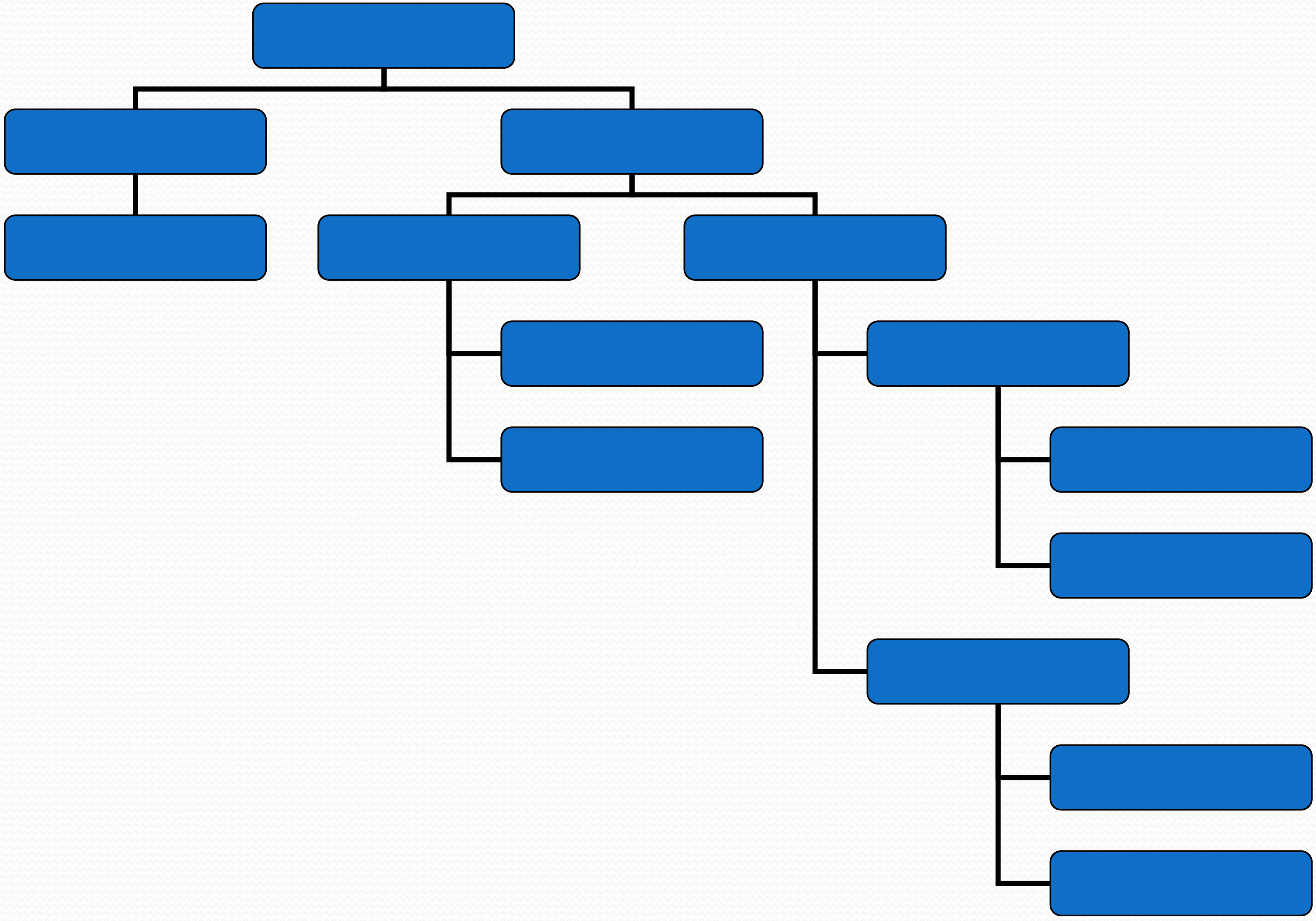
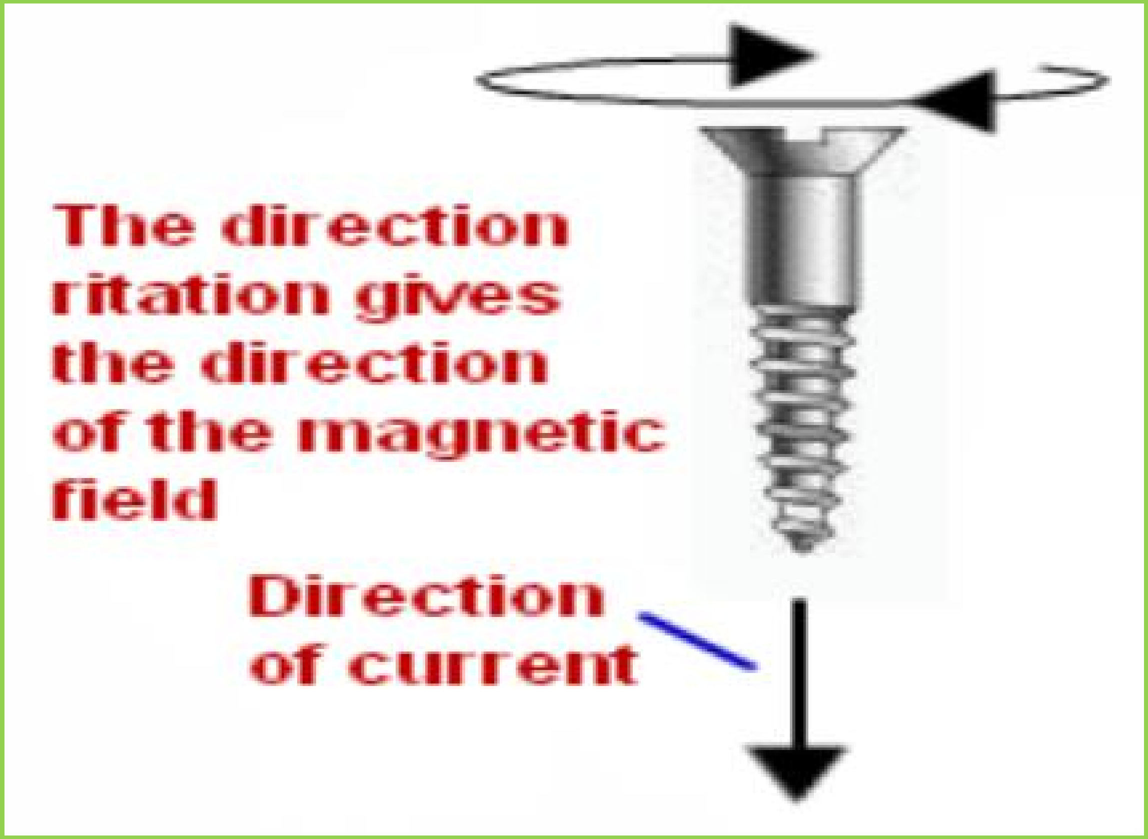
BASIC PRINCIPLES OF MACHINE OPERATION

Electrical Machines

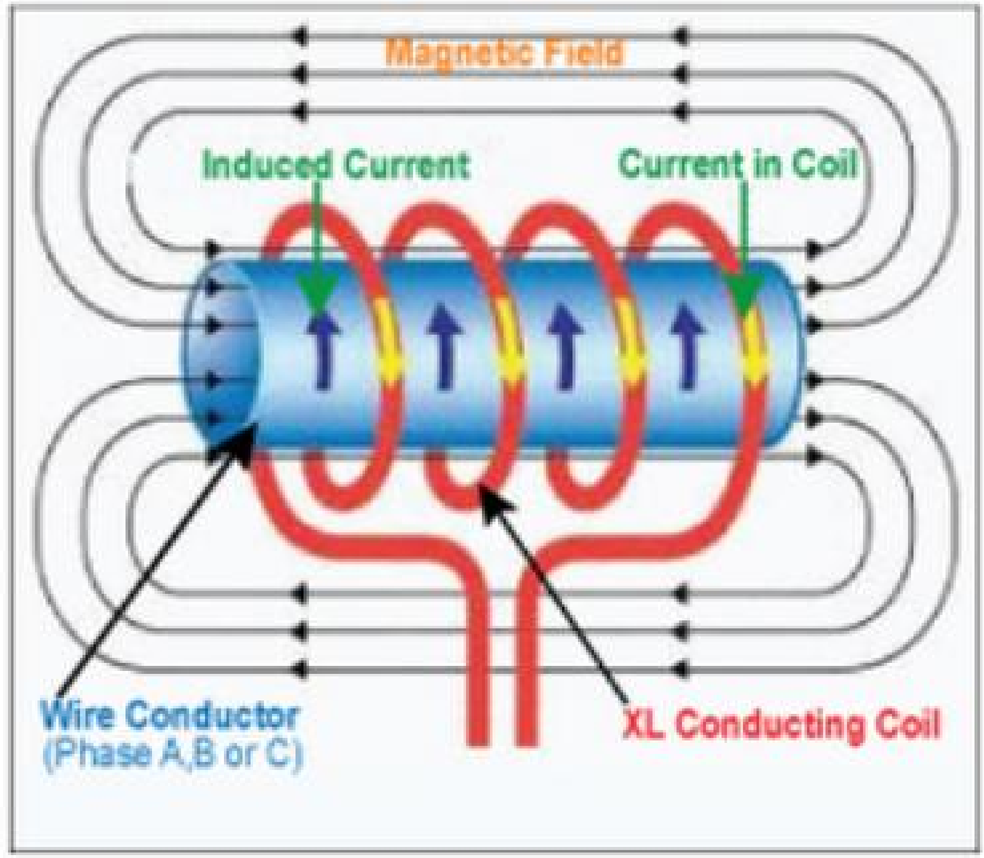


Maxwell's Cork screw Rule



Faraday's Law of Electromagnetic Induction

Faraday's Law states that the induced electromotive force (emf) in a closed circuit is equal to the time rate of change of the magnetic flux through the circuit.



Faraday's Law of Electromagnetic Induction

There are several different ways to generate current (Amps) using Electro-Magnetic Induction (EMI). For example:

- **Electric current can be generated only if either the magnetic field is changing (like XL Technology) or the conductor is moving (like the Faraday Flashlight).**
- **No matter how the change occurs, voltage and current will be generated.**
  - **The change could be produced by:**

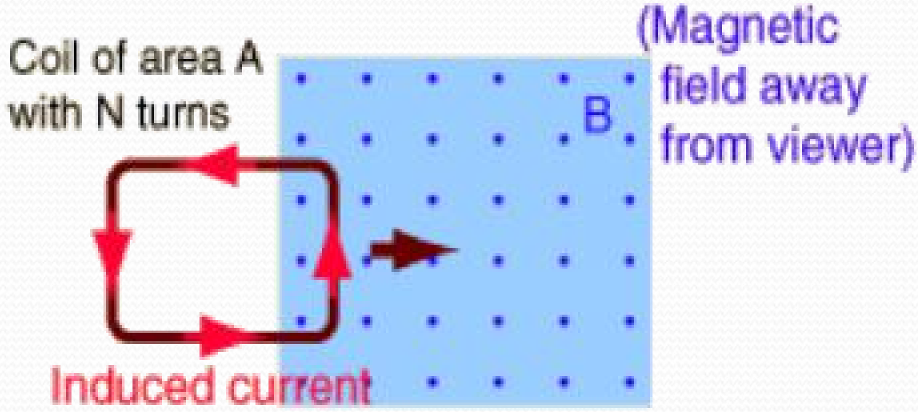
    changing the magnetic field strength (XL Technology),

    moving a magnet toward or away from the coil,

    moving the coil into or out of the magnetic field (Faraday Flashlight)

    or by rotating the coil relative to the magnet as in the case of generators, motors, etc., which spin a coil of wire (the moving conductor) around a magnet to generate a steady flow of current (Amps)

Faraday’s Law of Electromagnetic Induction



A coil of wire moving into a magnetic field is one example of an emf generated according to Faraday's Law. The current induced will create a magnetic field which opposes the buildup of magnetic field in the coil.

Faraday's Law

$$\text{Emf} = -N\frac{\Delta\Phi}{\Delta t}$$

Lenz's Law

where N = number of turns

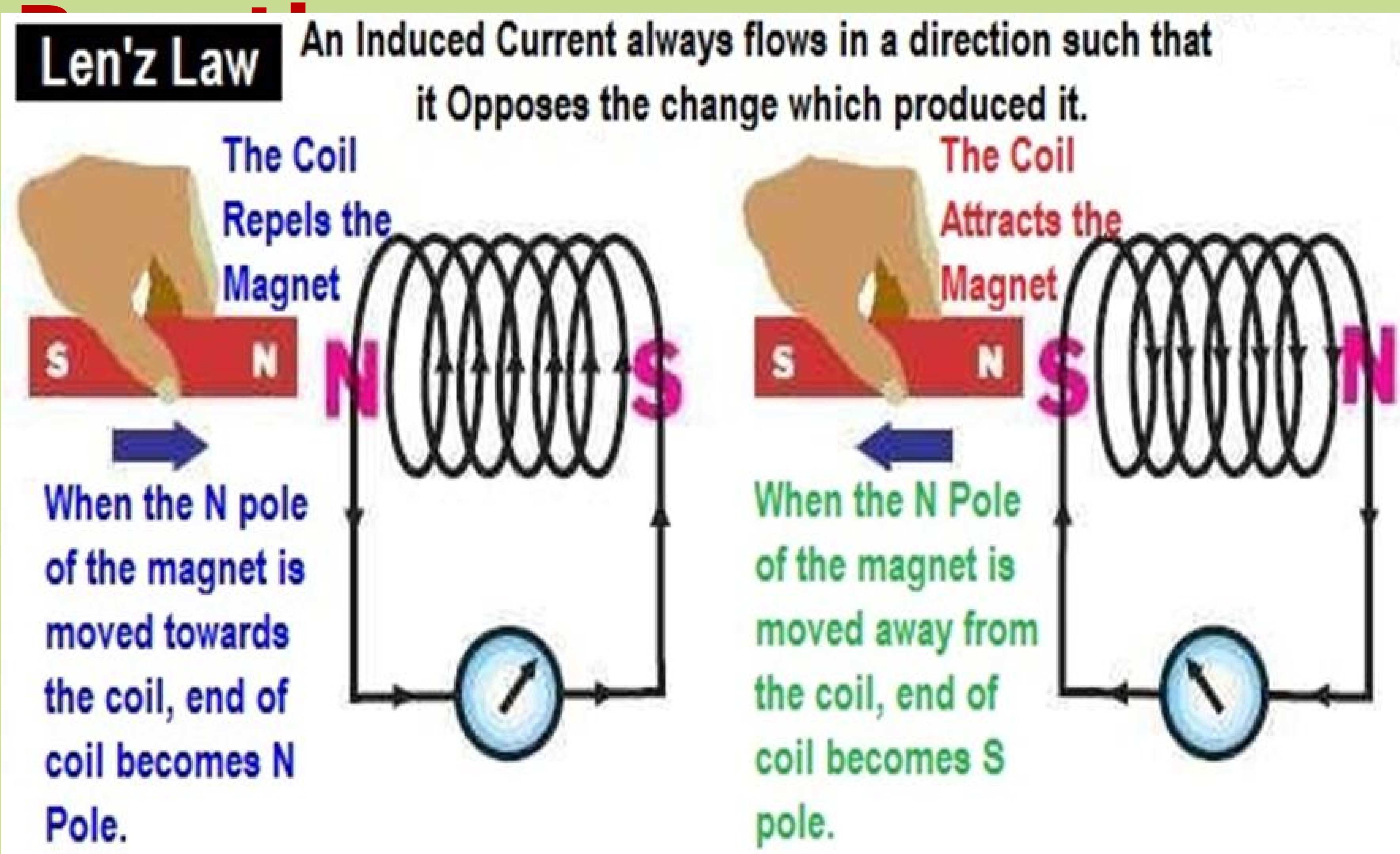
$\Phi = BA$ = magnetic flux

B = external magnetic field

A = area of coil

The minus sign denotes Lenz's Law. Emf is the term for generated or induced voltage.

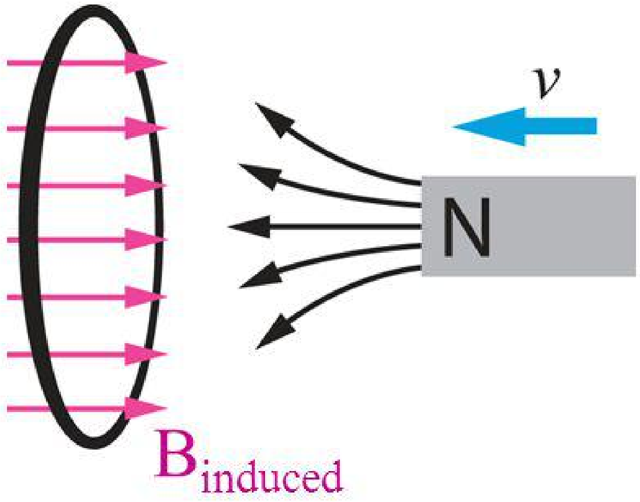
Lenz’s Law of Action and



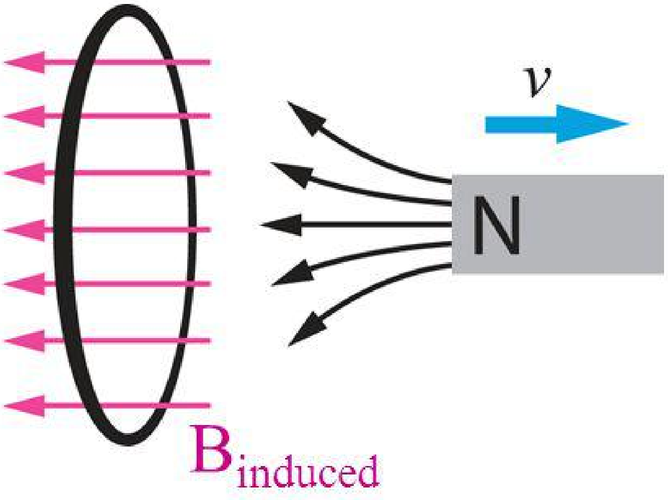
Lenz's Law

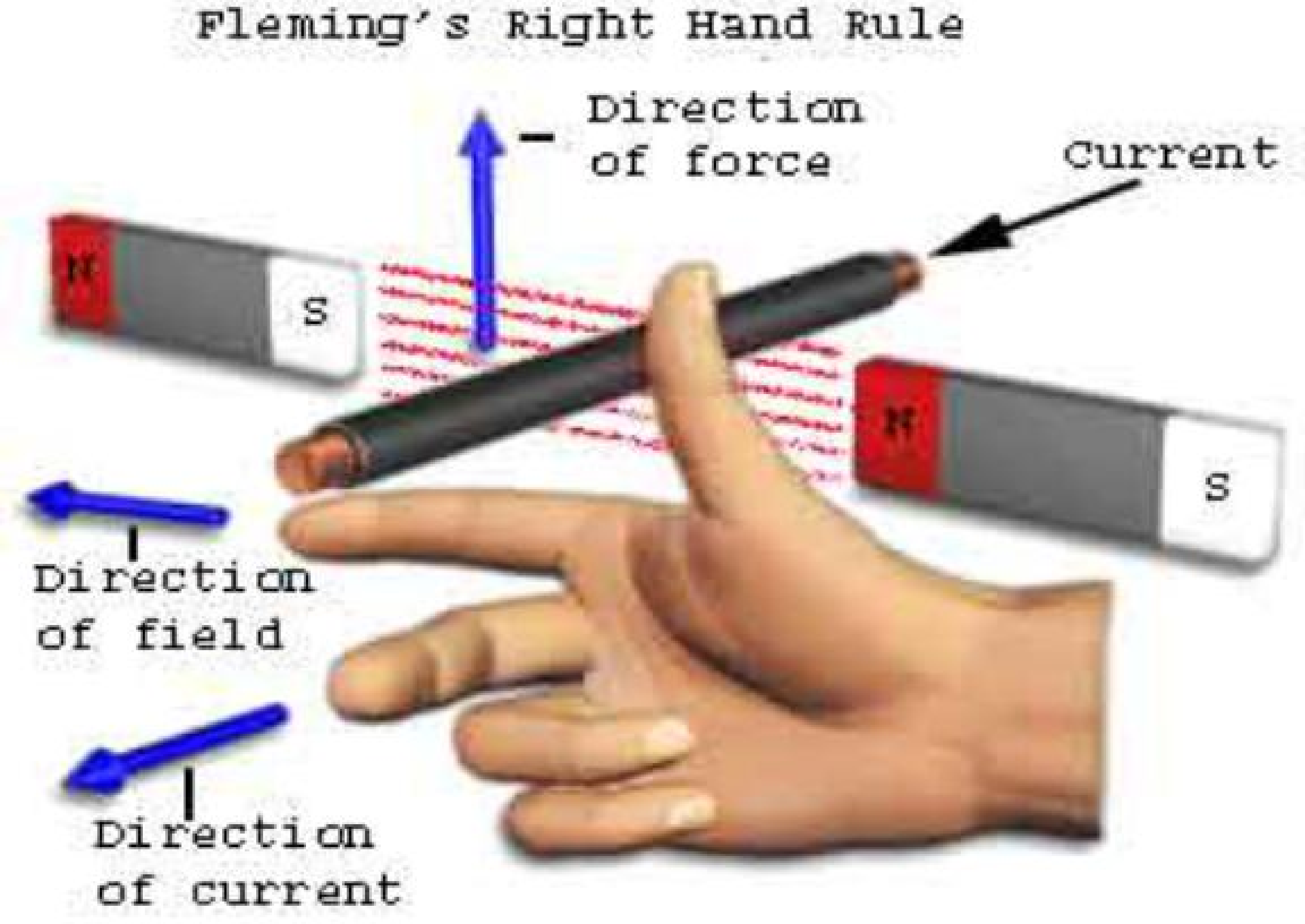
The *induced B field* in a loop of wire will **oppose the change in magnetic flux** through the loop.

If you try to **increase** the flux through a loop, the induced field will oppose that increase!



If you try to **decrease** the flux through a loop, the induced field will replace that decrease!




Fleming's Right Hand Rule
Direction of force
Current
N
S
N
S
Direction of field
Direction of current

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 left hand are kept at right angles to one another.

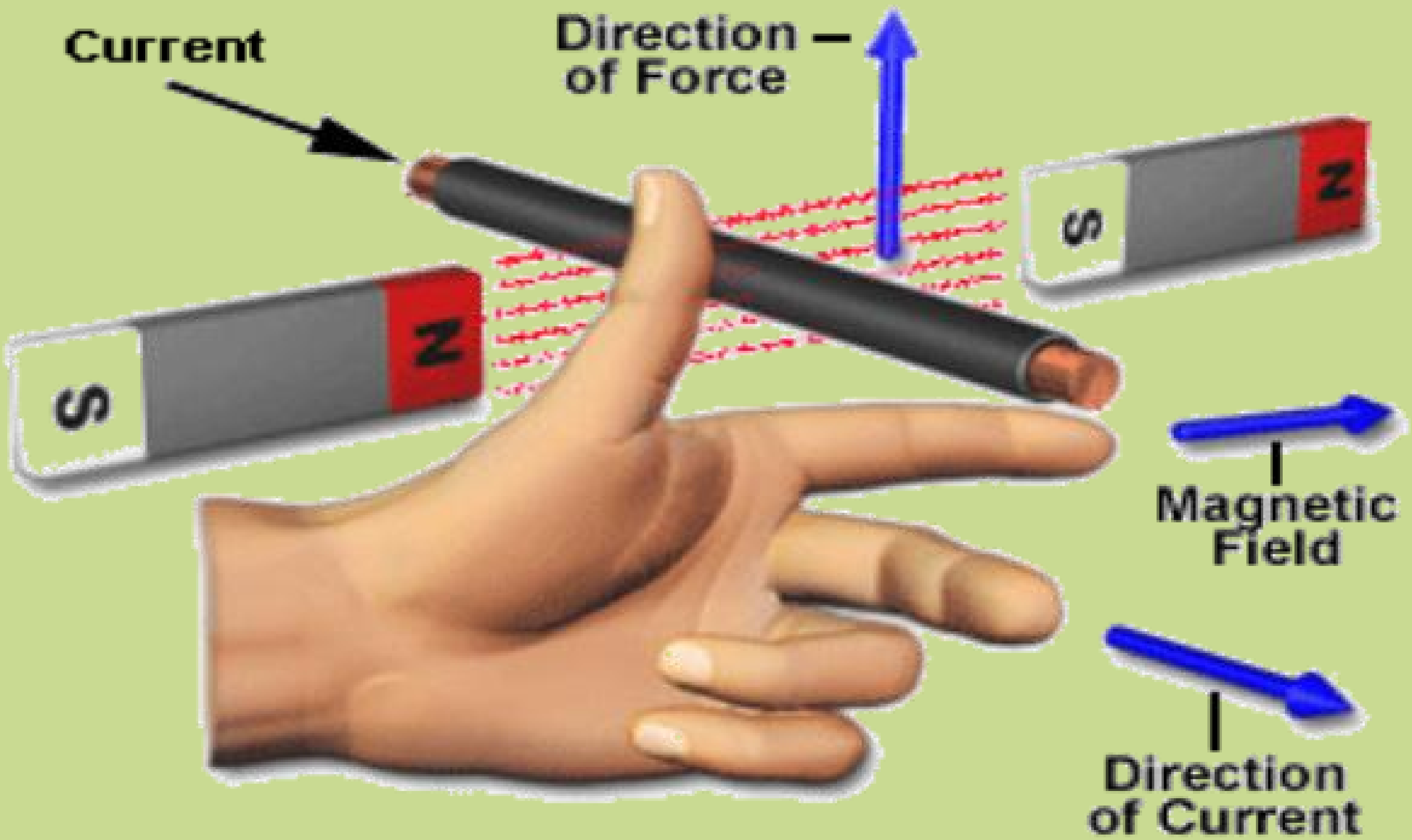
- The fore finger represent the direction of magnetic field

- 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

Left Hand Rule



Fleming’s left hand rule

- Used to determine the direction of force acting on a current carrying conductor placed in a magnetic field .
- The middle finger , the fore finger and thumb of the left hand are kept at right angles to one another .
  - The middle finger represent the direction of current
  - The fore finger represent the direction of magnetic field
  - The thumb will indicate the direction of force acting on the conductor .

This rule is used in motors.

eatures Of All Rotating Machines

Every electrical machine usually have.

- **Exciting or field winding:**
  Which produces the working flux.

- **Armature winding:**
  In which working emf is induced by the working flux.

Electrical Generator / Motors

An *electric generator* converts mechanical energy into electrical energy.

An *electric motor* converts electrical energy into mechanical energy.

Mechanical Input → **ELECTRICAL MACHINES Generator** → Electrical Output

Electrical input → **ELECTRICAL MACHINES Motor** → Mechanical output

Application of DC Machines

DC Motor

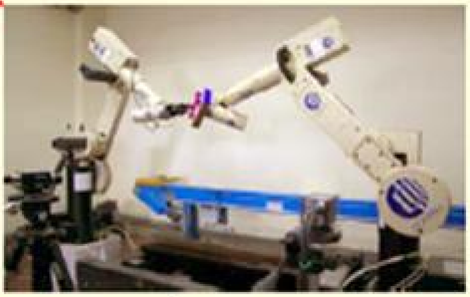
Paper Mills

Steel Mills

Mining

Machine Tools

Oil Rigs



Robots

Petrochemical

Application Of DC Machines

- DC motor can used either as a motor or a generator, at present its use as a generator is limited because of the widespread use of ac motors.

- Large DC motors are used in machine tools ,printing press, fans pumps, cranes, paper mills, traction textile mills and so forth.

- Small DC machines (fractional horse power rating) are used primarily as control devices, such as tachometer for speed sensing and

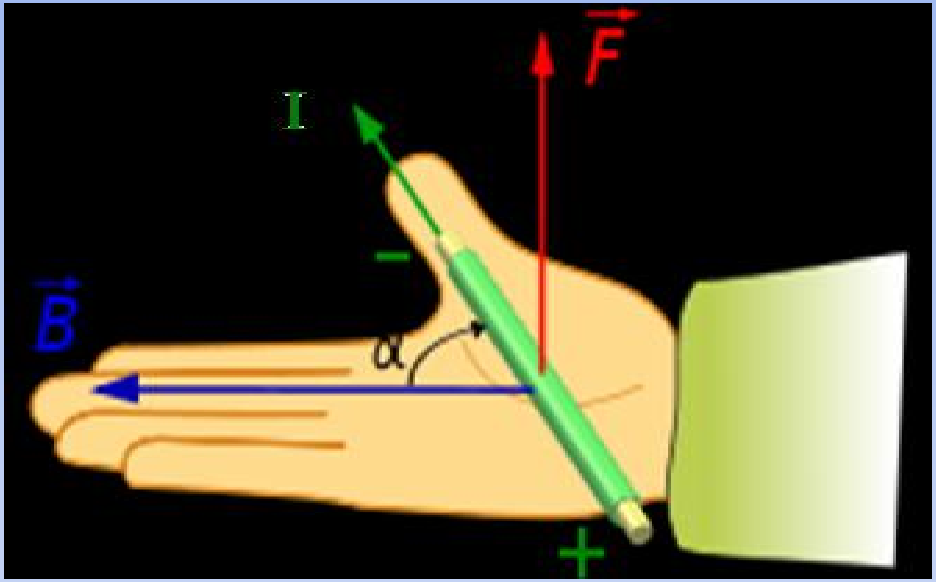
field

then a force is generated on current caring conductor.

$$\boxed{F = BIL.\ \sin\theta}$$

If all three B and L are Perpendicular to each other, then

$$\boxed{F = BIL}$$



If a conductor is moving in magnetic field then an is generated in a conductor .

$$\boxed{E = BVL.\ \sin\theta}$$

$$\boxed{E = BVL}$$

If B is Perpendicular to V

Machine

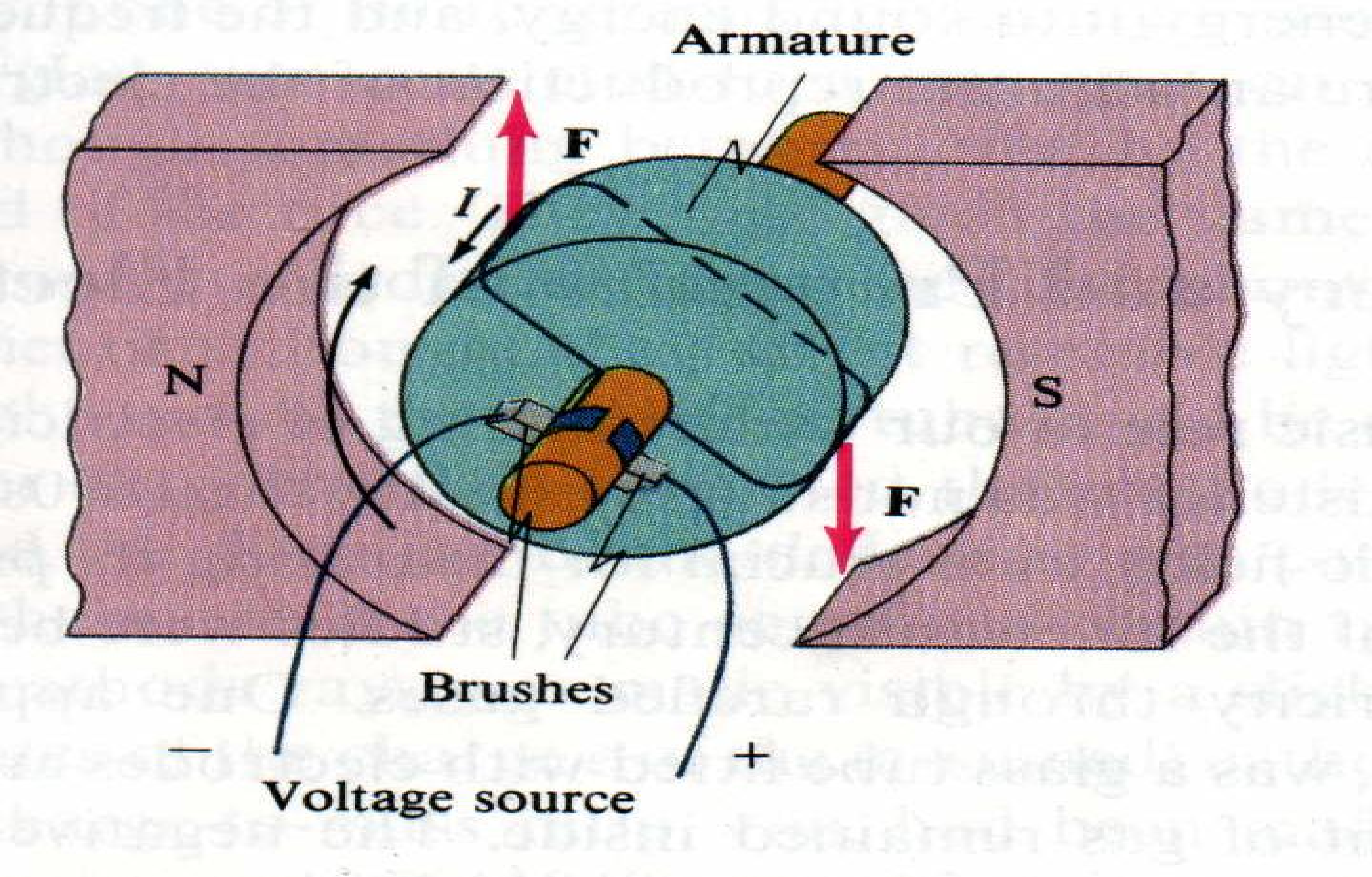
Stator:

- Yoke (or Frame)
- Poles & Pole shoe
- Field windings
- Brushes
- End covers

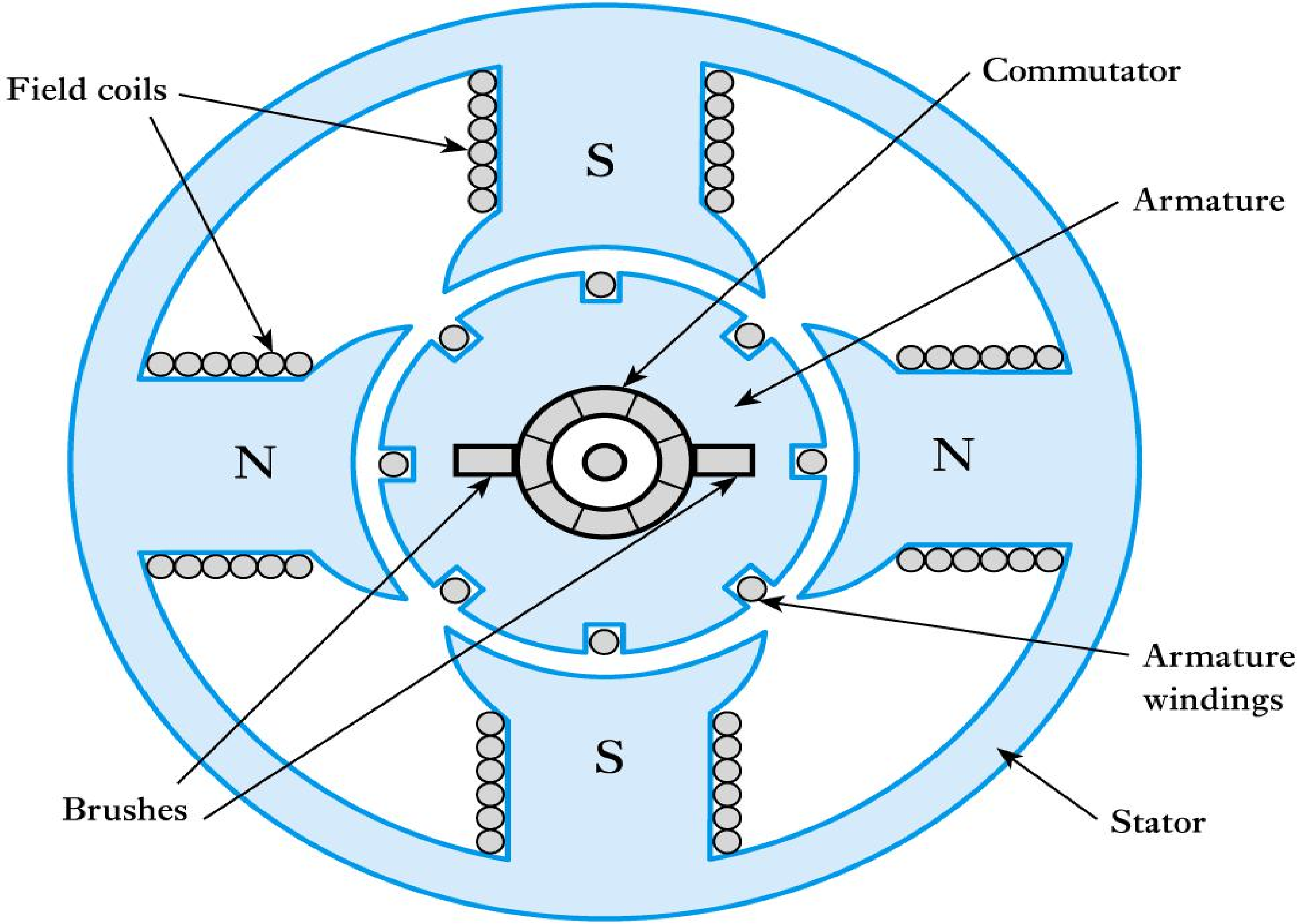
Rotor (Armature)

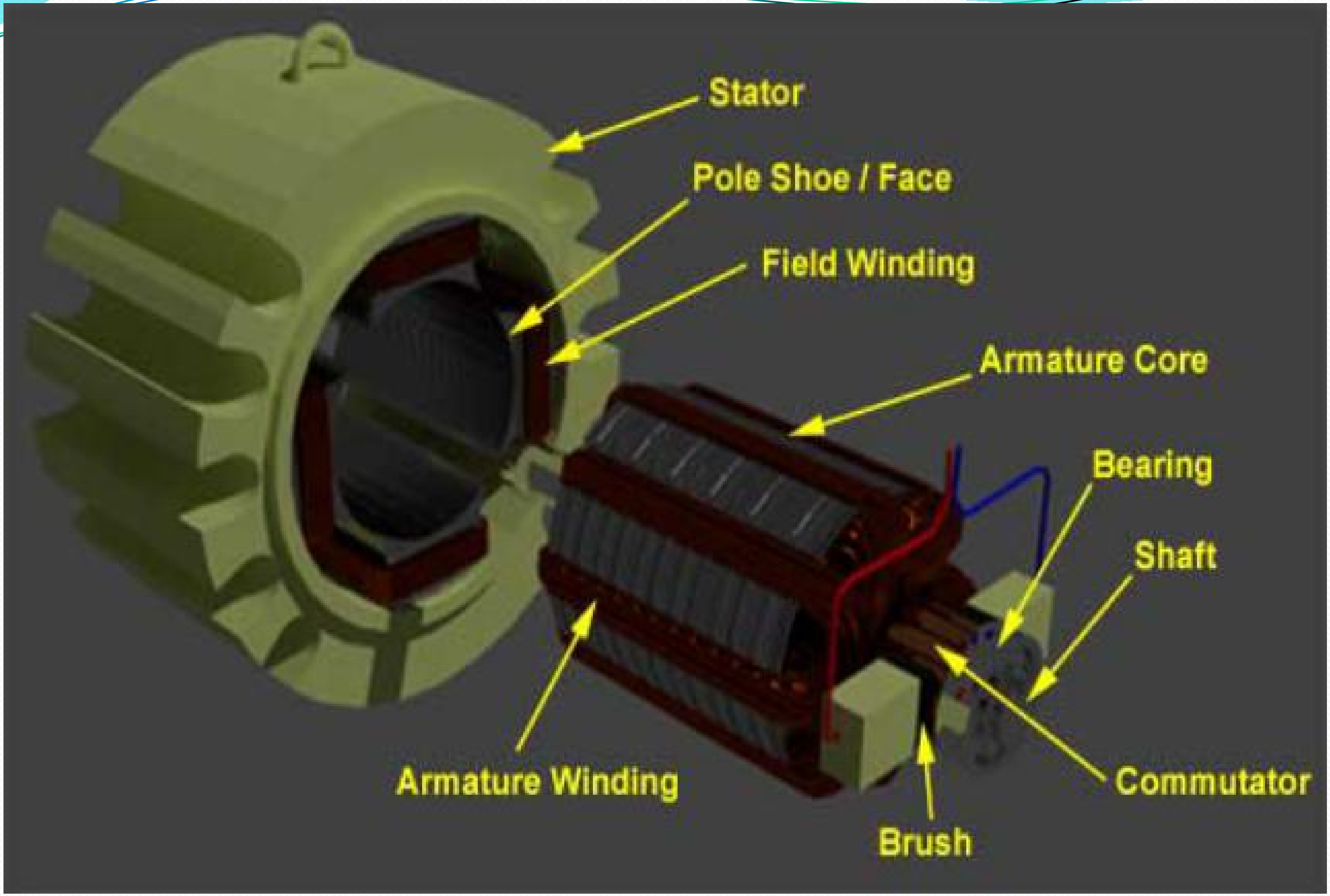
- Armature core
- Armature winding
- Commutator

Diagram of a Simple DC Machine



Four pole DC Machine




Stator
Pole Shoe / Face
Field Winding
Armature Core
Bearing
Shaft
Armature Winding
Commutator
Brush

Field System

The field system is to produce uniform magnetic field with in which the armature rotates. This consist of yoke and frame: Act as a mechanical support of the machine.

Yoke

Position :

Outermost cover of the d.c. mac

Functions:

It provides mechanical supports to the poles

It provides protection from harmful atmospheric elements like moisture, dust & various gas like SO_2, acidic fumes etc. to d.c. machine

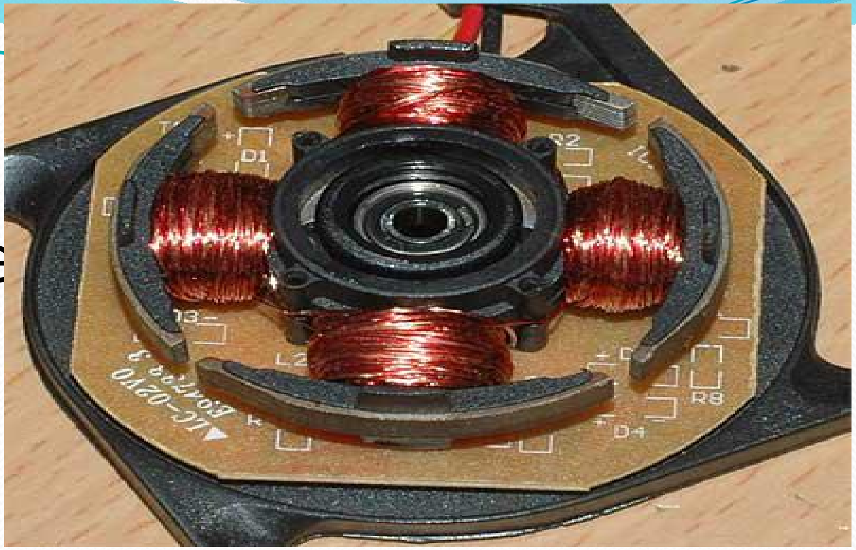
It provides low reluctance path to magnetic flux

Material:

It is prepared by using cast iron because it is cheapest.

For large machines cast steel, silicon steel is used which provides high permeability.

Poles



There are two parts of pole
(i) Pole core ii) Pole shoe

Pole Core:

Position :

In general a pole core is a rectangular cross-section and attached to yoke.

Material :

Generally used materials for the manufacturing of pole core are either cast iron.

Functions:

The main function of pole body is to act as support for the field coil, which is to be wound around it.

It provides low reluctance path to magnetic flux

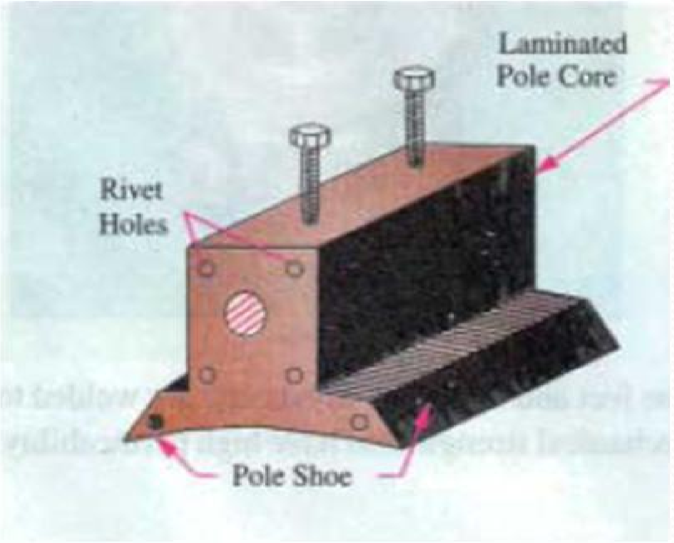
Pole shoe

Position :

Naturally pole shoe is a projection over pole

Functions

- Supports field coil
- Spreads out magnetic flux over a larger area of the air ga



Field Winding

In general, dc current (or voltage) is used for this type of winding.

Position :

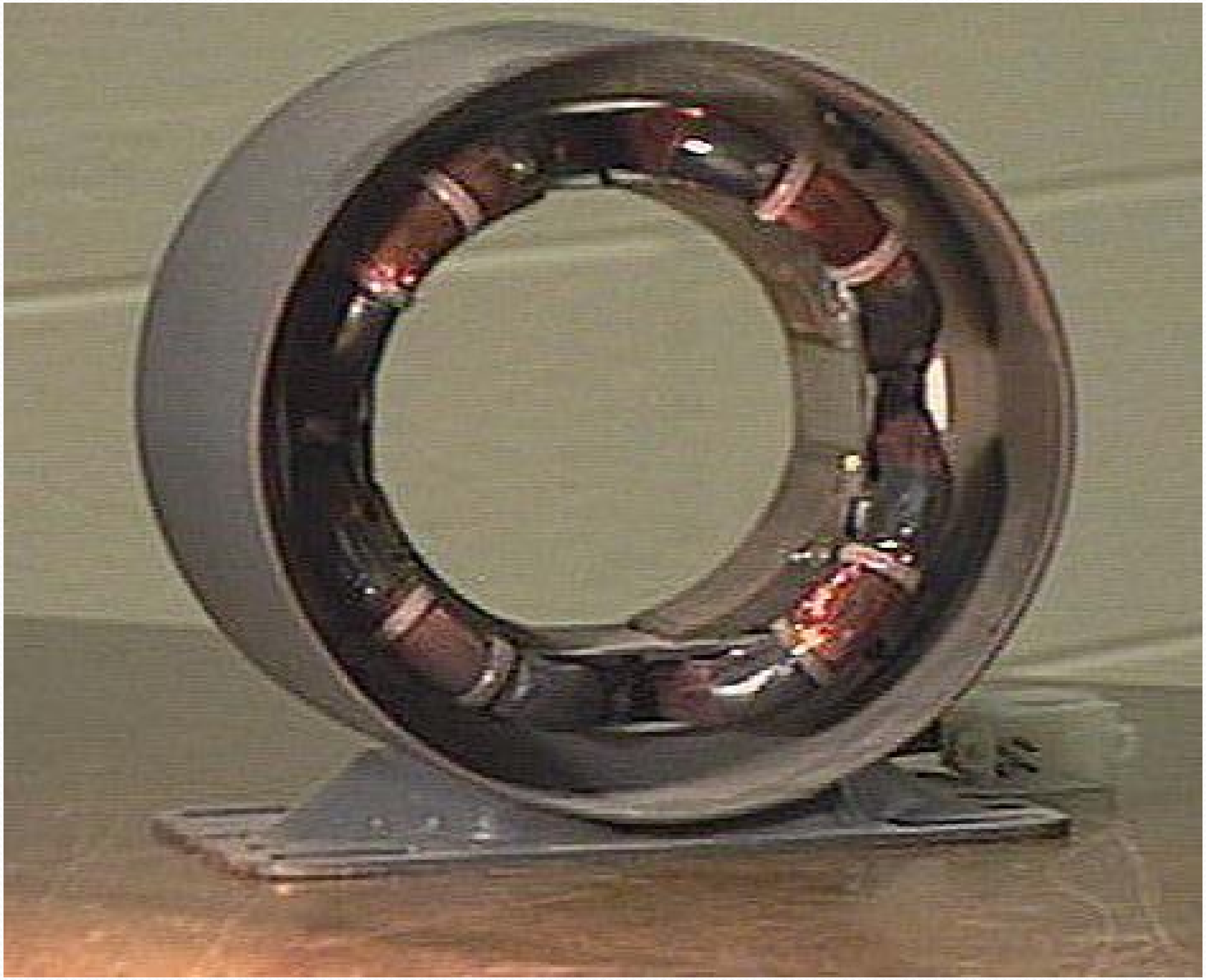
The Field winding is wound on the pole core with a definite direction.

Functions:

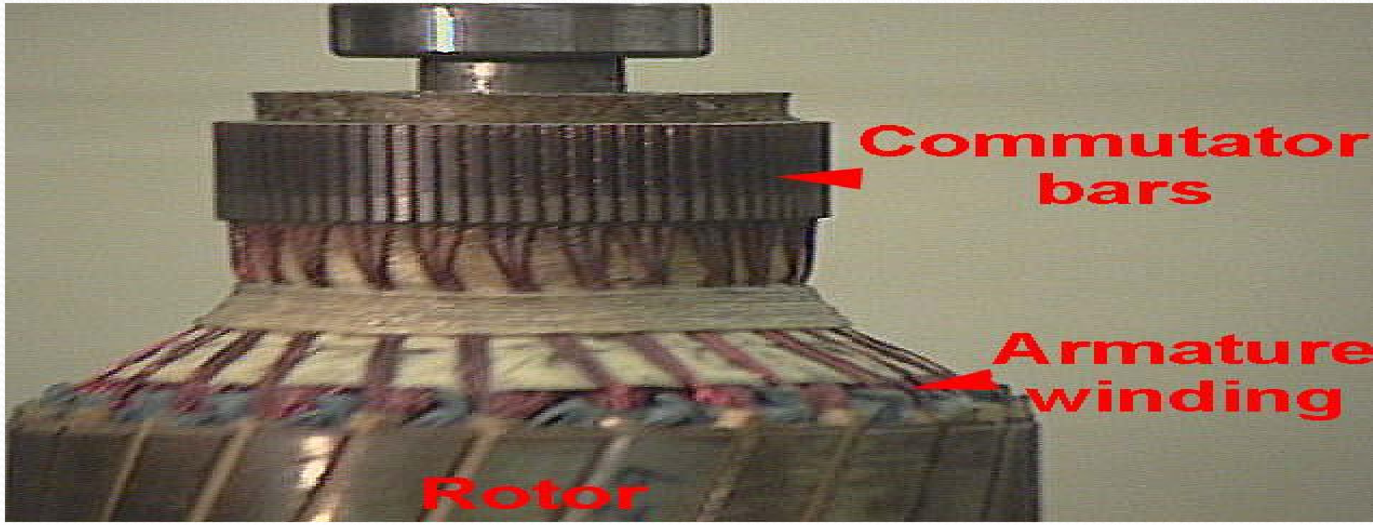
To carry current and to produce electromagnetic flux.

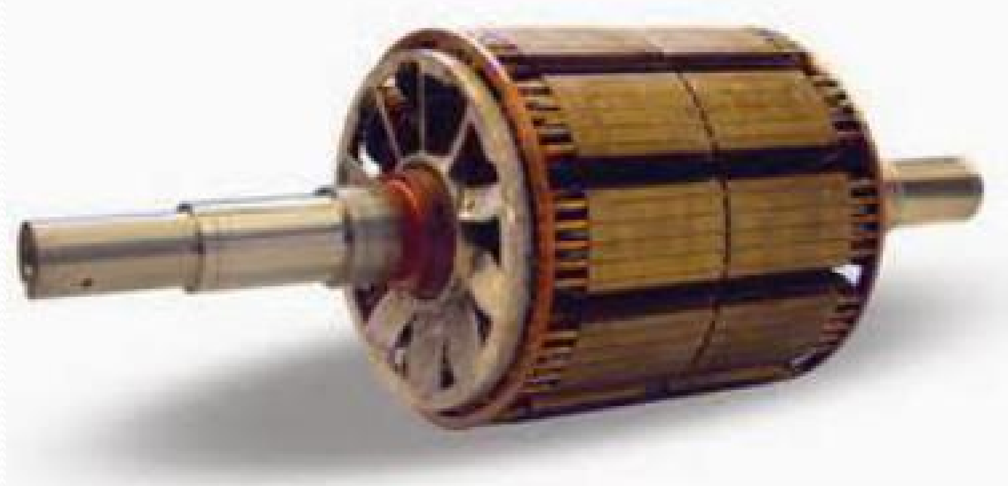
Material:

Copper is used to make windings



Rotor and rotor winding

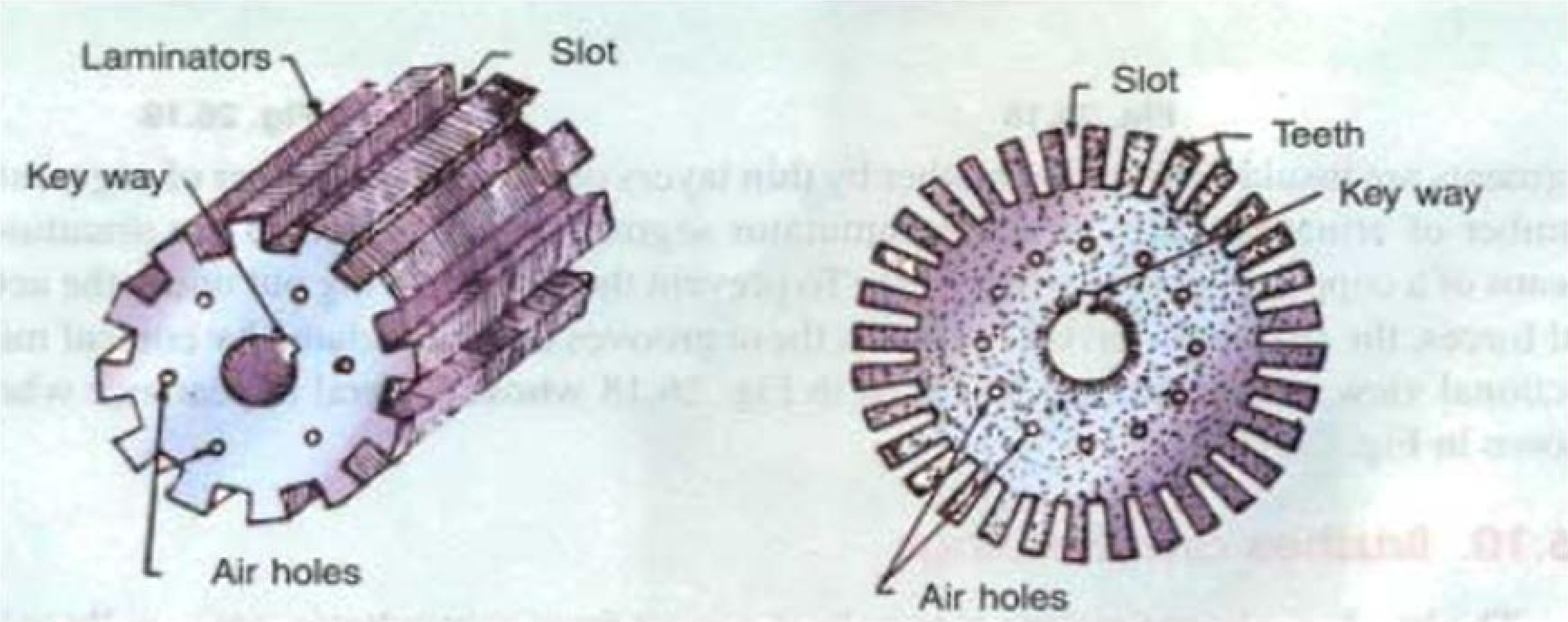




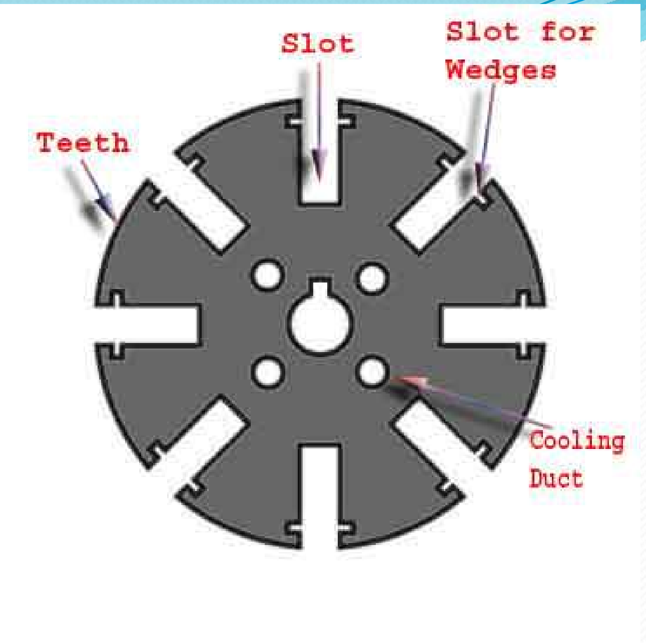
Armature core

It houses the armature conductor or coils and causes them to rotate and hence cut the magnetic flux of the field magnet.

Its most important function is to provide a path of very low reluctance to the flux through the armature from n-pole to s-pole



Armature cor



Position :

The armature core is a cylindrical s
built in laminations,   Mounted on the

Functions:

Armature core has a main function to act as a support to armature winding.

Material:

It is usually made of high grade silicon sheet steel. High grade silicon is used in   order to minimize the current losses due to hysteresis.

Armature Winding

In general, ac current (or voltage) is used for this type of winding.

Two types of armature windings are there :

(i) Lap winding, (ii) Wave winding

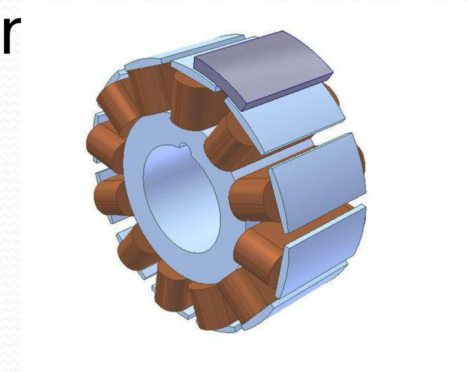
Position :

The Armature winding is placed on armature core .

Functions:

To carry current and to produce electr

flux.



Material:

Copper is used to make windings

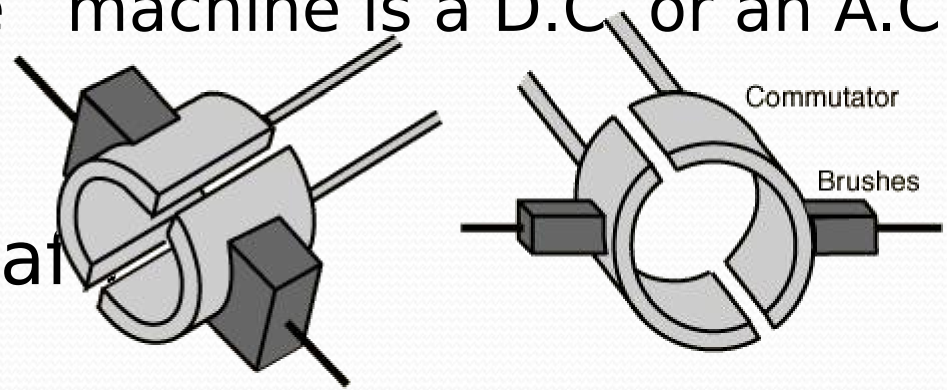
Commutator

Commutator is a most important and vital part in a D.C machine without   which the generator fails to work.

Commutator is the part through which one can determine weather the   machine is a D.C or an A.C.

Position :

It is placed on shaf



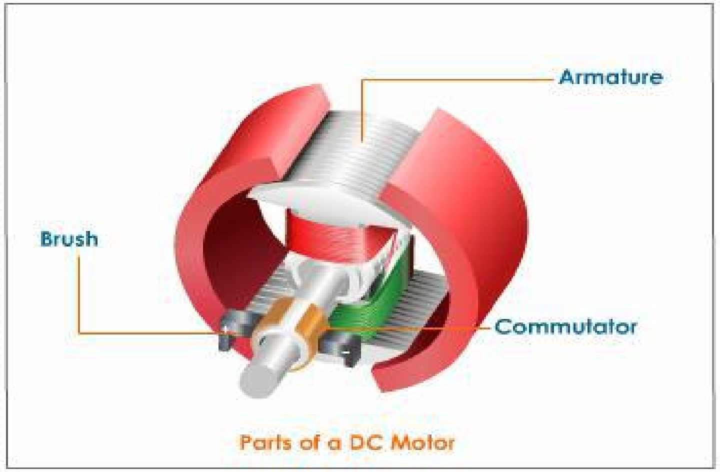
Commutator

Functions:

Rectification of current(or voltage) is main function of commutator.

For generator: converts AC to DC

For motor : converts DC to AC



Material:

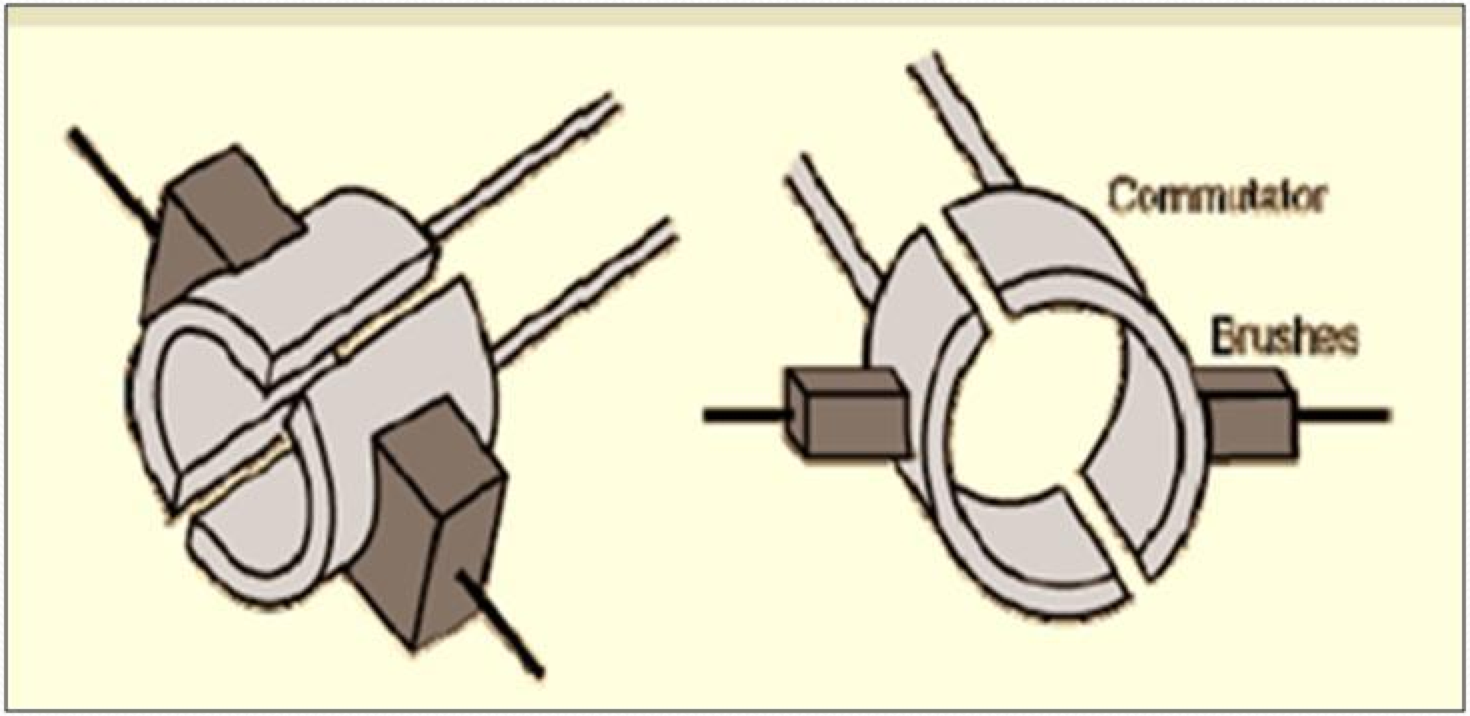
It is made from a number of wedge-shaped hard-drawn copper

bars or segments insulated from each other and from the shaft.

The segments form a ring around the shaft of the armature.

Brushes

The purpose of brush is to ensure electrical connections between the rotating commutator and stationary external load circuit. It is made of carbon and rest on commutator



Brushes

Position :

They are housed in a box type brush holders which are open at

both the ends. And they are placed on commutator

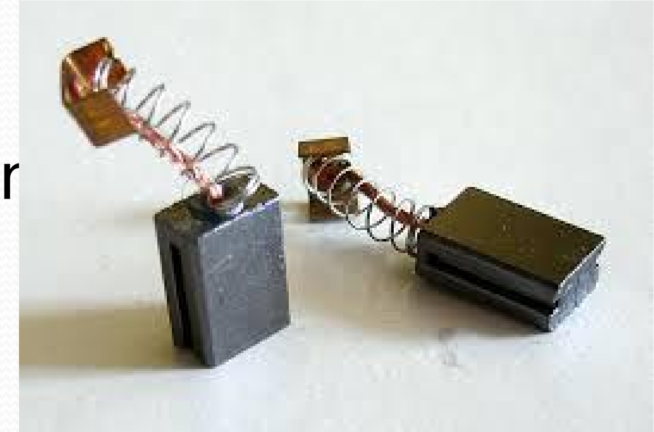
Functions:

Brushes and brush gears are used for the transmission of current from the Commutator to the external load circuit.

Material:

In general carbon is used for the r

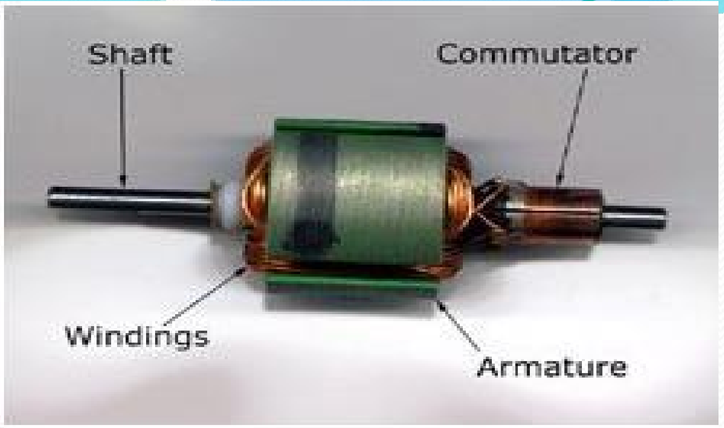
these brushes.



End covers:

They are placed at both end side

Shafts



Position :

The shaft is supported on both the ends by bearings which help in easy movement of the shaft.
Shaft is the central one over which the whole (rotor) parts are
loaded.

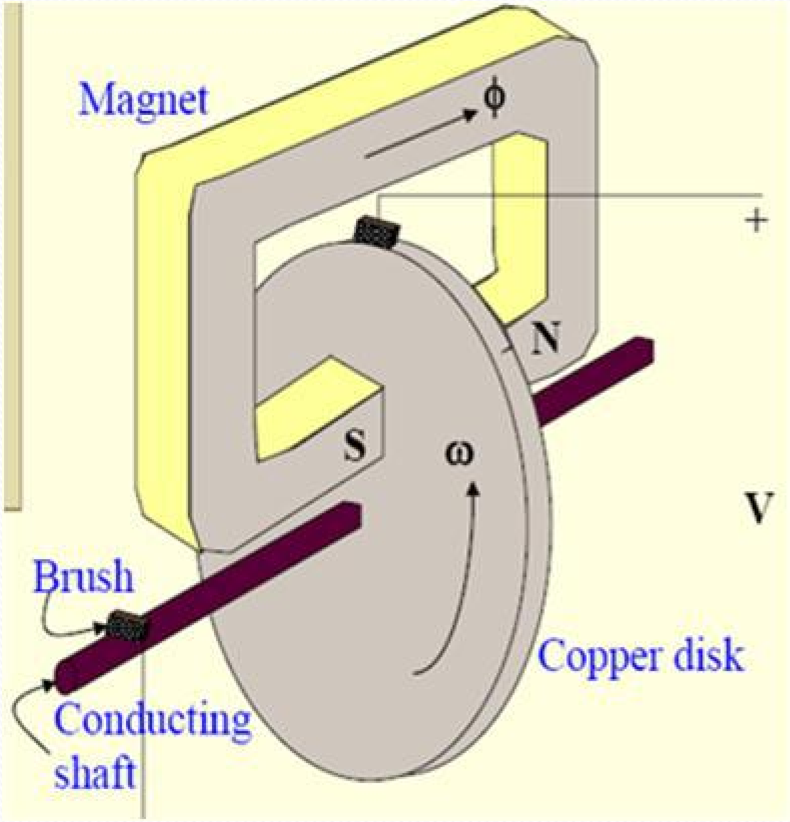
Functions:

To support rotor parts and can rotates to armature.

Principle Of Operation

Energy conversion is based on the principle of the production of induced emf.

Faraday Law



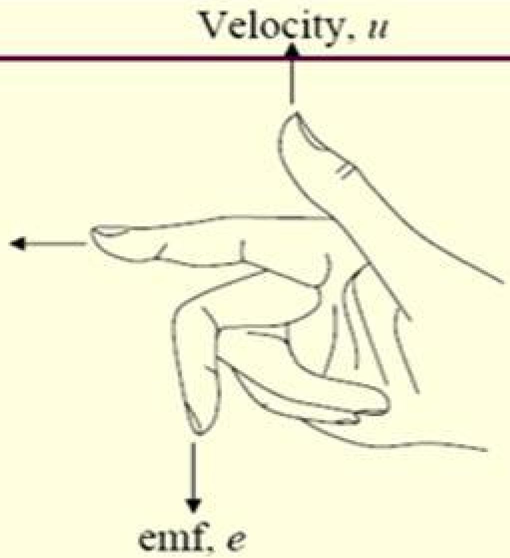
An emf is induced in a circuit placed in the magnetic field if either:

The magnetic field varying in the circuit is time varying,

Or there is a relative motion between the circuit and the magnetic field such that the conductor comprising the circuit cross the magnetic flux lines.

Principle Of Operation

Right hand rule and Generator action



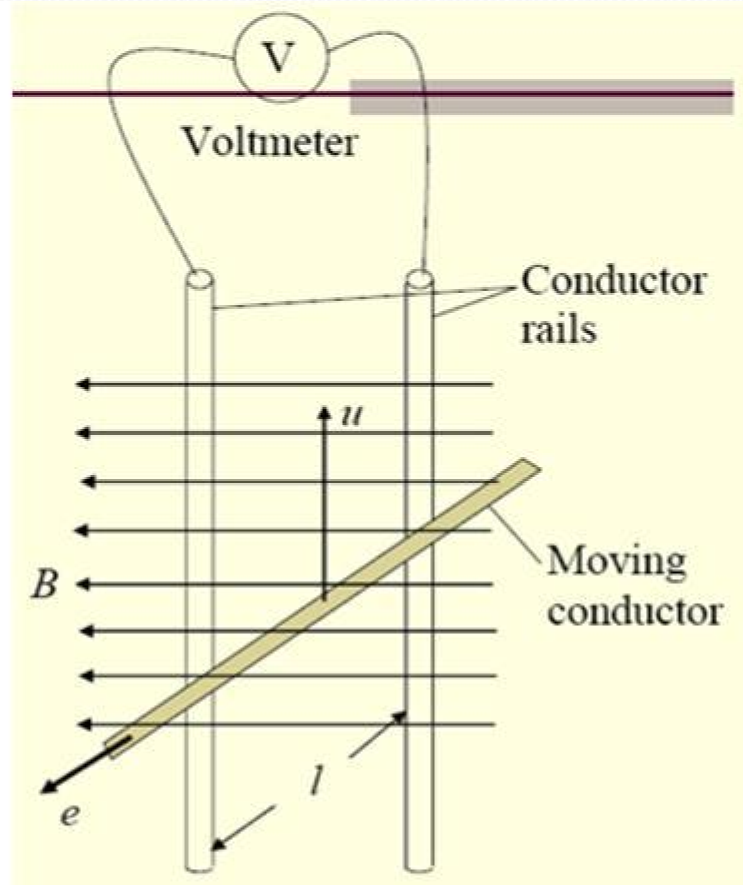
$$\Phi = B.A$$

$$\Phi = B.l.s$$

$$e = \frac{d\Phi}{dt} = \frac{dB.l.s}{dt}$$

$$e = B.l.\frac{ds}{dt} \qquad , u = \frac{ds}{dt}$$

Faraday's law or flux cutting rule → $\boxed{e = Blu}$



Principle of Operation of a D.C. Generator

Principle :

"It is based on the principle of production of dynamically (or motionally) induced e.m.f (Electromotive Force). Whenever a conductor cuts magnetic flux, dynamically induced e.m.f. is produced in it according to Faraday's Laws of Electromagnetic Induction. This e.m.f. causes a current to flow if the conductor circuit is closed. "

Faraday's Laws of Electromagnetic Induction.: Whenever the magnetic flux linked with a circuit changes, an e.m.f. is always induced in it.

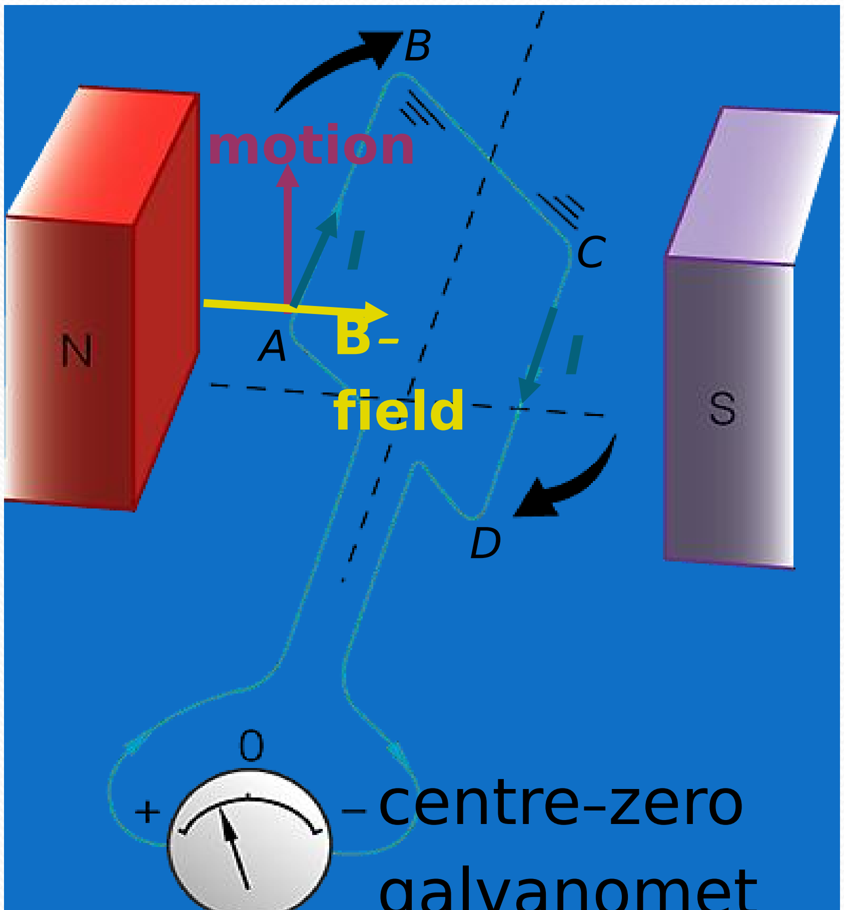
or

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

Induced voltage and current in a rotating coil

When the coil is rotated,

By Fleming's right-hand rule...

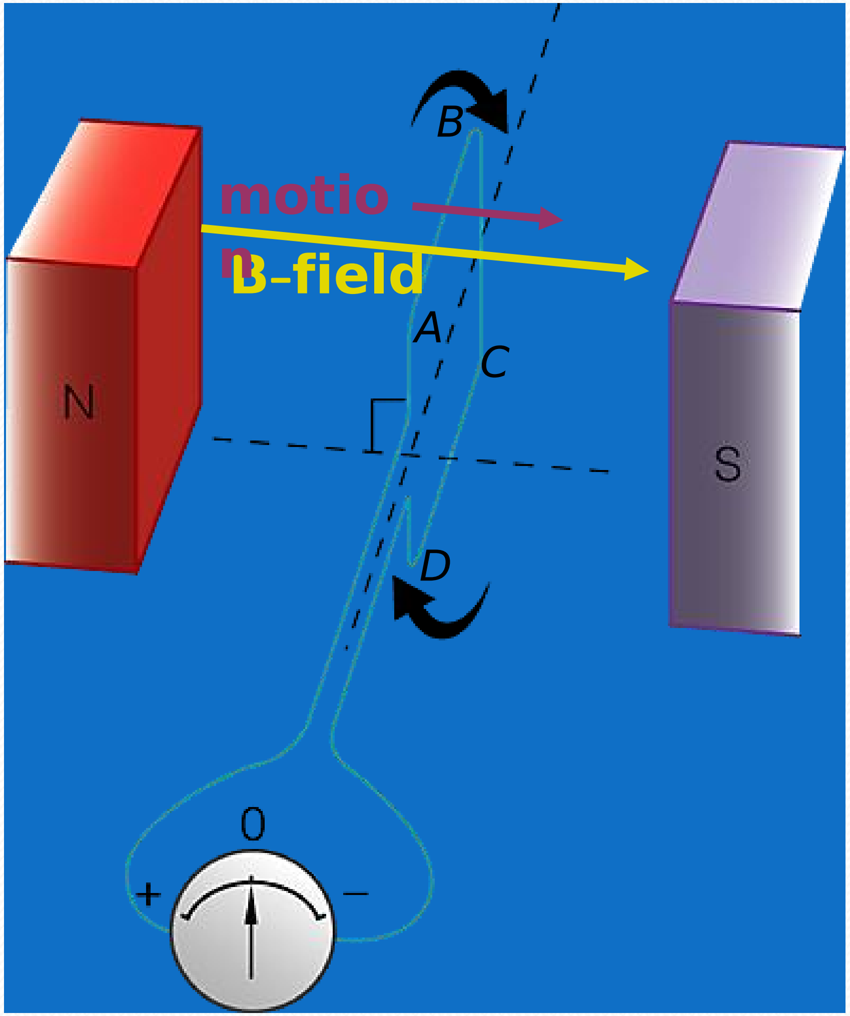


AB moves upwards, *CD* moves downwards

voltage is induced across *AB* and *CD*

drives *I* through coil & the outside circuit

Induced voltage and current in a rotating coil



After $1/4$ turn, coil passes through the vertical position.

B–field parallel to…

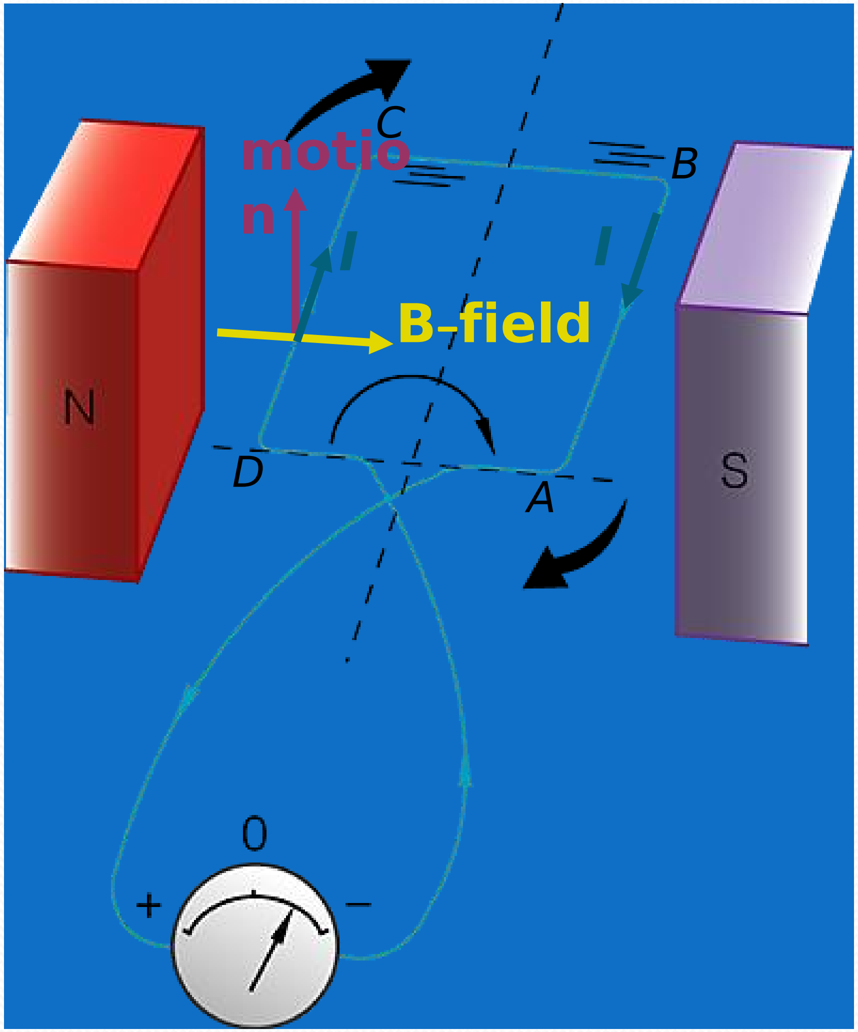
motion of *AB* & *CD*

no field lines are cut

no induced voltage

no induced *I*

Induced voltage and current in a rotating coil



After $1/2$ turn,

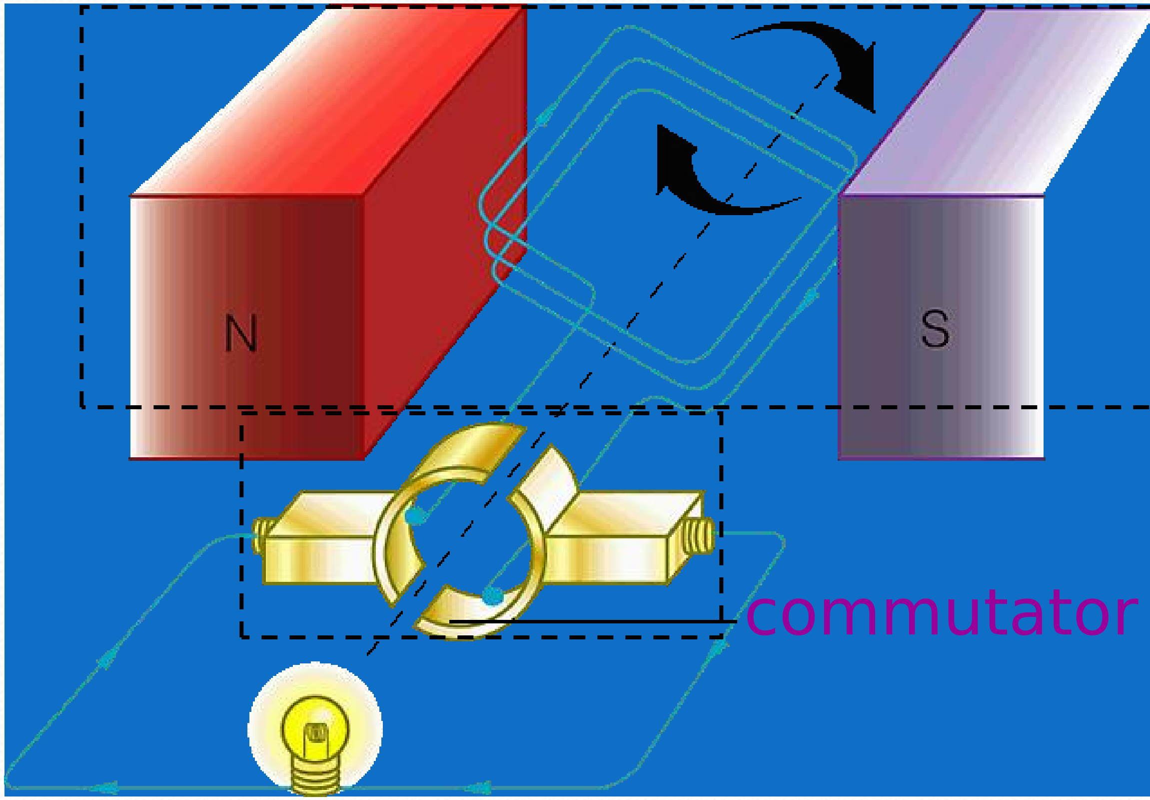
AB moves downwards, *CD* moves upwards

induced *I* flows in opposite direction in the outside circuit

If rotation goes on…

a.c.

Simple d.C. Generator



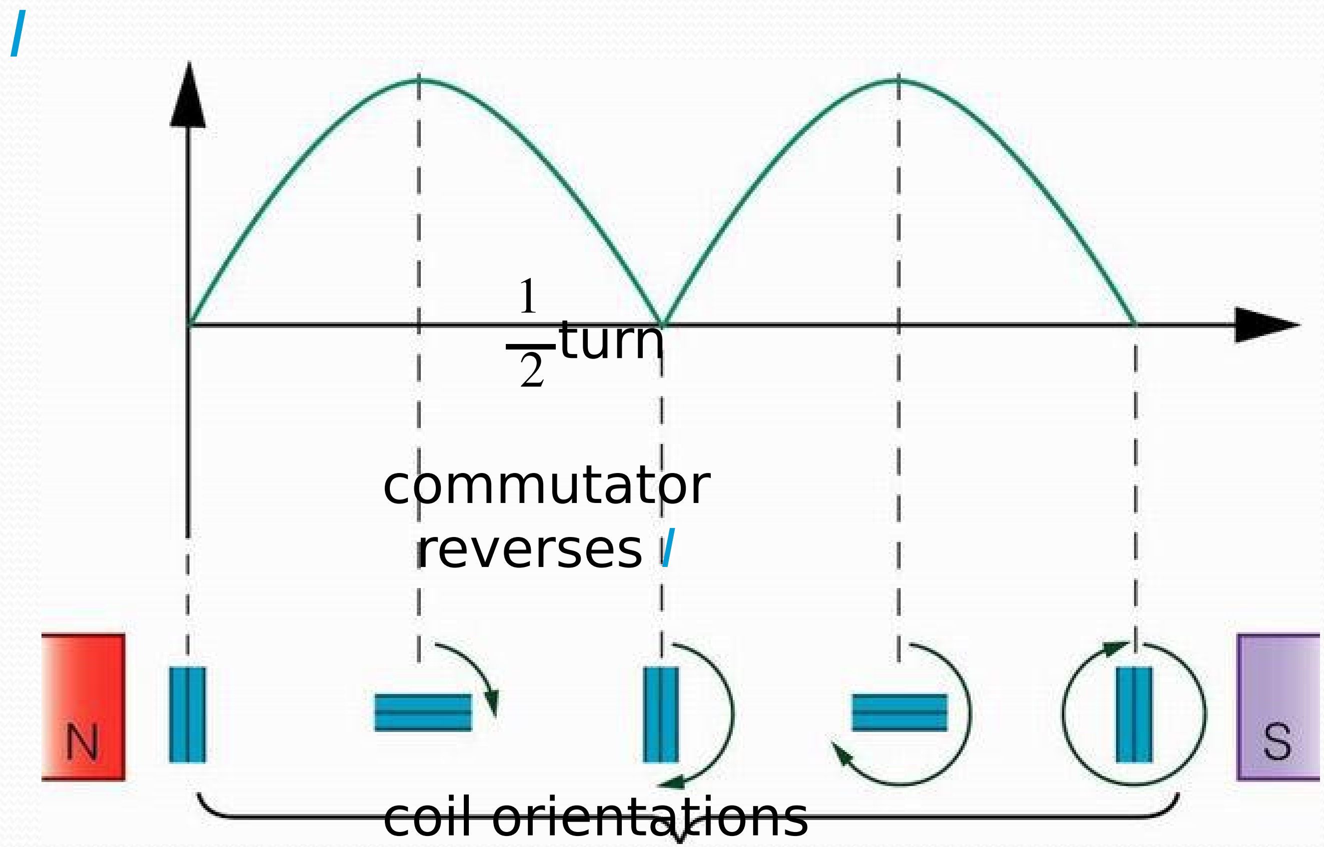
Every time the coil passes through the vertical, it reverses coil's connections with outside circuit.

I in the outside circuit always flows in 1 direction.

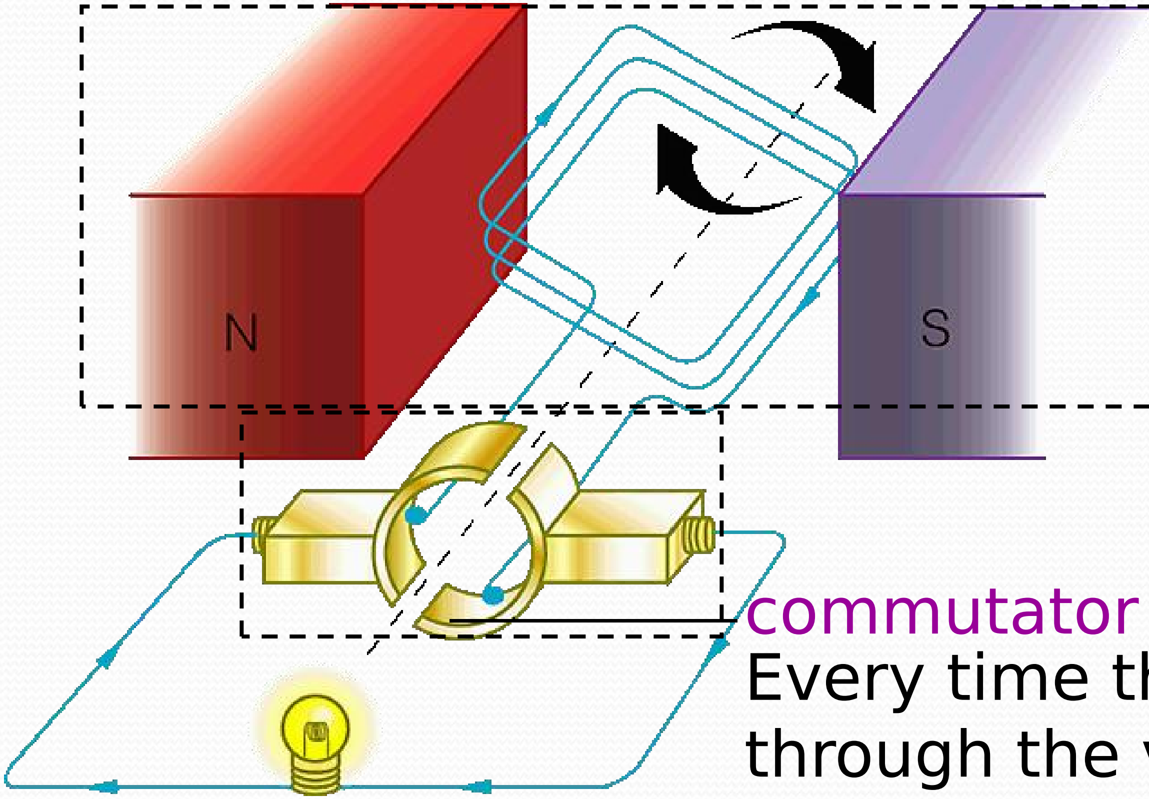
Simple d.C. Generator

Current in d.c. generator:

But, *I* varies during 1 complete rota



Simple d.c. generator



d.c. generator

commutator

Every time the coil passes through the vertical, it reverses coil's connections with outside circuit.

I in the outside circuit always flows in 1 direction.

Simple d.c. generator

Current in d.c. generator:

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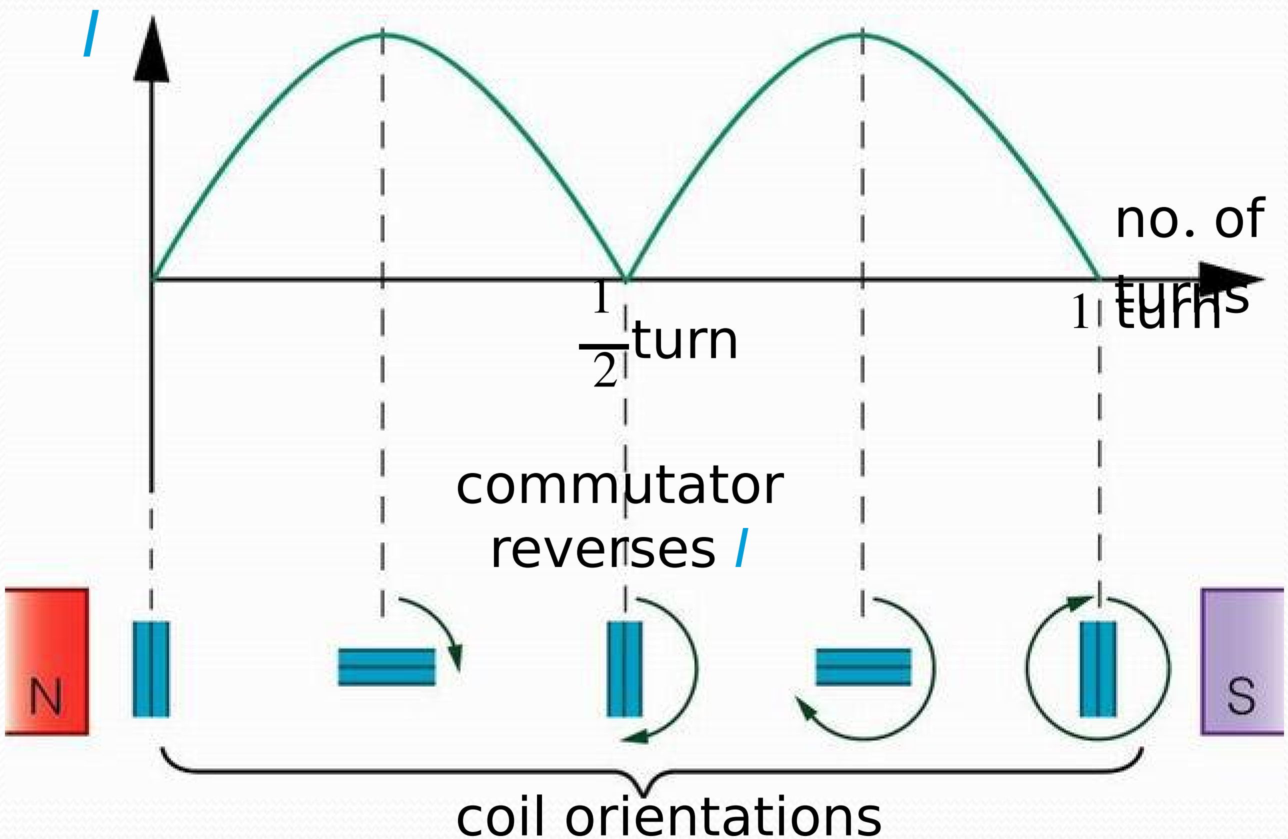


Induced EMF (Ea)

Let

Φ = flux/pole in weber

Z = total number of armature conductors

= No. of slots x No. of conductors/slot

P = No. of generator poles

A = No. of parallel paths in armature

N = armature rotation in revolutions per minute (r.p.m)

E = e.m.f induced in any parallel path in armature

Generated e.m.f Eg = e.m.f generated in any one of the parallel paths i.e E.

E.M.F equation of a Generator

Average e.m.f geneated /conductor = **dΦ/dt** volt (n=1)

Now, flux cut/conductor in one revolution **dΦ = ΦP** Wb

No.of revolutions/second = N/60

Time for one revolution, **dt = 60/N** second

Hence, according to Faraday's Laws of Electromagnetic Induction,
EMF generated per conductor =

$$\frac{d\phi}{dt} = \frac{\phi PN}{60} \text{ volt}$$

For a simplex wave wound generator

No. of parallel paths = 2

No. of conductor (in se

$$\frac{\phi PN}{60} \times \frac{Z}{2} = \frac{\phi ZPN}{120} \text{ volt}$$

EMF generated /path =

For a simplex lap wound generator

No. Of parallel paths = P

No. of conductor (in se

$$\frac{\phi PN}{60} \times \frac{Z}{P} = \frac{\phi ZN}{60} \text{ volt}$$

EMF generated /path =

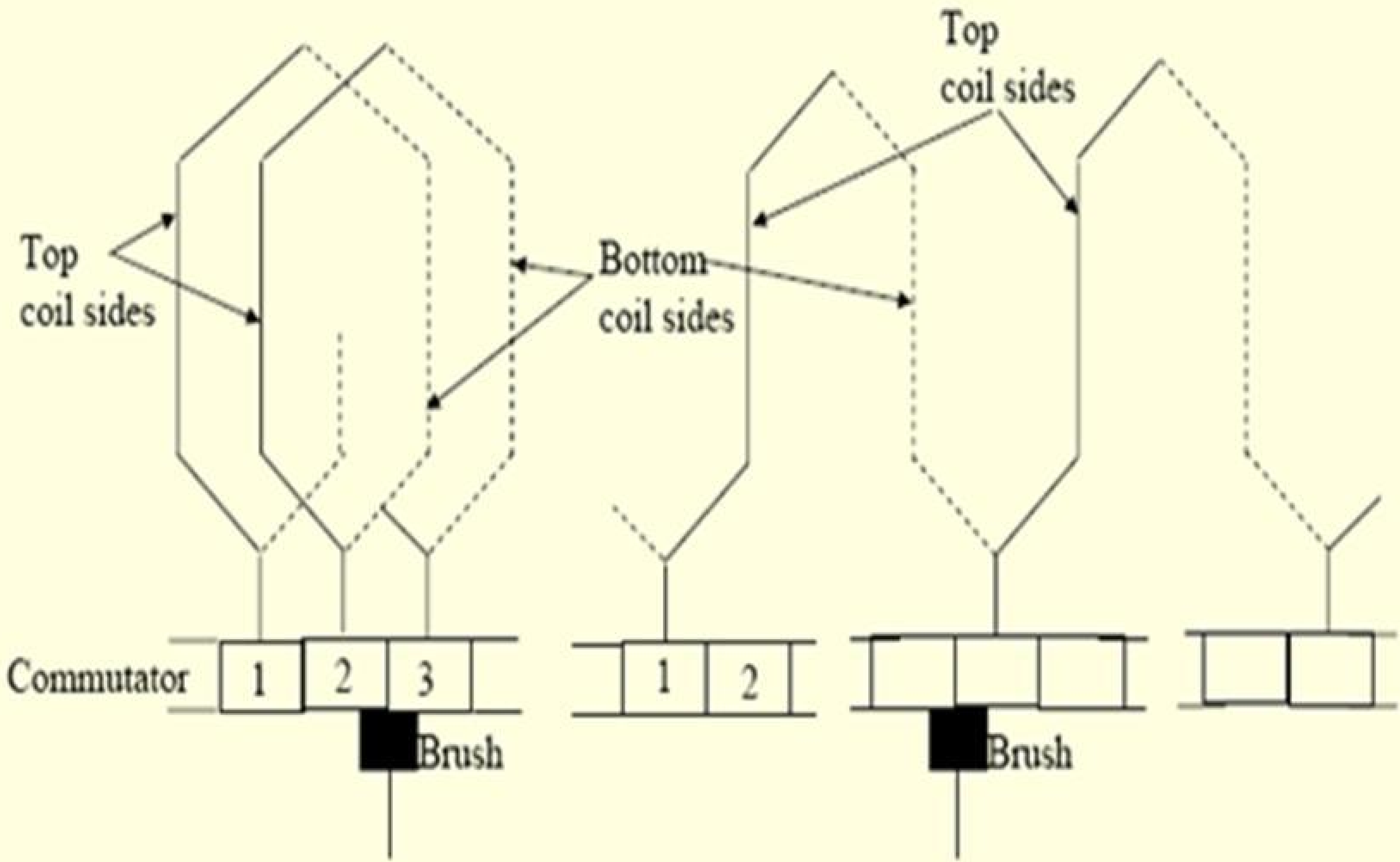
E.M.F equation of a Generator

In general generated EMF $E_g = \dfrac{\phi ZN}{60} \times \dfrac{P}{A}$ volt

Where A $=$ 2 for simplex wave winding

$=$ P for simplex lap winding

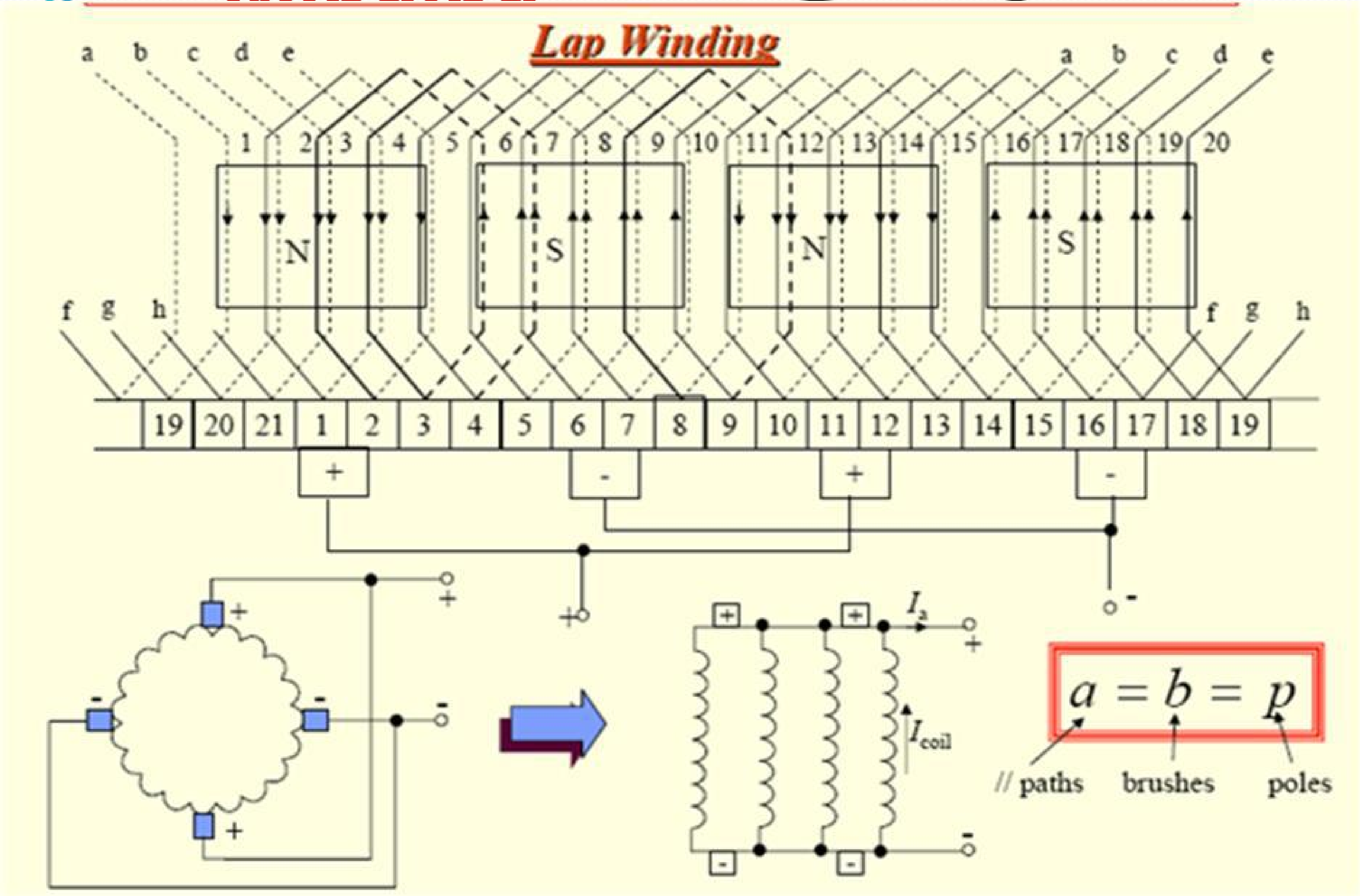
Armature Winding



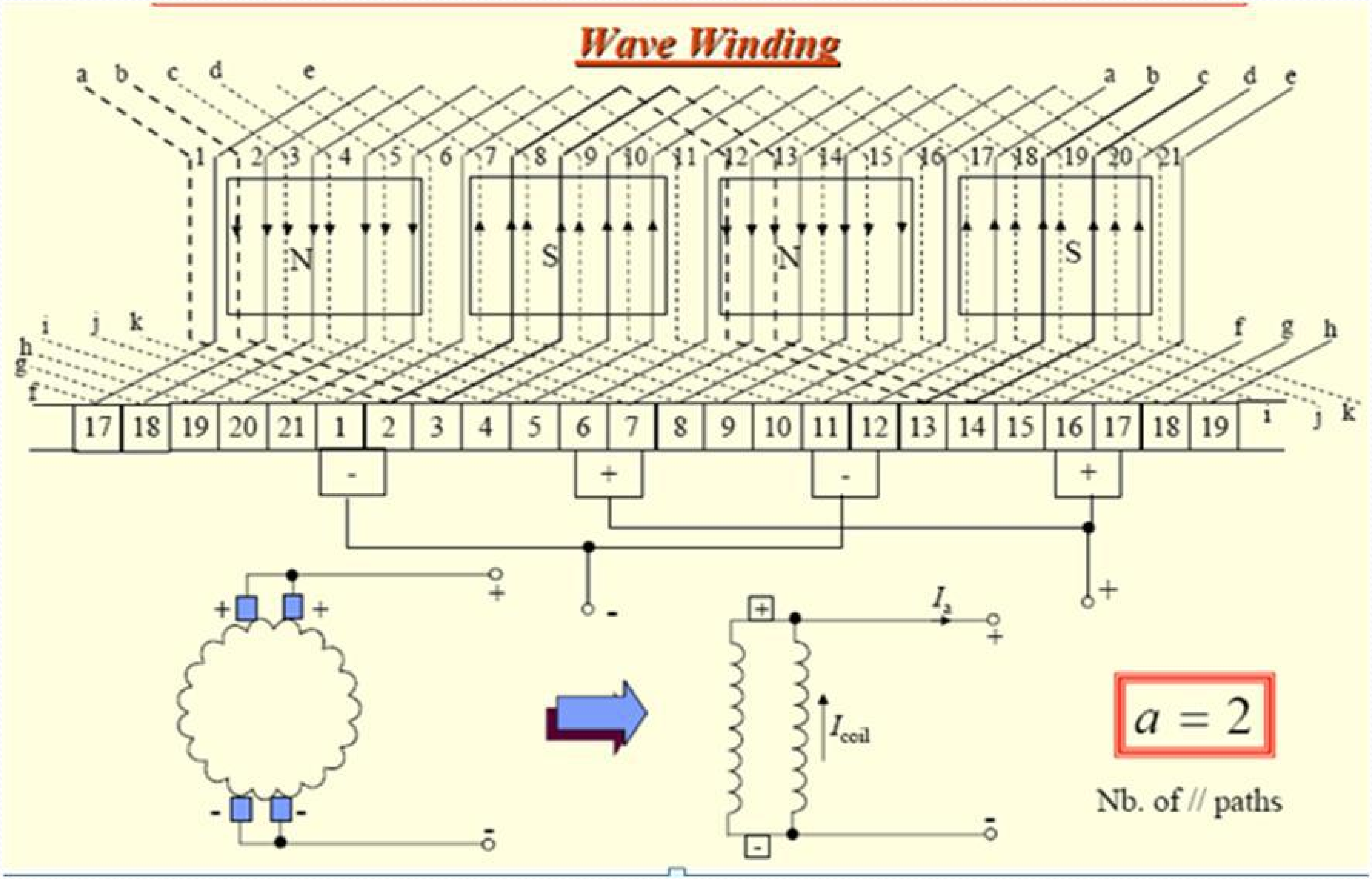
Elements of Lap Winding

Elements of Wave Winding

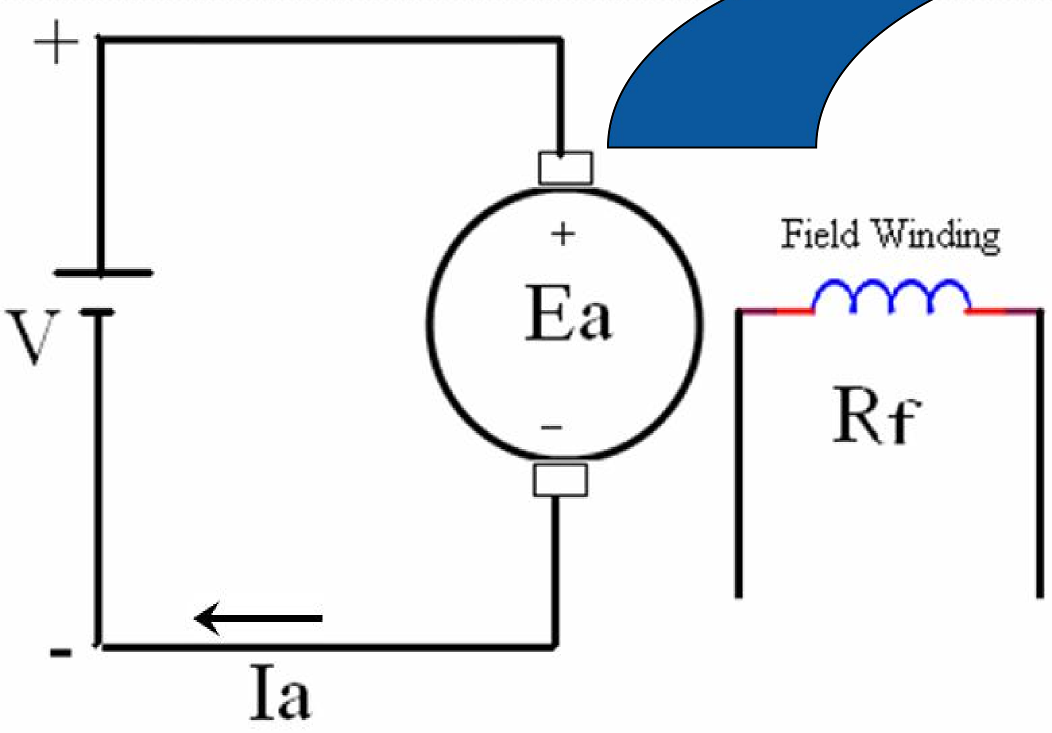
Armature Winding

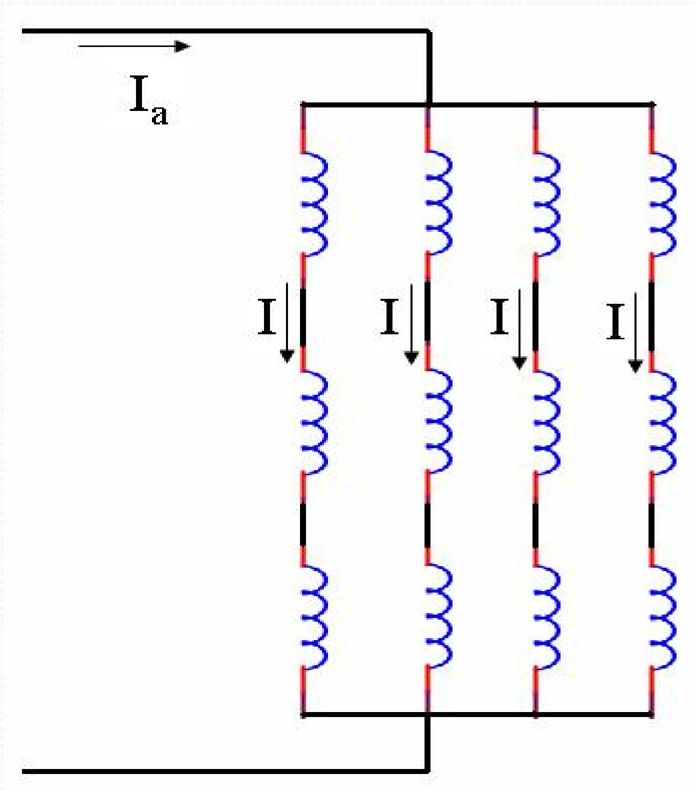


Armature Winding



Electrical Circuit of DC Machine

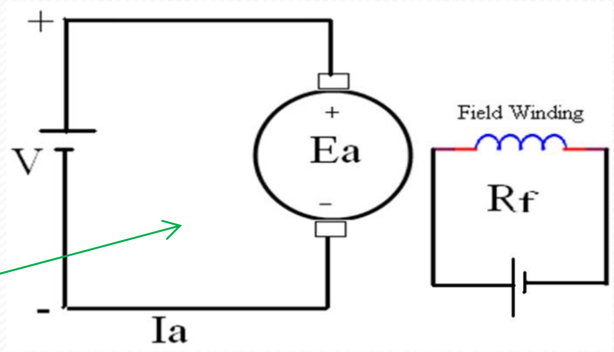


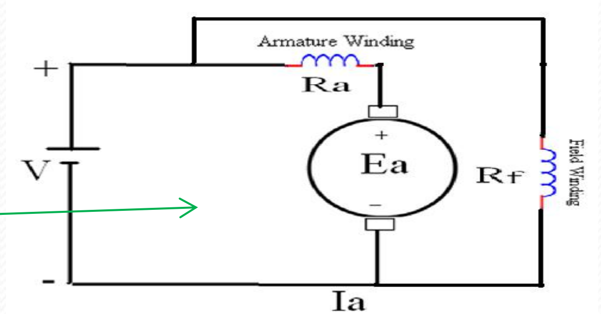


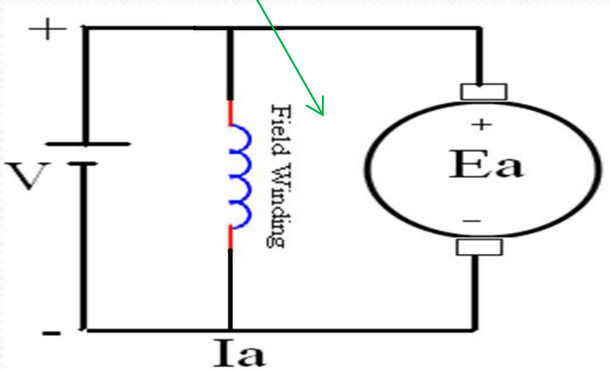
$E_a = V – R.\ I_a$

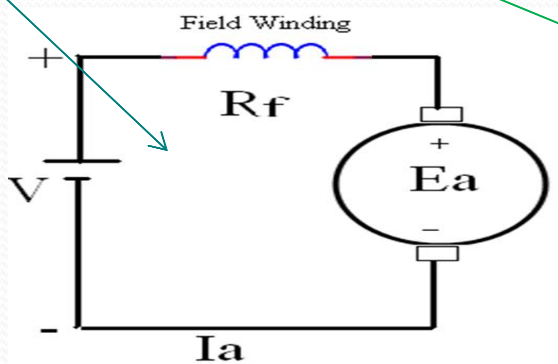
Types of DC Machine

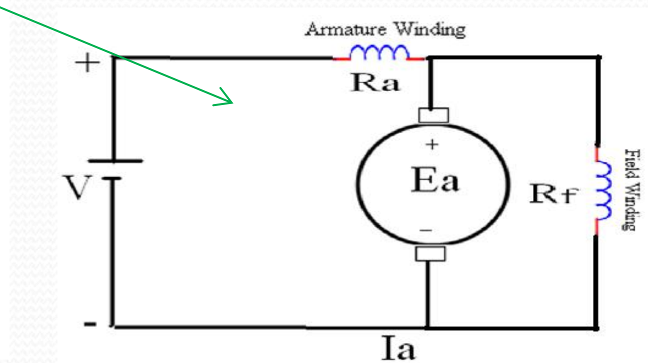
- Direct Current (DC) Machine
  - Self Excited
    - Shunt
    - Series
    - Compound Cumulative &Differential
  - Separately Excited



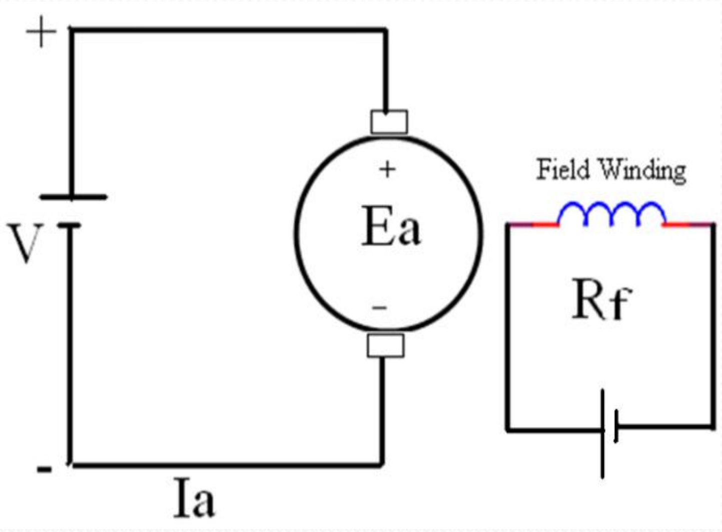








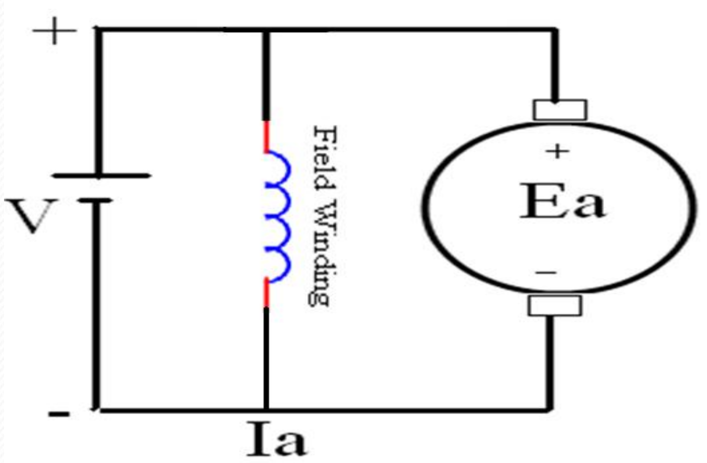
Separately Excited DC Generator



Separately generators are normally low voltage, heavy current generators.

They are used in electroplating, electro-refining of metals and in dc ship propulsion.

Shunt Generator



The field coil of shunt generator is wound with many turns, so resistance of the field winding is very high..

They are used in small installations, as charging accumulators, as main generators on board ship.

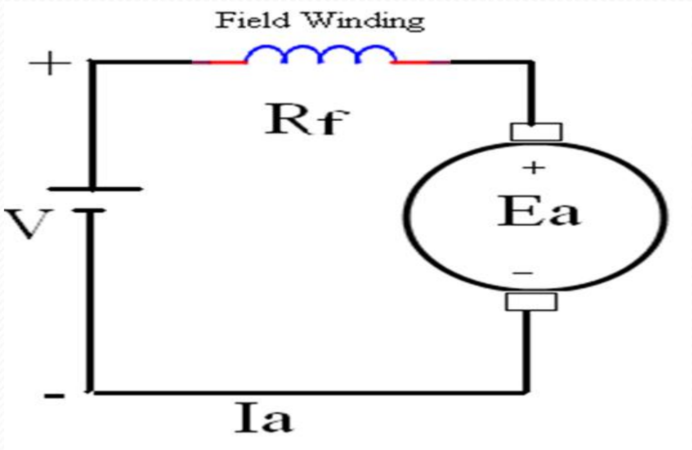
$$V_f = R_f I_f = V_t$$
$$E_a = V_t + I_a r_a$$

$$V_t = I_L R_L$$
$$I_a = I_L + I_f$$

Series Generator

The field coil of series generator is wound with few turns of thick wire, so resistance of the field winding is very low.

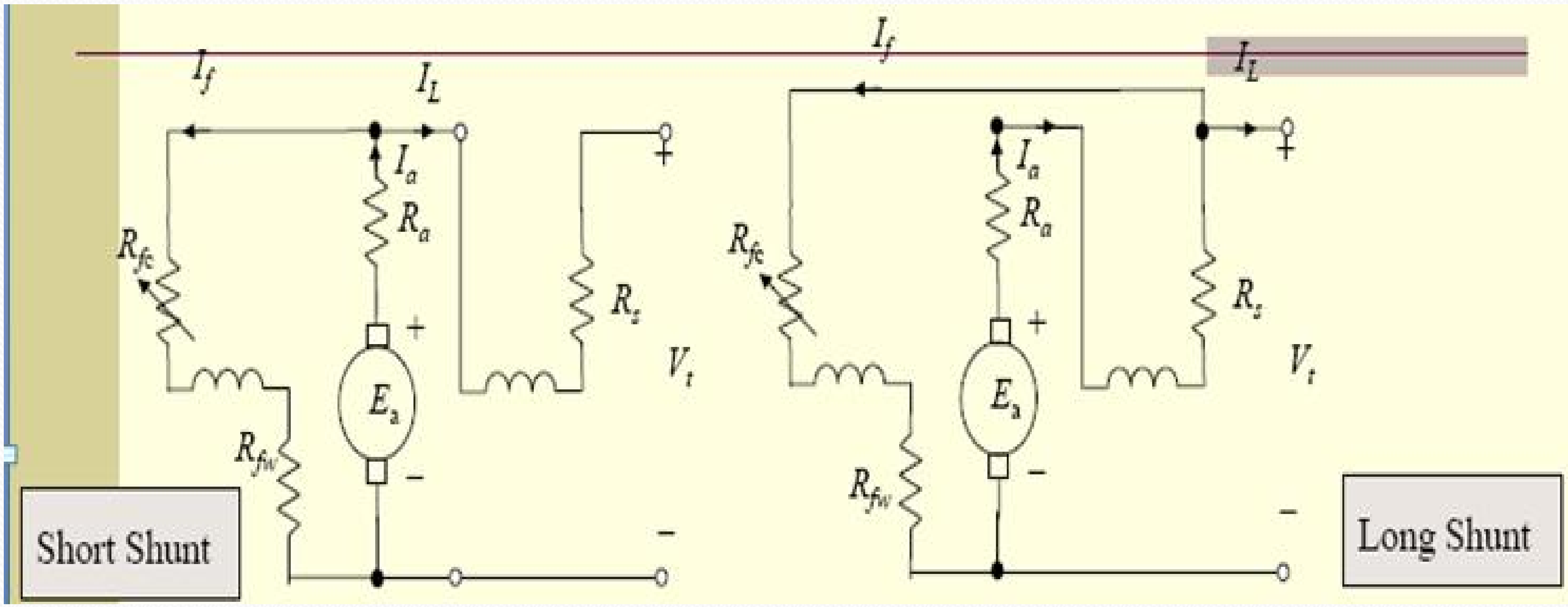
They are used in special purpose as Boosters.



$$V_t = E_a - I_a(r_a + R_s)$$

$$I_L = I_a = I_f$$

Compound Generator



$$V_t = E_a - I_a R_a - I_L R_s$$

$$I_L = I_a - I_f$$

$$I_f = \frac{E_a - I_a R_a}{R_{fw} + R_{fc}}$$

$$V_t = E_a - I_a (R_a + R_s)$$

$$I_L = I_a - I_f$$

$$I_f = \frac{V_t}{R_{fw} + R_{fc}}$$

DC GENERATOR CHARACTERISTICS

In general, three characteristics specify the steady-state performance of a DC generators:

1. Open-circuit characteristics (No load characteristics) : Generated voltage versus field current at constant speed. (E/I_f)

2. Internal characteristic : Terminal voltage versus field current at constant armature current and speed. (E/I_f)

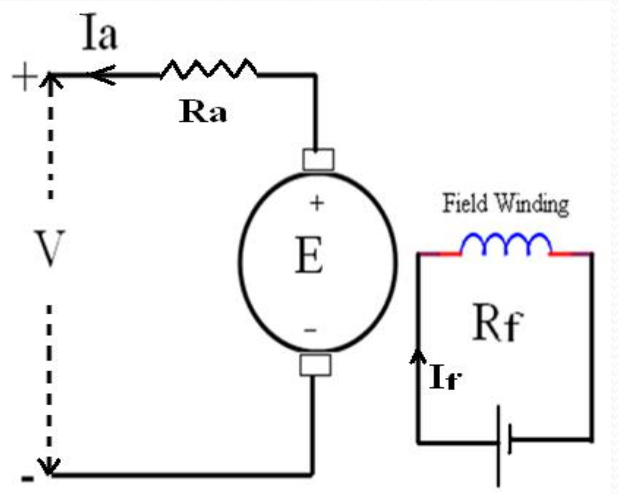
3. E … (Load
C … l voltage versus
lo … speed. (V/Ia)

$$E \; 6 \; \frac{p\,f\,NZ}{60\;A} \;\mu\; \varphi \;\mu\; I_f$$

$$E \; 6 \; KI_f$$

$$E \; 6 \; V \;.\; I_a R_a$$

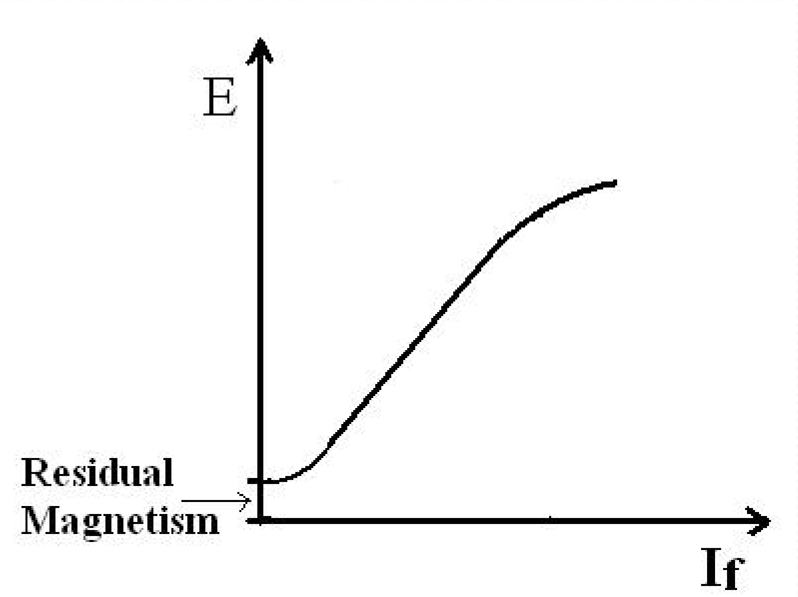
Characteristics of Separately-Excited DC Generators:



1. Open-circuit characteristics
   (No load characteristics): (E/I_f)

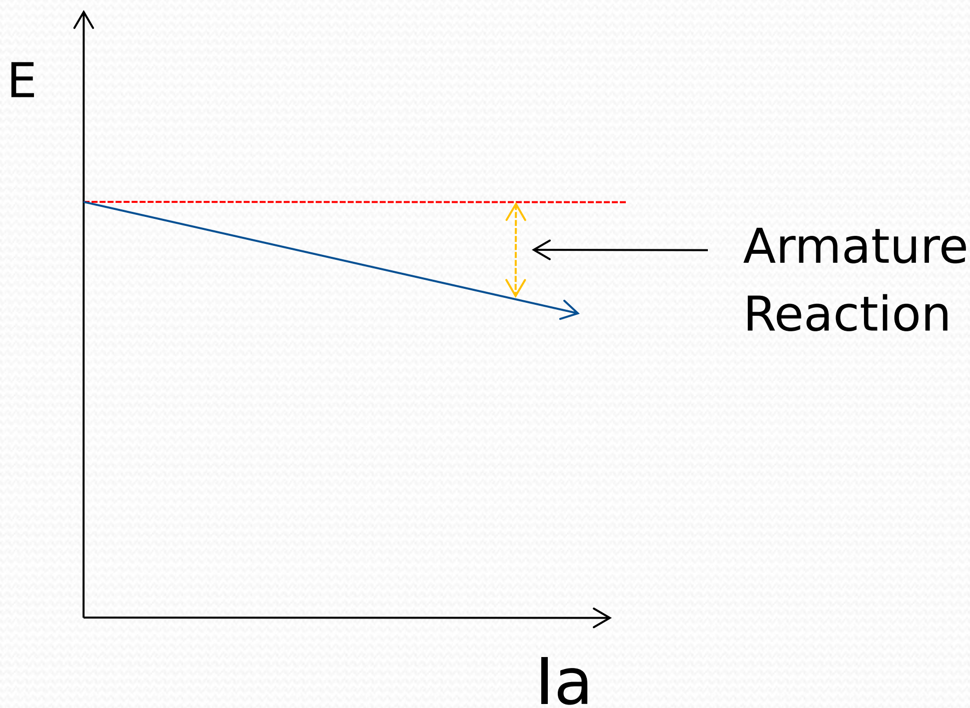
$$E = \frac{p\phi NZ}{60A} \propto \phi \propto I_f$$

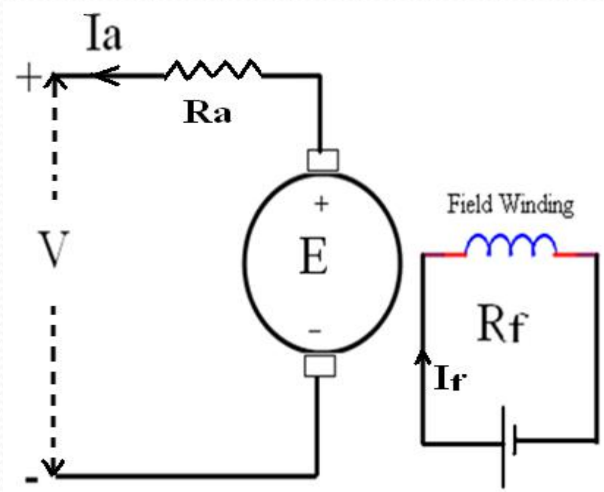
$$E = KI_f$$



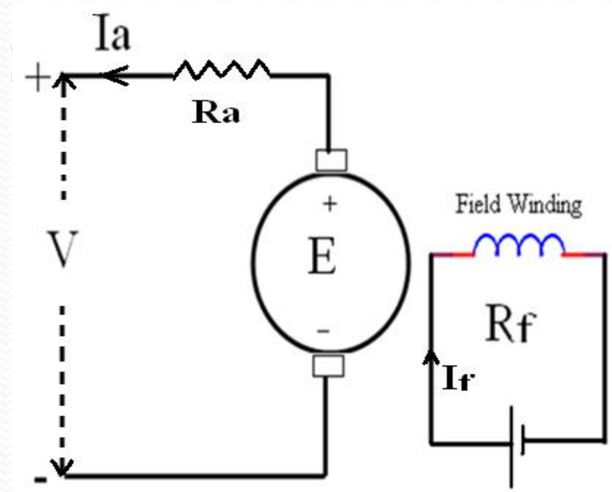
2. Internal characteristic :(E/I_a)

$E\ 6\ V\ .\ I_a R_a$





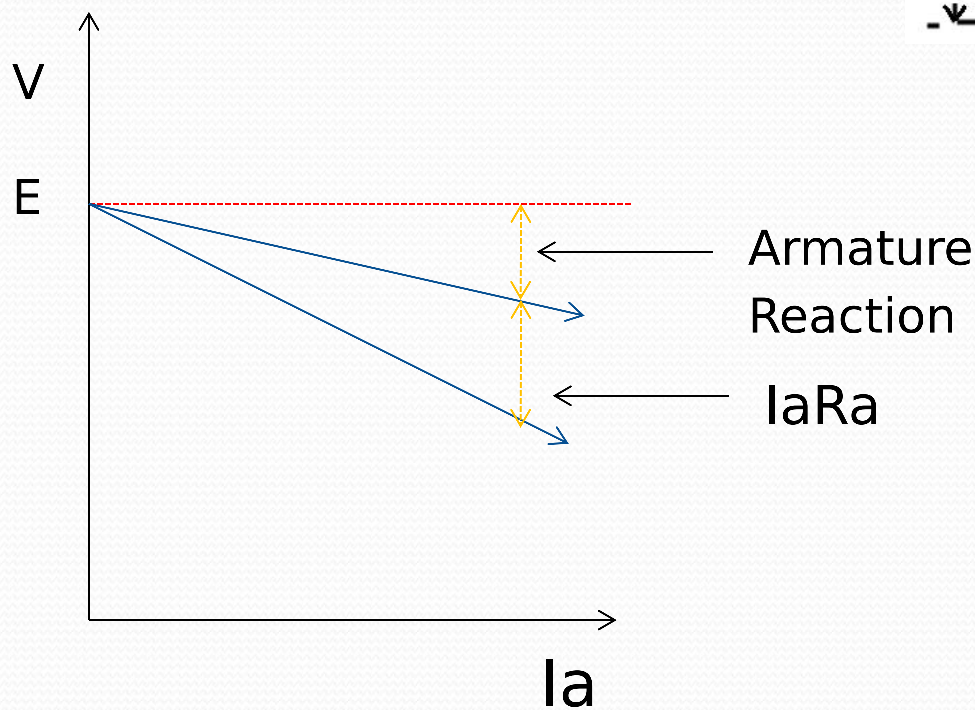
3. External characteristic (Load Characteristics)



(V/

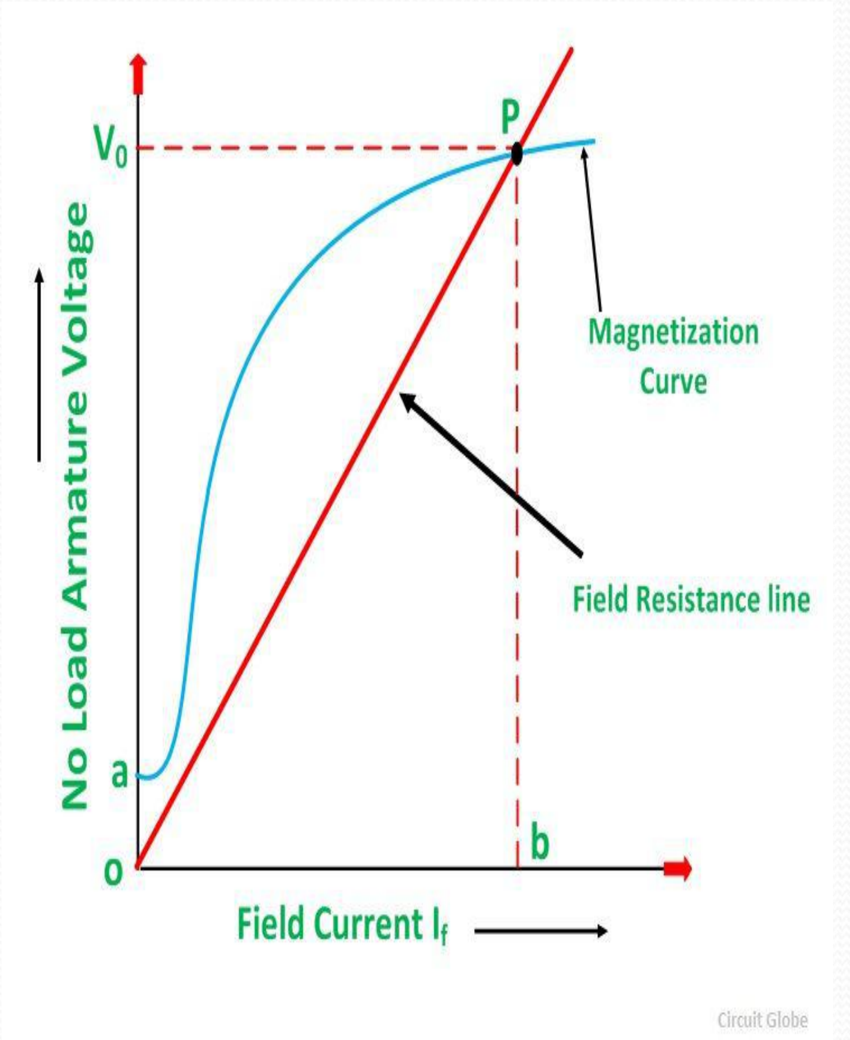
$$E \; 6 \, V \; . \; I_a R_a$$

$$V \; 6 \; 0 I_a R_a \; . \; E$$



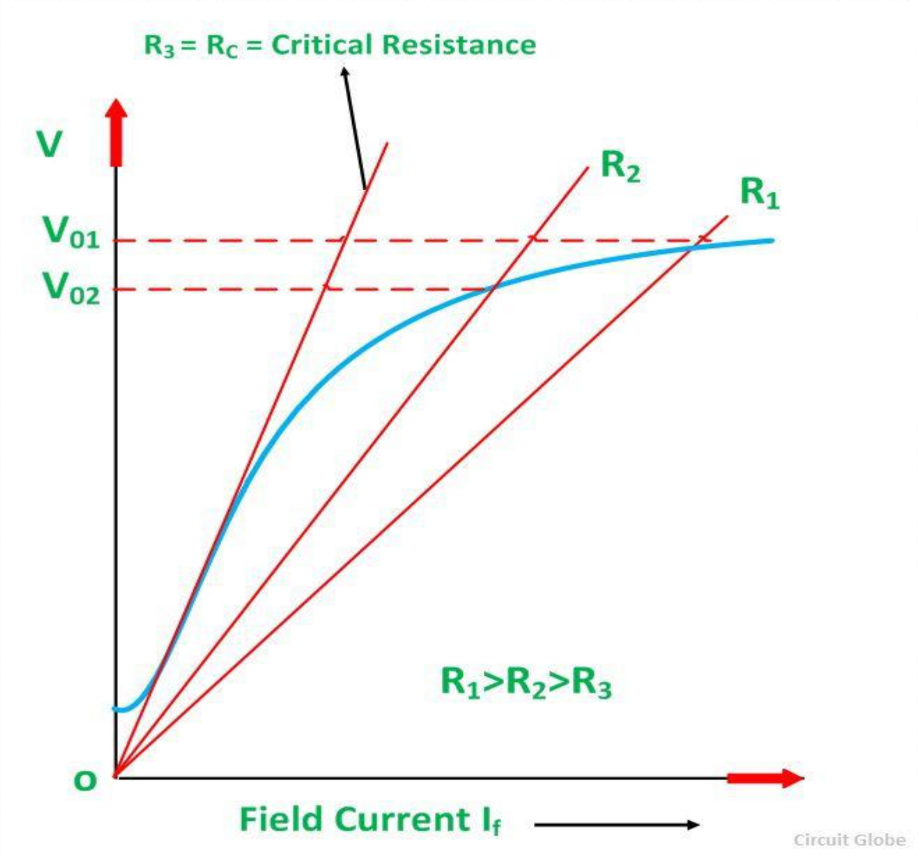
Magnetic or Open Circuit Characteristic of Shunt Wound DC Generator

Due to residual magnetism the curves start from a point A slightly up from the origin O. The upper portions of the curves are bend due to saturation.



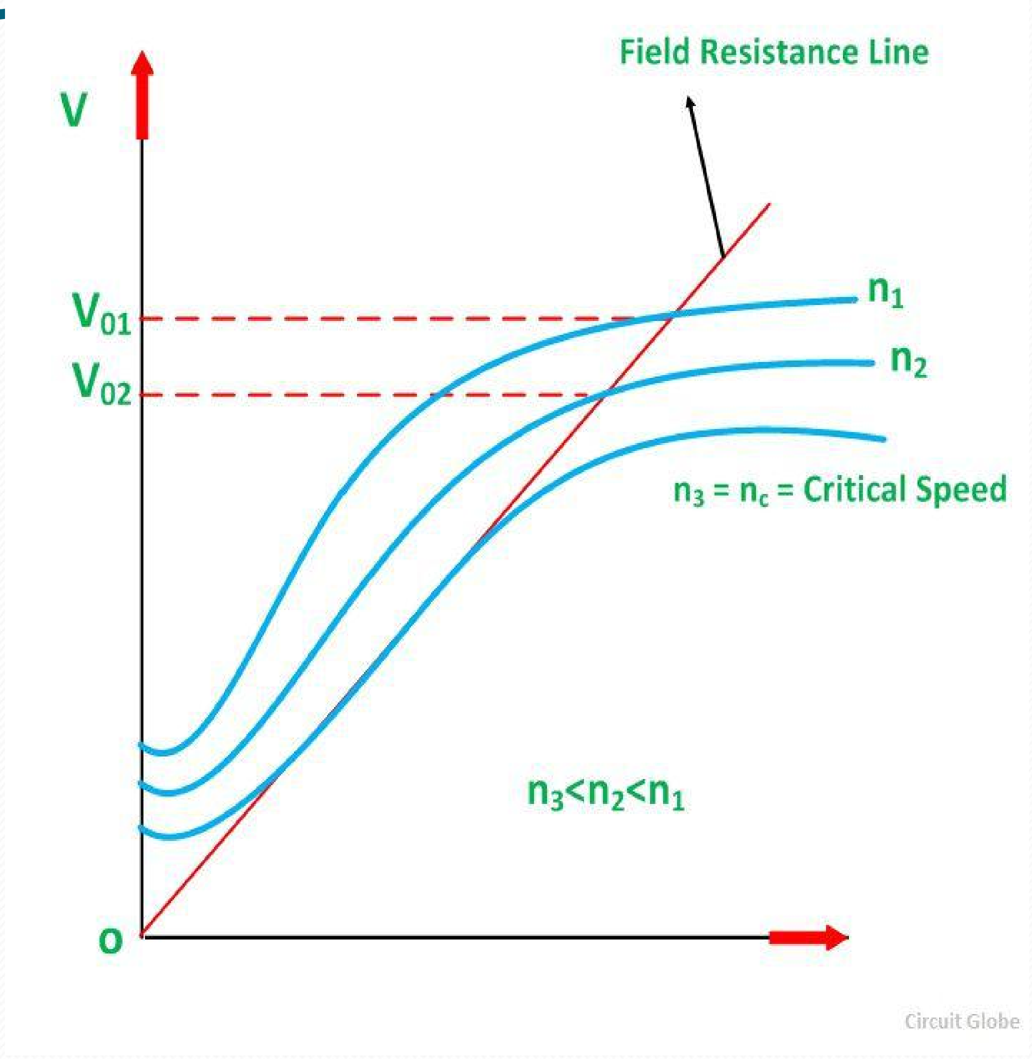
Critical Load Resistance of Shunt Wound DC Generator

This is the minimum external load resistance which is required to excite the shunt wound generator.



Critical speed

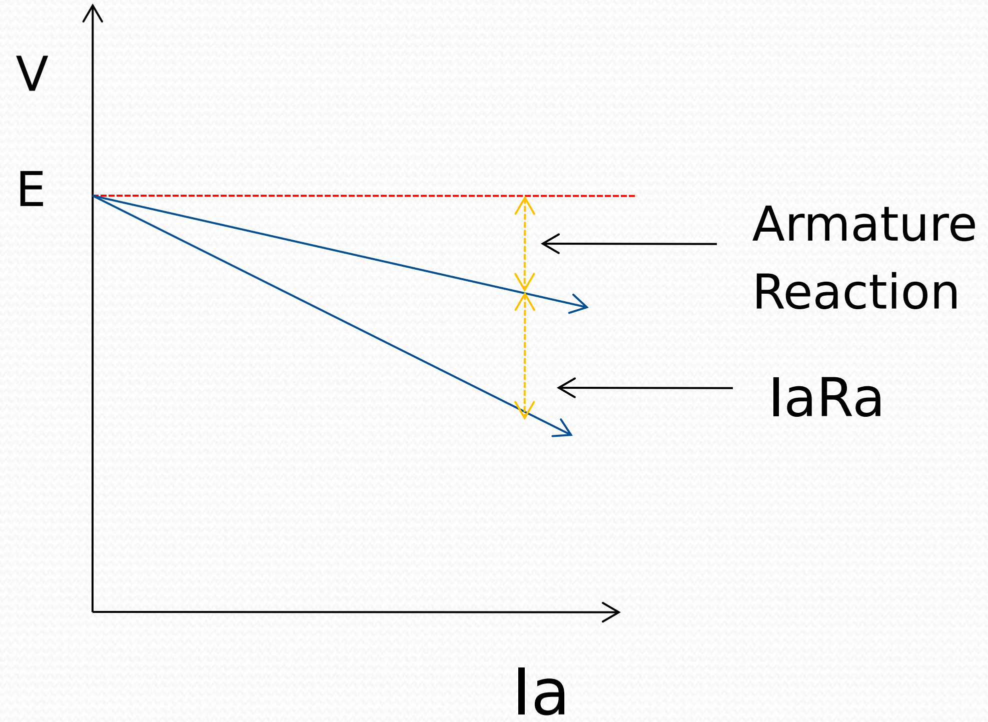
The external load resistance of the machine needs to be maintained greater than its critical value otherwise the machine will not excite or will stop running if it is already in motion.



Internal Characteristic of Shunt Wound DC Generator

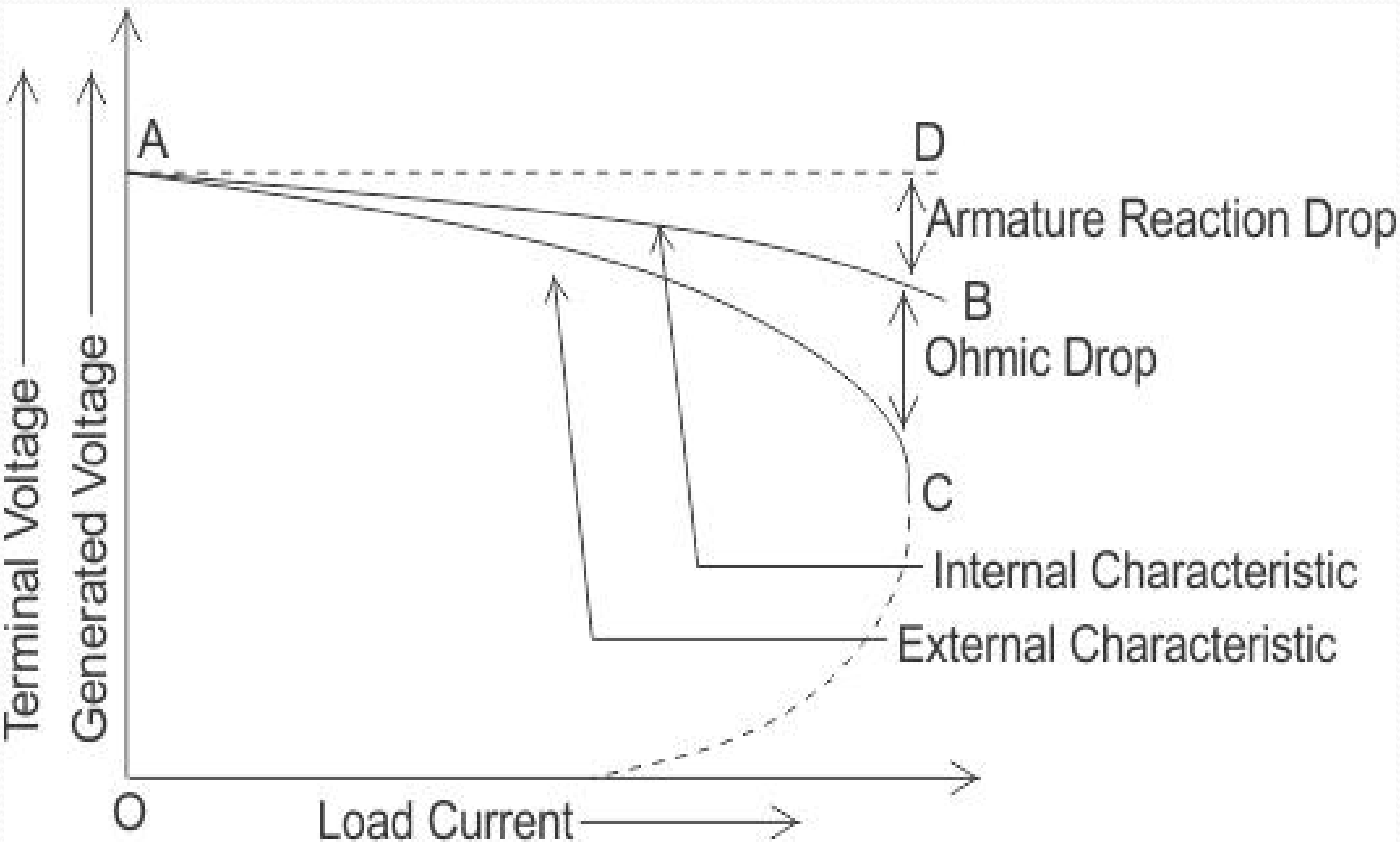
When the generator is loaded then the generated voltage is decreased due to armature reaction.

So, generated voltage will be lower than the emf generated at no load.



The internal characteristic curve represents the relation between the generated voltage E_g and the load current I_L.

Characteristics of DC shunt Generators:



External Characteristic of Shunt Wound DC Generator

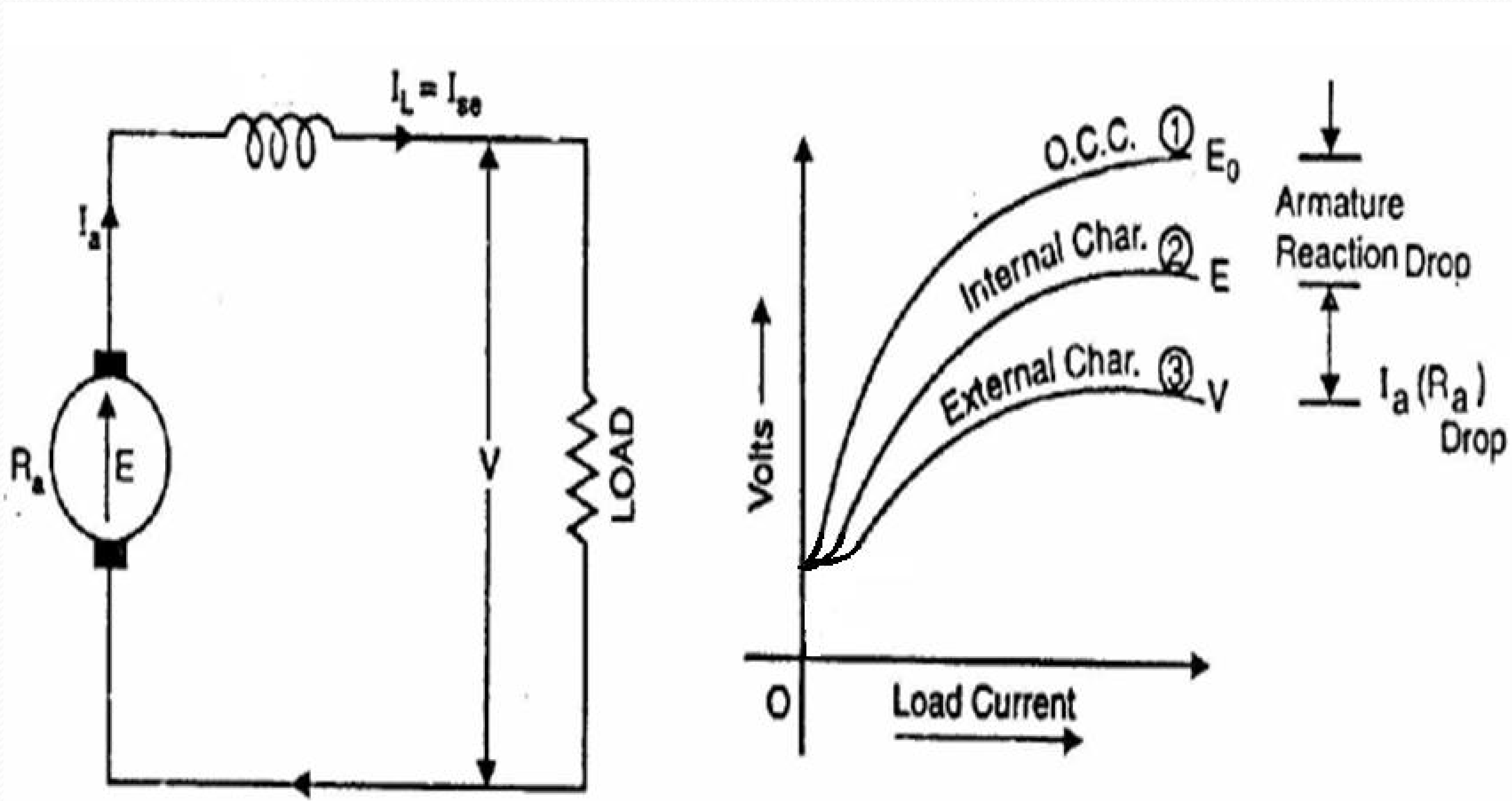
When the load resistance of a shunt wound DC generator is decreased, then load current of the generator increased.

But the load current can be increased to a certain limit with (upto point C) the decrease of load resistance.

Beyond this point, it shows a reversal in the characteristic.

Any decrease of load resistance, results in current reduction and consequently, the external characteristic curve turns back as shown in the dotted line and ultimately the terminal voltage becomes zero.

Characteristics of DC series Generator



Commutation

The reversal of current in a coil as the coil passes the brush axis is called commutation.

When commutation takes place, the coil undergoing commutation is short circuited by the brush. The brief period during which the coil remains short circuited is known as **commutation period Tc.**

If the current reversal is completed by the end of commutation period, it is called **ideal commutation.**

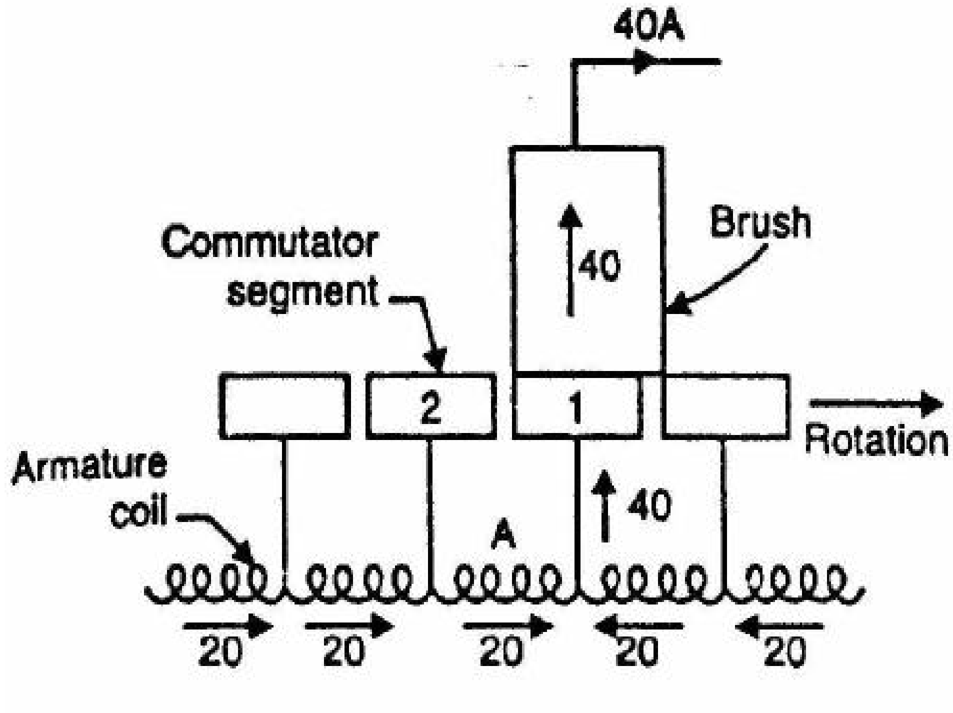
If the current reversal is not completed by that time, then sparking occurs between the brush and the commutator which results in progressive damage to both.

Ideal Commutation

the brush is in contact with segment 1 of the commutator.

The commutator segment 1 conducts a current of 40 A to the brush; 20 A from coil A and 20 A from the adjacent coil as shown.

The coil A has yet to undergo commutation.



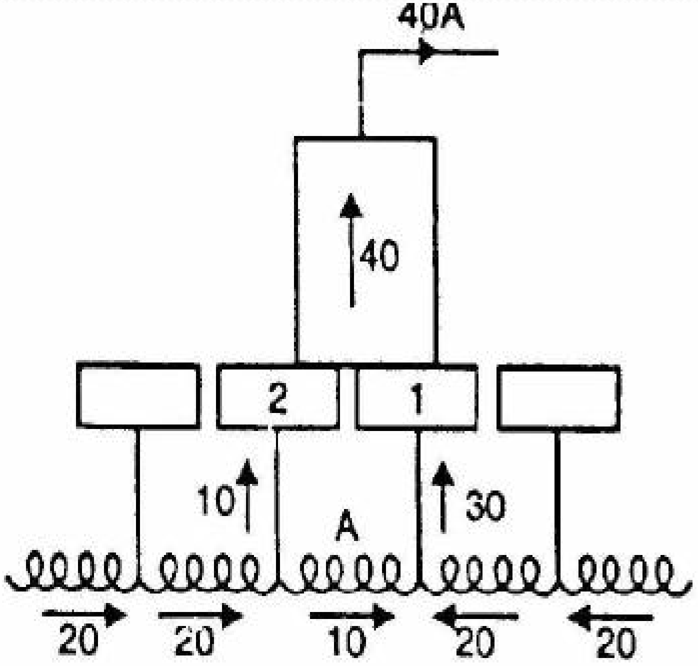
(i)

Ideal Commutation

There are now two parallel paths into the brush as long as the short-circuit of coil A exists.

For this condition, the resistance of the path through segment 2 is three times the resistance of the path through segment 1 **(Q contact resistance varies inversely as the area of contact of brush with the segment).**

The brush again conducts a current of 40 A; 30 A through segment 1 and 10 A through segment 2.



(ii)

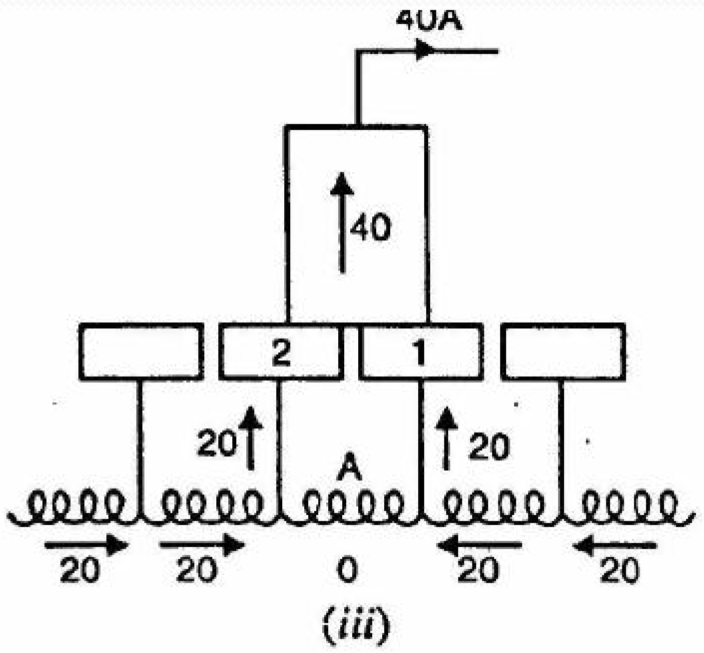
Note that current in coil A (the coil undergoing commutation) is reduced from 20 A to 10 A.

Ideal Commutation

The instant when the brush is one-half on segment 2 and one-half on segment 1.

The brush again conducts 40 A; 20 A through segment 1 and 20 A through segment 2 (Q now the resistances of the two parallel paths are equal).

Note that now. current in coil A is zero.

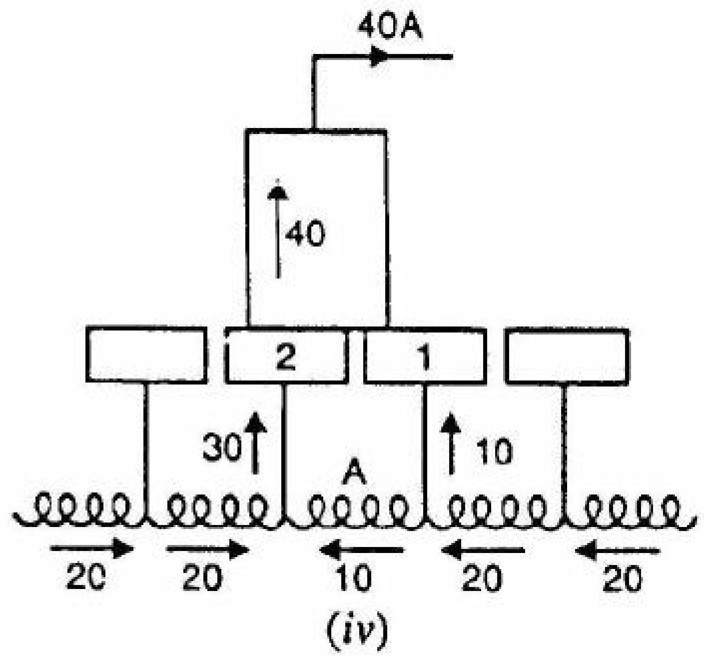


Ideal Commutation

Fig. shows the instant when the brush is three-fourth on segment 2 and one-fourth on segment 1.

The brush conducts a current of 40 A; 30 A through segment 2 and 10 A through segment 1.

Note that current in coil A is 10 A but in the reverse direction to that before the start of commutation.

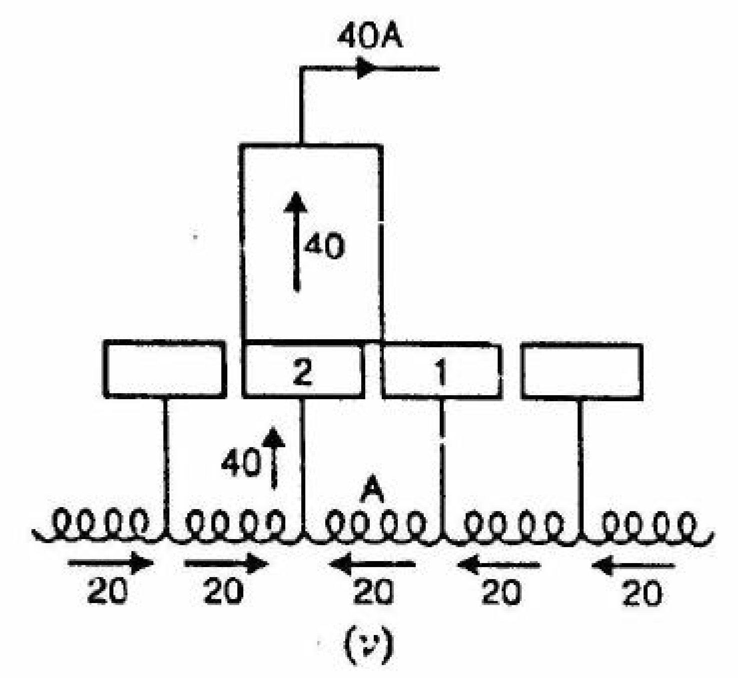


the action of the commutator in reversing the current in a coil as the coil passes the brush axis.

Ideal Commutation

Fig. shows the instant when the brush is in contact only with segment 2.

- The brush again conducts 40 A; 20 A from coil A and 20 A from the adjacent coil to coil A.
- Note that now current in coil A is 20 A but in the reverse direction. Thus the coil A has undergone commutation.
- Each coil undergoes commutation in this way as it passes the brush axis.



Note that during commutation, the coil under consideration remains shortcircuited by the brush.

Ideal Commutation

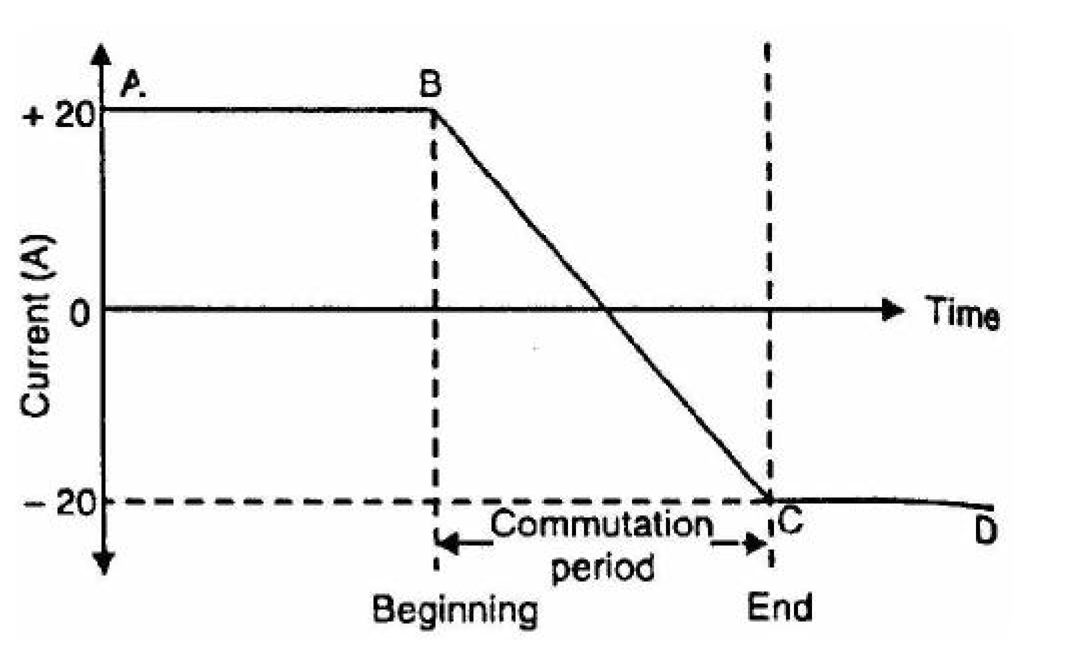
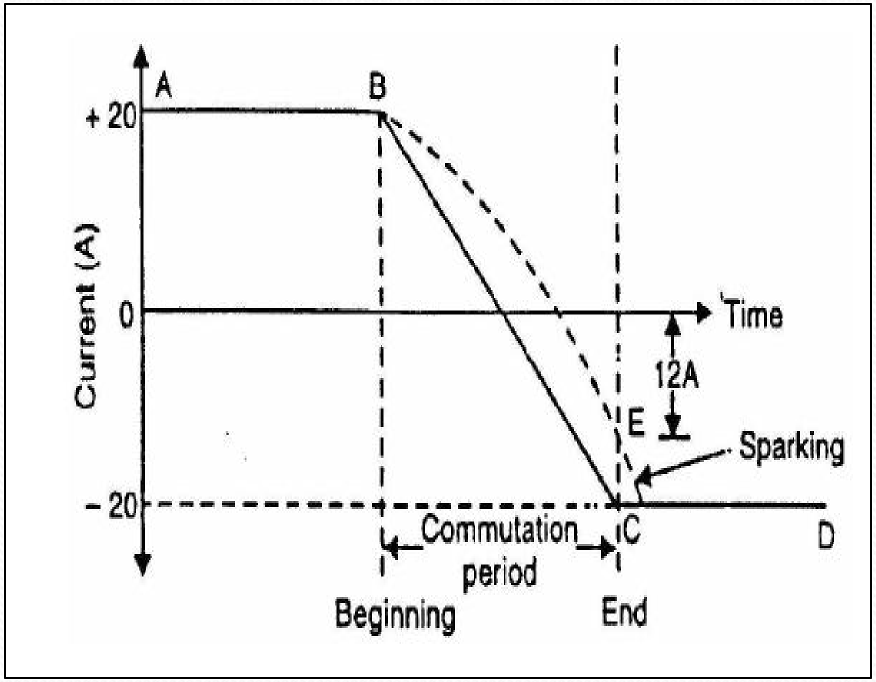


Fig. shows the current-time graph for the coil A undergoing commutation.

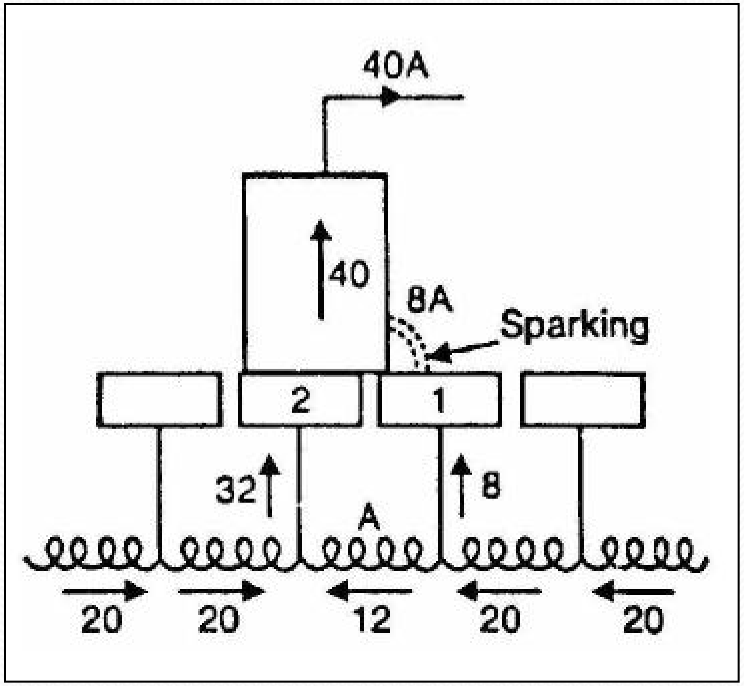
Practical difficulties



The straight line RC represents the ideal commutation whereas the curve BE represents the change in current when self-inductance of the coil is taken into account

Practical difficulties

When the current in the coil undergoing commutation changes, self-induced e.m.f. is produced in the coil. This is generally called reactance voltage. This reactance voltage opposes the change of current in the coil undergoing commutation.



Methods of improving commutation

Improving commutation means to make current reversal in the short-circuited coil as sparkless as possible.

The following are the two principal methods of improving commutation:

(i) Resistance commutation

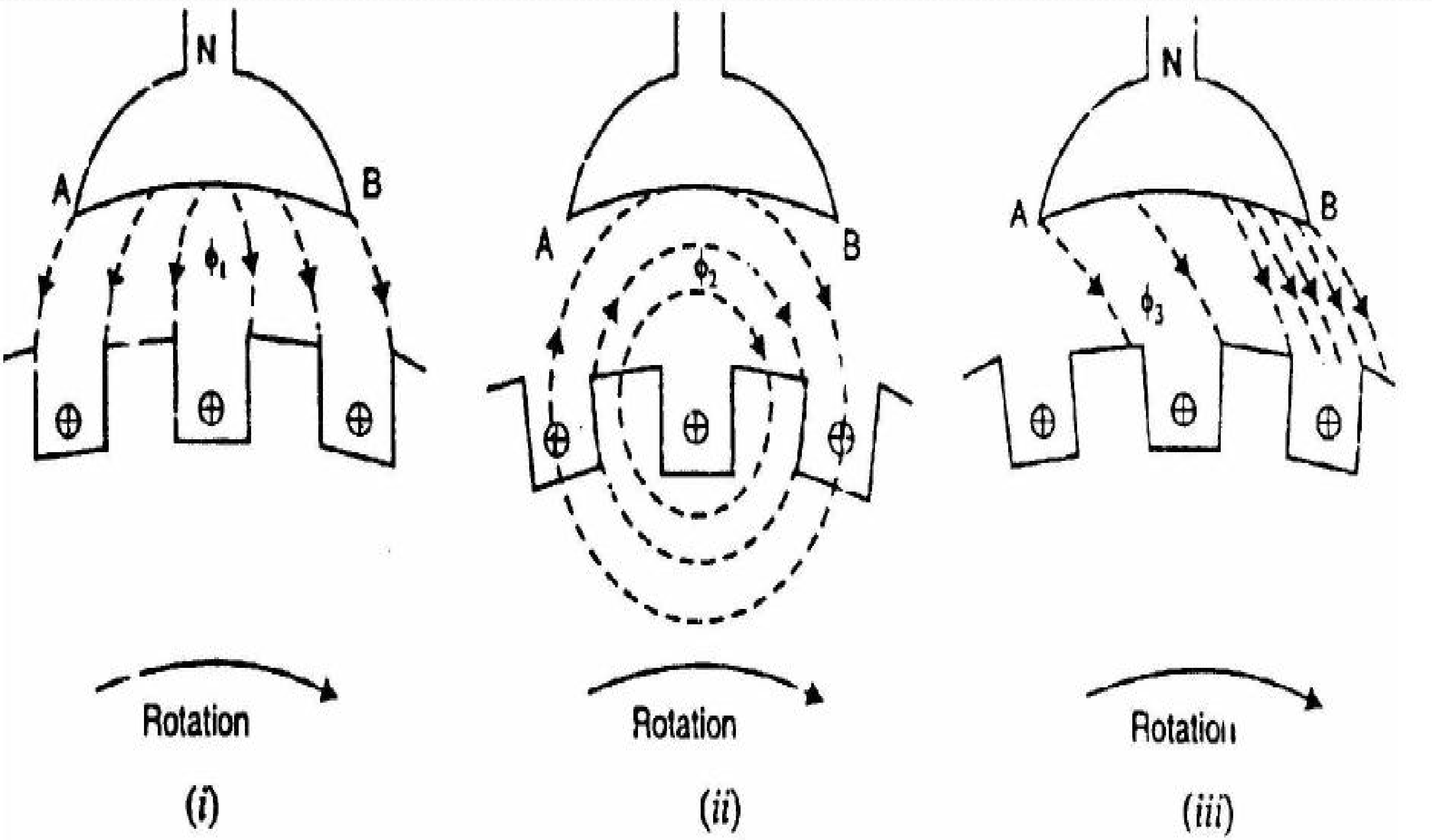
(ii) E.M.F. commutation

Armature Reaction

The only flux acting in a d.c. machine is that due to the main poles called main flux. However, current flowing through armature conductors also creates a magnetic flux (called armature flux) that distorts and weakens the flux coming from the poles.

This distortion and field weakening takes place in both generators and motors. **The action of armature flux on the main flux is known as armature reaction.**

Armature Reaction



Armature Reaction

This unequal field distribution produces the following two effects:

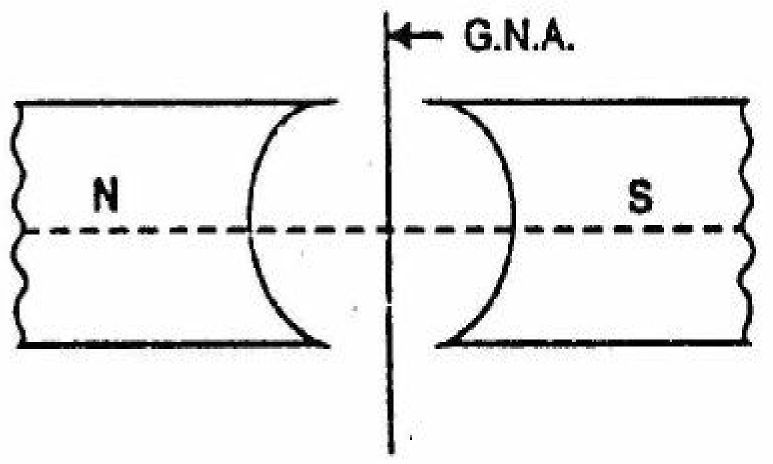
(i) **The main flux is distorted.**

(ii) Due to higher flux density at pole tip B, saturation sets in. Consequently, the increase in flux at pole tip B is less than the decrease in flux under pole tip A.

Flux f3 at full load is, therefore, less than flux f1 at no load. As we can see, the weakening of flux due to armature reaction depends upon the position of brushes.

Geometrical and Magnetic Neutral Axes

The geometrical neutral axis (G.N.A.) is the axis that bisects the angle between the centre line of adjacent. Clearly, it is the axis of symmetry between two adjacent poles.

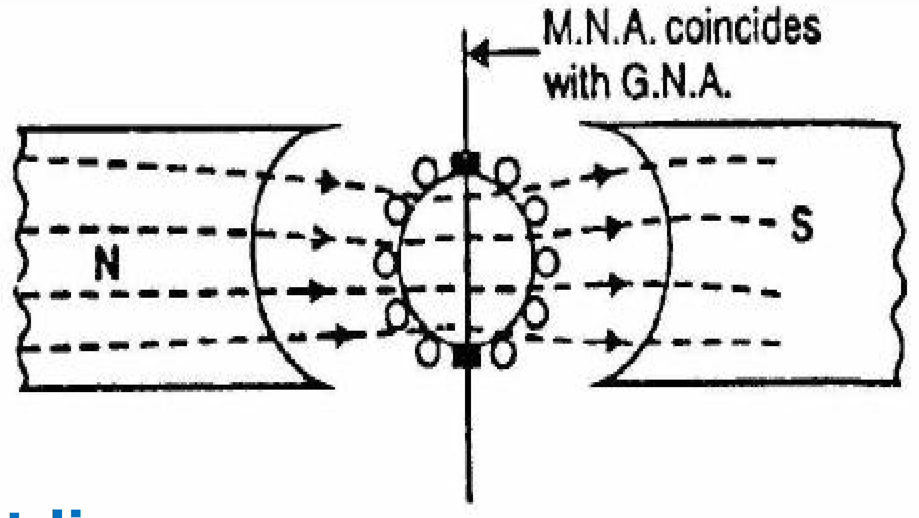


(i)

Geometrical and Magnetic Neutral Axes

The magnetic neutral axis (M. N. A.) is the axis drawn perpendicular to the mean direction of the flux passing through the centre of the armature.

Clearly, no e.m.f. is produced in the armature conductors along this axis because then they cut no flux. With no current in the armature conductors, the M.N.A. coincides with G. N. A.



(ii)

In order to achieve sparkless commutation, the brushes must lie along M.N.A.

Explanation of Armature Reaction

With no current in armature conductors, the M.N.A. coincides with G.N.A.

However, when current flows in armature conductors, the combined action of main flux and armature flux shifts the M.N.A. from G.N.A.

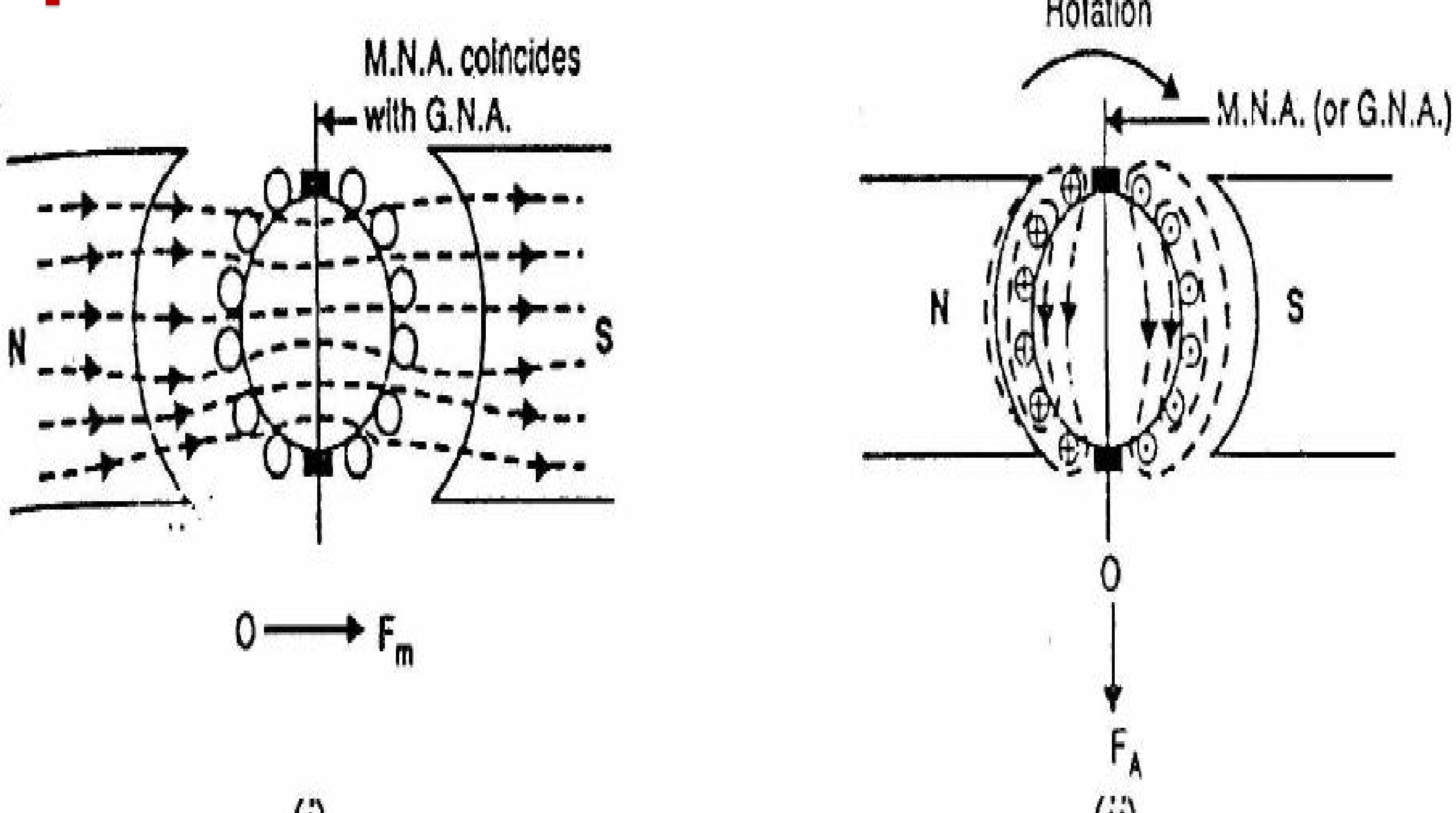
In case of a generator, the M.N.A. is shifted in the direction of rotation of the machine. In order to achieve sparkless commutation, the brushes have to be moved along the new M.N.A.

Under such a condition, the armature reaction produces the following two effects:

1. **It demagnetizes or weakens the main flux.**

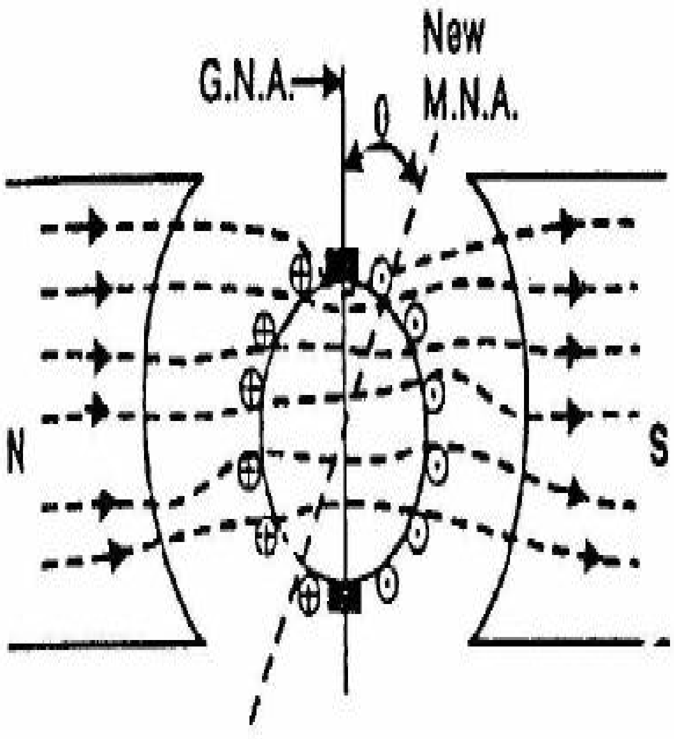
2. **It cross-magnetizes or distorts the main flux.**

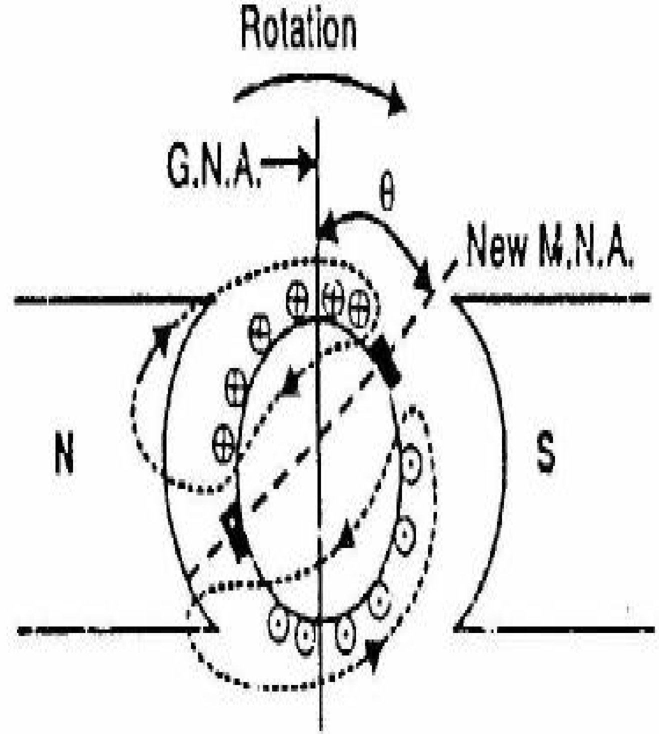
Explanation of Armature Reaction



(i) (ii)

Explanation of Armature Reaction





Conclusions

(i)With brushes located along G.N.A. (i.e., q = 0°), there is no demagnetizing component of armature reaction (Fd = 0). There is only distorting or crossmagnetizing effect of armature reaction.

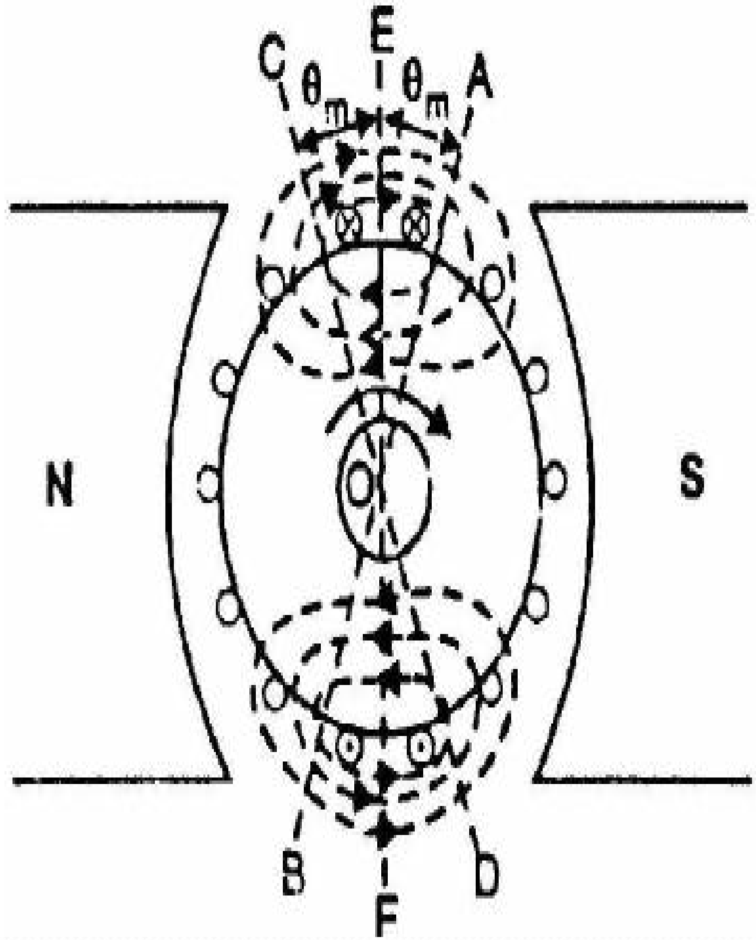
(ii) With the brushes shifted from G.N.A., armature reaction will have both

demagnetizing and distorting effects. Their relative magnitudes depend on

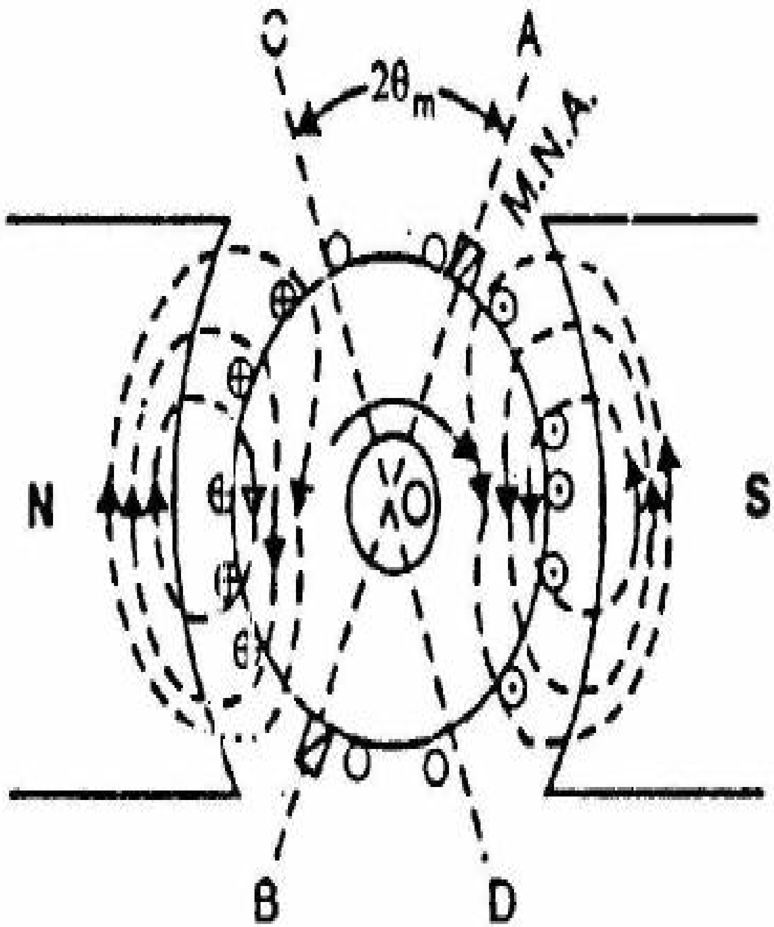
the amount of shift. This shift is directly proportional to the armature current.

(iii) The demagnetizing component of armature reaction weakens the main flux. On the other hand, the distorting component of armature reaction distorts the main flux.

(iv) The demagnetizing effect leads to reduced generated voltage while crossmagnetizing effect leads to sparking at the brushes.



C
E
A
θ_m
θ_m
N
S
B
F
D



C
A
$2\theta_m$
M.N.A.
N
S
B
D

Reduction of effect of armature reaction

The armature reaction causes the distortion in main field flux. This can be reduced armature teeth and air gap at pole tips offer reluctance to armature flux. Thus by increasing length of air gap, armature reaction effect is reduced.

If reluctance at pole tip is increased it will reduce distortion effect of armature reaction. By using special construction in which leading and trailing pole tip portion of lamination are alternately omitted.

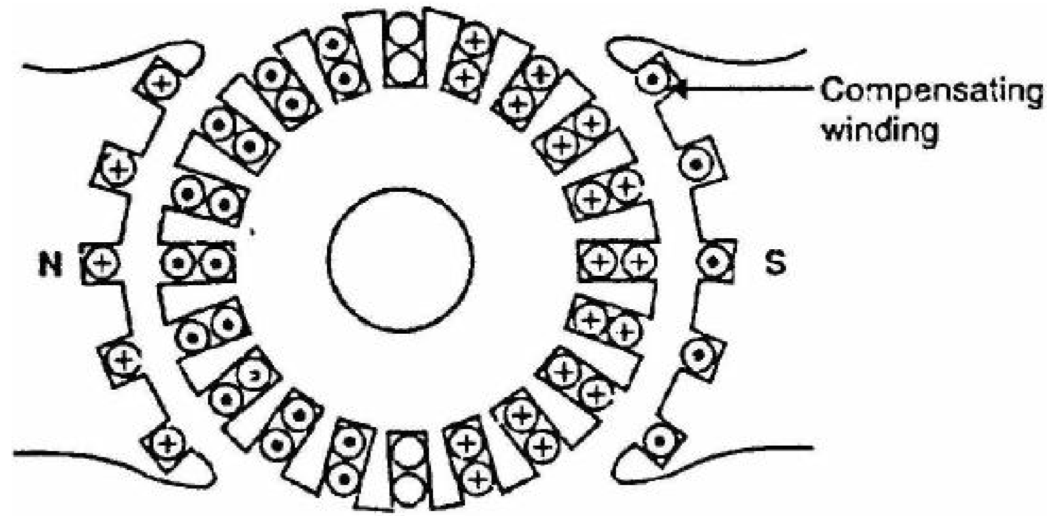
Reduction of effect of armature reaction

The effect of armature reaction causes shifting the magnetic neutral axis. Therefore there will be some flux density at brush axis which produces emf in the coil under going commutation. This will leads to delayed commutation.

Thus armature reaction at brush axis must be neutralized. This requires another equal and opposite mmf to that of armature mmf. This can be applied by interlopes which are placed at geometric neutral axis at mid way between the main poles.

In order to neutralize the crossmagnetizing effect of armature reaction, a compensating winding is used.

Compensating Windings



A compensating winding is an auxiliary winding embedded in slots in the pole faces .

It is connected in series with armature in a manner so that the direction of current through the compensating conductors in any one pole face will be opposite to the direction of the current through the adjacent armature conductors