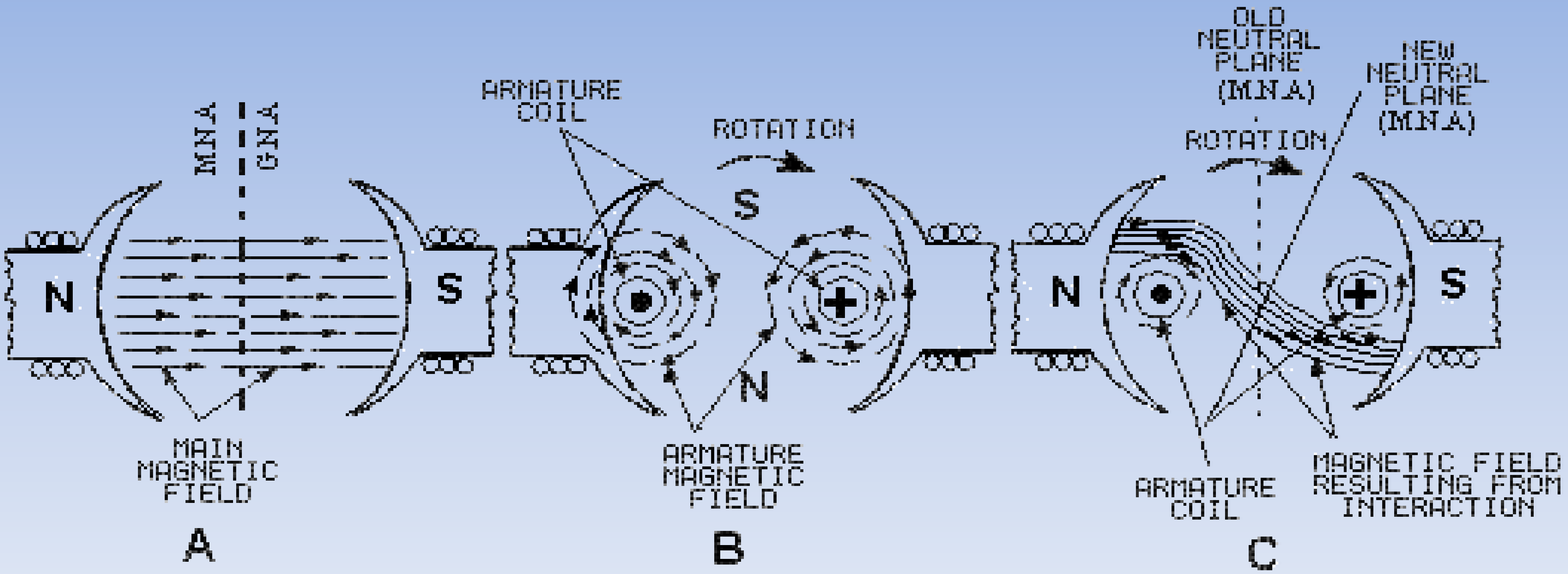
- The effect of magnetic field set up by armature current on the distribution of flux under main poles of a generator. The armature magnetic field has two effects:

  - (i) It demagnetizes or weakens the main flux

  - (ii) It cross-magnetizes or distorts.

Armature Reaction

Interaction of Main field flux with Armature field flux



Effects of Armature Reaction

- It decreases the efficiency of the machine
- It produces sparking at the brushes
- It produces a demagnetizing effect on the main poles
- It reduces the emf induced
- Self excited generators some times fail to build up emf

Remedies

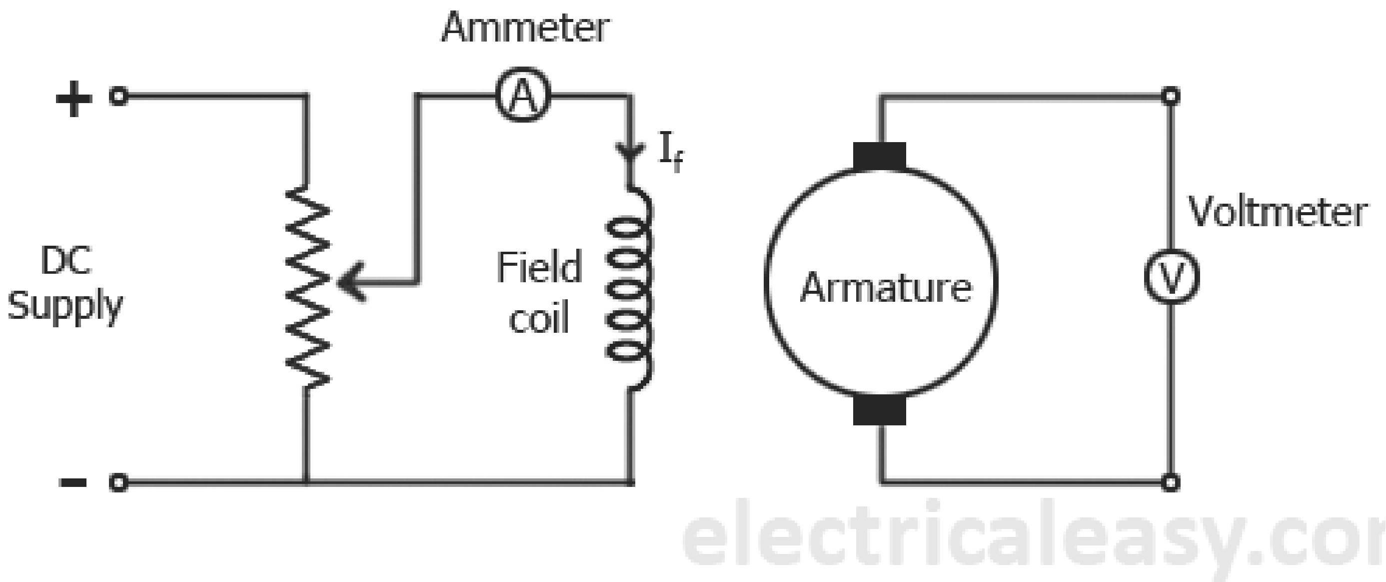
1.Brushes must be shifted to the new position of the MNA
2.Extra turns in the field winding
3.Slots are made on the tips to increase the reluctance
4. The laminated cores of the shoe are staggered
5. In big machines the compensating winding at pole shoes produces a flux which just opposes the armature mmf flux automatically.

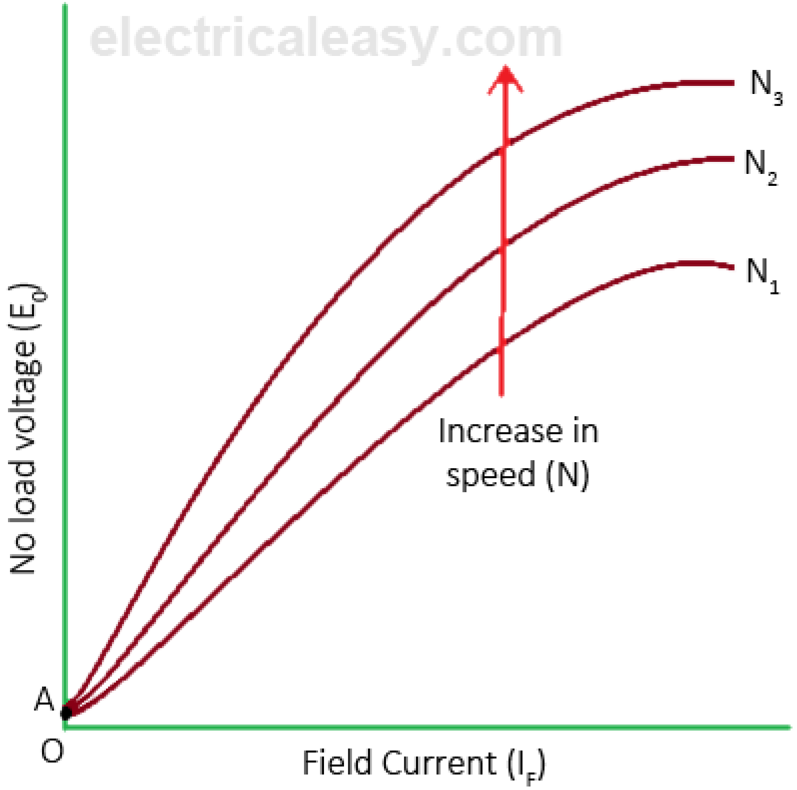
Note : MNA (**Magnetic Neutral Axis**) may be defined as the axis along which no emf is generated in the armature conductors as they move parallel to the flux lines. Brushes are always placed along the MNA because reversal of current in the armature conductors takes place along this axis.

No Load Characteristics of DC Generator

- **Open circuit characteristic** is also known as **magnetic characteristic** or **no-load saturation characteristic**. This characteristic shows the relation between **generated emf at no load** (E0) and the **field current (If**) at a given **fixed speed**.
- The O.C.C. curve is just the magnetization curve and it is practically similar for all type of generators. The data for O.C.C. curve is obtained by operating the generator at no load and keeping a constant speed. Field current is gradually increased and the corresponding terminal voltage is recorded

- From the emf equation of dc generator, we know that **Eg = kϕ**. Hence, the generated emf should be directly proportional to field flux (and hence, also directly proportional to the field current).
- However, even when the field current is zero, some amount of emf is generated (represented by OA in the figure below). This initially induced emf is due to the fact that there exists some residual magnetism in the field poles. Due to the residual magnetism, a small initial emf is induced in the armature. This initially induced emf aids the existing residual flux, and hence, increasing the overall field flux. This consequently increases the induced emf. Thus, O.C.C. follows a straight line.
- However, as the flux density increases, the poles get saturated and the ϕ becomes practically constant. Thus, even we increase the I_f further, ϕ remains constant and hence, Eg also remains constant. Hence, the O.C.C. curve looks like the B-H characteristic.





Open Circuit Characteristic (O.C.C.)

DC Motors

Module III- 2

- 3.2.0 To understand DC motors
- 3.2.1 To list the types of DC Motors
- 3.2.2 To explain the working principle of DC motor
- 3.2.3 To illustrate the significance of back emf in DC motor
- 3.2.4 To explain the necessity of starter in a DC motor
- 3.2.5 To compare different types of DC motors with characteristics and speed

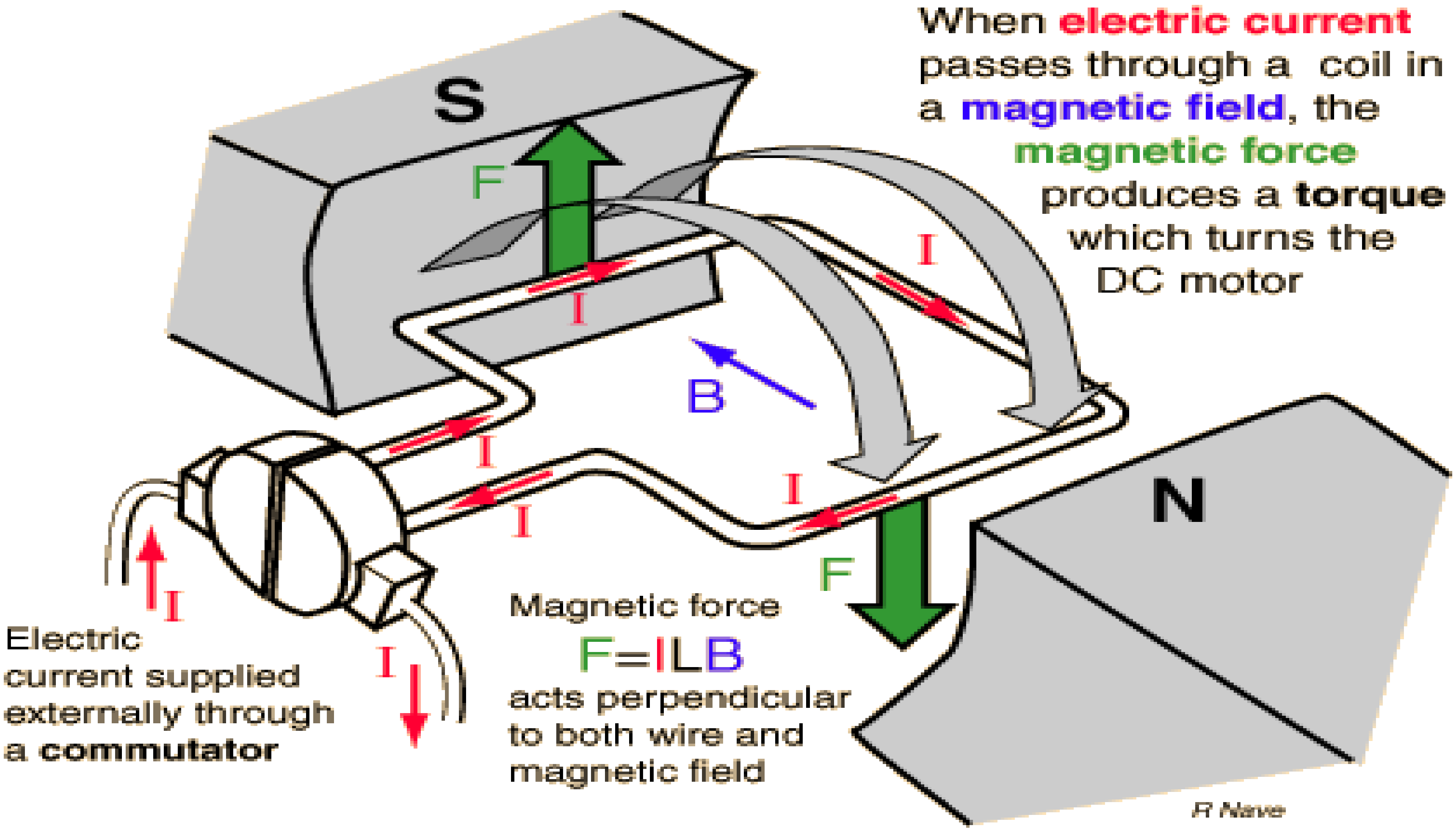
Motor

- Electromechanical device that converts electrical energy to mechanical energy.
- Mechanical energy used to
  - Rotate pump impeller, fan, blower
  - Drive compressors
  - Lift materials
- Motors in industry: 70% of electrical load.

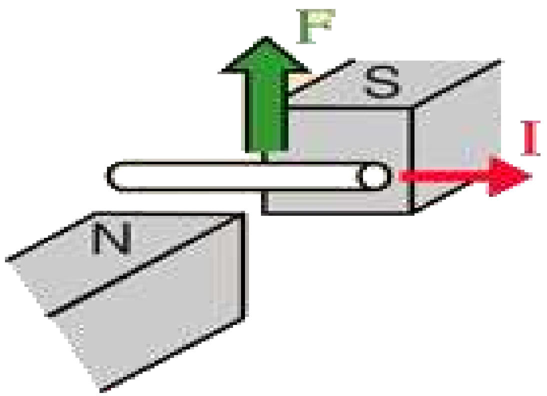
Electric Motor

- An electromagnet is the basis of an electric motor
- An electric motor is all about magnets and magnetism: A motor uses **magnets** to create motion.
- Opposites attract and likes repel. Inside an electric motor, these attracting and repelling forces create **rotational motion**.
- A motor consist of two magnets.

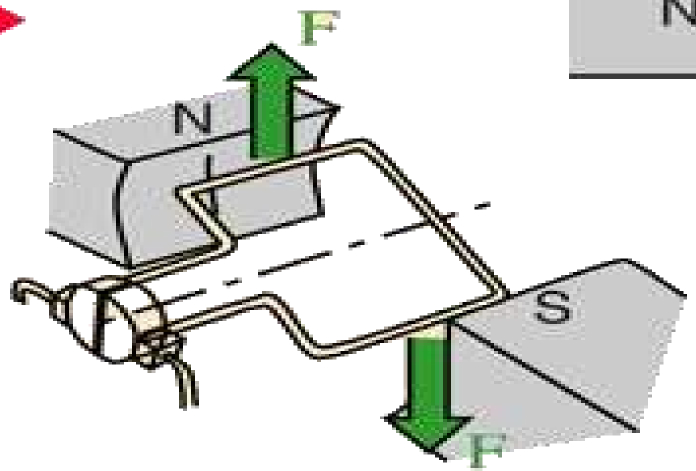
Working principle of DC motor



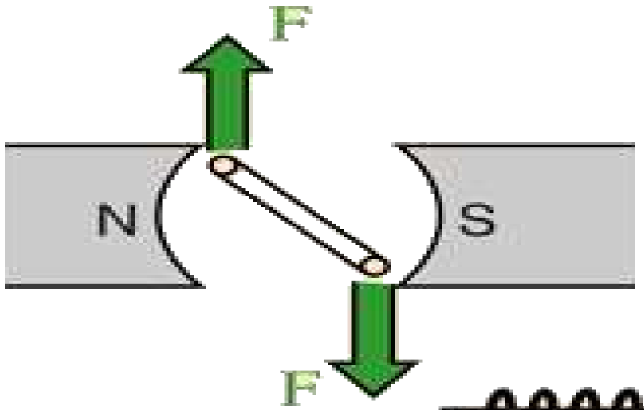
PRINCIPLE OF HOW MOTORS WORK



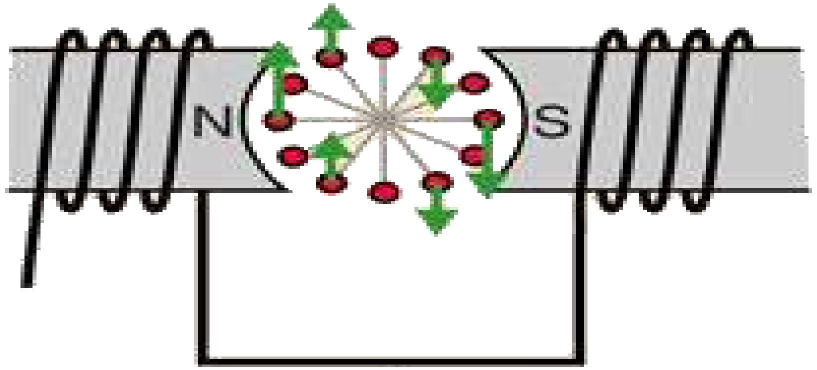
An electric current in a magnetic field will experience a force.



If the current-carrying wire is bent into a loop, then the two sides of the loop which are at right angles to the magnetic field will experience forces in opposite directions.



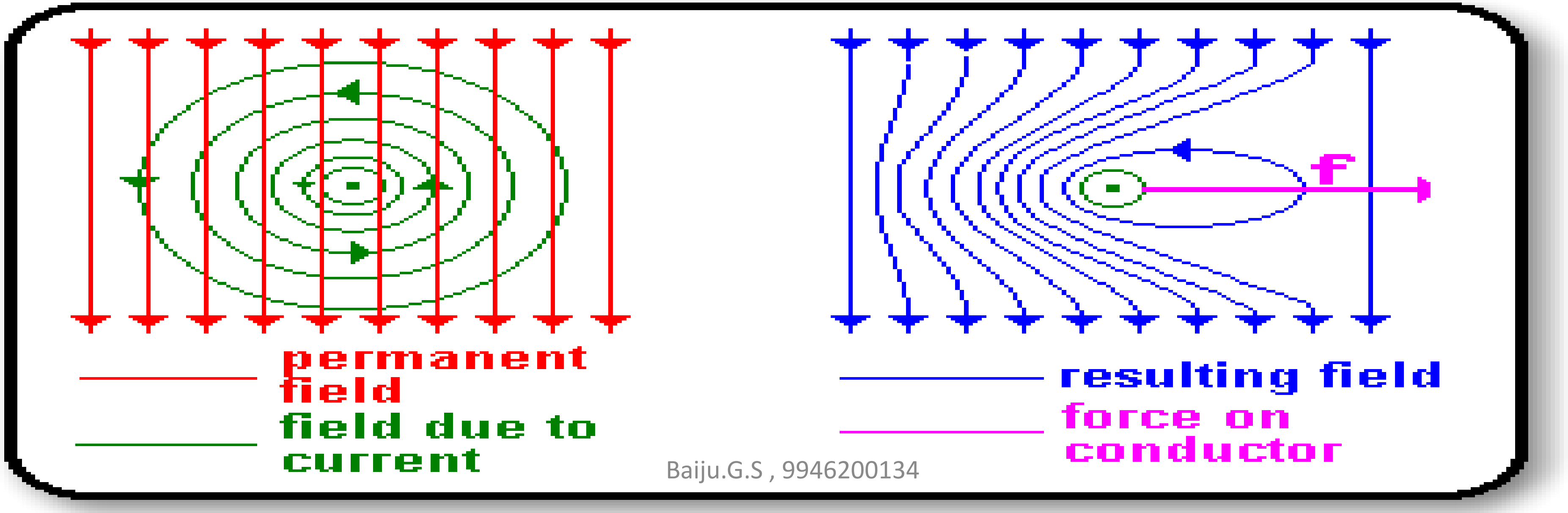
The pair of forces creates a turning influence or torque to rotate the coil.



Practical motors have several loops on an armature to provide a more uniform torque and the magnetic field is produced by an electromagnet arrangement called the field coils.

The force on a current-carrying conductor in a magnetic field :

- When a current-carrying conductor is placed in a magnetic field, there is an interaction between the magnetic field produced by the current and the permanent field, which leads to a **force** being experienced by the conductor:

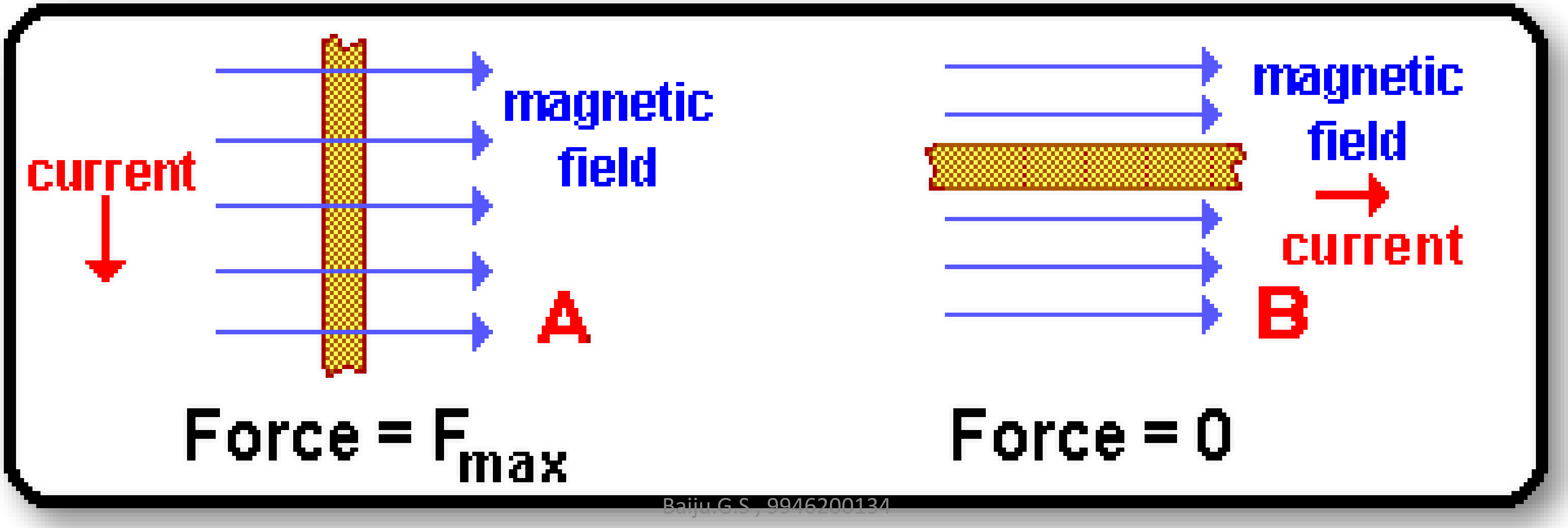


Magnetic Force On A Current Carrying Conductor

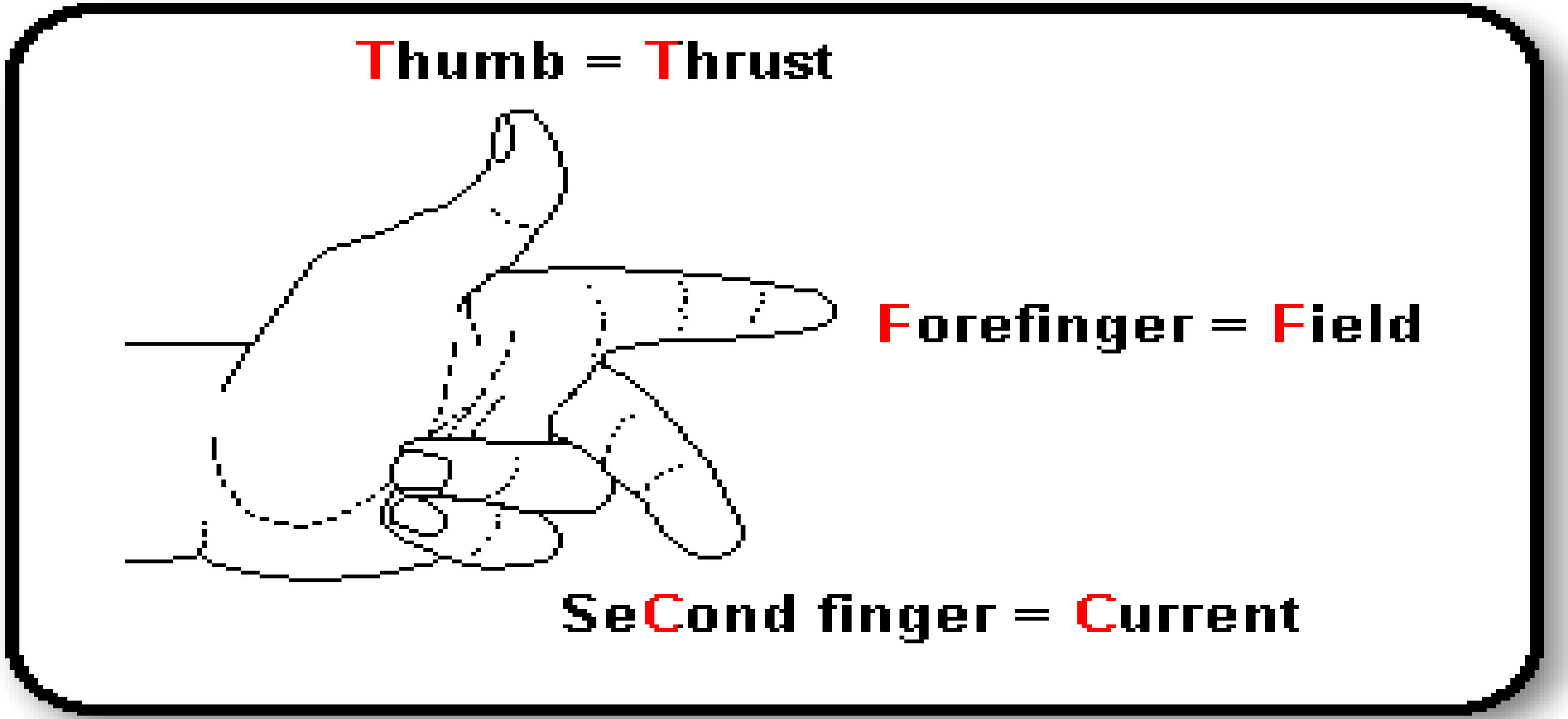
- The magnetic force (F) the conductor experiences is equal to the product of its length **L** within the field, the current **I** in the conductor, the external magnetic field **B** and the sine of the angle between the conductor and the magnetic field. In short

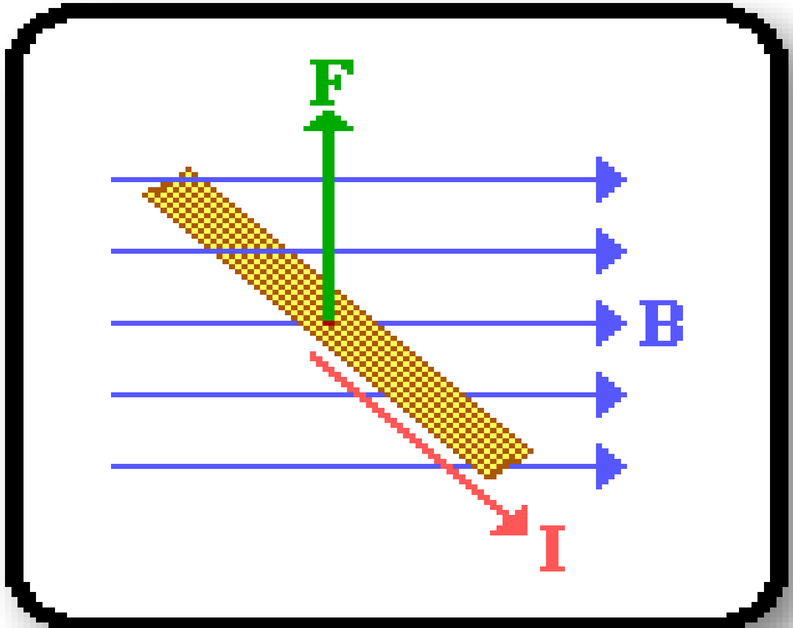
$$F = BIL\,(\sin\theta)$$

- The magnitude of the force on the conductor depends on the magnitude of the current which it carries. The force is a maximum when the current flows **perpendicular** to the field (as shown in diagram A on the left below), and it is zero when it flows **parallel** to the field (as in diagram B, on the right):



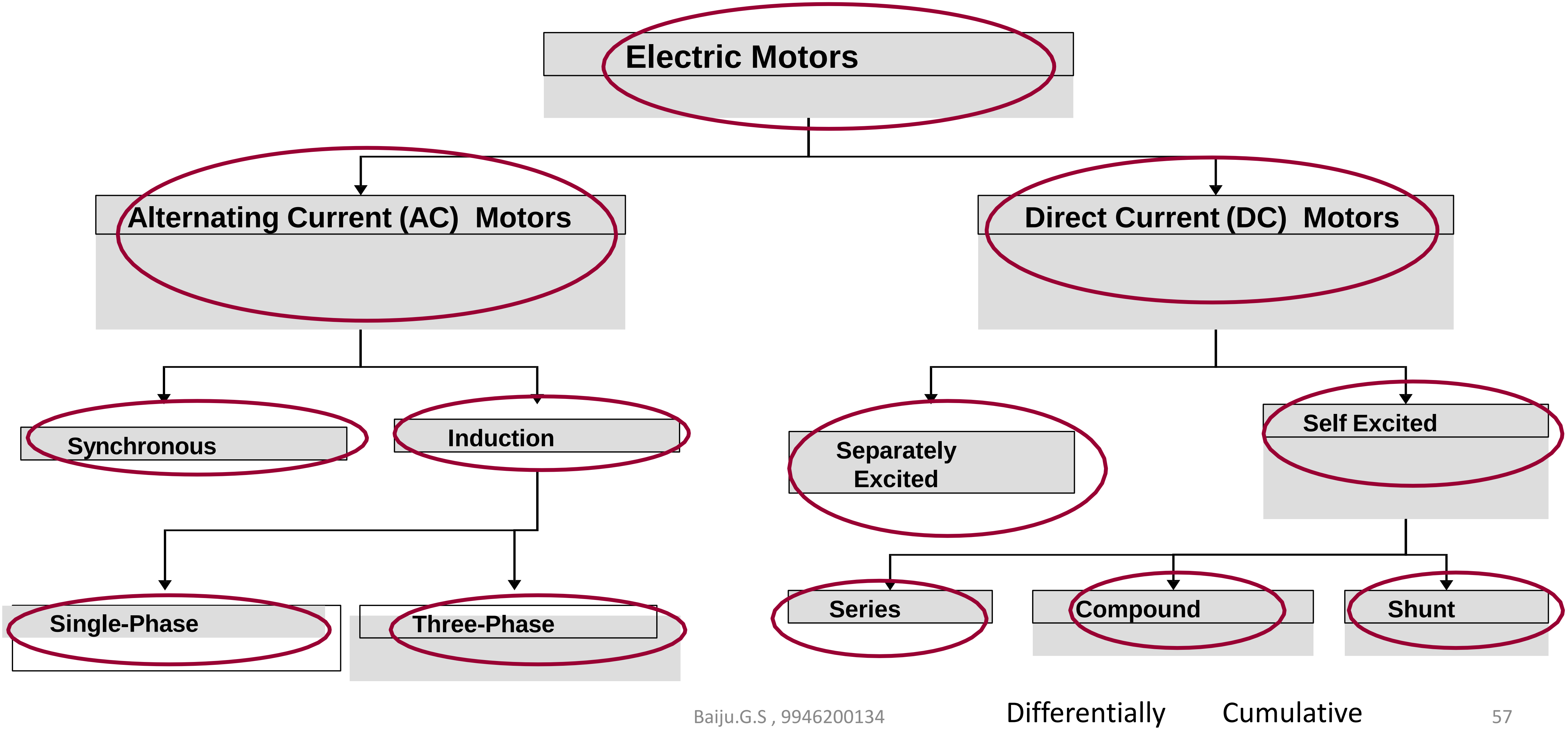
Fleming’s left-hand rule





Fleming's left hand rule states that, when u keep the thumb, index finger and middle finger of the left hand right angle to each other, if the middle finger shows the direction of current, index finger shows the direction of magnetic field, then the thumb will show the direction of motion. This law explains the working of a DC motor.

CLASSIFICATION OF MOTORS



Types of DC Motor

- **Separately excited DC motor: field current supplied from a separate force**
- **Self-excited DC motor:**

1.Shunt motor : the field winding (shunt field) is connected in parallel with the armature winding.

2.Series motor : the field winding (shunt field) is connected in series with the armature winding.

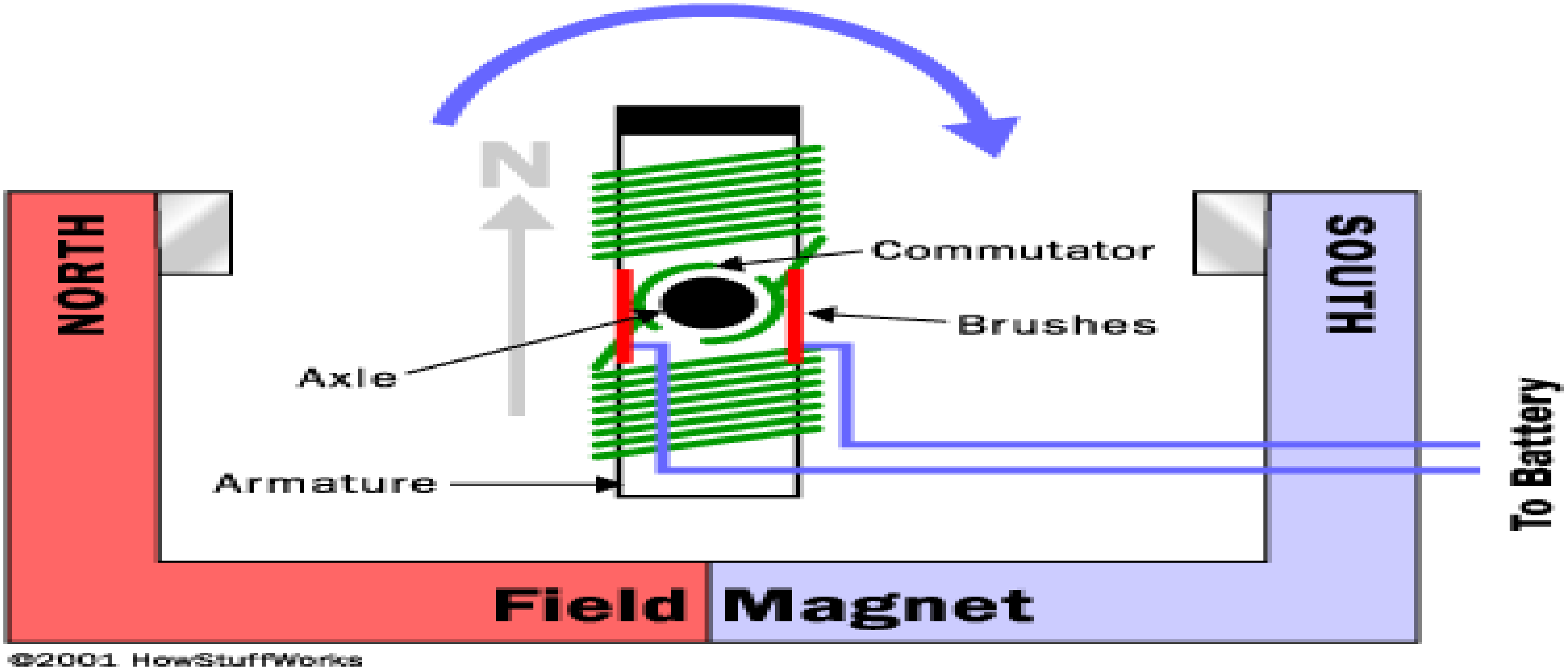
3.Compound motor : compound motor is a combination of shunt and series motor.

Differentially compound and Cumulative compound

Parts of the Motor

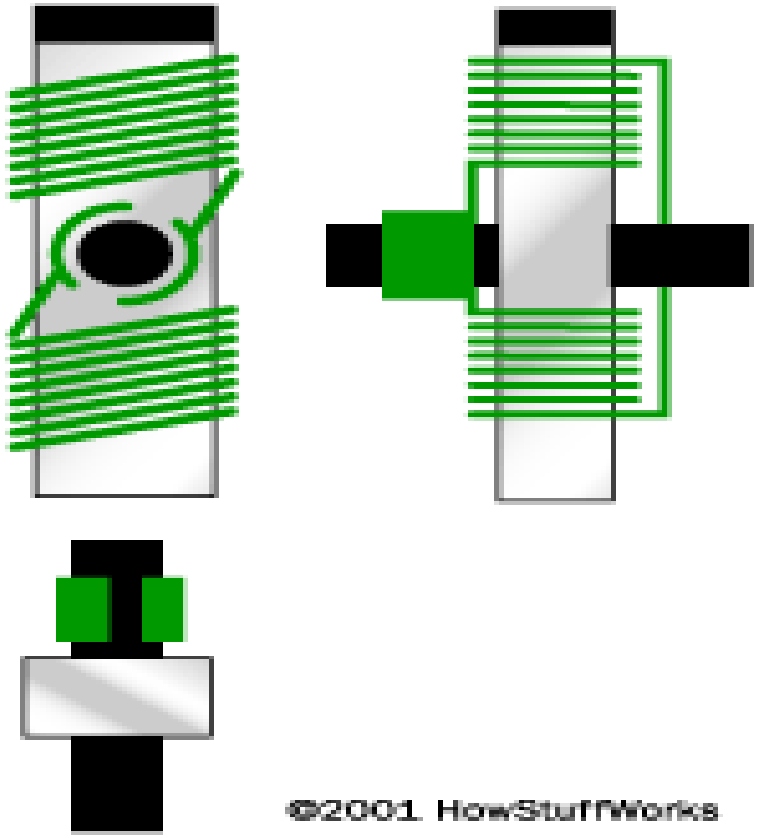
- **Armature or rotor**
- **Commutator**
- **Brushes**
- **Axle**
- **Field magnet**
- **DC power supply of some sort**

Motor Illustration



Armature

- **The armature is an electromagnet made by coiling thin wire around two or more poles of a metal core.**
- The armature has an **axle**, and the commutator is attached to the axle.
- When you run electricity into this electromagnet, it creates a magnetic field in the armature that attracts and repels the magnets in the stator. So the armature spins through 180 degrees.
- To keep it spinning, you have to change the poles of the electromagnet.



Commutator and Brushes

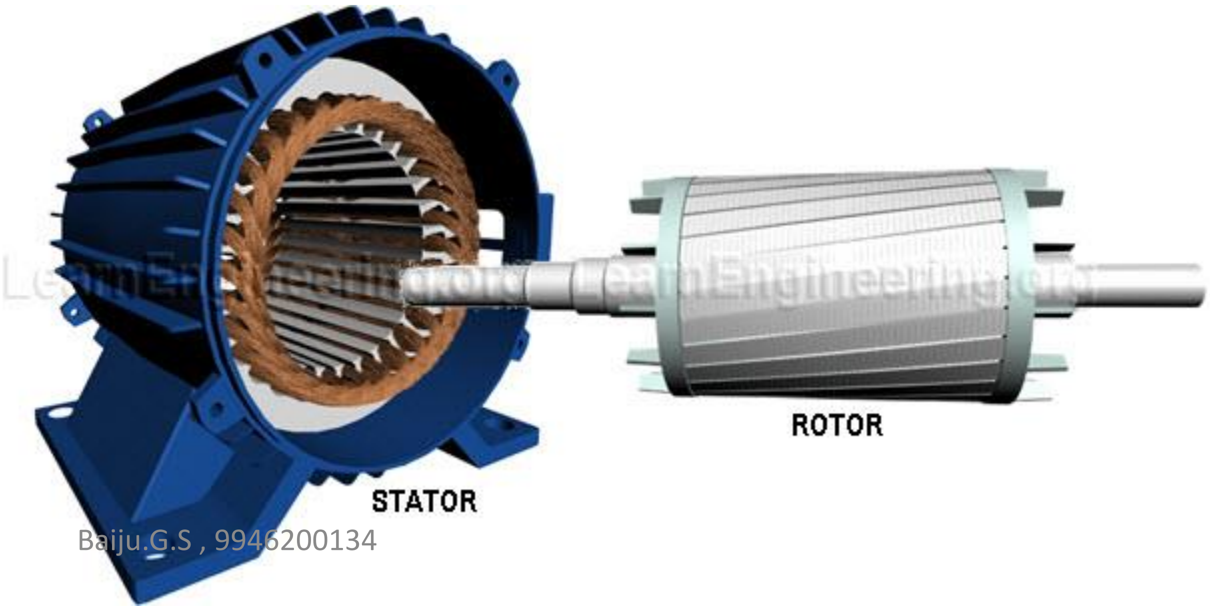
- Commutator is simply a pair of plates attached to the axle. These plates provide the two connections for the coil of the electromagnet.

- Commutator and brushes work together to let current flow to the electromagnet, and also to flip the direction that the electrons are flowing at just the right moment.

- The contacts of the commutator are attached to the axle of the electromagnet, so they spin with the magnet. The brushes are just two pieces of springy metal or carbon that make contact with the contacts of the commutator.

Stator

- **Stator**: This is the stationary part which keeps the field windings, gets the supply and forms the outside portion of the **motor**. The **DC motor's stator** consists of 2 or more magnet pole pieces and that too permanent. Here, a coil is wounded on a magnetic component to form the **stator**



Example of Motor

Back Emf in DC Motor

- When a **dc** voltage V is applied across the **motor** terminals, the armature starts rotating due to the torque developed in it. As the armature rotates, armature conductors cut the pole magnetic field, therefore, as per law of electromagnetic induction, an **emf** called **back 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 or Counter EMF (Eb).***

- The equation to find out back emf in a DC motor is given below,

$$Eb \quad = \mathbf{P\varphi NZ/60A}$$

$$Eb \quad = \mathbf{K\varphi\ ,\ \ K = PNZ/60A}$$

significance of Back EMF

- **Back emf** is very **significant** in the working of a **DC motor**. The presence of **back emf** makes the **DC 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.

Armature current , Ia = V- Eb/ Ra

When the motor is running on no load, small torque is required to overcome the friction and windage losses. Therefore, the armature current Ia is small and the **back emf** is nearly equal to the applied voltage.

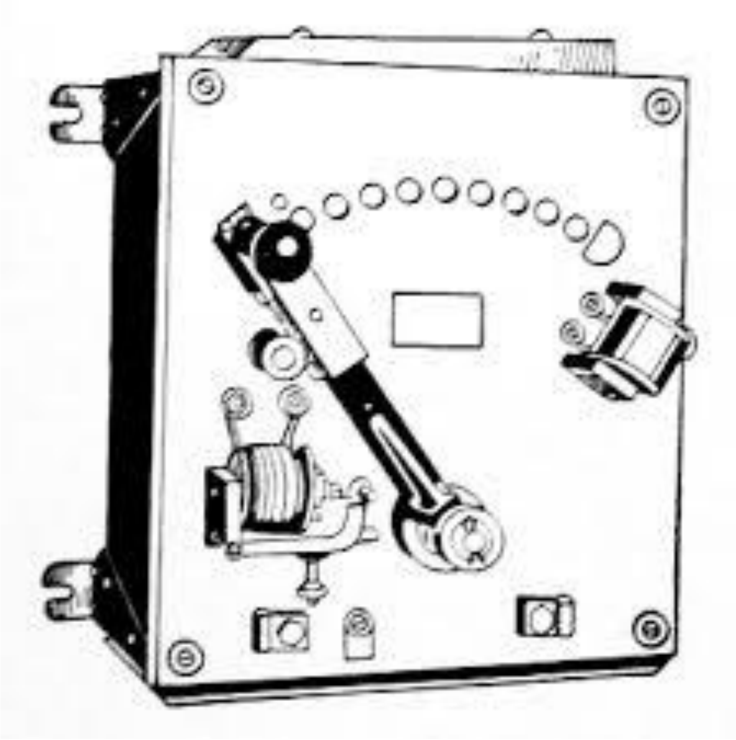
If the motor is suddenly loaded, the first effect is to cause the armature to slow down. Therefore, the speed at which the armature conductors move through the field is reduced and hence the **back emf** Eb falls.

The decreased **back emf** allows a larger current to flow through the armature and larger current means increased driving torque.

- Thus, the driving torque increases as the motor slows down. The motor will stop slowing down when the armature current is just sufficient to produce the increased torque required by the load.
- **If the load on the motor is decreased**, the driving torque is momentarily in excess of the requirement so that armature is accelerated.
- As the armature speed increases, the **back emf** Eb also increases and causes the armature current **Ia** to decrease. The motor will stop accelerating when the armature current is just sufficient to produce the reduced torque required by the load.
- Therefore, the **back emf** in a DC motor regulates the flow of armature current i.e., it automatically changes the armature current to meet the load requirement.

Startor in DC Motor

- Starters are used to protect **DC motors** from damage that can be caused by very high current and torque during startup. They do this by providing external resistance to the **motor**, which is connected in series to the **motor's** armature winding and restricts the current to an acceptable level



Necessity of startor in DC Motor

- At starting, heavy current is drawn by the dc motor from the supply as some time is required by the motor to gain speed and hence to built up back emf. If the **starter** is not present then there will be overheating of armature and voltage drop in supply takes place.

- **What will happen if DC motor is used without starter**?

  It **would** cause intolerably heavy sparking at the brushes which may destroy the commutator and brush-gear

Characteristics of DC motors

- Generally, three **characteristic** curves are considered important for **DC motors** which are, (i) Torque vs. armature current, (ii) Speed vs. armature current and (iii) Speed vs. torque. These are explained below for each type of **DC motor**
- When armature conductors of a **DC motor** carry current in the presence of stator field flux, a mechanical **torque** is developed between the armature and the stator. **Torque** is given by the product of the force and the radius at which this force acts.
- $\mathbf{T_a = (PZ / 2\pi A) \times \Phi . I_a}$

- These characteristics are determined by keeping the following two relations in mind.
  $T_a \propto \phi . I_a$ and **$N \propto E_b/\phi$**
- These above equations can be studied at - emf and torque equation of dc machine.
- For a DC motor, magnitude of the back emf is given by the same emf equation of a dc generator

  i.e. $E_b = P\phi NZ / 60A$. For a machine, P, Z and A are constant,

  therefore, $N \propto E_b/\phi$

Characteristics of DC motors

- **1. Torque vs. armature current (T_a-I_a)**

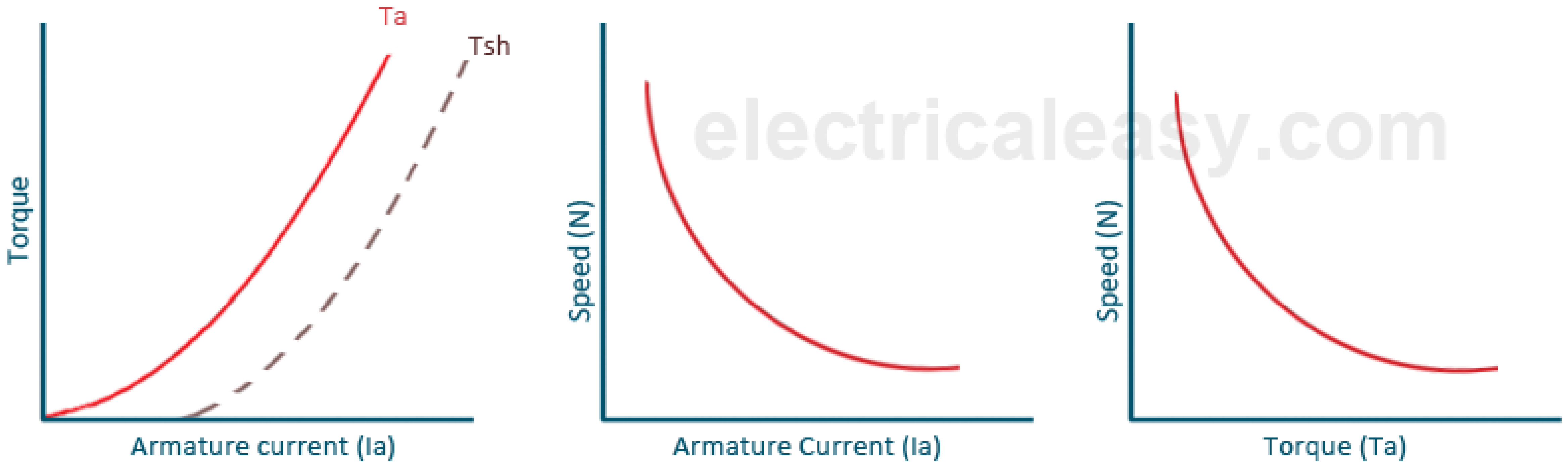
  $T_a \propto \phi.I_a$

- **2. Speed vs. armature current (N-Ia)**

  $N \propto E_b/\phi$

- **3. Speed vs. torque (N-Ta)**

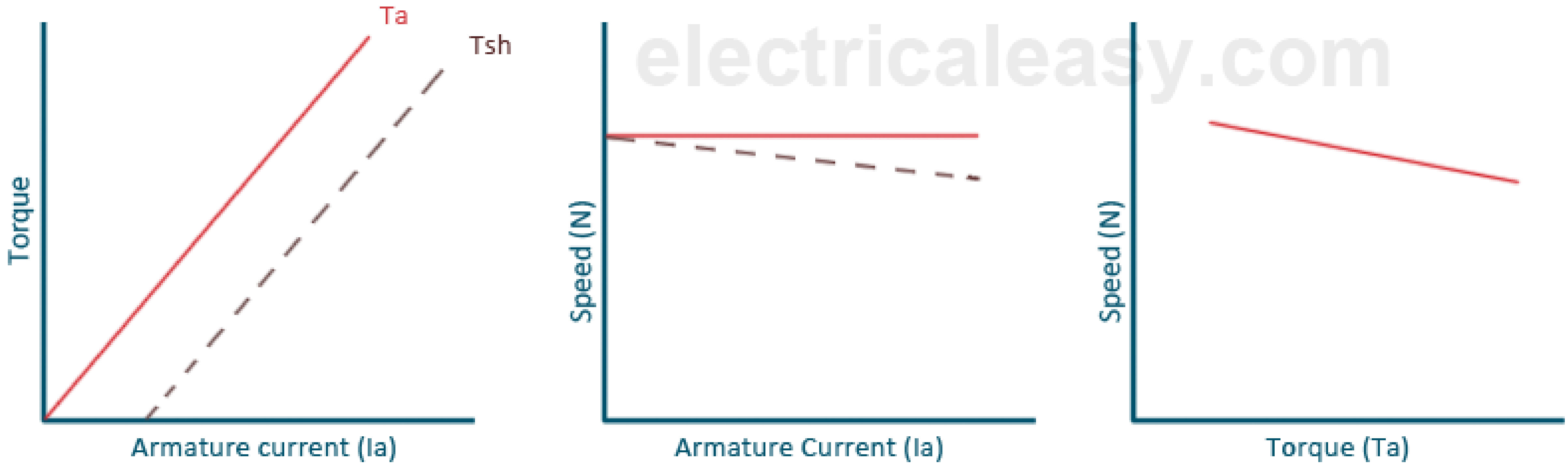
Characteristics of DC Series motors



Characteristics of DC series motor

- **Torque vs. armature current (T_a-I_a)**
- This characteristic is also known as **electrical characteristic**. We know that torque is directly proportional to the product of armature current and field flux, $T_a \propto \phi.I_a$. In DC series motors, field winding is connected in series with the armature, i.e. $I_a = I_f$. Therefore, before magnetic saturation of the field, flux ϕ is directly proportional to Ia. Hence, before magnetic saturation Ta α Ia^2. Therefore, the Ta-Ia curve is parabola for smaller values of Ia.
  After magnetic saturation of the field poles, flux ϕ is independent of armature current Ia. Therefore, the torque varies proportionally to Ia only, T ∝ Ia. Therefore, after magnetic saturation, Ta-Ia curve becomes a straight line.
  The shaft torque (Tsh) is less than armature torque (Ta) due to stray losses. Hence, the curve Tsh vs Ia lies slightly lower.
- In DC series motors, (prior to magnetic saturation) torque increases as the square of armature current, these motors are used where high starting torque is required.

- **Speed vs. armature current (N-Ia)**
- We know the relation, $N \propto E_b/\phi$
  For small load current (and hence for small armature current) change in back emf Eb is small and it may be neglected. Hence, for small currents speed is inversely proportional to ϕ. As we know, flux is directly proportional to Ia, speed is inversely proportional to Ia. Therefore, when armature current is very small the speed becomes dangerously high. That is **why a series motor should never be started without some mechanical load**.
- But, at heavy loads, armature current Ia is large. And hence, speed is low which results in decreased back emf Eb. Due to decreased Eb, more armature current is allowed.
  Speed vs. torque (N-Ta)
- This characteristic is also called as **mechanical characteristic**. From the above two **characteristics of DC series motor**, it can be found that when speed is high, torque is low and vice versa.



Characteristics of DC shunt motor

Characteristics of DC shunt motors

- **Torque vs. armature current (Ta-Ia)**
- $T_a \propto \phi . I_a$

In case of DC shunt motors, we can assume the field flux ϕ to be constant. Though at heavy loads, ϕ decreases in a small amount due to increased armature reaction. As we are neglecting the change in the flux ϕ, we can say that torque is proportional to armature current. Hence, the Ta-Ia characteristic for a dc shunt motor will be a straight line through the origin.

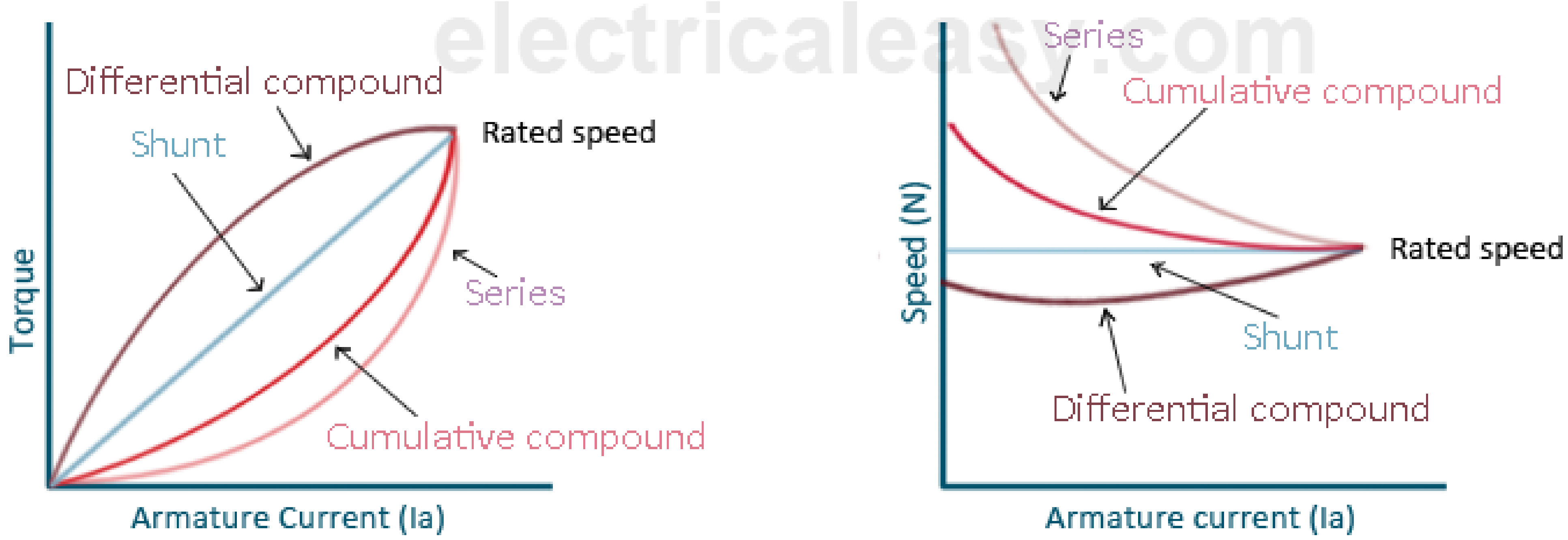
Since heavy starting load needs heavy starting current, **shunt motor should never be started on a heavy load**.

Speed vs. armature current (N-Ia)

$N \propto E_b/\phi$

- As flux ϕ is assumed to be constant, we can say N ∝ Eb. But, as back emf is also almost constant, the speed should remain constant. But practically, ϕ as well as Eb decreases with increase in load. Back emf Eb decreases slightly more than ϕ, therefore, the speed decreases slightly.
- Generally, the speed decreases only by 5 to 15% of full load speed. Therefore, **a shunt motor can be assumed as a constant speed motor**. In speed vs. armature current characteristic in the following figure, the straight horizontal line represents the ideal characteristic and the actual characteristic is shown by the dotted line.

Characteristics of DC Compound motor



Characteristics of DC compound motor

• Characteristics of DC compound motor

- DC compound motors have both series as well as shunt winding. In a compound motor, if series and shunt windings are connected such that series flux is in direction as that of the shunt flux then the motor is said to be cumulatively compounded. And if the series flux is opposite to the direction of the shunt flux, then the motor is said to be differentially compounded. Characteristics of both these compound motors are explained below.

  (a) Cumulative compound motor

  Cumulative compound motors are used where series characteristics are required but the load is likely to be removed completely. Series winding takes care of the heavy load, whereas the shunt winding prevents the motor from running at dangerously high speed when the load is suddenly removed. These motors have generally employed a flywheel, where sudden and temporary loads are applied like in rolling mills.

- **(b) Differential compound motor**

  Since in differential field motors, series flux opposes shunt flux, the total flux decreases with increase in load. Due to this, the speed remains almost constant or even it may increase slightly with increase in load ($N \propto E_b/\phi$). Differential compound motors are not commonly used, but they find limited applications in experimental and research work.

Thank you

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