Elements of Electrical Engineering

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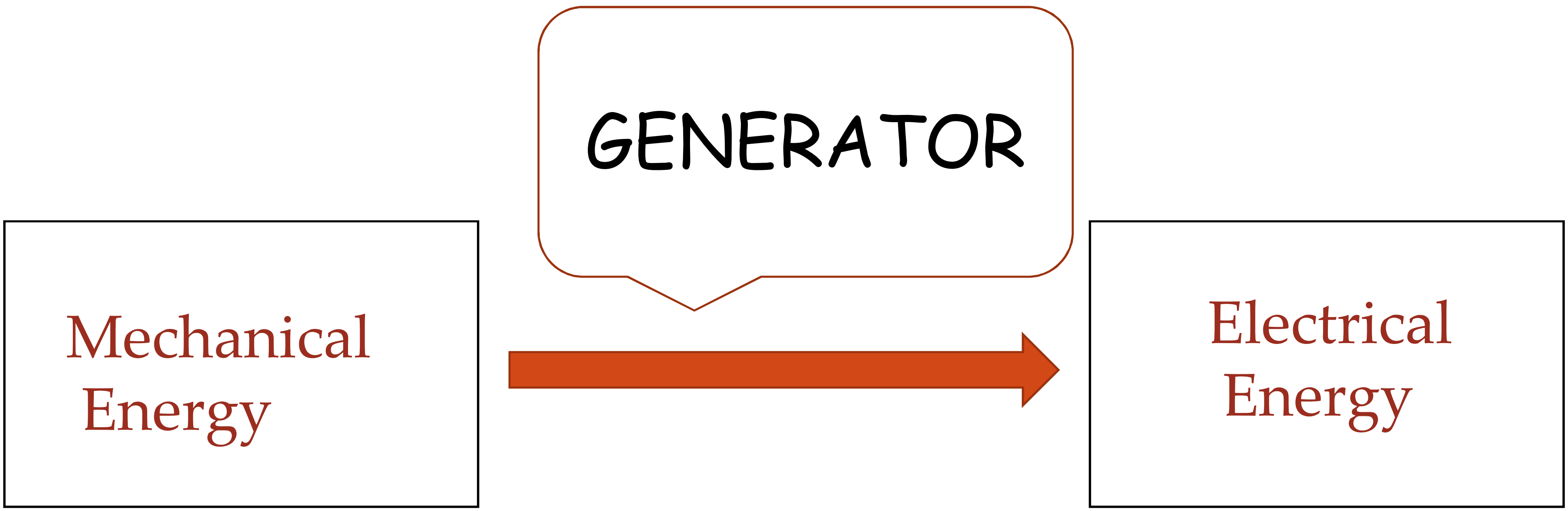
Generators

Function:

Generators are the electrical machines which convert mechanical energy into electrical energy.



https://www.youtube.com/watch?v=Ylgb8FFMgd4

Working Principle of a DC Generator

- According to ***Faraday's laws of electromagnetic induction***, whenever a conductor is placed in a varying magnetic field (OR a conductor is moved in a magnetic field), an emf (electromotive force) gets induced in the conductor.

- The **magnitude of induced emf** can be calculated from the emf equation of dc generator.

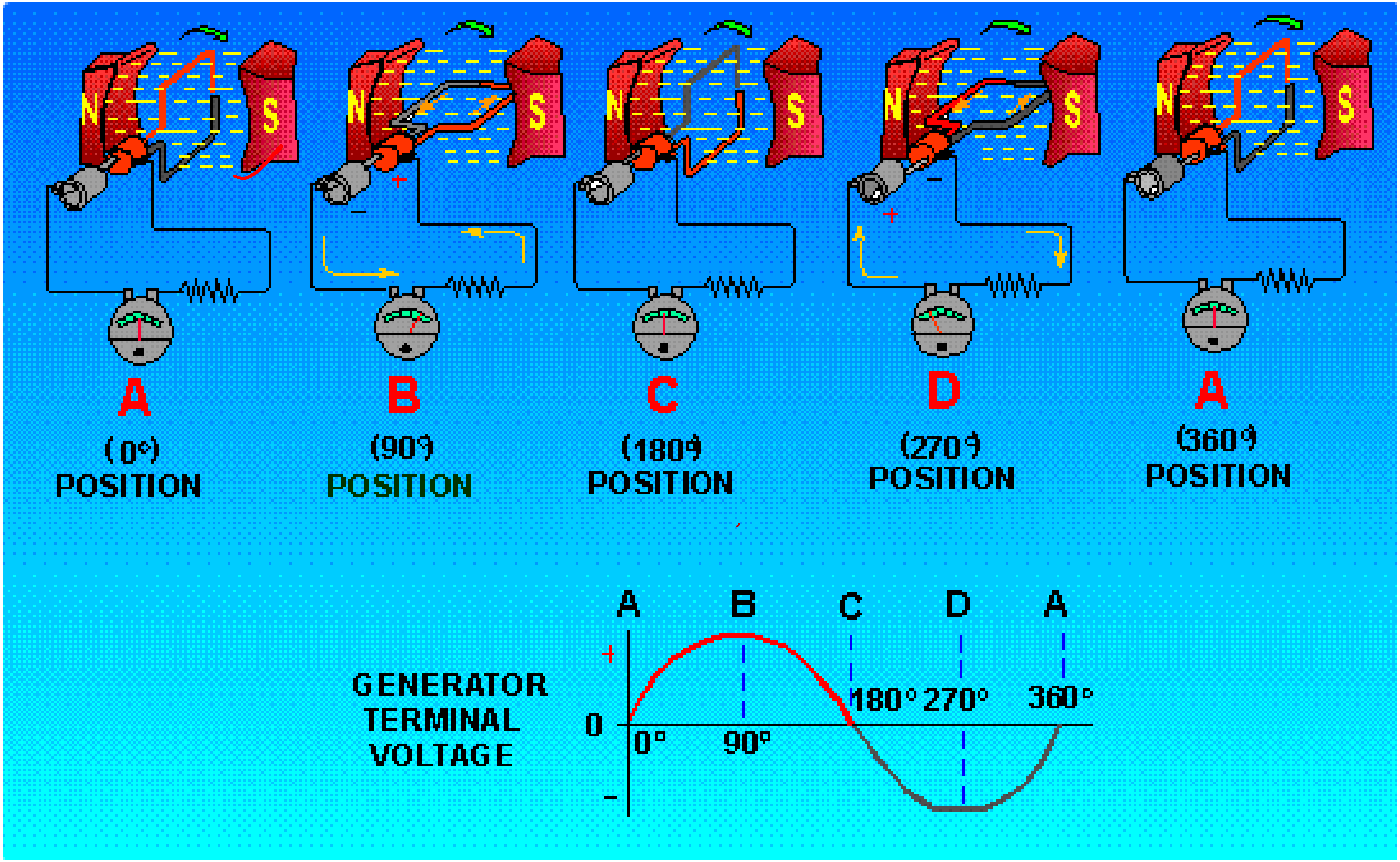
- If the conductor is provided with the closed path, the induced current will circulate within the path.

- In a DC generator, field coils produce an electromagnetic field and the armature conductors are rotated into the field.

- Thus, an electromagnetically induced emf is generated in the armature conductors.

- The direction of induced current is given by **Fleming's right hand rule**

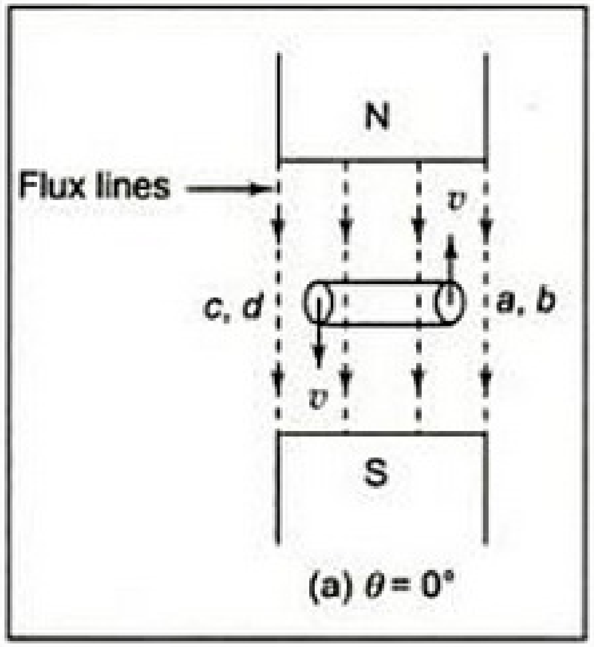
Illustration of working of a DC Generator



Generator working principle in steps

Case I: θ=0º

- The velocity component (v) is in parallel with the flux lines or in other words, the angle between the velocity and flux lines is zero.
- Hence the emf induced is zero.
- E=0



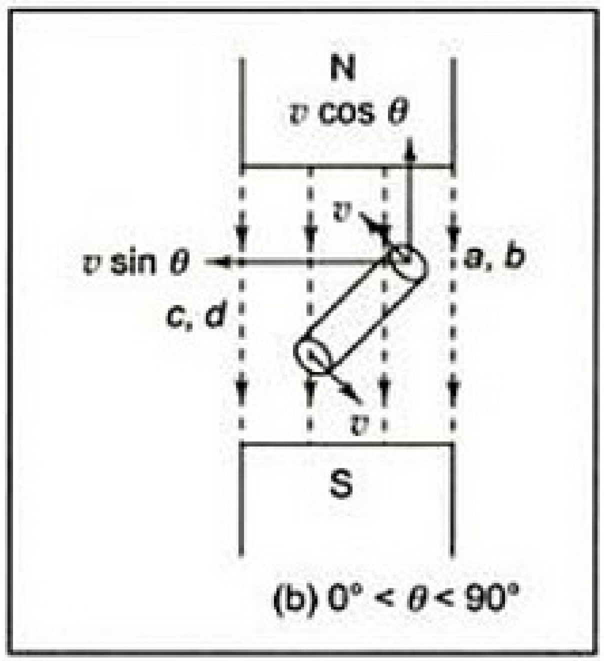
(a) $\theta = 0°$

Case II: 0º< θ < 90º

- The velocity component is making an angle with the flux lines.
- The velocity component is resolved into two components
  - Vsinθ

The vsinθ is 90º with respect to flux lines and it is doing useful work and due to this, emf is induced.

- $e_{min} < e < e_{max}$



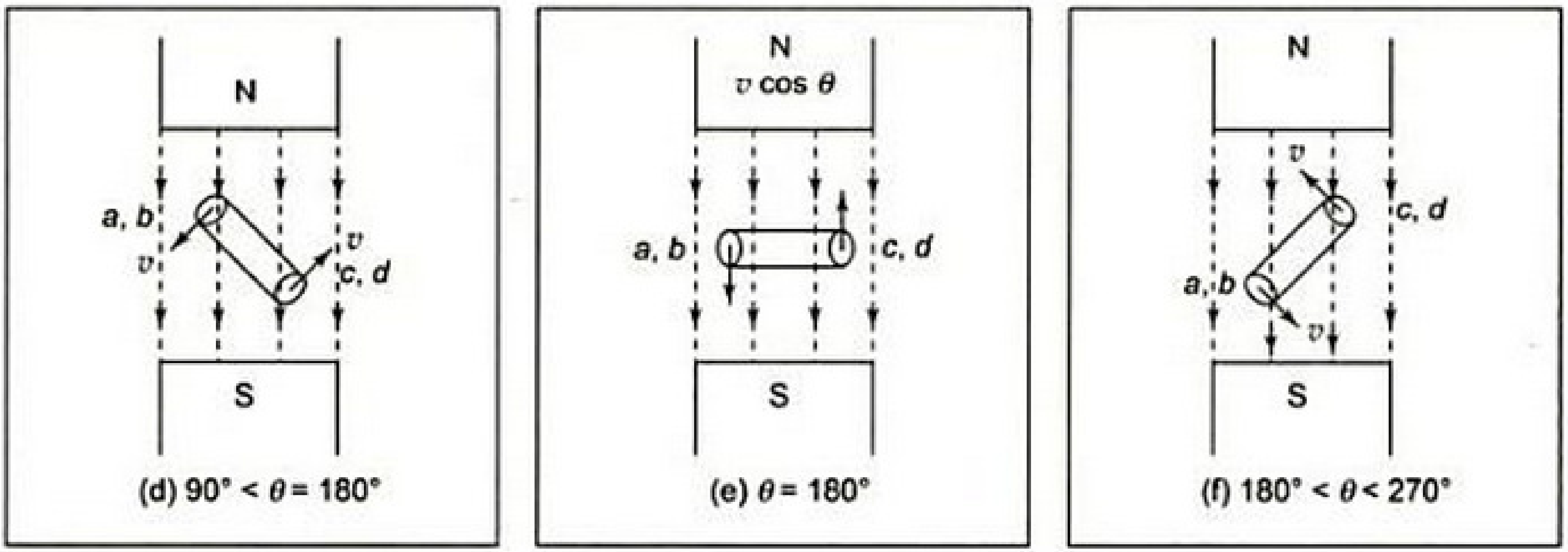
(b) $0° < \theta < 90°$

Case III: $\theta = 90^o$

The velocity component is making an angle 90^o with the flux lines and due to this, emf is induced.

$E = e_{max}$

For remaining cases, the illustration is shown below,

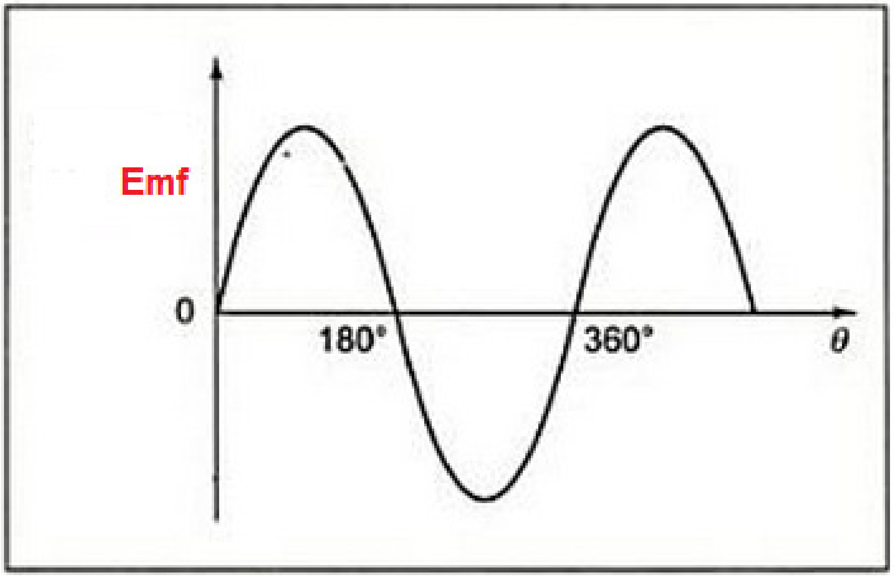


(d) $90° < \theta = 180°$ (e) $\theta = 180°$ (f) $180° < \theta < 270°$

The emf completes one complete cycle for 360^o .

- Emf induced is the alternating type because

  - during positive half cycle, the conductor comes under the influence of north pole
  - during negative half cycle, the conductor comes under the influence of south pole



How to convert AC to DC?

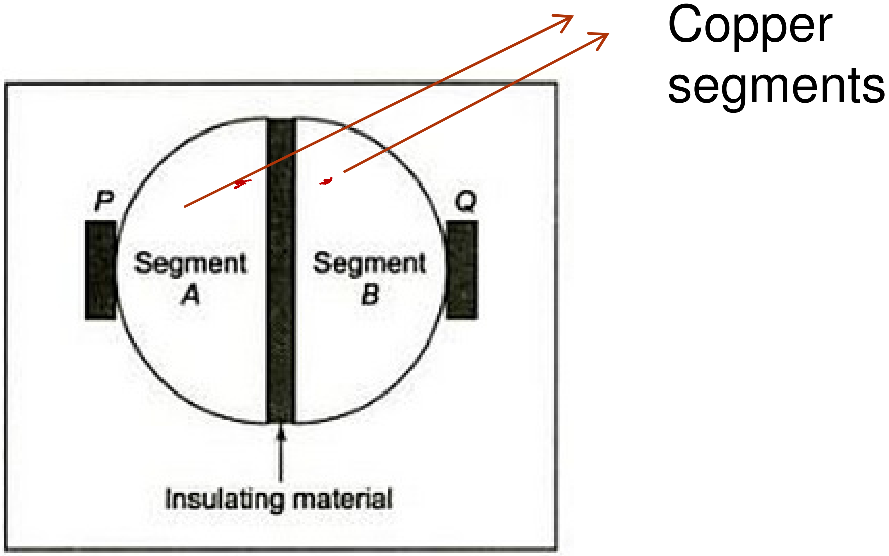
❑ It is observed that the emf induced is the alternating type, but it is required to obtain unidirectional emf from the DC machines.

❑ The alternating emf can be converted into pulsating dc using the **split ring/commutator.**

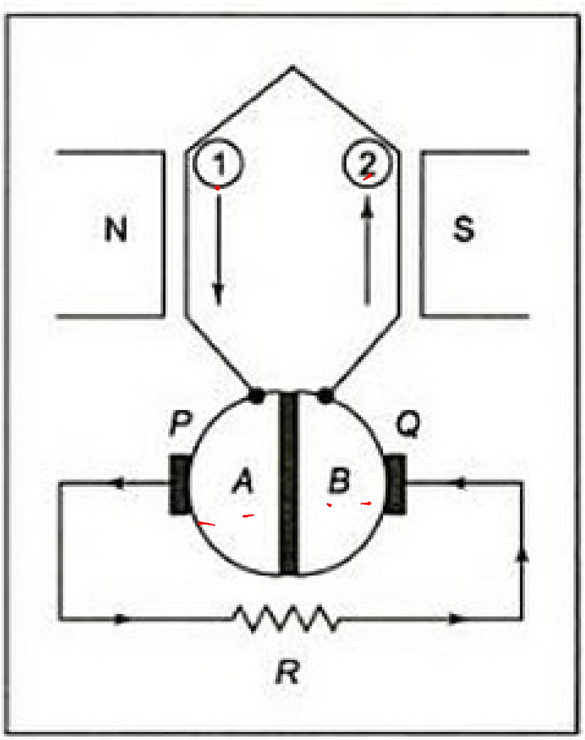
Commutator Action

↓ AC – DC

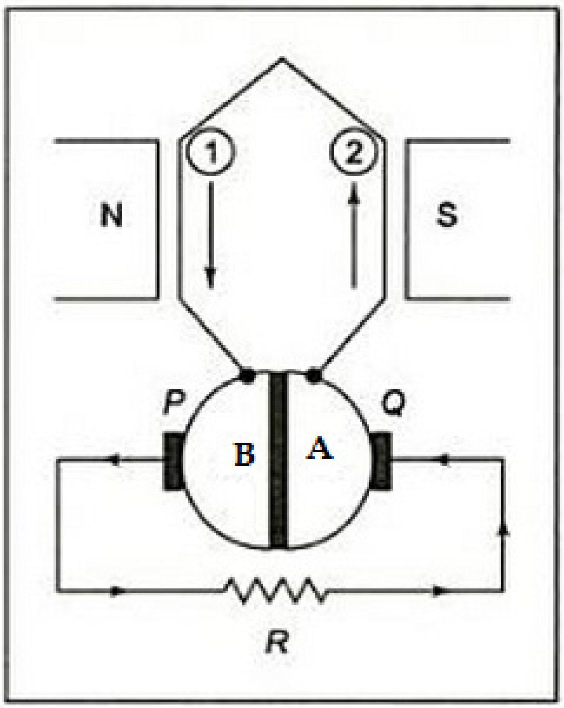
Mechanical Rectifier

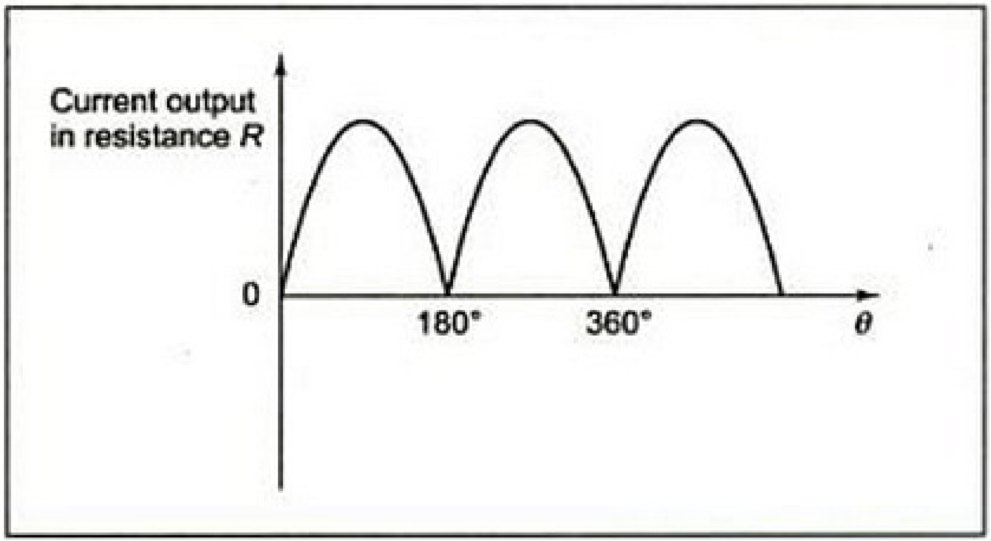


• During positive half cycle, A segment will be at P and B will be at Q.



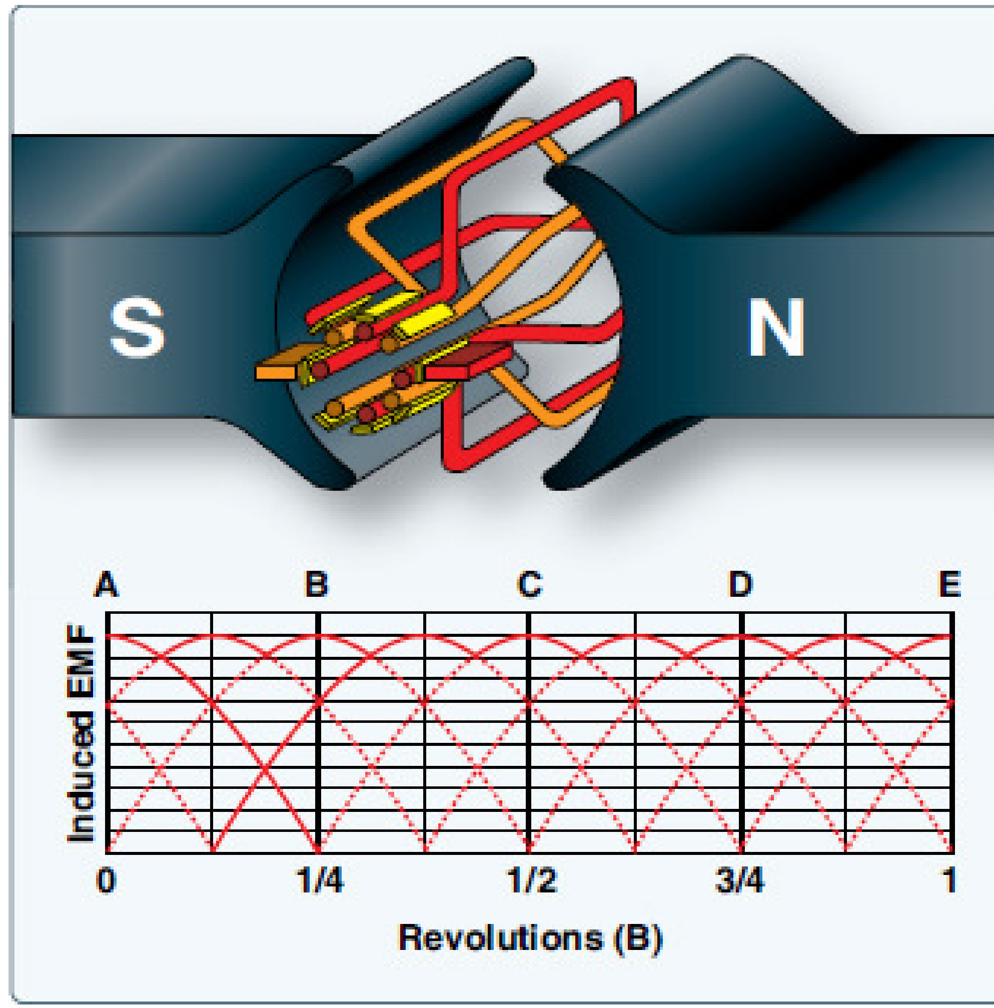
- During negative half cycle, the time at which the current changes the direction, the segment A will move to Q and B will move to P.





← **Single loop or coil generator**

Multi loop or coil generator →



EMF equation in 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
  - Total flux produced by all the poles = $\Phi * P$
  - Time taken to complete one revolution = 60/ N
  - N is the speed of the armature conductor in rpm.
- Now, according to **Faraday’s law of induction**, the induced emf of the armature conductor is denoted by “e” which is equal to rate of cutting the flux.

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

Therefore,

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

- Let us suppose there are
  - Z total numbers of conductor in a generator, and arranged in such a manner that all parallel paths are always in series. Here,
  - A = number of parallel paths
  - Then, Z/A = number of conductors connected in series
  - We know that Induced emf in each path is same across the line
  - Therefore, Induced emf of DC generator
    - E = **Emf of one conductor × number of conductor connected in series.**

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

$$e = \frac{\phi PNZ}{60A}$$

- Simple wave wound generator Numbers of parallel paths are only 2 = A.

Lap-wound generator Here, number of parallel paths is equal to number of conductors in one path i.e.
Therefore, P = A

Lap

$A = P$

wave

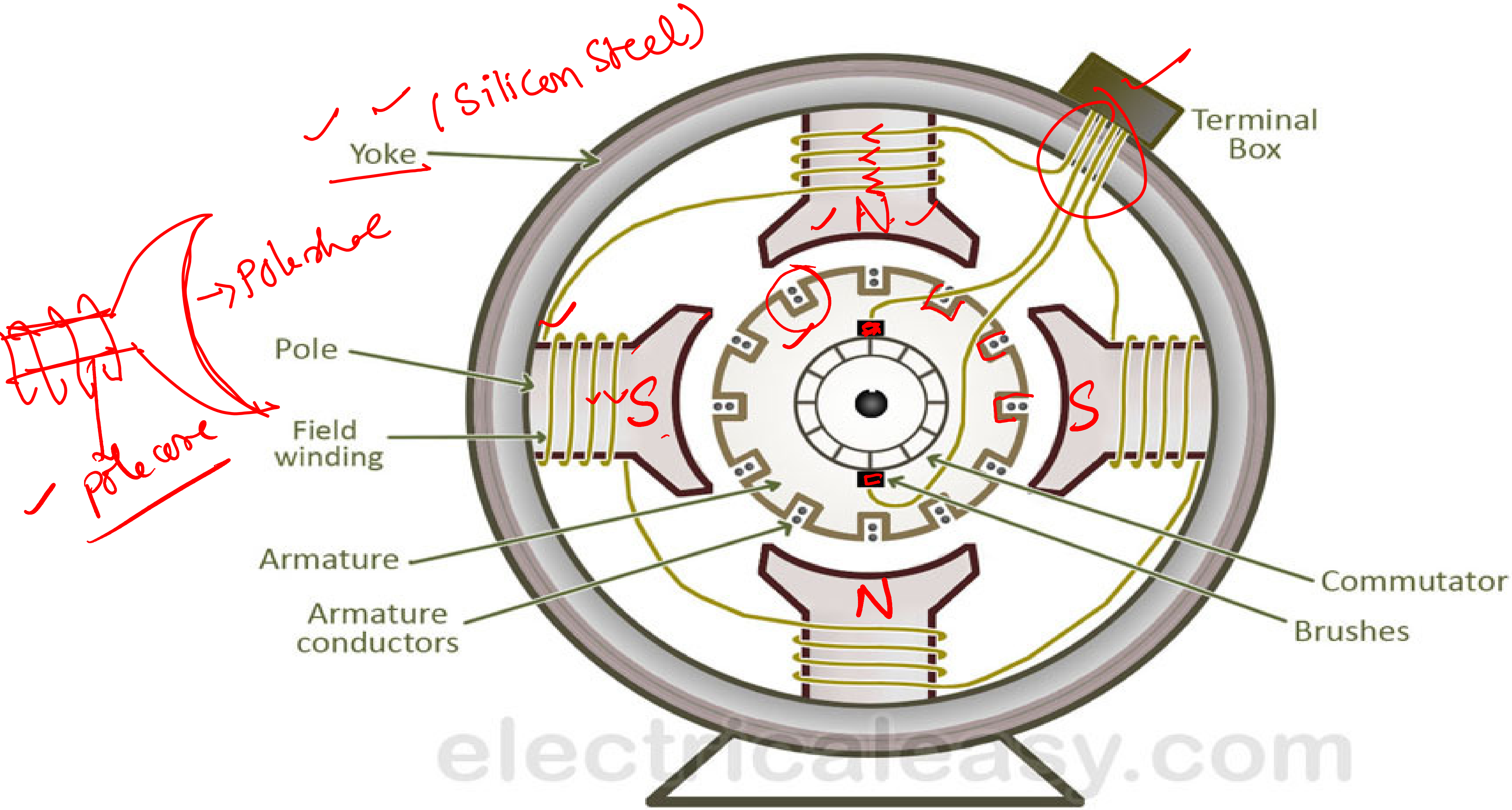
$A = 2$

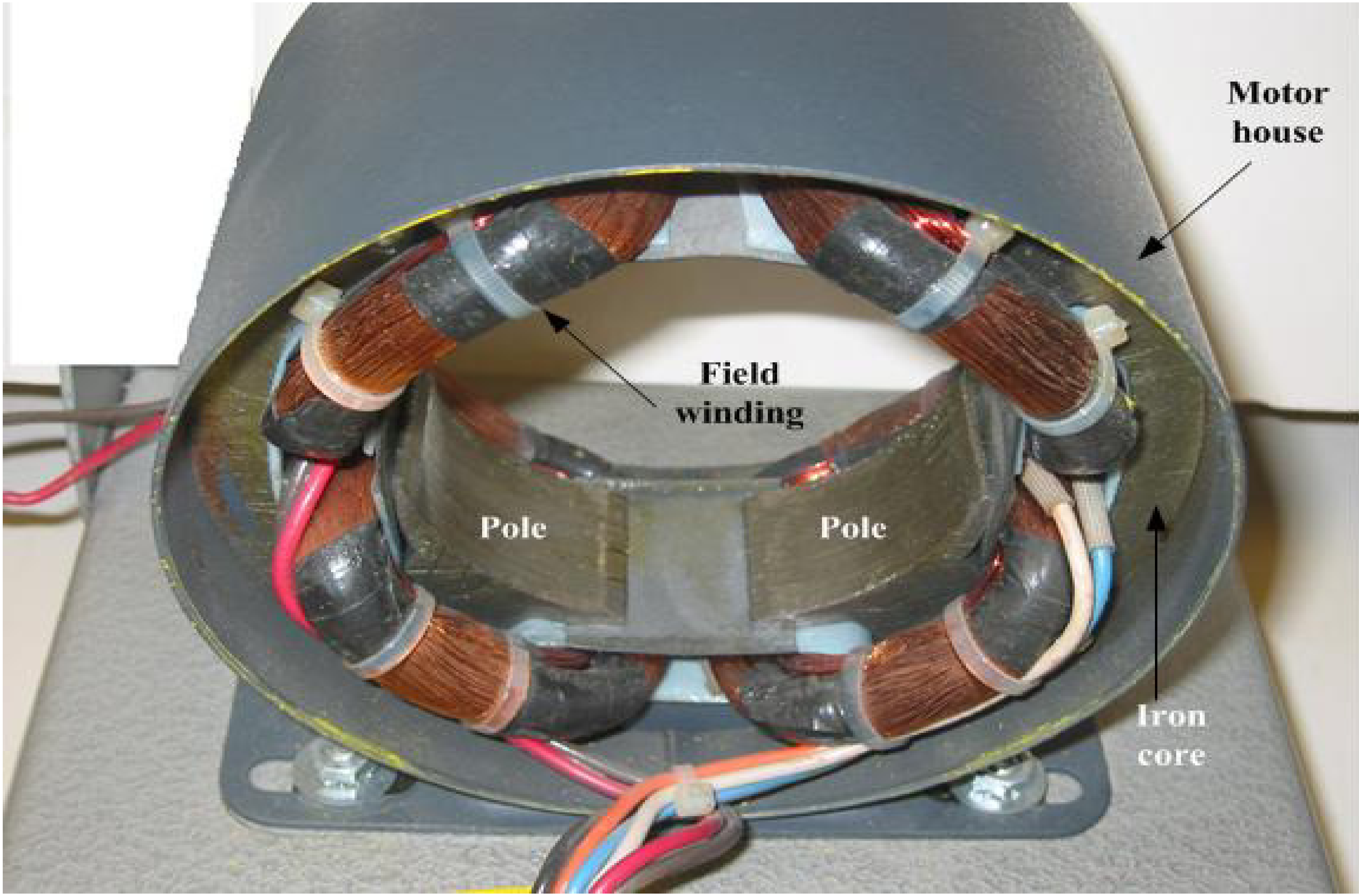
Construction of a DC generator

electromagnet
Permanent mag

Stationary parts: Yoke, Field poles, Pole shoe, Field windings,

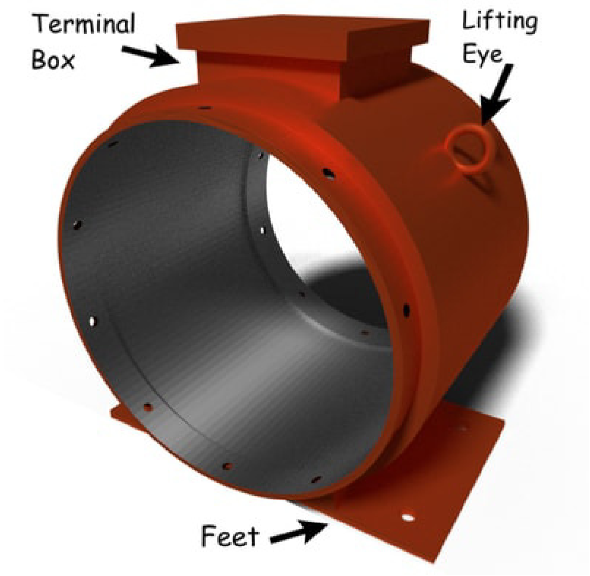
Moving parts: Armature core, Armature winding, Commutator, Brushes




Motor
house
Field
winding
Pole
Pole
Iron
core

Stationary Parts

Yoke:



- The outer frame of a dc machine is called as yoke.
- It is made up of cast iron or steel.
- It not only provides mechanical strength to the whole assembly but also carries the magnetic flux produced by the field winding

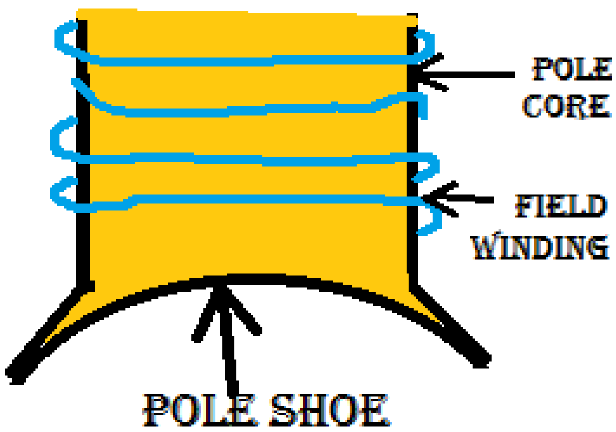
***Poles and pole shoes*:**

- *Poles are joined to the yoke with the help of bolts or welding.*
- They ***carry field winding*** and pole shoes are fastened to them.

Pole shoes serve two purposes;

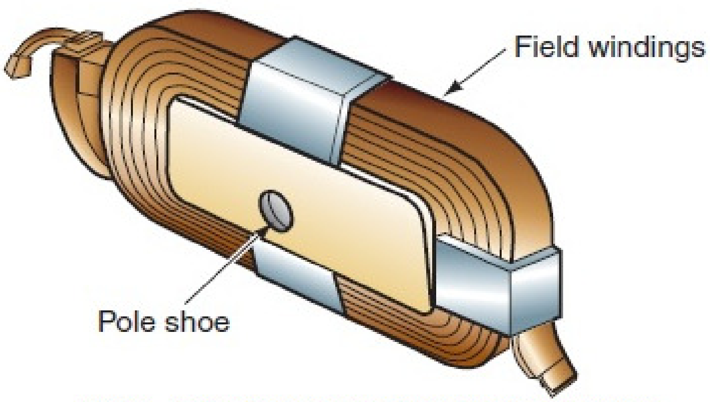
(i) They support field coils

(ii) Spread out the flux in air gap uniformly

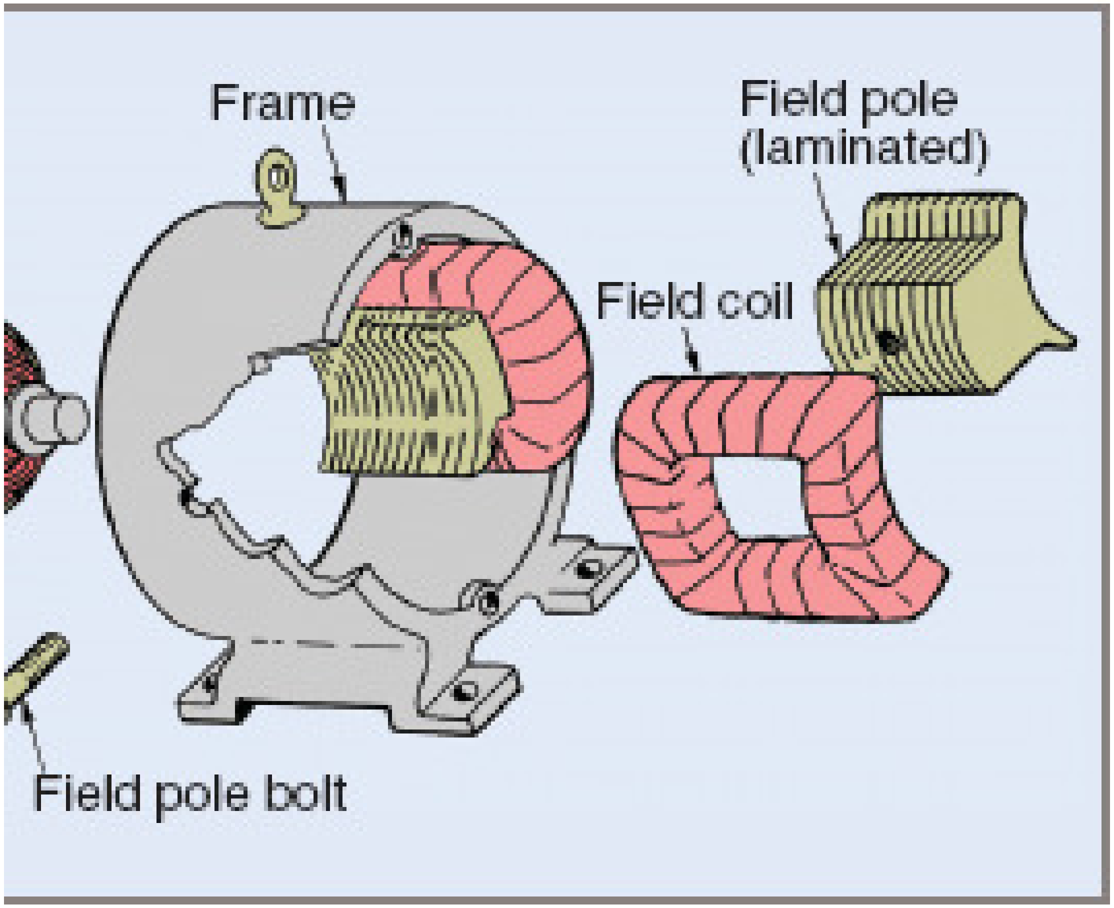


***Field winding*:**

- They are usually made of copper.
- Field coils are former wound and placed on each pole and are connected in series.
- They are wound in such a way that, when energized, they form alternate North and South poles



FIELD COIL WOUNDED AROUND ON POLE SHOE



Rotating parts of the DC machine

Armature core:

- Armature core is the *rotor of the machine*.
- It is *cylindrical in shape* with slots to carry armature winding.
- The armature is built up of **thin (about 0.4 to 0.6 mm thick) laminated circular steel disks for *reducing eddy current losses***.

- It may be provided with air ducts for the axial air flow for cooling purposes. Armature is keyed to the shaft
- Practical D.C machines have air gaps ranging from 0.5 mm to 1.5 mm.

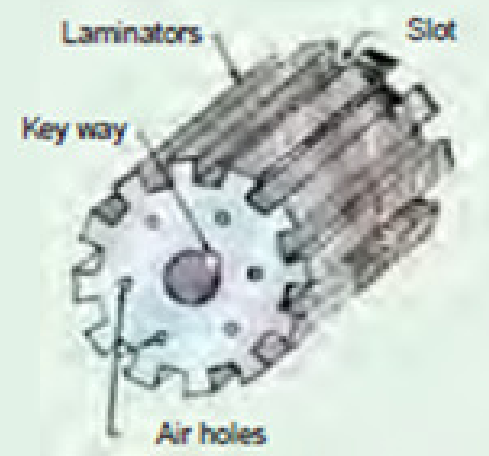


Fig. 26.15

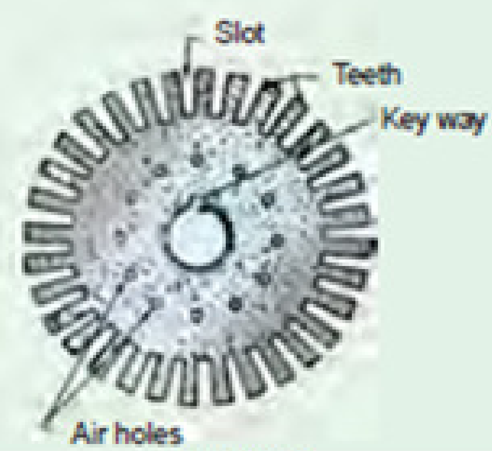


Fig. 26.16

Armature winding:

- **It is usually a former wound copper coil which rests in armature slots.**
- **The armature conductors are insulated from each other and also from the armature core.**
- **Armature winding can be wound by one of the two methods; Lap and Wave**

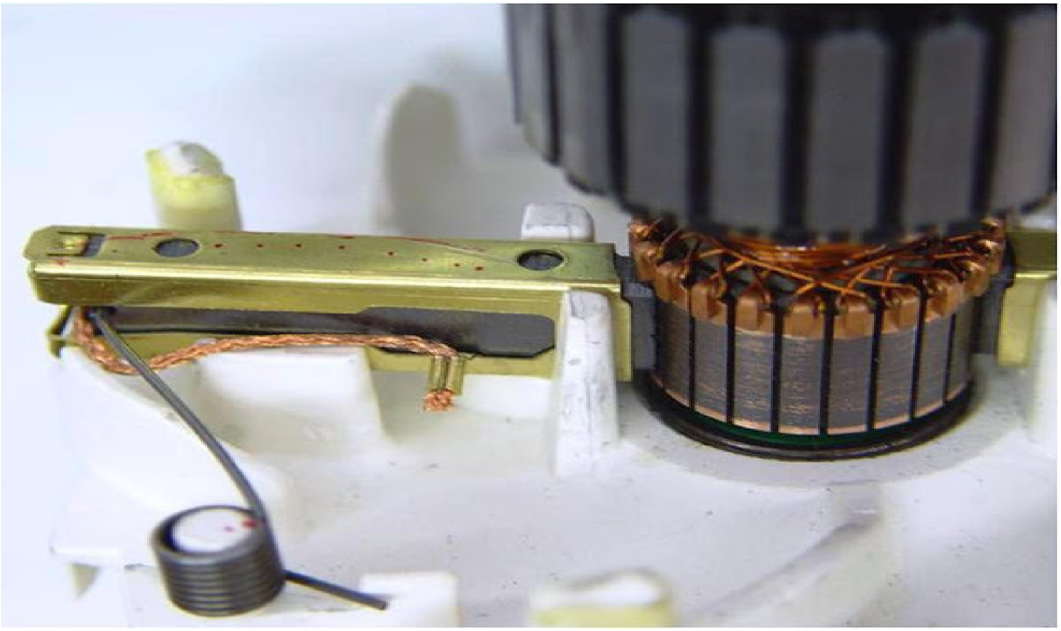
Commutator and brushes:

- **Physical connection to the armature winding is made through a commutator-brush arrangement.**
- **The function of a commutator, in a dc generator, is to collect the current generated in armature conductors.**
- **Whereas, in case of a dc motor, commutator helps in providing current to the armature conductors.**
- **A commutator consists of a set of copper segments which are insulated from each other.**

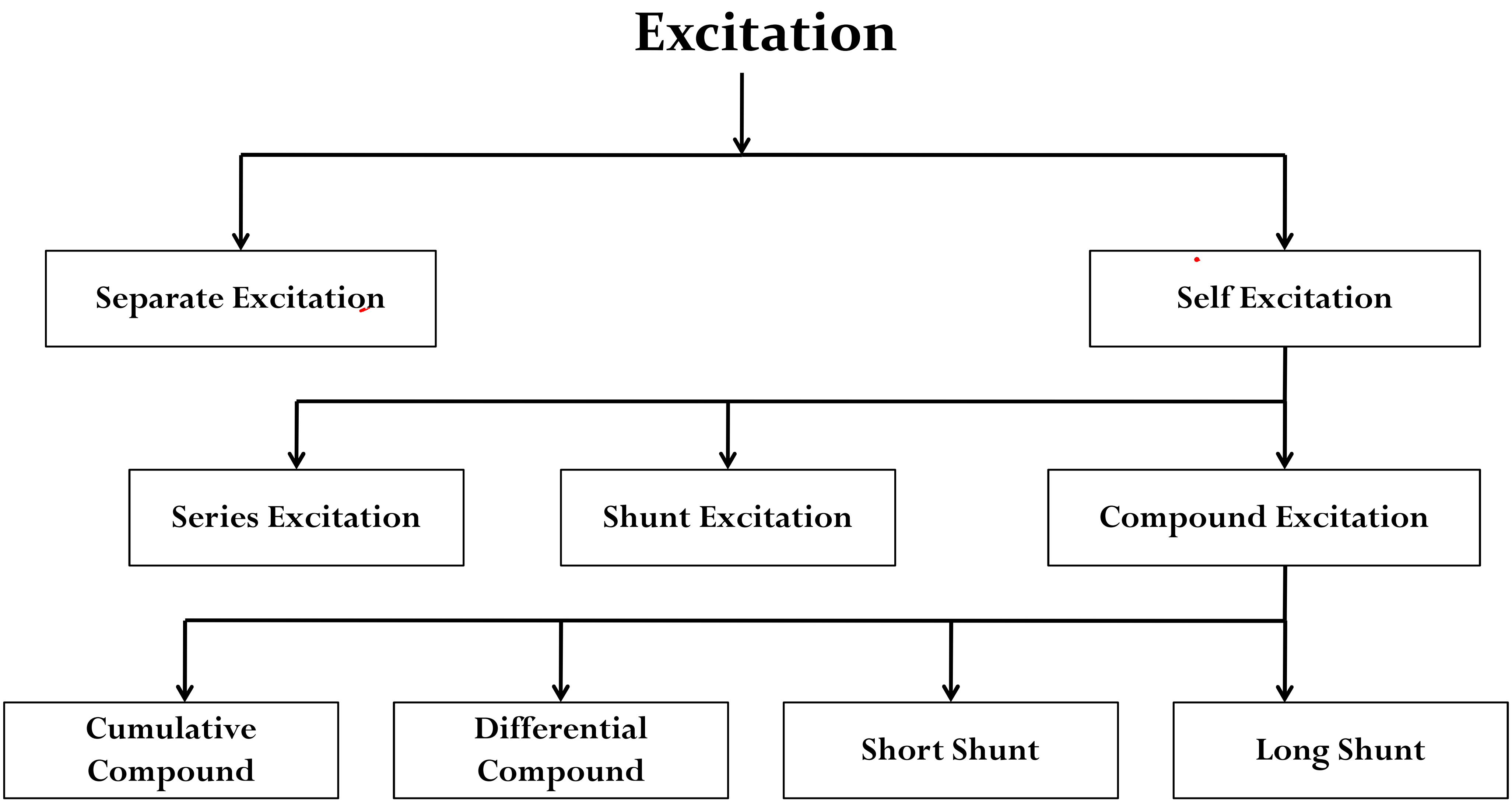
- A commutator is a mechanical rectifier which converts the alternating voltage generated in the armature winding into direct voltage across the brushes.
- The number of segments is equal to the number of armature coils.
- Each segment is connected to an armature coil and the commutator is keyed to the shaft.

Brushes

are usually made from carbon or graphite. They rest on commutator segments and slide on the segments when the commutator rotates keeping the physical contact to collect or supply the current.



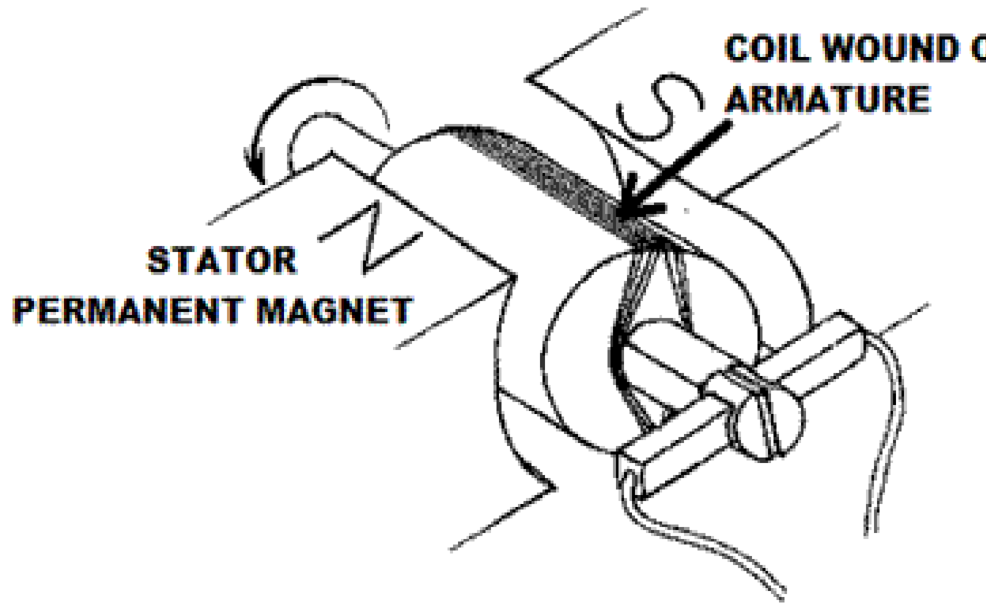
Methods of Excitation



Types of Generator

Permanent Magnet Generator

Vhen the flux in the magnetic circuit is stablished by the help of permanent nagnets then it is known as Permanent nagnet dc generator.



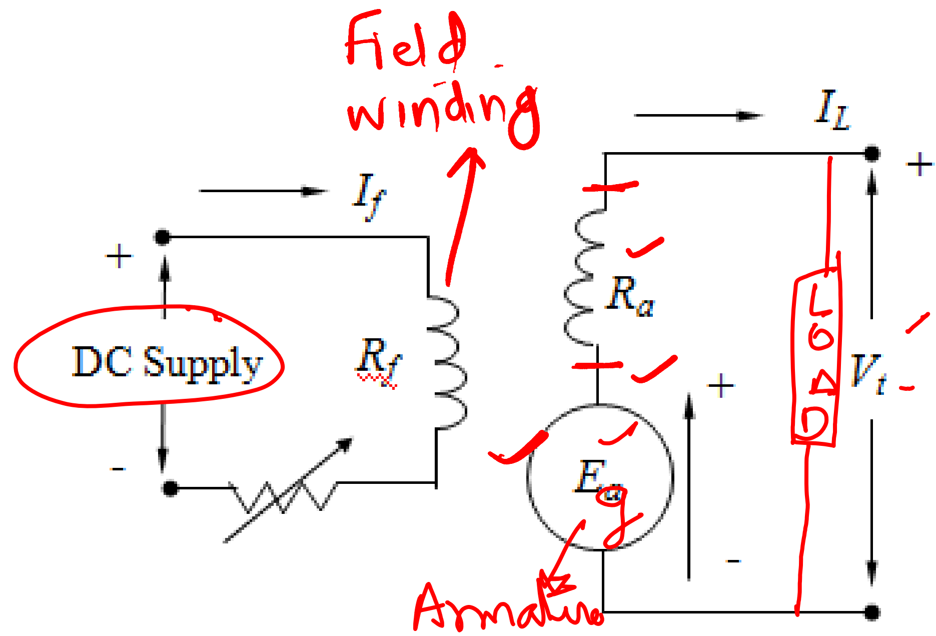
PERMANENT MAGNET DC GENERATOR

This type of dc generators generates very low power. So, they are rarely found n industrial applications.

They are normally used in small applications like dynamos in motor cycles.

Separately Excited Generator

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



Separately-Excited

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

Voltage drop in the armature = $I_a \times R_a$ (Ra is the armature resistance)

$V_t = E_g - I_a R$

Let, $I_a = I_L = I$ (say)

Then, voltage across the load, $V = E_g - IR_a$

Power generated, $P_g = E_g \times I$

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

Self Excited Generator

- These are the generators whose field magnets are energized by the electric current supplied by themselves.

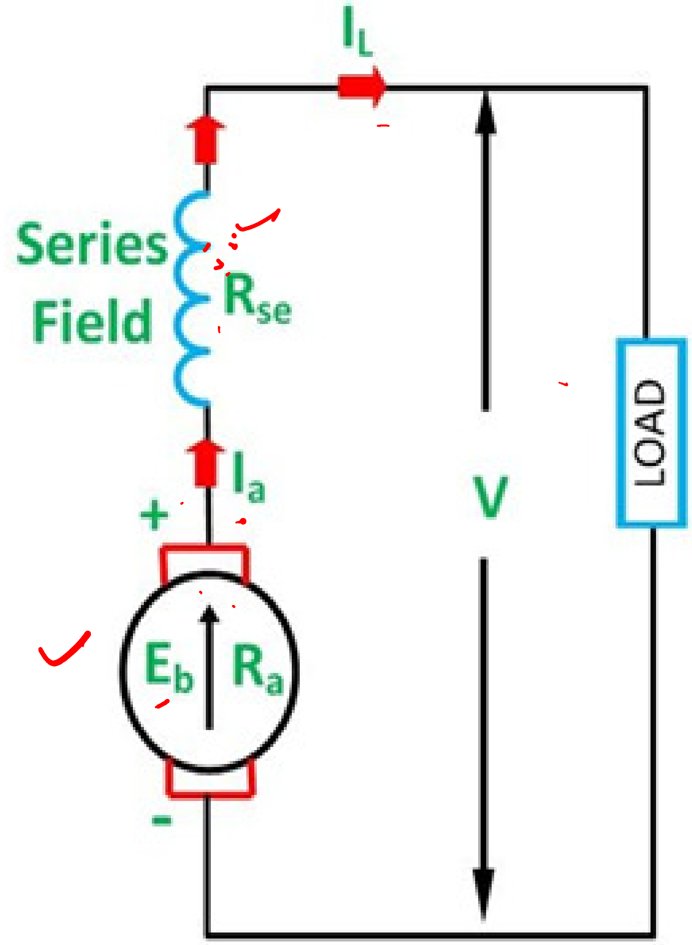
- In these type of machines field coils are internally connected with the armature.

- Due to residual magnetism some flux is always present in the poles. When the armature is rotated some emf is induced. Hence some induced electric current is produced.

- As the pole flux strengthened, it will produce more armature emf, which cause further increase of electric current through the field.

- This increased field electric current further raises armature emf and this cumulative phenomenon continues until the excitation reaches to the rated value.

Series Wound Generator



In these type of generators, the field windings are connected in series with armature conductors

whole electric current flows through the field coils as well as the load.

As series field winding carries full load electric 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

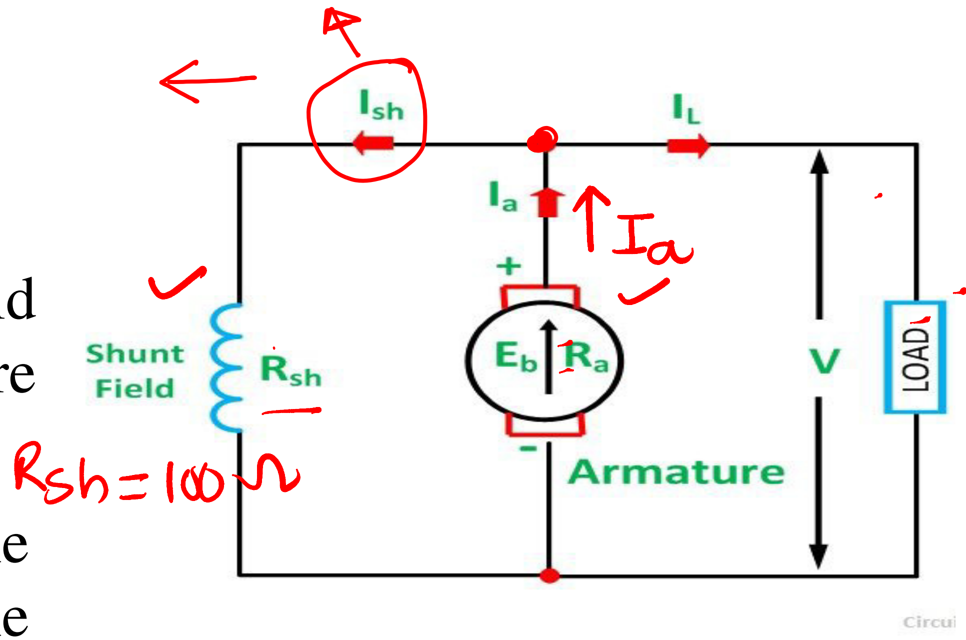
$I_a = I_{sc} = I_L = I$ (say)

Voltage across the load $V = E_g - I(R_a + R_{sc})$, Power generated $P_g = E_g \times I$

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

→ Parallel

2. Shunt Wound Generator



n these type of DC generators the field windings are connected in parallel with armature conductors

In shunt wound generators the voltage in the field winding is same as the voltage across the terminal.

R_{sh} = Shunt winding resistance
I_{sh} = Current flowing through the shunt field

$$I_a = I_{sh} + I_L$$

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, $P_L = V \times I_L$

The effective power across the load will be maximum when I_L will be maximum.
So, it is required to keep shunt field electric current as small as possible.
For this purpose the resistance of the shunt field winding generally kept high (100 Ω) and large no of turns are used for the desired emf.

3. Compound Wound Generator (Shunt + series)

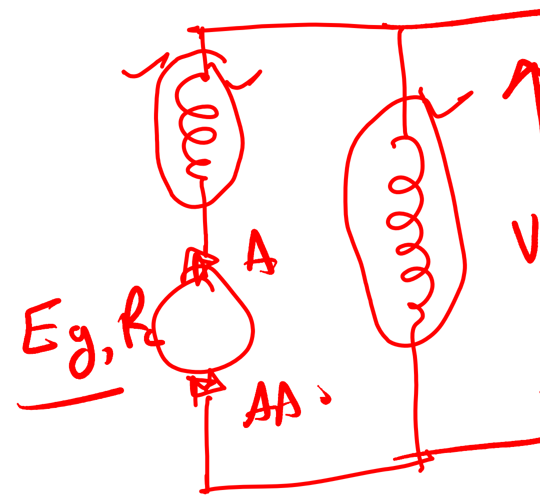
In a compound-wound generator, there are two sets of field windings on each pole—one is in series and the other in parallel with the armature. This combination of windings is called ***compound wound DC generator***.

Compound wound 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.

This type of DC generators may be of two types-

short shunt compound wound generator and

long shunt compound wound generator



DC Generator

emf equation

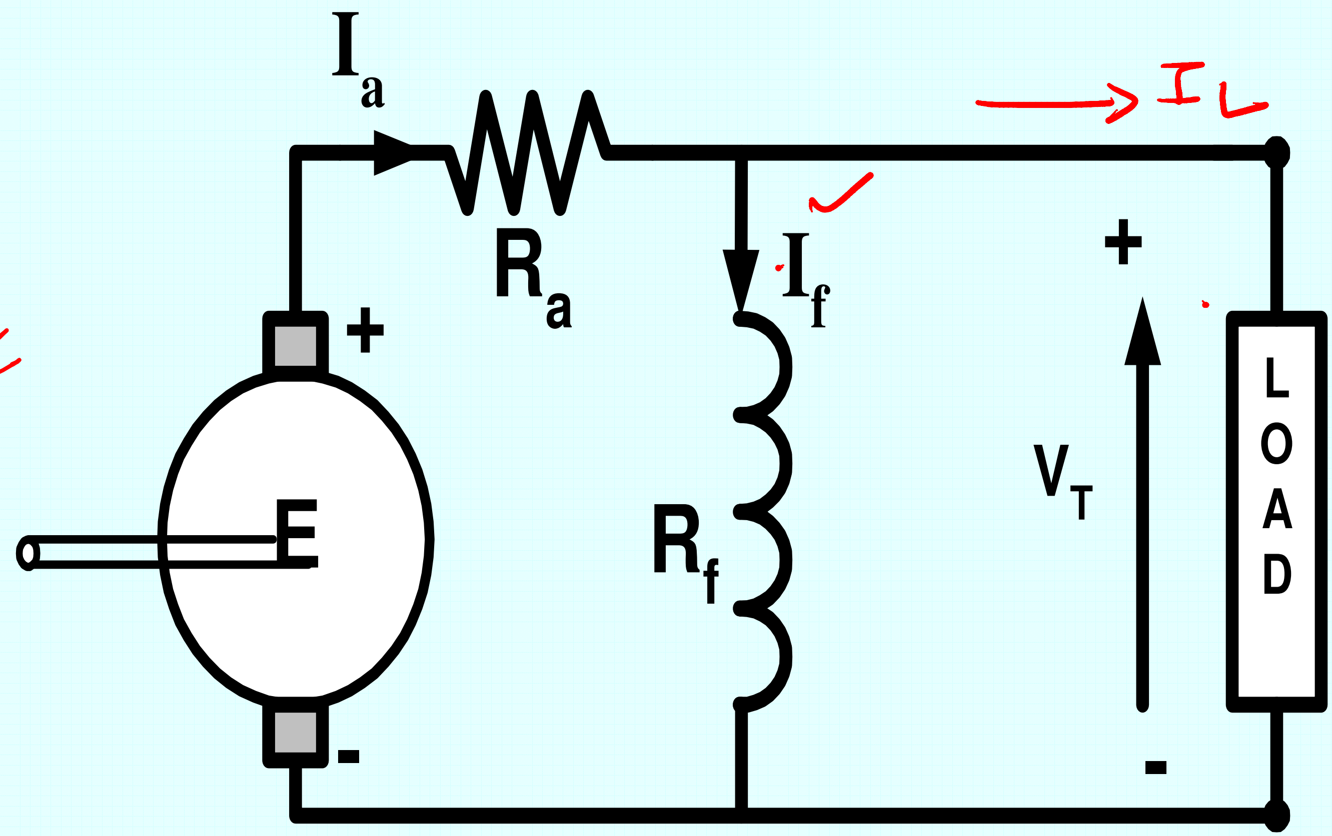
$$E_a = \frac{\Phi N z}{60}\frac{p}{a}$$

$$\boxed{V_L = E_a - I_a R_a}$$

$$I_f = \frac{V_L}{R_f}$$

$$I_a = I_f + I_L$$

Shunt



Note: $V_T = V_L$

i.e. Terminal Voltage is the Load Voltage

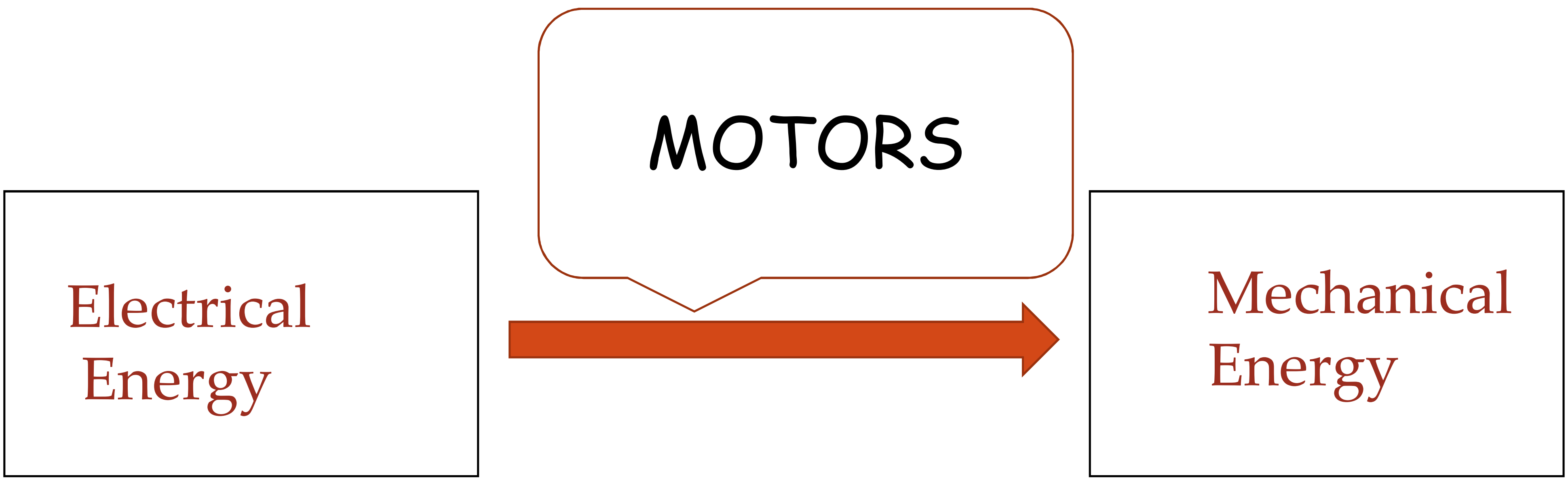
MOTORS

https://www.youtube.com/watch?v=43XAuU-515g&t=706s

Function:

Motors are the electrical machines which convert electrical energy into mechanical energy.

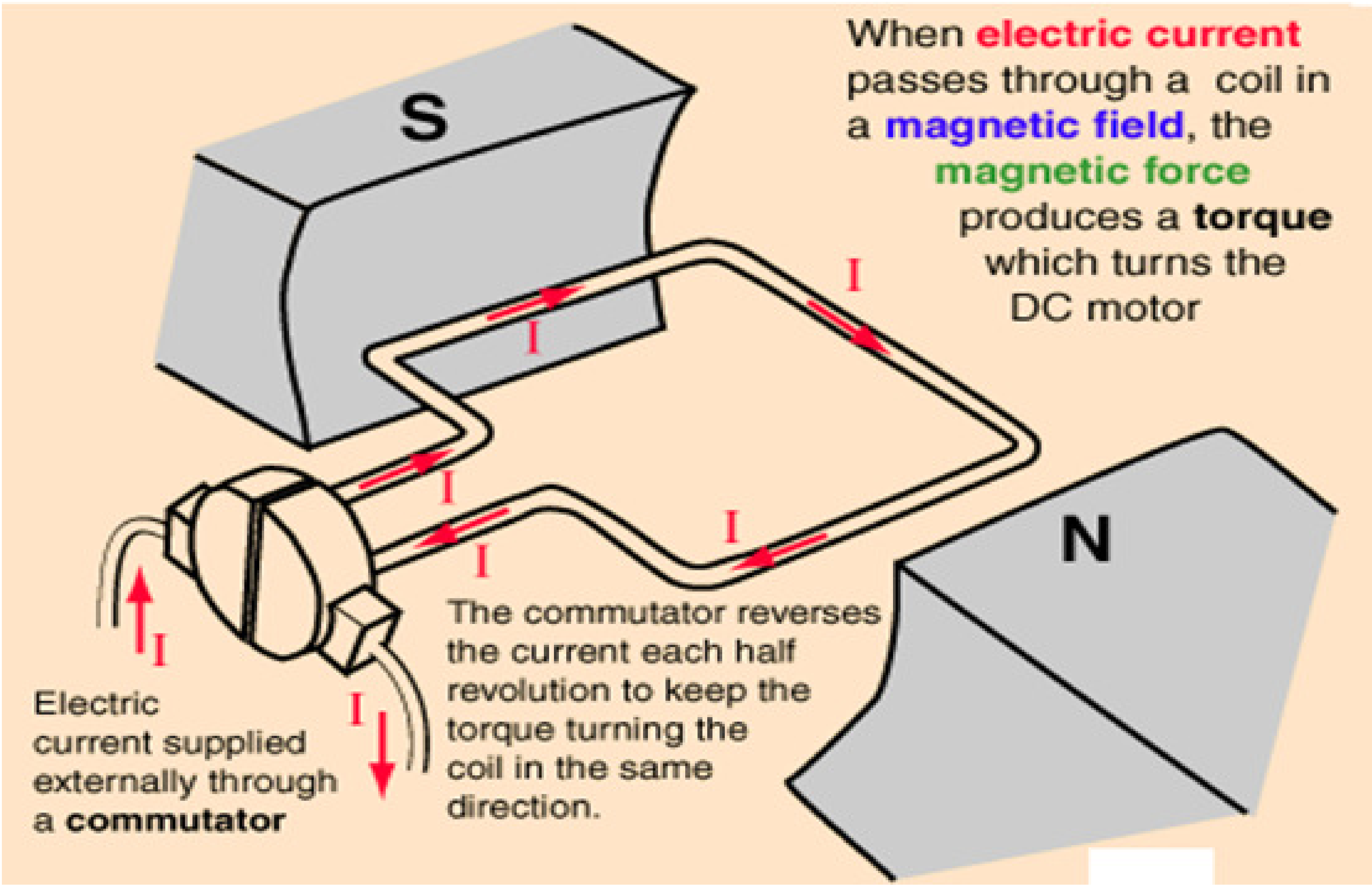
https://www.youtube.com/watch?v=6MnmcMYbsfQ



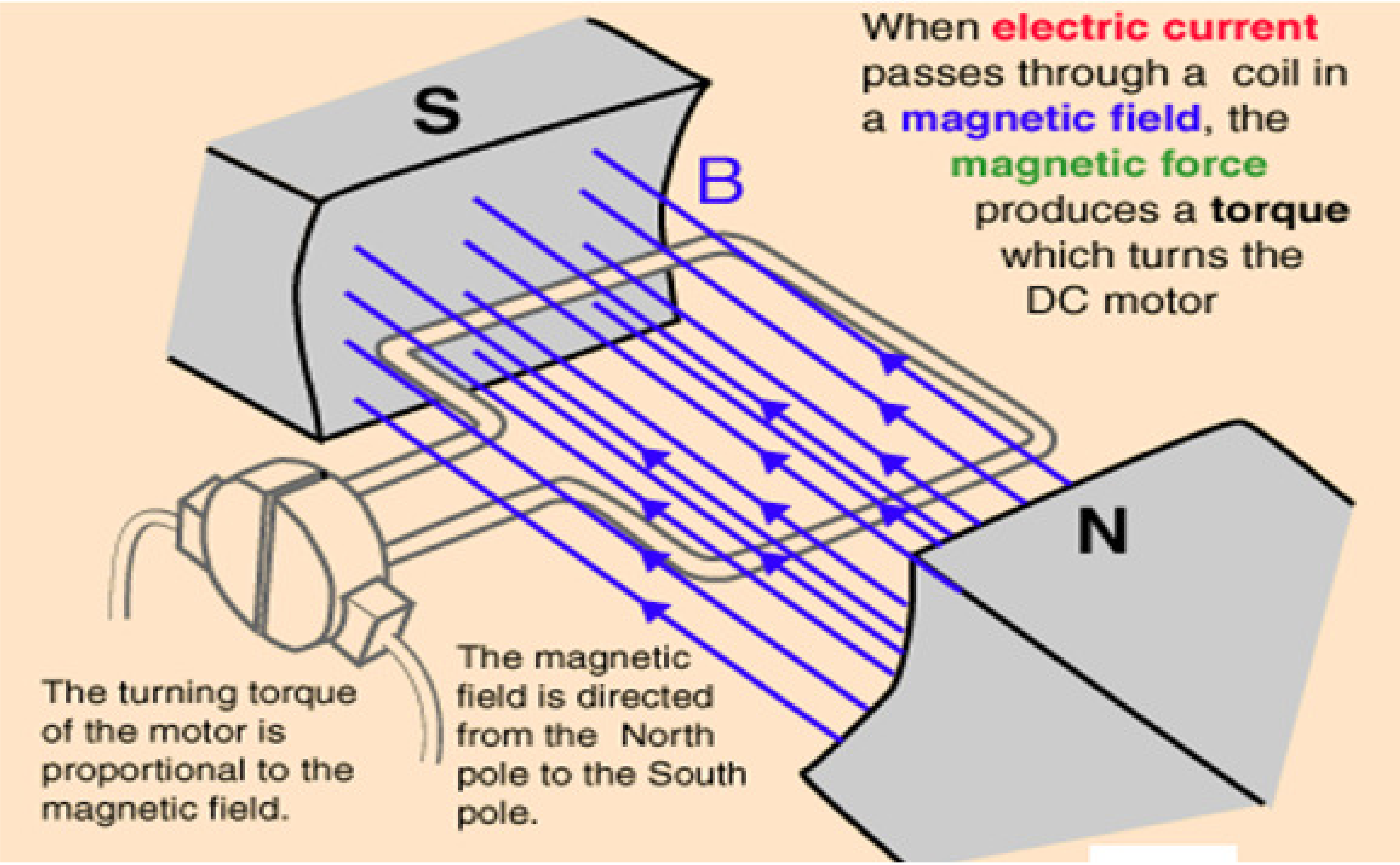
https://www.youtube.com/watch?v=j_F4limaHYI

Physical structure

Current carrying in the conductor

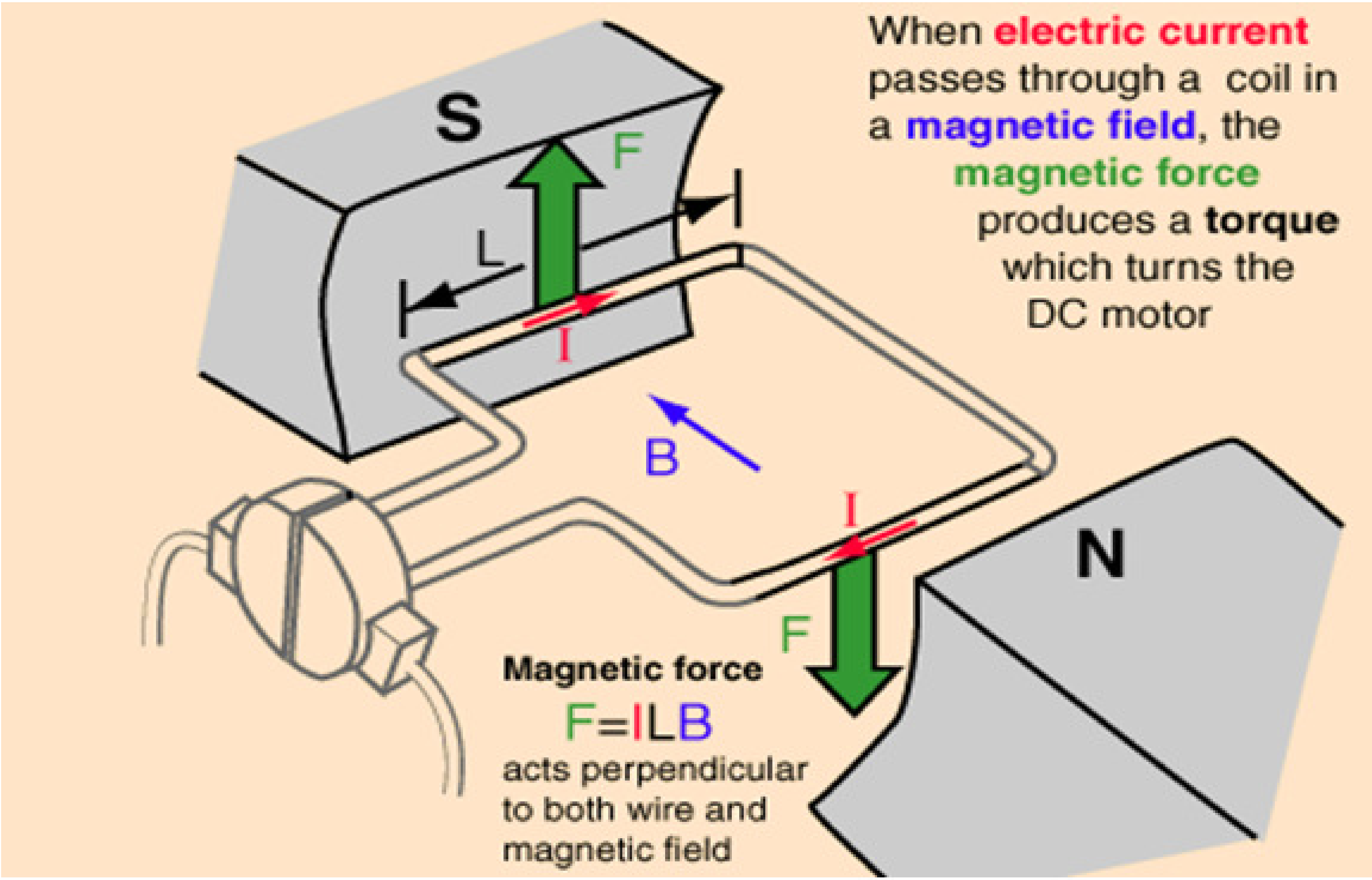


Magnetic field

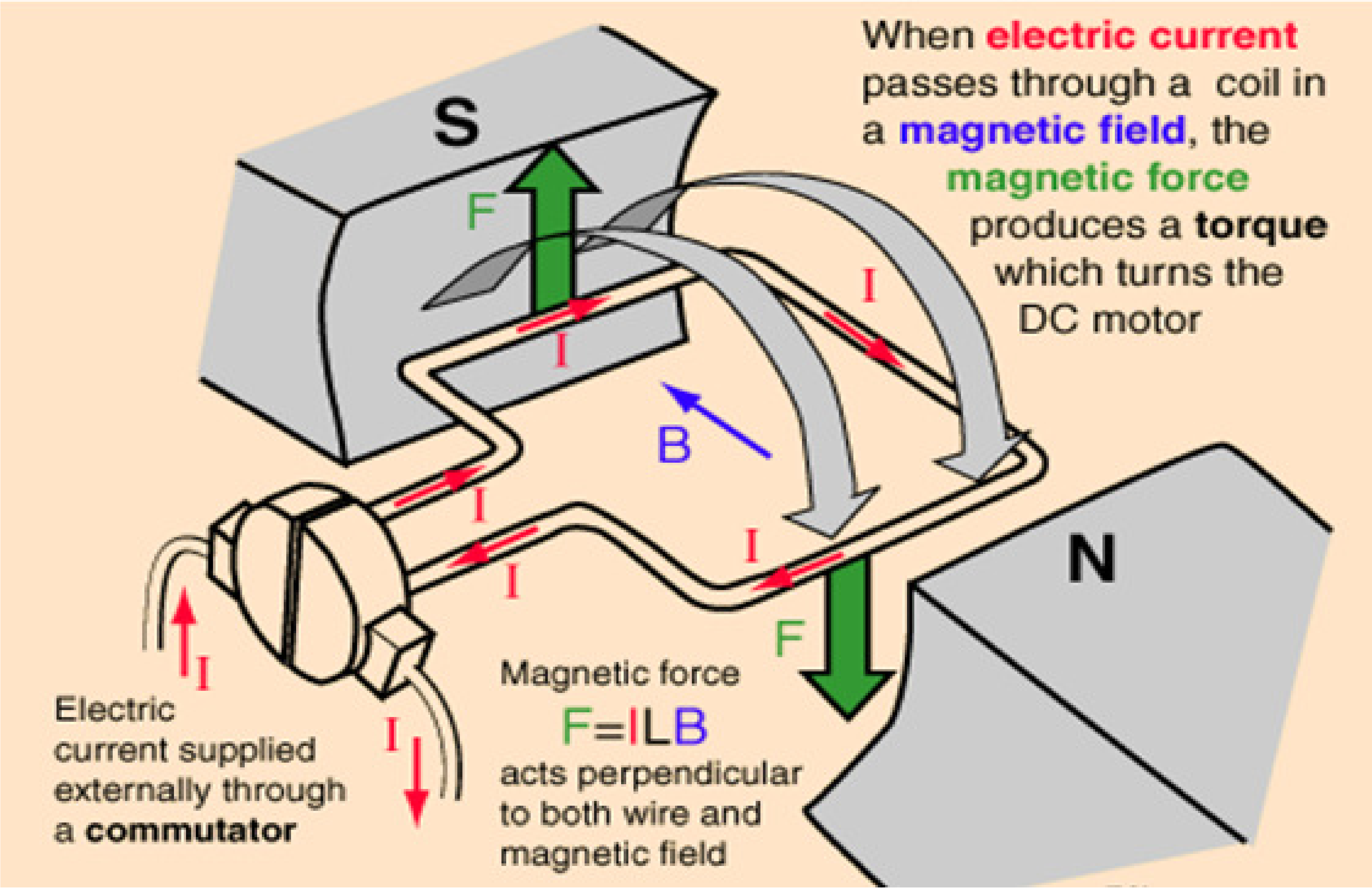


DC Motor Operation

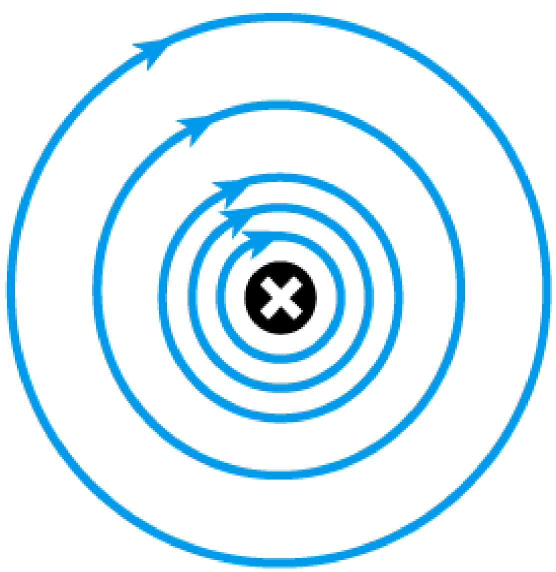
Resultant force



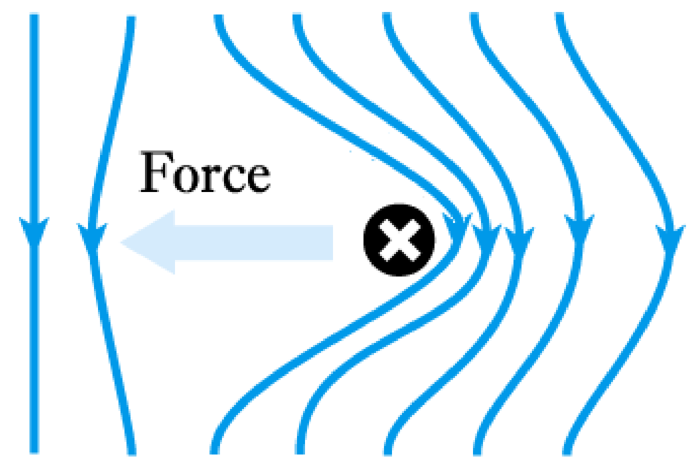
DC Motor Operation



- When current flows in a conductor it produces a magnetic field about it - as shown in (a) below
  - when the current-carrying conductor is within an externally generated magnetic field, the fields interact and a force is exerted on the conductor - as in (b)



(a) The magnetic field about a current flowing into the page



(b) The effects of an external magnetic field

Working Principle of a DC Motor

- A motor is an electrical machine which converts electrical energy into mechanical energy.
- The **principle of working of a DC motor**

  is that "*whenever a current carrying conductor is placed in a magnetic field, it experiences a mechanical force".*
- The direction of this force is given by Fleming's left hand rule and
- it's magnitude is given by $F = BIL$.
  - Where, B = magnetic flux density,
  - I = current and
  - L = length of the conductor within the magnetic field.

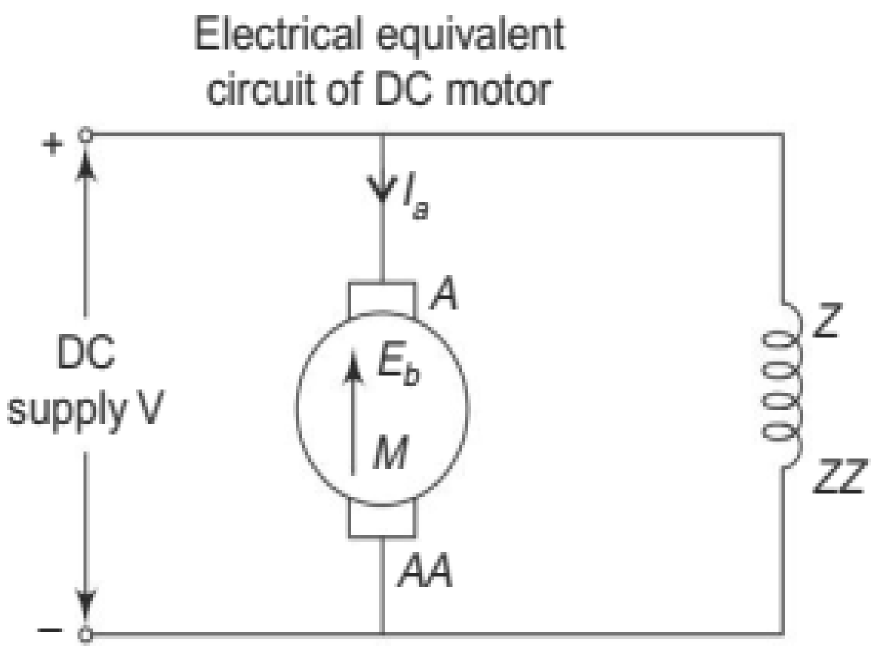
Concept of back emf (E_b)

$v_t = E_g - I_a R_a$

❑ A motor has coils turning inside magnetic fields, and a coil turning inside a magnetic field induces an emf. As per Lenz's law, this induced emf opposes the voltage applied to the armature. Hence, it is called the **counter or back emf**.

❑ There also occurs a potential drop in the armature circuit due to its resistance.

❑ Thus, the applied voltage has to overcome the back emf in addition to supplying the armature circuit drop and producing the necessary torque for the continuous rotation of the armature.

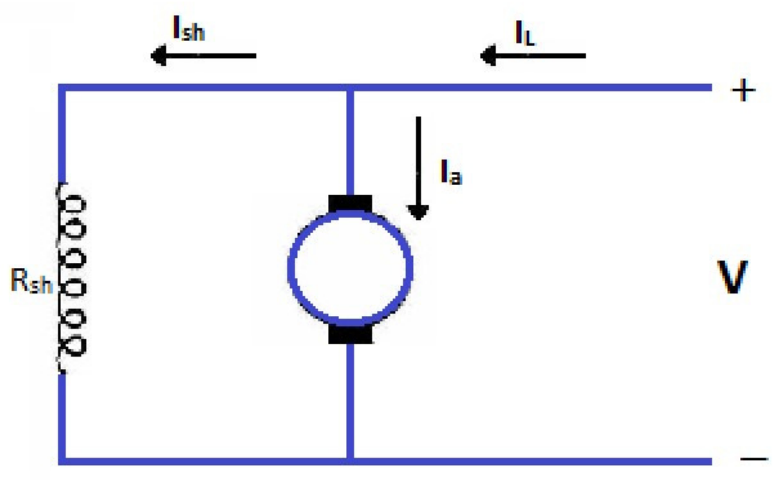


$$V = E_b + I_a R_a,$$

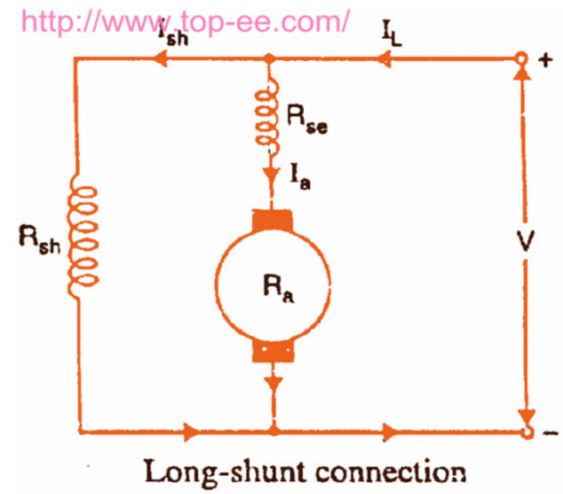
E_b = back EMF
I_a = current flowing in the armature circuit
R_a = resistance of armature circuit
V = applied voltage

Types of DC Motors and Electrical Equivalent

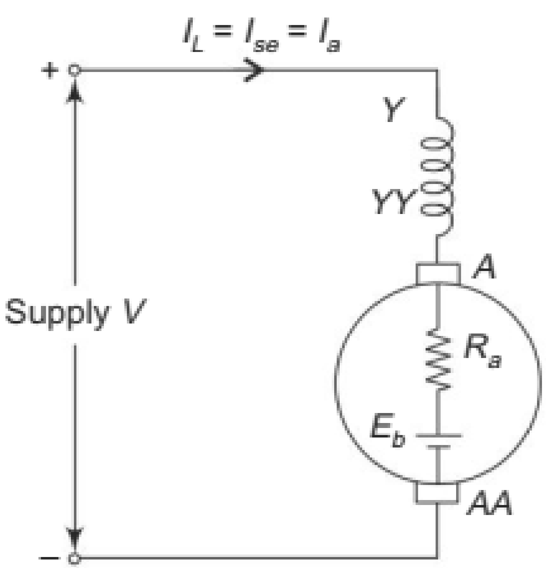
DC Shunt Motor:



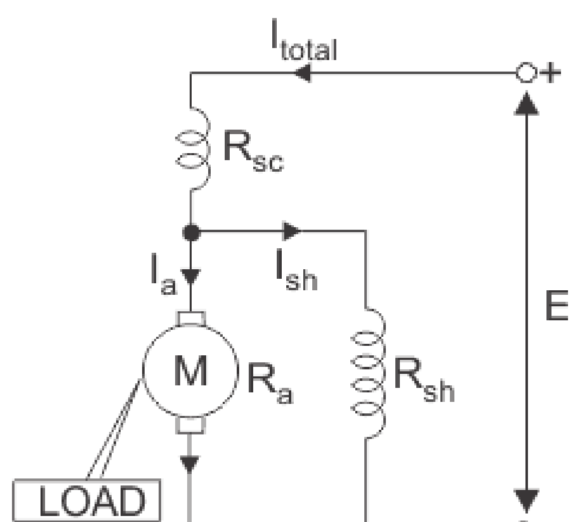
DC Compound motor: Long shunt motor



DC Series Motor:



Short shunt motor



Torque and speed equations of DC motors

$T = E_b I_a$

$$T_a = \frac{P\phi Z}{2\pi A} I_a; \text{ (N-m)}$$

$$N \alpha \frac{E_b}{\phi}$$

$$N \alpha \frac{V - I_a R_a}{\phi}$$

$$E_b = \frac{\varphi p N}{60} \times \frac{Z}{A}$$

Ta – Armature torque

P – number of poles

Z – number of conductors

A – number of parallel paths

Ia – Armature current

N – Speed in rpm

ø – flux in webers

V – Supply voltage

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

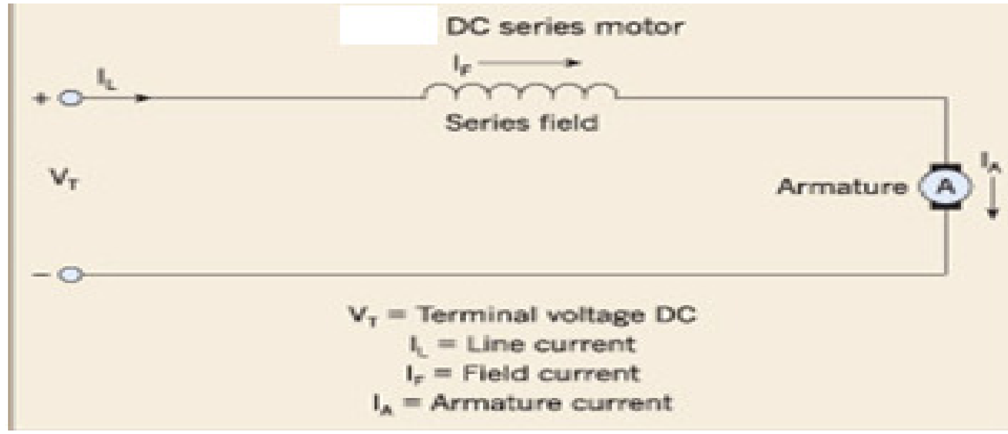
$E_b = \frac{P \phi N Z}{60 A}$

$E_b \propto N\phi$

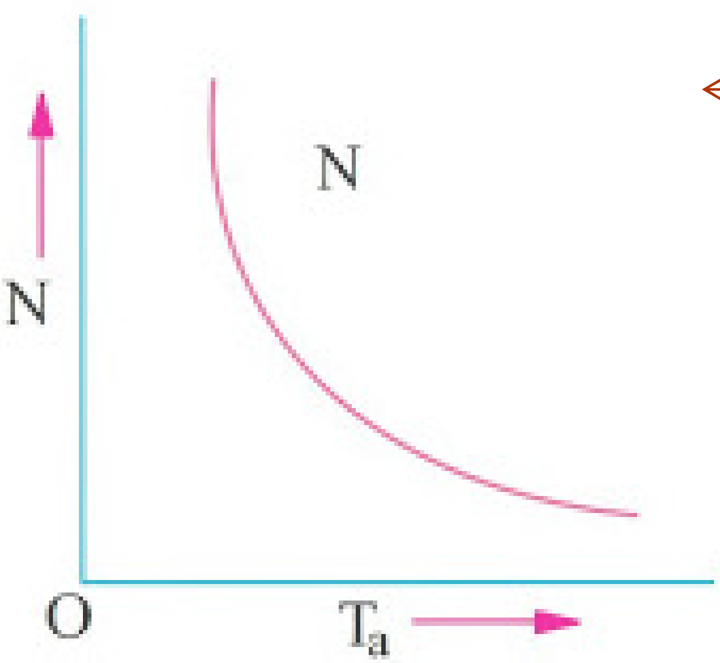
Characteristics of motor

Electrical (Ia, Ta)

Mechanical (Ia,N) and (Ta, N)



Characteristics of DC Series Motor



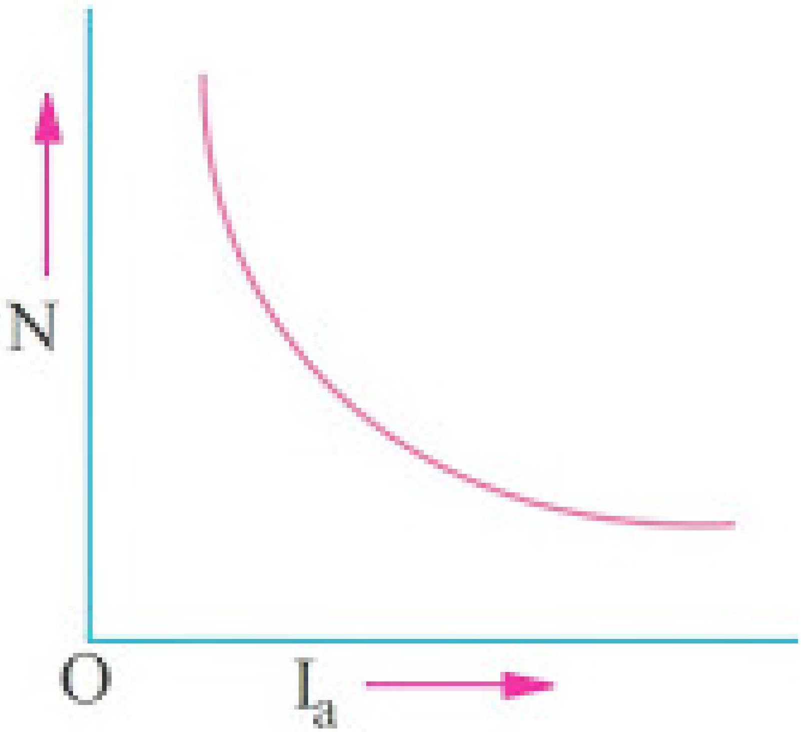
← **N/T_a Characteristic (Mechanical)**

In case of series motors, $T \propto I_a^2$ and $N \propto \frac{1}{I_a}$

Hence we can write, $\boxed{N \propto \frac{1}{\sqrt{T}}}$

N/I_a Characteristic

$$N \propto E_b/\Phi$$



$$\boxed{N \propto \frac{1}{I_a}}$$

Series motor cannot be started with no load.

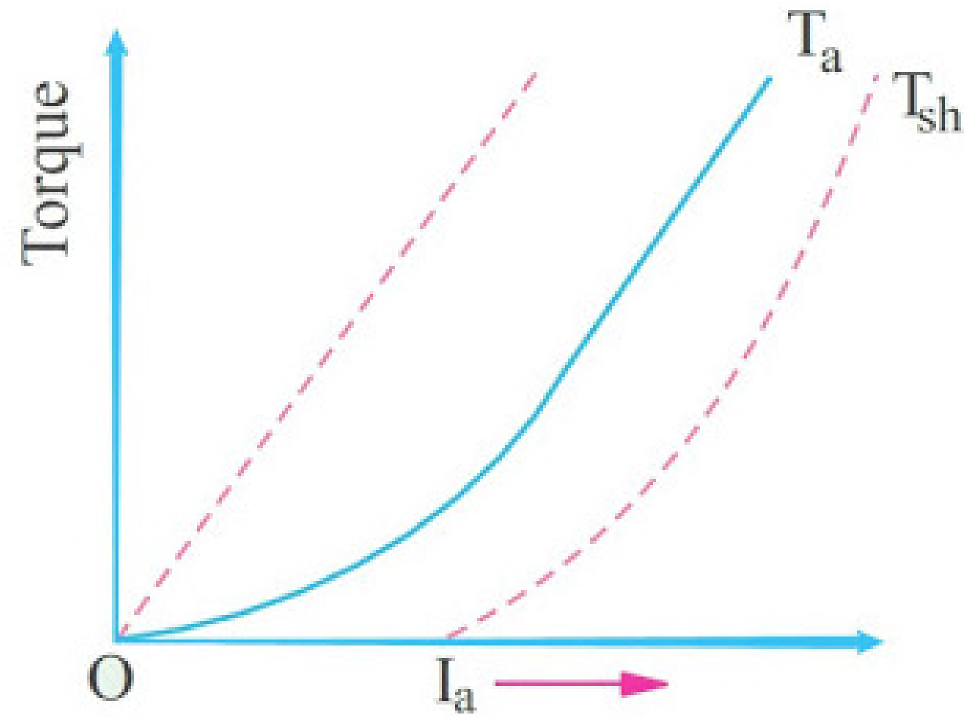
T_a/I_a Characteristic

$$T_a \propto \Phi I_a.$$

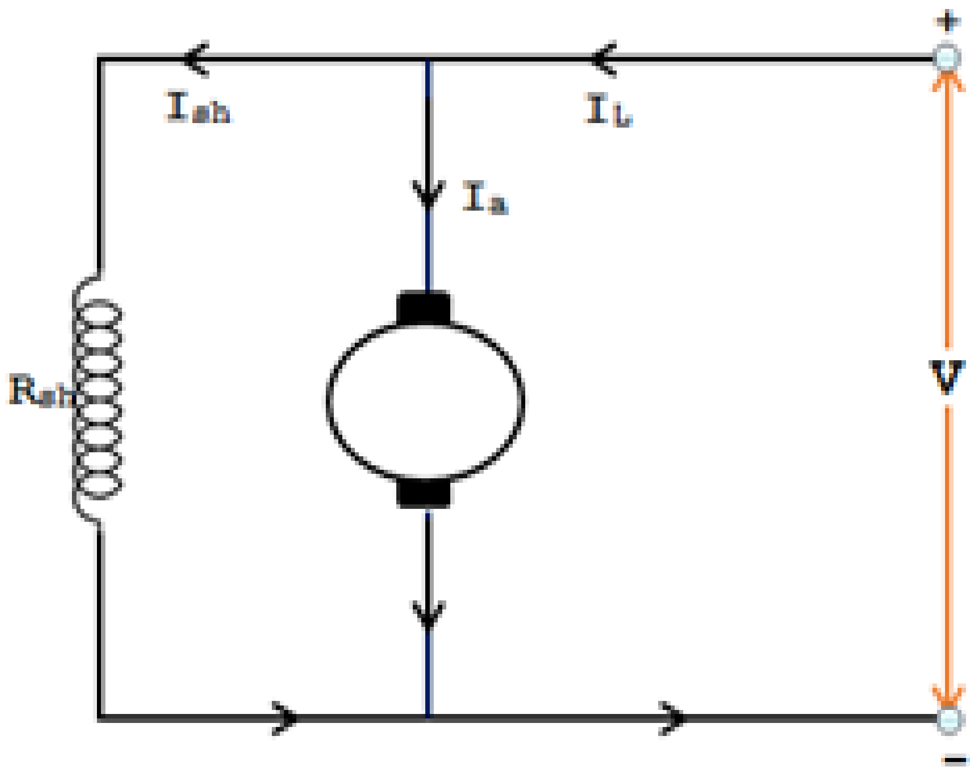
$$T_a \propto \Phi i_a$$

$$\therefore T_a \propto I_a^{\,2} \quad \text{before saturation}$$

$$T_a \propto I_a \quad \textit{after saturation}$$

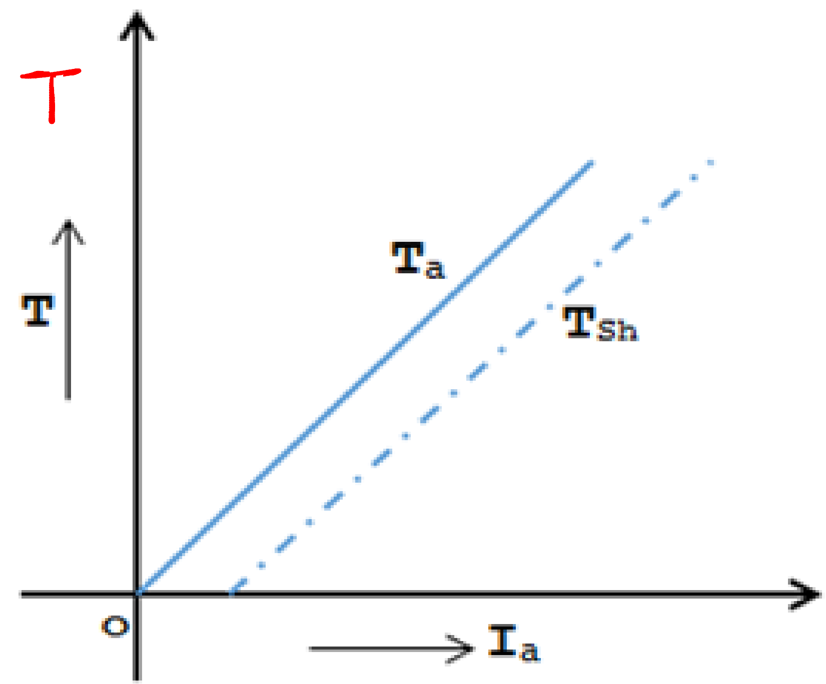


DC Shunt Motor

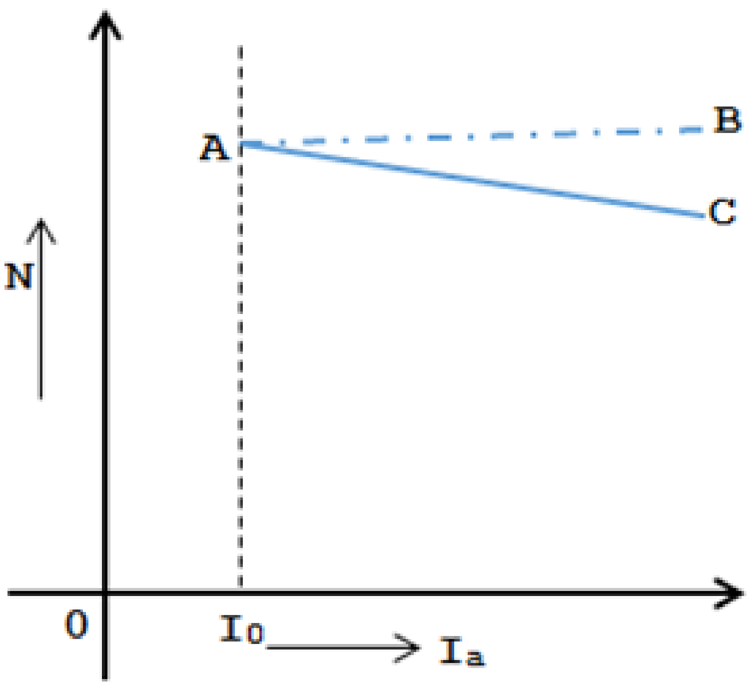


Torque V_s Armature current characterist

- $T_a \propto \Phi i_a$
- flux Φ is constant



- **Speed V_s Armature Current Characteristic**



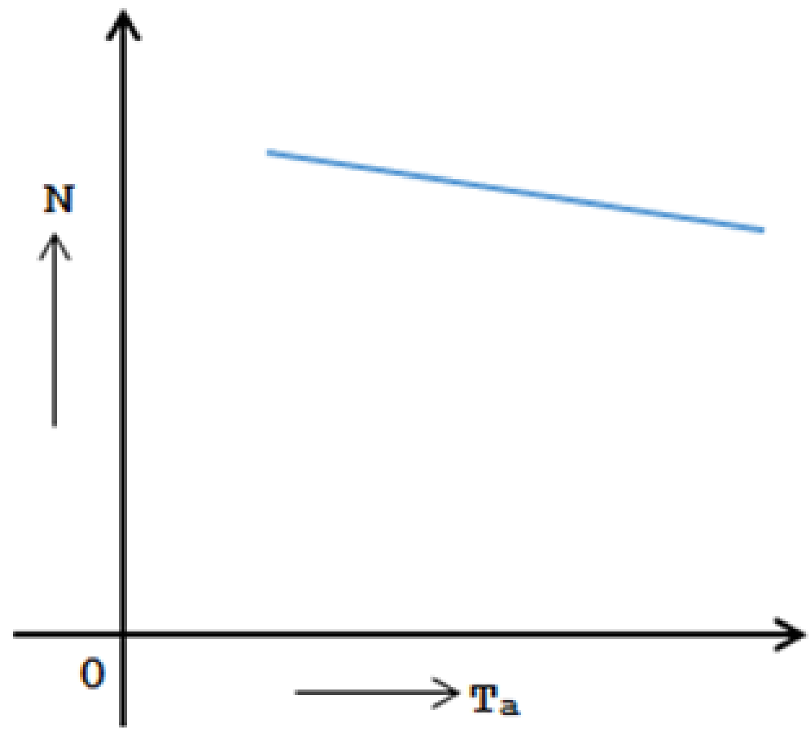
From the speed equation we get,

$$N \propto \frac{V - I_a R_a}{\phi}$$

$$\propto V - I_a R_a$$

Ø is constant

- **Speed V_s Armature Torque**



$$T_a = \frac{P\phi Z}{2\pi A} I_a ; \text{(N-m)}$$

Type of Motor	**Characteristics**	**Applications**
Shunt	Speed is fairly constant and medium starting torque.	1. Blowers and fans 2. Centrifugal and reciprocating pumps 3. Lathe machines 4. Machine tools 5. Milling machines 6. Drilling machines
Series	High starting torque. No load condition is dangerous. Variable speed.	1. Cranes 2. Hoists, Elevators 3. Trolleys 4. Conveyors 5. Electric locomotives
Cumulative compound	High starting torque. No load condition is allowed.	1. Rolling mills 2. Punches 3. Shears 4. Heavy planers 5. Elevators
Differential compound	Speed increases as load increases.	Not suitable for any practical applications

Starters

Starters are used to reduce initial high current

$$V = E_b + I_a R_a,$$

When the motor is standstill (not running), N is zero and results in E_b is zero

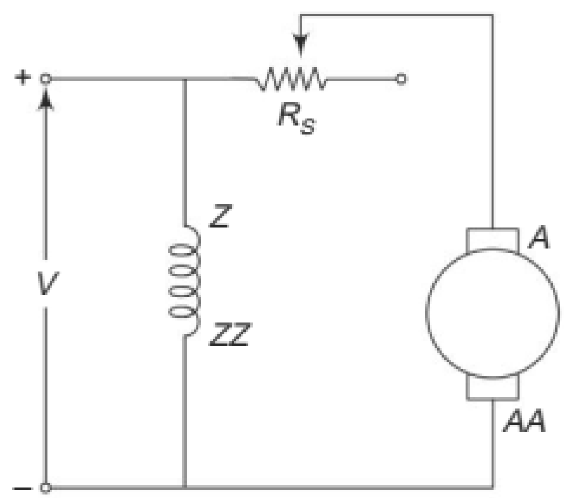
$$N \propto \frac{E_b}{\phi}$$

E_b is zero and Ra is very small , consequently dangerous amount of current will allows to flow in armature winding and it may damages the motor.

$$I_a = \frac{V}{R_a}.$$

high starting current

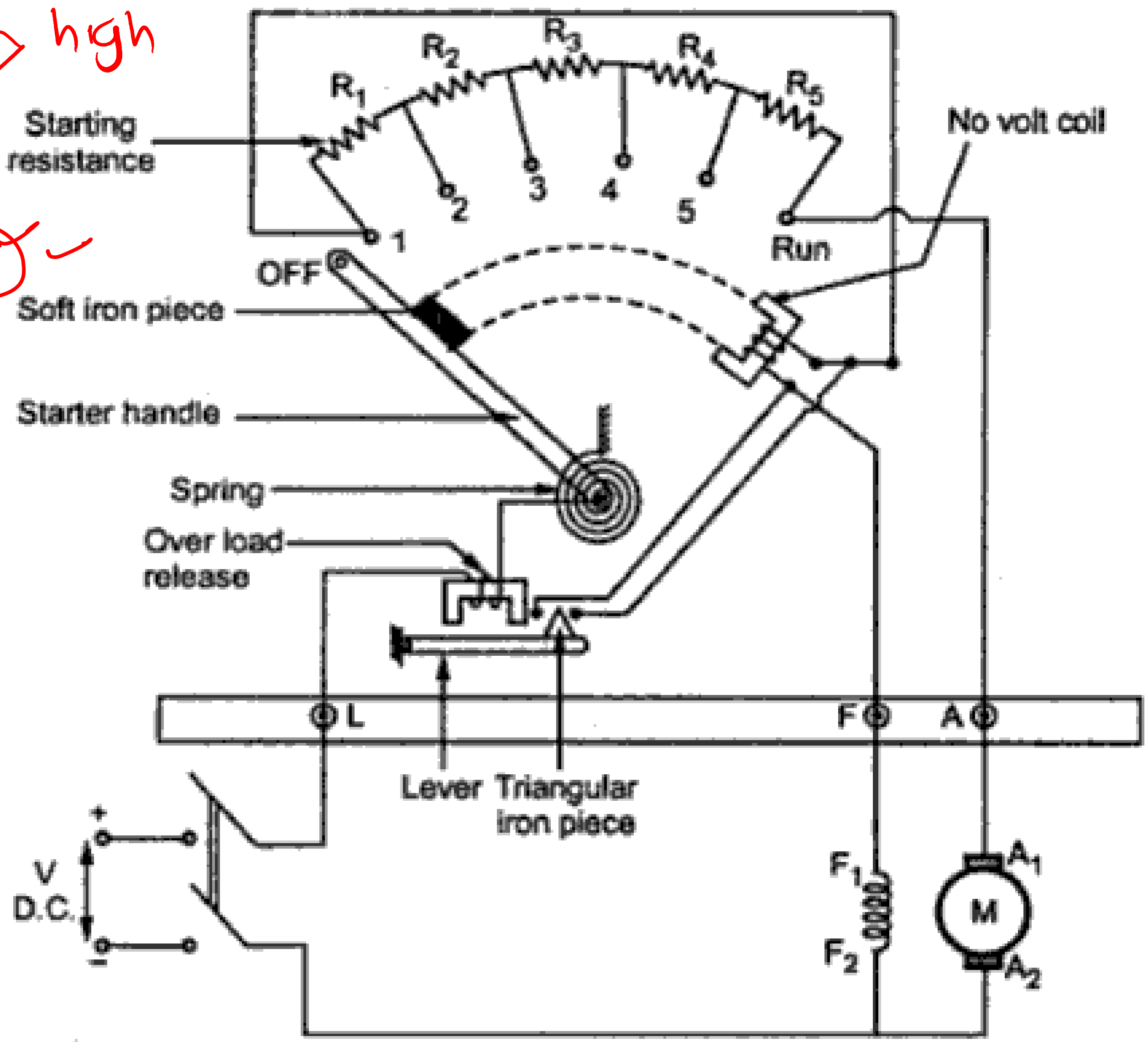
To limit such inrush currents an additional resistance is connected in series with the armature winding while starting the motor is known as Starter.



$N = 0$, $R =$ very high (100Ω)

$R = 0$

$N = 1000$ rpm



3 point Starter

Farday's Law of electromagnetic Induction

→ This law is based on conductor and it's flux linkages with magnetic field.

* There is two possible ways to flux linkages between conductor and magnetic field.

i) conductor is rotating and magnetic field is stationary.

ii) conductor is stationary and the magnetic field is rotating.

any of the above cases, the flux linkage between conductor and magnetic field can occur.

First one is called dynamically induced emf (EMF).

which is the principle of operation of AC & DC Generators

Second one is called Statically induced emf (EMF) which is the operating Principle of Transformer

~~Sa Dyn~~ Let the flux linking with the coil of 'N' turns changed by an amount $d\phi$ in short time dt.

(E) EMF induced $\propto \frac{d\phi}{dt}$

$$E \propto \frac{d\phi}{dt}$$

$$E = -N\frac{d\phi}{dt} \text{ volts}$$

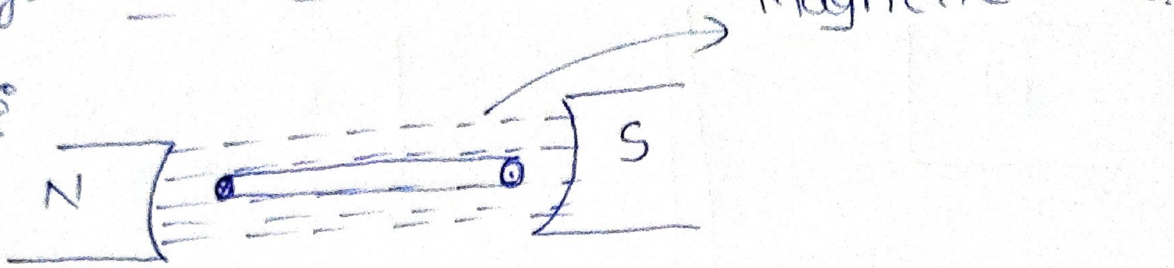
N represents no of turns

'–' indicates the Lenz's law effect

> While dynamically induced EMF means " a moving conductor in a uniform magnetic field and EMF is induced due to flux linkage between conductor and magnetic field.

Things to observe

at $\theta = 0^\circ$



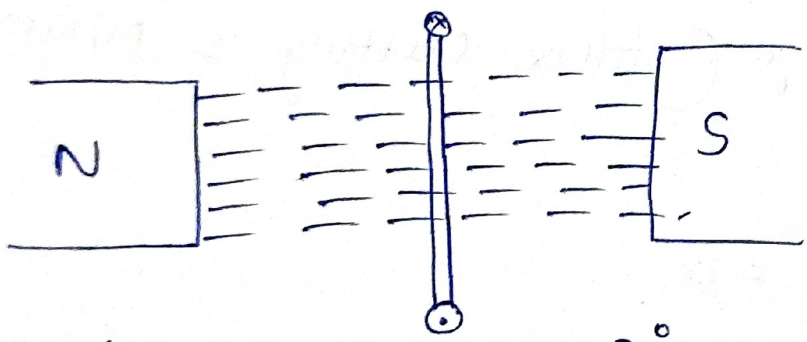
~~at~~ conductor is at 0°

$$e = -N\frac{d\phi}{dt}$$

no flux linkages (flux cut by the conductor)

$e = 0.$

at $\theta = 90^\circ$

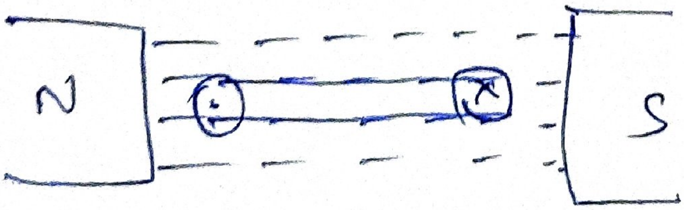


~~at~~ conductor is at 90°

maximum flux linkages with conductor and the

EF induced is High

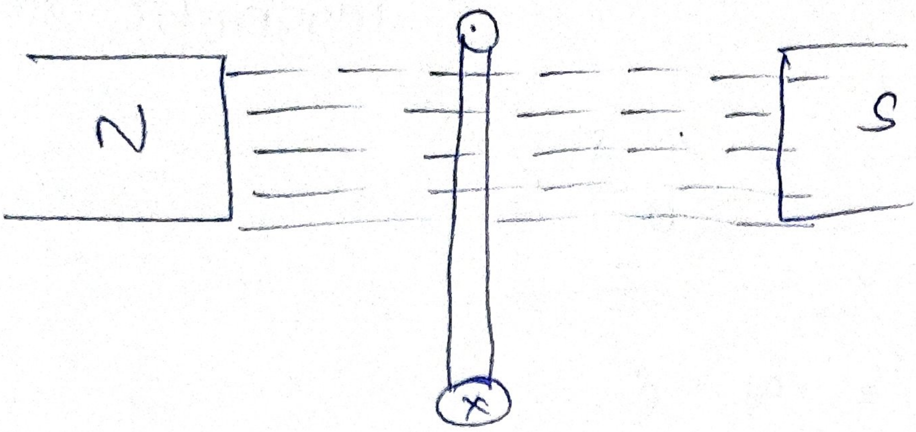
$\theta = 180^\circ$



~~at~~ conductor is at 180°

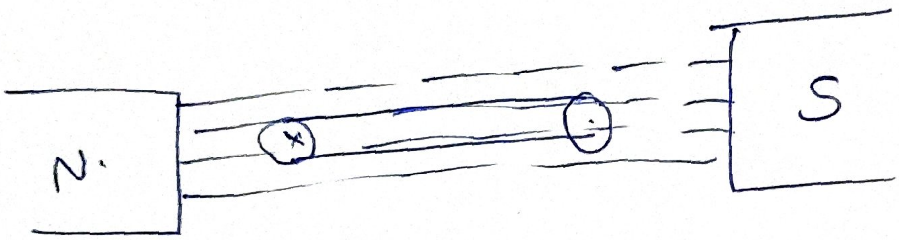
$e = 0.$

at 270°



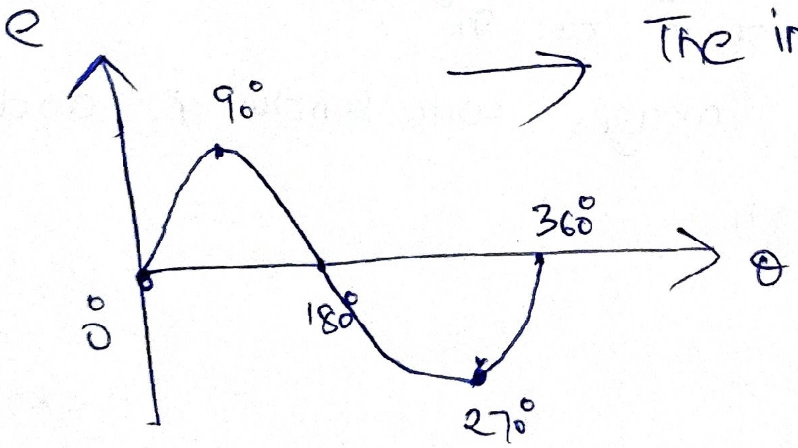
e = maximum (~~max~~ highest flux cuts)

at 360°



$e = 0$ (flux cutting is minimum)

$e = 0$



→ The induced EMF is AC in nature

EMF Equation of DC Generator

Let us consider a generator having "z" number of conductors and magnetic field system producing "ø" flux per pole and running at the speed of "N" revolutions per minute. So

ø = Flux per Pole in webers

Z = Total number of conductors in armature

p = Number of poles.

N = Speed of the armature in rpm.

A = Number of parallel paths in armature winding

E_g = Induced EMF

From Farday's Law of electro magnetic induction

Average EMF per conductor

$$E_g = \frac{d\phi}{dt} \rightarrow (1)$$

Flux cut by conductor in one revolution = øp

$$d\phi = \phi p \rightarrow (2)$$

Number of revolution per second = N/60

Time taken for one revolution $= \frac{60}{N}$

$$dt = \frac{60}{N} \rightarrow (3)$$

Substitute (2) & (3) in (1)

$$E_g = \frac{\phi N p}{60}$$

The induced emf for "Z" number of Conductors in any one of the armature parallel Path

$$E_g = \frac{\phi Z N P}{60}$$

~~If DC Gener~~ of DC Generator is having "A" number of Parallel paths, then

$$E_g = \frac{\phi Z N P}{60 A}$$

→ If DC Generator is constructed with wave winding $A = 2$ $E_g = \frac{\phi Z N P}{120}$

→ If DC Generator is constructed with LAP winding $A = P$ $E_g = \frac{\phi Z N}{60}$

The induced emf for "z" number of conductors in any one of the armature parallel path

$$E_g = \frac{\phi Z N P}{60}$$

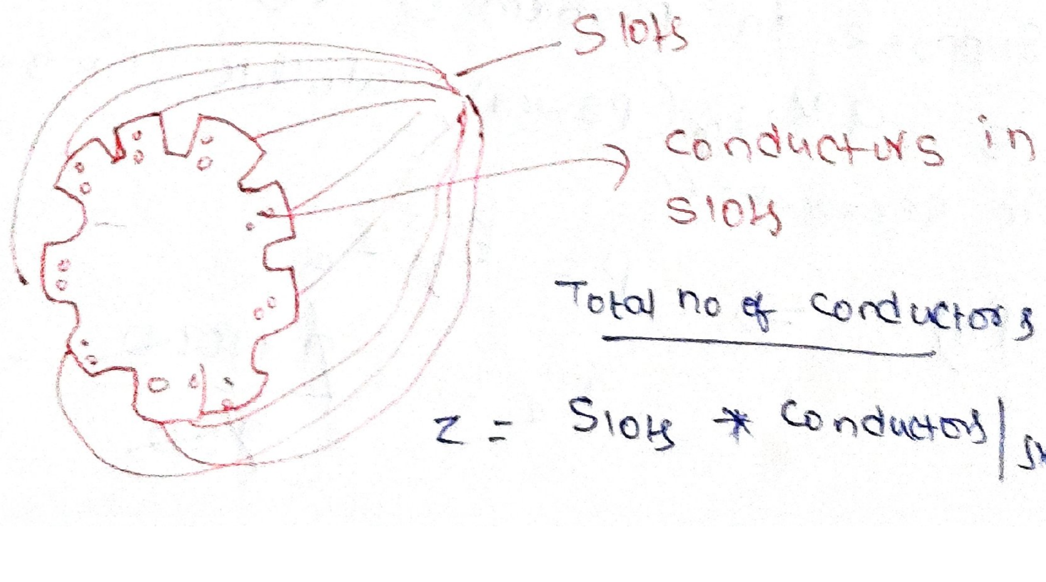
~~of DcGener~~ of Dc Generator is having "A" number of Parallel paths, then

$$E_g = \frac{\phi Z N P}{60 A}$$

→ If Dc Generator is constructed with wave winding $A=2$ $E_g = \frac{\phi Z N P}{120}$

→ If Dc Generator is constructed with LAP winding $A=P$ $E_g = \frac{\phi Z N}{60}$

Pb) 1 A 4-Pole wave-wound dc Generator is having 50 slots with 20 conductors per slot and rotating at 1500 rpm. The flux per pole is 0.018 wb. Caluclate the EMF Generated!



Total no of conductors

$Z =$ Slots $*$ Conductors / Slot

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Sol :-

$P = 4$

$A = 2$ [wave winding]

$\phi = 0.018$ wb

$N = 1500$

$Z =$ number of Slots * number of conductors)

$= \cancel{200}\ 50 \times 20 = 1000$

$$E_g = \frac{\phi Z N P}{60 A} = \frac{0.018 \times 1000 \times 1500 \times 4}{60 \times 2}$$

$$= 900V$$

Pb) 2 Solve the above problem with lap windi[ng]

Sol :- $P = 4$; $A = P$ (Lap winding); $\phi = 0.018$ wb

$N = 1500$; $Z = 1000$

$$E_g = \frac{\phi Z N \cancel{P}}{60 \cancel{A}} = \frac{\phi Z N}{60} = \frac{0.018 \times 1000 \times 1500}{60}$$

$$= 450V$$

Suppose in problem ① & ② Generator rating is 9 KW (power); calulate current flowing in generator.

Pb) 1 $\Rightarrow$ $P = E_g \cdot I_a$

$$I_a = \frac{\cancel{9} \times 100\cancel{0}}{\cancel{9}0\cancel{0}} = 10A$$

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Pb2) $P = E_g \cdot I_a$

$$I_a = \frac{\cancel{9}^{1} \times 100\cancel{0}}{\cancel{45}\cancel{0}_{5}} = 20\,A$$

Obs

Observation

→ ~~Lap~~ wave winding is used for high voltage. low current applications.

→ Lap winding is used for low voltage high current application

Pb) Caluclate the Generated emf of a 4-Pole, wave wound armature having 38 Slots with 18 Conductors per slot when driven at 1000 rpm. The flux per Pole is 0·018 wb

Sol

$P = 4$

$A = 2$ (wave winding)

N = no of Slots = 38

number of Conductors per slot = 18

$Z = 38 \times 18 = 684$

$\phi = 0{\cdot}018\,wb$; $N = 1000$

$$E_g = \frac{\phi Z N P}{60 A} = \frac{0{\cdot}018 \times 684 \times 1000 \times 4}{60 \times 2}$$

$= 410{\cdot}4\,V$

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Pb) A 6-pole lap wound dc Generator has 400 conductors on its armature. The flux per pole is 0.02 wb. Calculate.

i) The speed at which the Generator must be run to generate 400V.

ii) The speed ~~the~~ if the Generator were wave wound to generate 200V.

Sol :

$$E_g = \frac{\phi Z N P}{60 A}$$

Lap winding $A = P$

$$\cancel{400} \quad E_g = \frac{\phi Z N}{60}$$

$$400 = \frac{0.02 \times 400 \times N}{60}$$

$$N = 3000 \text{ rpm.}$$

ii)

$$E_g = \frac{\phi Z N P}{60 A}$$

wave winding $A = 2$

$$1 \cancel{200} = \frac{0.02 \times \cancel{400} \times N \times \cancel{6}}{\cancel{60}\ \cancel{20}\ \cancel{2}}$$

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$$200 = \frac{0.02 \times 400 \times N}{60} \times \frac{6}{2}$$

$=$

$N = 500$ rpm.

Pb) A dc Generator develops an emf of 200V when driven at 900 rpm with a flux per pole 0.04 wb. It is desired that this emf be increased to 250V at 1000 rpm. what should be the value of flux per pole under new circumstances

$$E_g = \frac{\phi Z N P}{60 A}$$

from above equation

$E_g \propto \phi Z N P$

$E_g \propto \phi$; $E_g \propto Z$; $E_g \propto N$; $E_g \propto P$

$E_g \propto 1/A$

from above problem the mentioned about E_g, N and ϕ

$E_g \propto \phi N$

$E_{g_1} = \phi_1 N_1$ $\quad (200 \propto \cancel{\phi}\ 1000 \times 0.04)$

$E_{g_2} = \phi_2 N_2$ $\quad (250 \propto \phi \times 900)$

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$$\frac{200}{250} = \frac{900 \times 0.04}{1000 \times \phi}$$

$$\phi = 0.045 \text{ wb}$$

Therefore, required flux per pole to develop 250V at 1000 rpm is 0.045 wb.

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P5) A DC Generator develops an emf of 220V at 1200 rpm and had the parallel paths of two; if the parallel paths are charged to s… and speed of machine is 1500 rp… calculate the new EMF

Sol :—
$$E_g = \frac{\phi Z N P}{60 A}$$

from the given problem data

$$E_g \propto N \; ; \; E_g \propto 1/A$$

$$E_{g_1} = \frac{N_1}{A_1} \longrightarrow (1)$$

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erator develops
200 rpm and had the
s of two; if the
s are changed to six
machine is 1500 rpm
new EMF

$\frac{\phi Z N P}{60 A}$

given problem data

N ; $E_g \propto 1/A$

N_1
$\longrightarrow$ ①

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$$E_{g2} = \frac{N_2}{A_2} \rightarrow (2)$$

$$\frac{E_{g1}}{E_{g2}} = \frac{N_1/A_1}{N_2/A_2}$$

$$\frac{E_{g1}}{E_{g2}} = \frac{N_1 A_2}{N_2 A_1}$$

$$E_{g2} = E_{g1} \cdot \frac{N_2 A_1}{N_1 A_2}$$

$$E_{g2} = \frac{220 * 1500 * 2}{1200 * 6}$$

$$E_{g2} = 91.66 \text{ V}$$

Pb) A Dc Generator develops an emf of 220V at 1200 rpm with a flux per Pole 0.04 wb. what will be the flux value to induce 240V at 1400 rpm.

Sol:

$$E_g = \frac{\phi Z N p}{60 A}$$

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$$E_{g1} = \phi_1 N_1 \rightarrow (1)$$

$$E_{g2} = \phi_2 N_2 \rightarrow (2)$$

$$\frac{(1)}{(2)} \Rightarrow \frac{E_{g1}}{E_{g2}} = \frac{\phi_1 N_1}{\phi_2 N_2}$$

$$\frac{220}{240} = \frac{0.04 \times 1200}{\phi \times 1400}$$

$$1400\,\phi = \frac{0.04 \times 1200 \times 240}{220}$$

$$\phi = \frac{0.04 \times 1200 \times 240}{220 \times 1400}$$

$$\phi = \underline{0.037 \text{ wb}}$$

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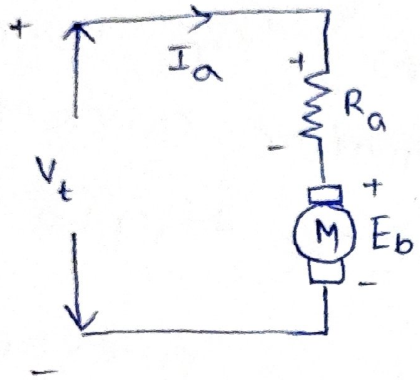
SIGNIFICANCE OF BACK EMF

The applied voltage and back emf in dc Motor are in opposition, hence the net voltage across the armature is given as $V - E_b$. If the armature resistance is R_a, then current drawn by armature is I_a.

let us represent it;



$$V_t = E_b + I_a R_a.$$

$$I_a = \frac{V_t - E_b}{R_a}.$$

"I_a" represents the current flowing in motor.

suppose $V_t = 230\,V$

$R_a = 1\ \Omega$

at Motor Strating no Emf It will take certain time to develop; so $E_b = 0$

$$I_a = \frac{V_t - 0}{R_a} = \frac{230}{1} = 230\ A$$

'Very dangerous Current motor will damage.

Once EMF is developed $E_b = 225V$

$$I_a = \frac{230 - 225}{1} = \underline{\underline{5A}}$$

The presence of back EMF ~~makes~~ self the regulates the armature current and automatically regulated torque and speed through armature current. When load on the motor is increased; speed falls down. The back EMF reduces due to decrease in speed ($E_b = \frac{\phi ZNP}{60A}$; $E_b \propto N$). In turn the motor draw more armature current ($\uparrow I_a = \frac{V_t(\text{fixed}) - E_b\downarrow}{R_a(\text{fixed})}$). The torque is proportional to armature current so motor again attains it torque delivering capacity. Thus the equilibrium is again attained

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Torque Equation of DC Motor

The voltage equation of a dc motor can be expressed as:

$$V_t = E_b + I_a R_a \rightarrow (1)$$

Multiply Equation (1) with I_a

$$(V_t) I_a = E_b I_a + I_a^2 R_a \rightarrow (2)$$

$V_t I_a$ = input power supplied by moto

$E_b I_a$ = Output Power developed in motor

$I_a^2 R_a$ = Losses in motor.

So from Eq.(2)

input = output + losses.

The output power ($E_b I_a$) is the value actually converts into mechanical power

$P_m = \omega . T$ = [Expression for ~~angular~~ real mechanical power]

$$P_m = \omega T = \frac{2\pi N . T}{60} \rightarrow (3)$$

$$P_m = E_b I_a \rightarrow (4)$$

where $E_b = \dfrac{\phi Z N P}{60 A}$

Equate (3) & (4) $\Rightarrow$ (3) = (4)

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$$\frac{\phi Z N P}{\cancel{60} A} \cdot I_a = \frac{2\pi N T}{\cancel{60}}$$

$$T = \frac{PZ}{2\pi A} \phi I_a$$

$$T = 0.159 \frac{PZ}{A} \phi I_a$$

$$\boxed{T = 0.159\, \phi Z I_a \cdot \frac{P}{A}}$$

The Torque developed by dc motor is directly proportional to the flux and armature current.

(i) In case of shunt motors, ϕ is practically constant, hence $\boxed{T \propto I_a}$

(ii) In case of series motor, ϕ is proportional to I_a $\boxed{T \propto I_a^2}$

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b) A 4-Pole, 500 V, 75.6 kW wave connected Shunt motor has 600 conductors. The flux per pole is 45 mwb. Its armature resistance ~~is 250A~~ is 0.2Ω. Calculate the i) motor speed ii) useful torque developed &

Sol :-

$$V_t = E_b + I_a R_a \rightarrow (1)$$

$$P = V_t \cdot I_a$$

$$(75.6 \times 1000) = \cancel{250}) (500) \cdot I_a$$

$$I_a = \frac{75.6 \times 1000}{500}$$

$$I_a = 151.2\,A \rightarrow (2)$$

Sub (2) in (1)

$$500 = E_b + (151.2)(0.2)$$

$$E_b = 500 - (151.2)(0.2)$$

$$= 469.76\,V$$

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

A = 2 (Since it is wave winding)

$$469.76 = \frac{(0.045)\left(\cancel{600}^{\cancel{10}\,5}\right) \times N \times 4}{\cancel{60}_{1} \times \cancel{2}}$$

$$N = 521.95 \text{ rpm}$$

$$T_a = 0.159\, \phi Z I_a \left[\frac{P}{A}\right]$$

$$T_a = 0.159 \times 0.045 \times 600 \times 151.2 \times \left[\frac{4}{2}\right]$$

$$T_a = 1298.2 \text{ N-m}$$

SPEED CONTROL of DC MOTOR

DC Motor speed control Theory

To derive the speed of a DC motor, we start with the equation of the DC motor's EMF. We know that; EMF of DC motor can be expressed as:

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

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

A, Z, P and 60 are constants; so

let us assume $K = \frac{PZ}{60A}$

$$N = \frac{E_b}{K\phi} \rightarrow (1)$$

we $V_t = E_b + I_a R_a$

$$E_b = V_t - I_a R_a \rightarrow (2)$$

Sub (2) in (1)

$$N = \frac{V_t - I_a R_a}{K\phi} \rightarrow (3)$$

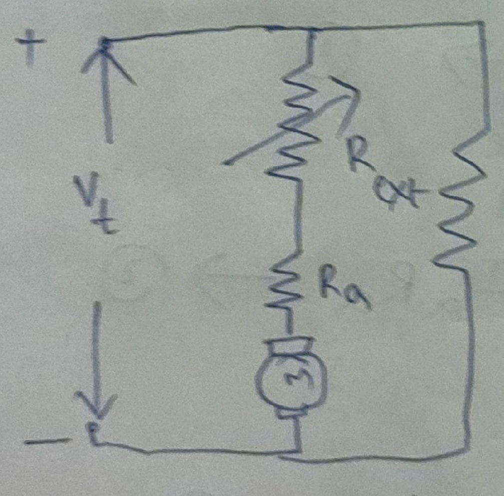
from Eq. (3); It can be understandes that speed contorol can be possible either by controlling

① Armature Voltage.
② Armature ~~Resistance Current~~ Resistance
③ flux in the motor.

Based on these ; speed control of DC motor can be classified as.

i) Armature resistance control
ii) field flux control
iii) Armature Voltage control
— ward Leonard Method.

Armature Resistance Control Method



→ This method is used to control the speed of DC motor below its rated speed.

→ During this method, an external resistance will connected in series with armature resistance

→ Supply voltage will be maintained at t
rated value.

$$N = \frac{V_t - I_a R_a}{K\phi}$$

$$N \propto \frac{V_t - I_a(R_a + R_{ext})}{K\phi}$$

In this method; supply voltage and flux are kept constant

$$N \propto \underbrace{V_t - I_a(R_a + R_{ext})}_{E_b}$$

$(R_a + R_{ext}) > R_a$

$E_b \downarrow \rightarrow N \downarrow$

$$\boxed{E_b \propto N}$$

So in this way speed will reduce

Ex :— A DC Motor operating at a supply voltage of 220V and draws an armature current of 20 A with an armature resistance of 1 Ω

(i) Calculate the ~~emf~~ back emf in the motor.

(2) Earlier case suppose motor is operating at 1000 rpm. Now an external resistance of 1Ω is connected to motor. Calculate the new speed of motor.

Sol (i)

$$V_t = E_b + I_a R_a$$

$$E_b = (220) - (20)(1)$$

$$E_b = 220 - 20$$

$$E_b = 200V$$

(ii)

$$E_b = V_t - I_a(R_a + R_{ext})$$

$$= 220 - (20)(1+1)$$

$$= 220 - 40$$

$$= 180V$$

$$E_b \propto N \qquad \frac{E_{b_1}}{E_{b2}} = \frac{N_1}{N_2}$$

$$\frac{200}{180} = \frac{1000}{N_2}$$

$$N_2 = \frac{\cancel{1000}^{5} \times 180}{\cancel{200}\,1}$$

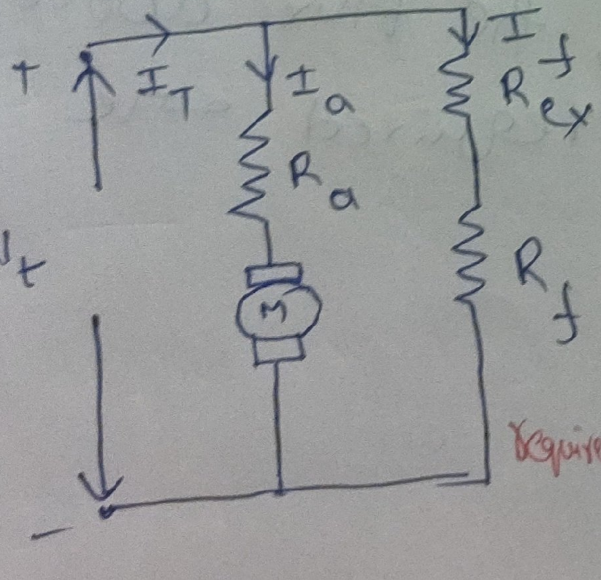
$$N_2 = 900 \text{ rpm}$$

Field Flux Control Method

→ This method is used to control the speed of a DC shunt motor above its rated value.

→ In this method, external resistance must be connected in series with field circuit.

→ Supply terminal voltage will be maintained at constant value.



I_f is the field current which is ~~the~~ used to produce the required flux in the DC motor

So as per KVL & KCL

$$I_f = \frac{V_t}{R_f}$$ → if external resistance is not connected

$$\downarrow I_f = \frac{V_t}{R_f + R_{ex}}$$ → if external resistance is connected

$I_f \downarrow$ means $\phi \downarrow$ so

$$N = \frac{V_t - I_a R_a}{K_e \phi}$$

$$\uparrow N \propto \frac{1}{\phi \downarrow}$$

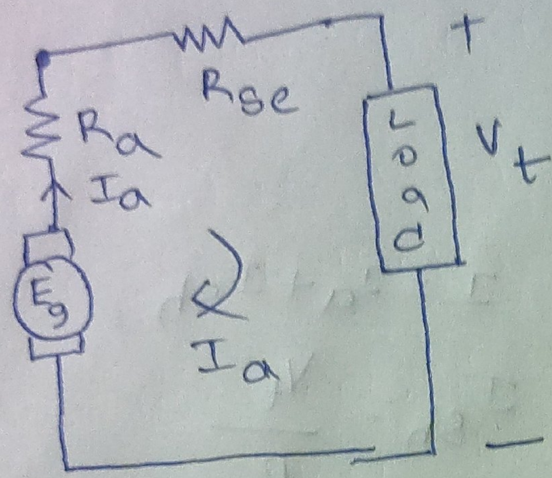
so $\phi \downarrow$; $N \uparrow$

So in this method, the flux above the rated values required are used.

DC Generators

In problems, they will ask on series and shunt generators.

Series Generator



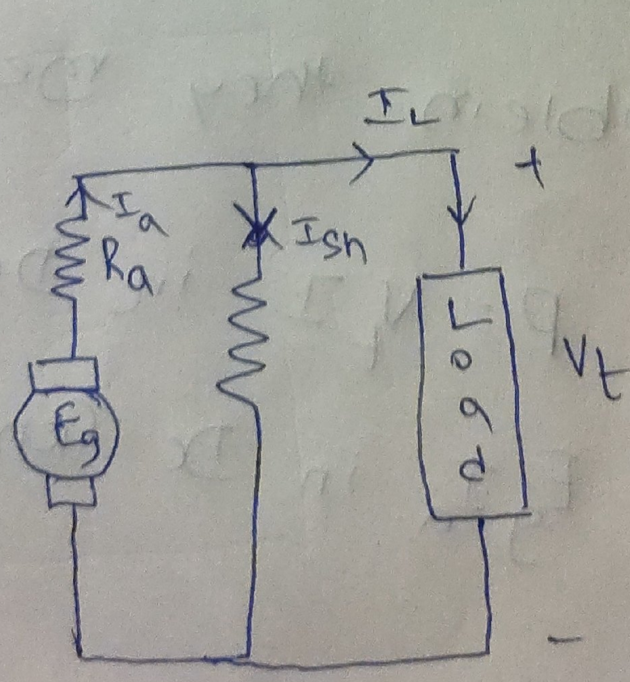
$$E_g = V_t + I_a(R_a + R_{se})$$

Shunt Generator

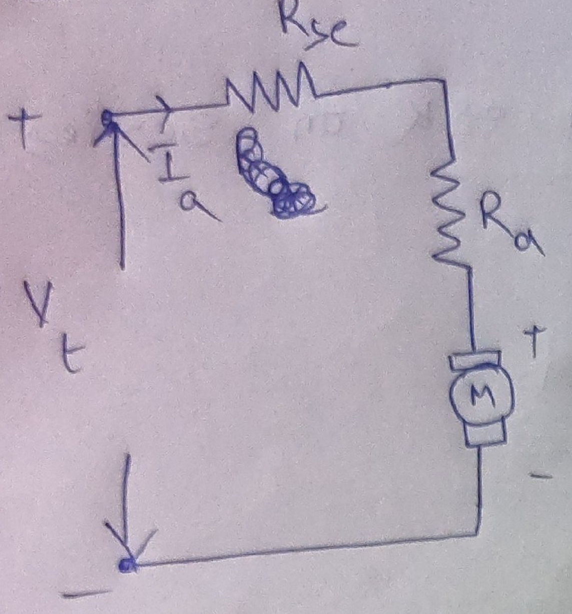
$$I_a = I_L + I_{sh}$$

$$E_g = V_t + I_a R_a$$

$$I_{sh} = \frac{V_t}{R_{sh}}$$



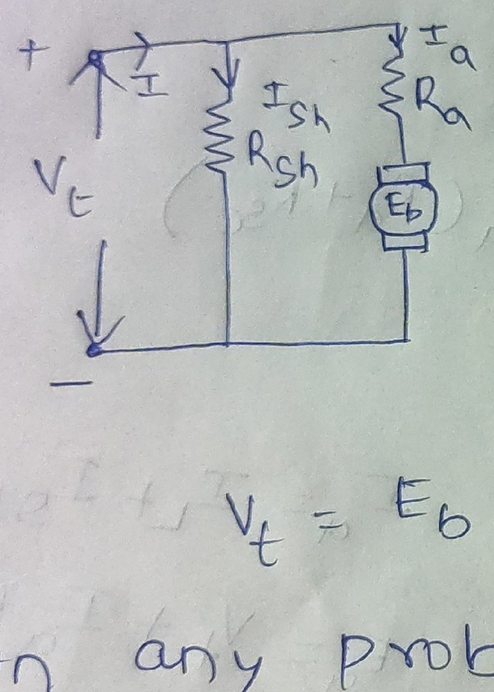
series Dc Motor



$V_t = E_b + I_a(R_a + R_{se})$

This equation is enough to solve the problem.

Dc Shunt Motor



$I = I_a + I_{sh}$

$I_{sh} = \frac{V_t}{R_{sh}}$

I is the total current

$I_a = I - I_{sh}$

$V_t = E_b + I_a R_a$

In any problem they mention about power then $P = V_t I$ in Dc motors

$P = E_g I_a$ in Dc Generators