BASIC PRINCIPLE OF TRANSFORMER

• The Principle of the operation of transformer is based on Farday's law of electromagnetic induction. Figure below shows the simple Structure of the transformer.

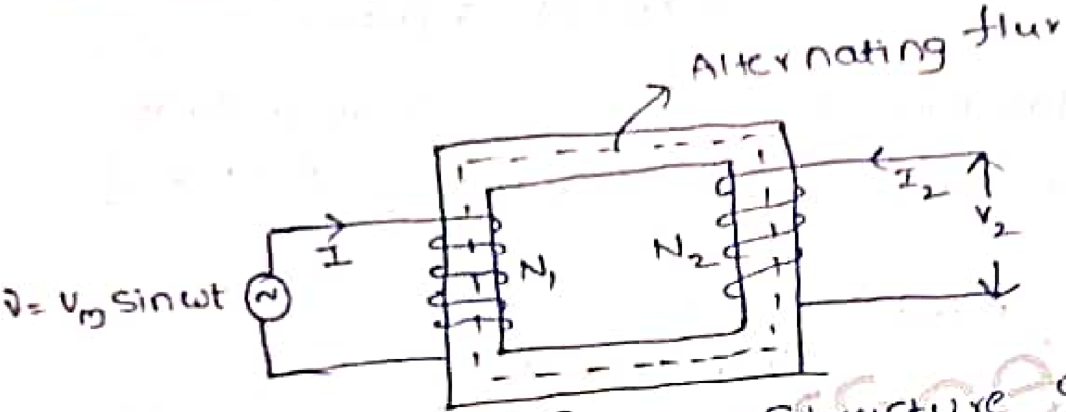


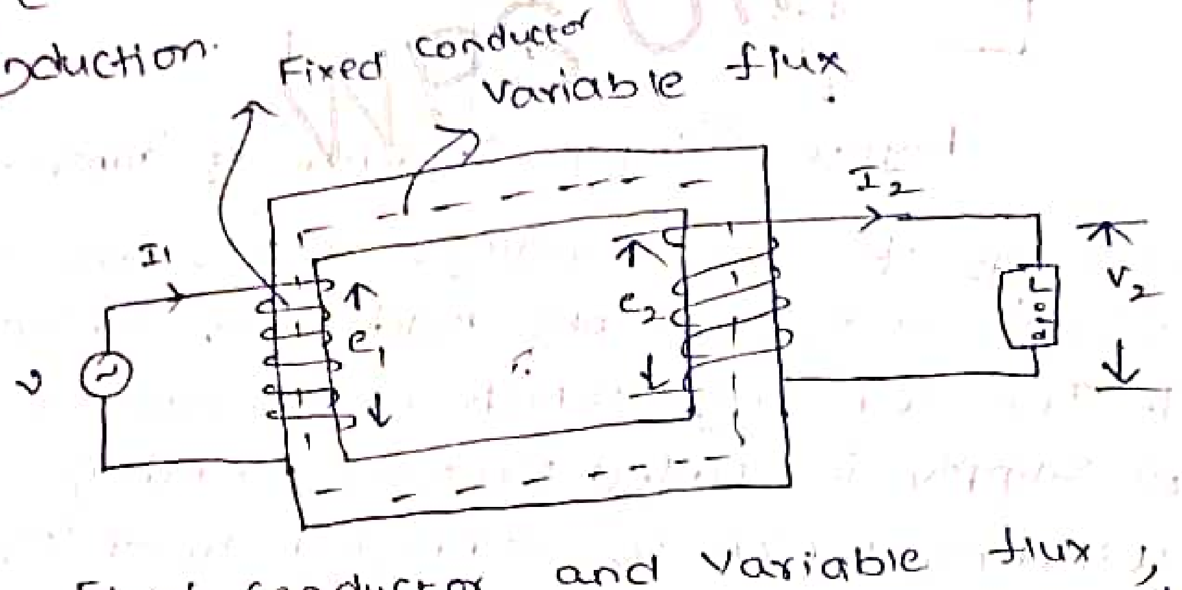
Figure. Simple Structure of Transformer

→ It consists of two windings and is placed on the single magnetic core made up of silicon steel. The winding which is connected to the supply is called Primary winding and winding which is connected to the load is called Secondary winding.

→ If Primary winding is excited with an AC supply of $v = V_m \sin\omega t$, the Primary winding will draw excitation current I_0 and produces the flux $\phi = \phi_m \sin\omega t$ and flux circulates in the magnetic core as shown in figure.

As per Faraday's law of electromagnetic induction, when there is variable magnetic field and fixed conductors, the variable magnetic field cuts both the windings and emf induced in ~~Prim~~ the windings. This type of emf is called statically induced emf.

→ In addition to, statically induced emf, the principle of mutual induction in transformer,



Fixed conductor and variable flux, emf is induced which is called statically induced EmF.

e_1 → induced based on farday's law

e_2 → induced based on mutual induction

Mutual Induction

The principle of mutual induction states that when two coils are inductively coupled & if current in one coil changed uniformly then an e.m.f gets induced in other coil.

"So Transformer works on the principle of faraday's law of electromagnetic induction (statically induced Emf) and principle of mutual induction"

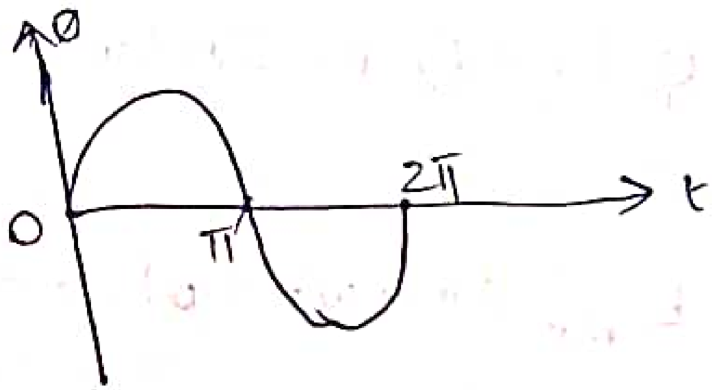
$$e_1 = -N_1 \frac{d\phi_1}{dt} \quad \text{(self induced Emf)}$$

$$e_2 = -N_2 \frac{d\phi}{dt} \quad \text{(mutual induced Emf)}$$

~~induced~~ ~~based~~ do

EMF EQUATION OF TRANSFORMER

The flux produced in Transformer can be defined as $\phi = \phi_m \sin \omega t$.



From Farday's law of electro magnetic induction,

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

Lenz's law

~~For analysis purpose ignore negative sign~~

$$e = N \frac{d\phi}{dt} \quad ; \quad \text{where } \phi = \phi_m \sin\omega t$$

$$e = -N_1 \frac{d}{dt} [\phi_m \sin\omega t] \quad \text{[in primary winding]}$$

$$e = -N_1 \phi_m \frac{d}{dt} [\sin\omega t]$$

$$e = -N_1 \phi_m (\cos\omega t) \cdot \omega$$

$$e = N_1 \phi_m \omega [-\cos\omega t]$$

$$-\cos\theta = \sin(\theta - 90^\circ)$$

$$e_1 = \phi_m \omega N_1 \sin(\omega t - 90^\circ)$$

$$e_1 = \phi_m (2\pi f) \cdot N_1 \sin(\omega t - 90^\circ) \rightarrow (1)$$

Compare Eq. (1) with,

$$e_1 = E_{M_1} \sin(\omega t + \phi) \rightarrow (2)$$

$$E_{m_1} = 2\pi f \phi_m N_1$$

$$\phi = -90^\circ$$

R.M.S value of e.m.f $= \frac{E_{m1}}{\sqrt{2}}$

$$= \frac{2\pi f \phi_m N_1}{\sqrt{2}}$$

$$= 4.44 f \phi_m N_1 \rightarrow (3)$$

Sub (3) in (1)

$E_1 = 4.44 \phi_m f N_1 \rightarrow (4)$ (self induced EMF) on primary side

$E_2 = 4.44 \phi_m f N_2 \rightarrow (5)$ (mutually induced EMF) on secondary side.

Relation between Induced EMF, current and Power

let us consider MVA rating of the transformer $= E.I = KVA$

$P = EI$

Primary side power $E_1 I_1$

secondary side power $E_2 I_2$

In ideal transformer,

Primary side Power = Secondary side Pow

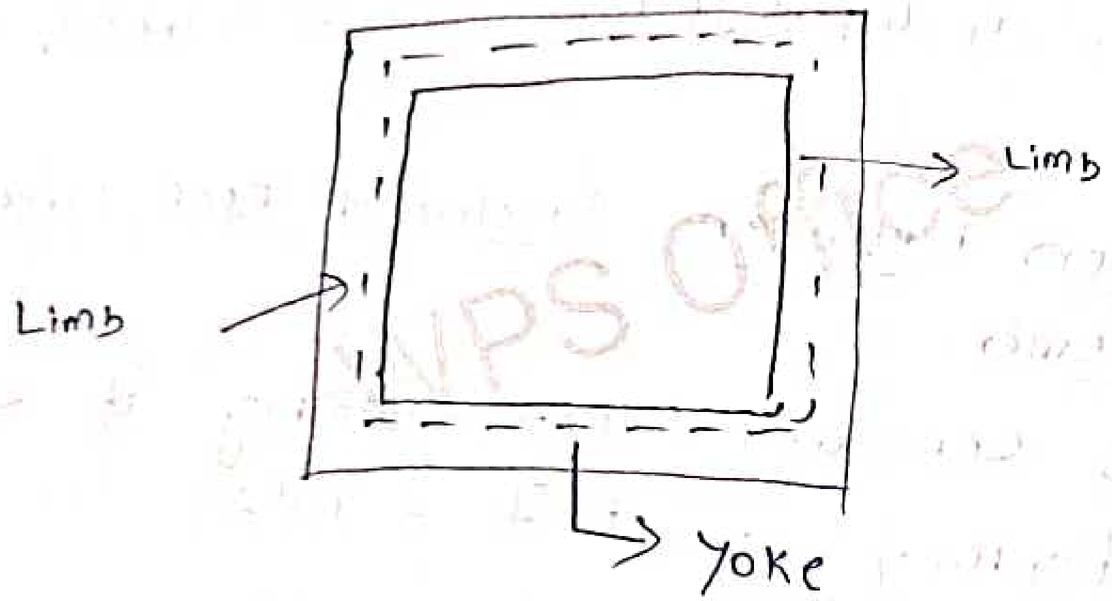
$E_1 I_1 = E_2 I_2$

$$\boxed{\frac{E_2}{E_1} = \frac{I_1}{I_2} = K}$$ ← for problem

Construction of a transformer

Transformer consists of two basic parts
i) magnetic core
ii) windings (or) coils.

Magnetic core



is magnetic core provides flux for T/F

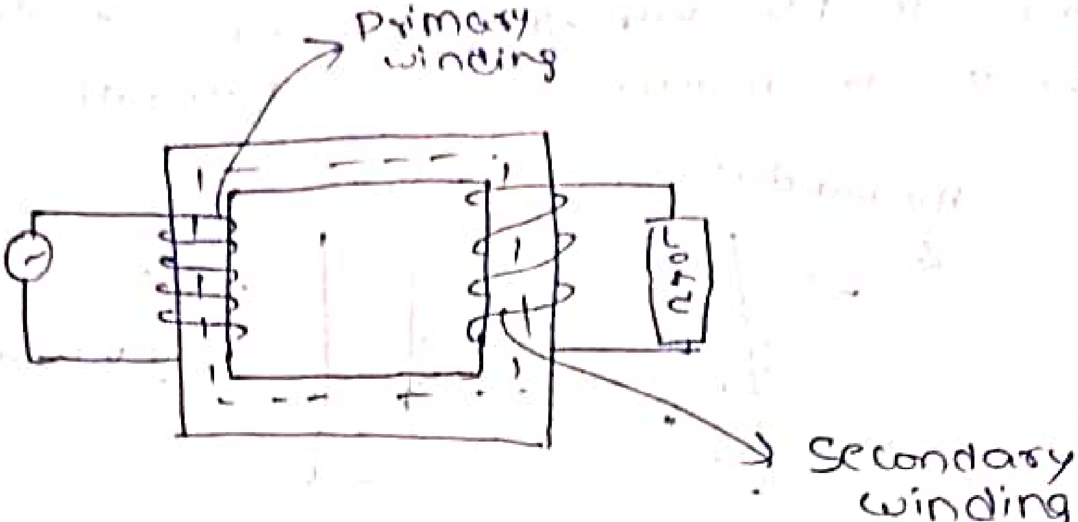
is core is made up of CRGO silicon

-eel.

silicon → high permeability and good flux

steel → for strongeness

② Windings (or) coils



→ Windings are made with either copper (or) Aluminium. Usually copper will be prefered due to its low resistivity. Need to provide turn to turn insulation. Insulation need to provide between primary and secondary.

T/FS are two types

1) Core type
2) Shell type

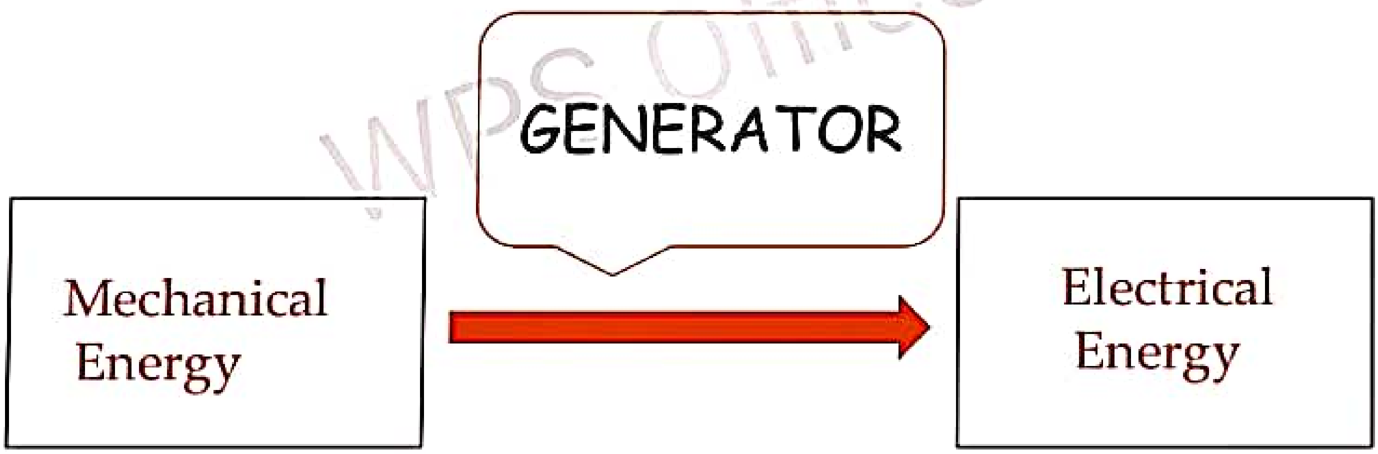
Core-type transformer

→ In this case coils are wound around the limbs.

→ each limb carries one winding

Function:

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



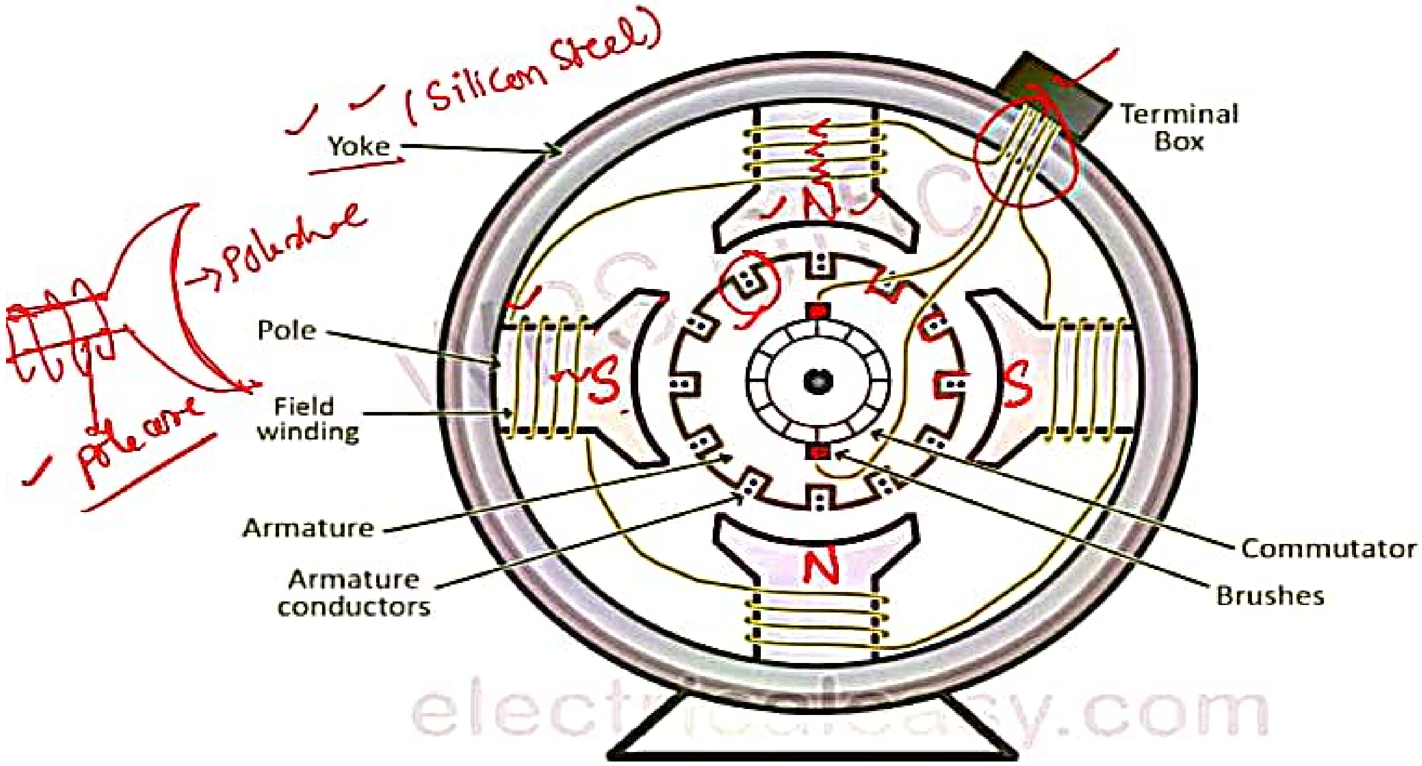
https://www.youtube.com/watch?v=Ylgb8FFMgd4

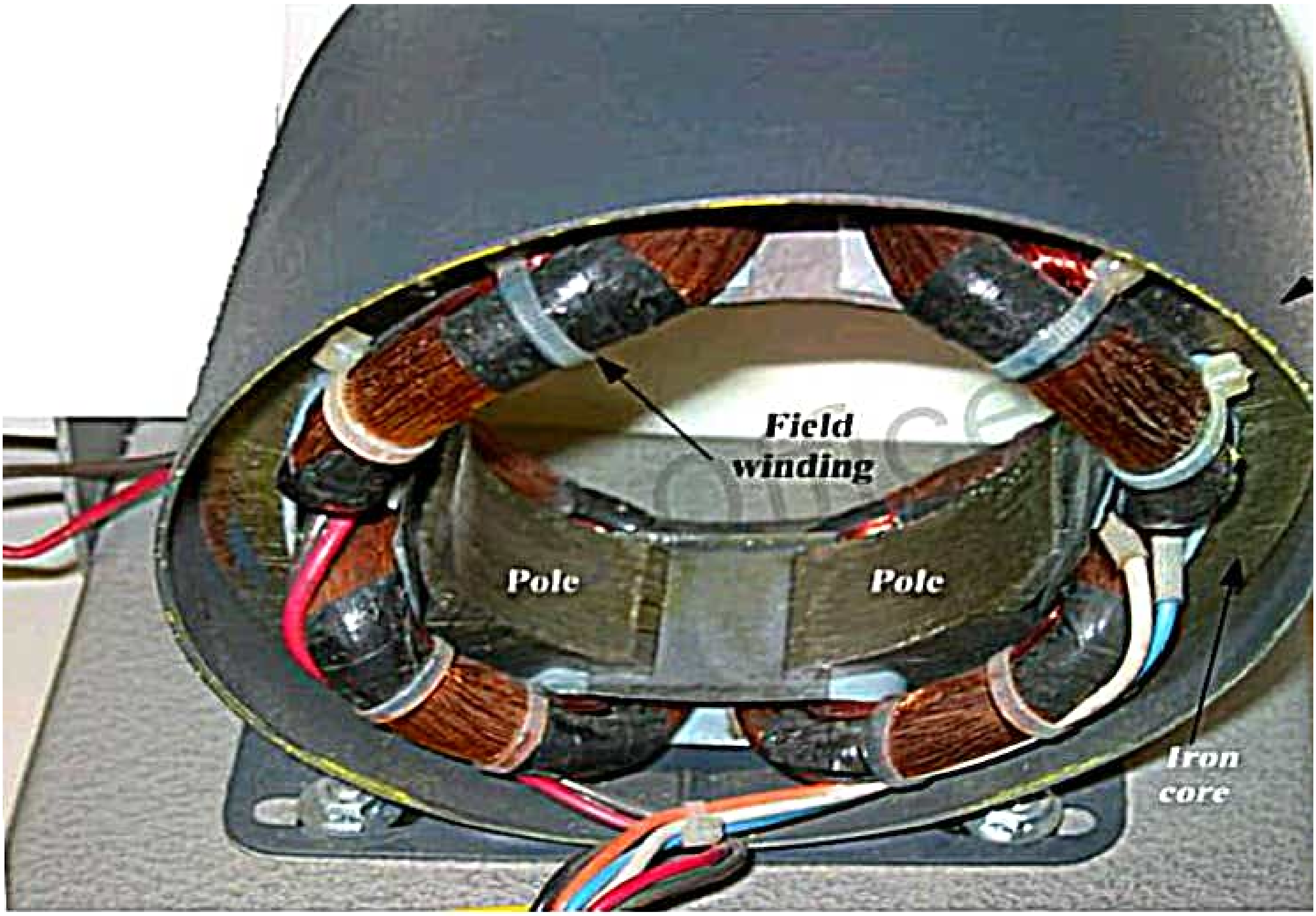
Construction of a DC generator

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

✓ electromagne
✓ Permanent ma

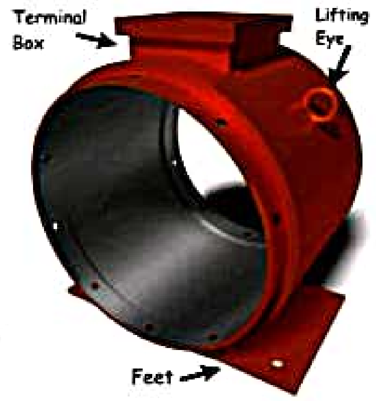
Moving parts: Armature core, Armature winding, Commutator, Brushes




Field
winding
Pole
Pole
Iron
core

Stationary Parts

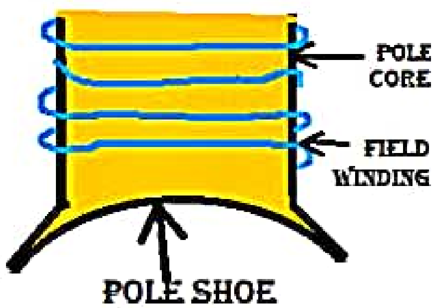
Yoke:



- 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.



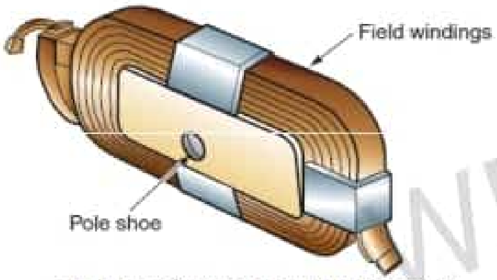
Pole shoes serve two purposes;

(i) They support field coils

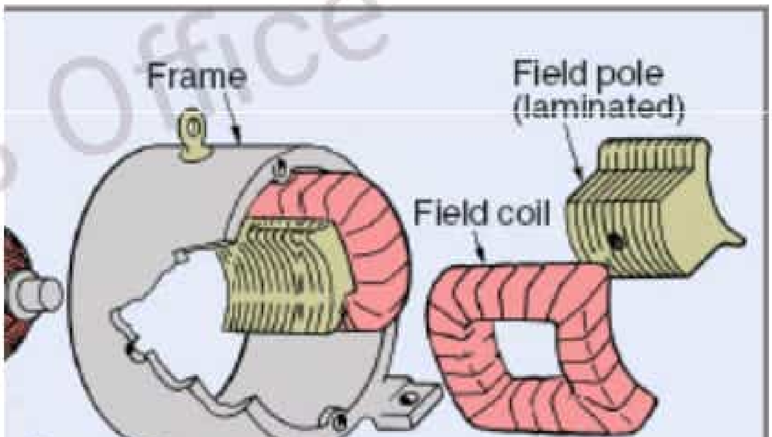
(ii) Spread out the flux in air gap uniformly

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.

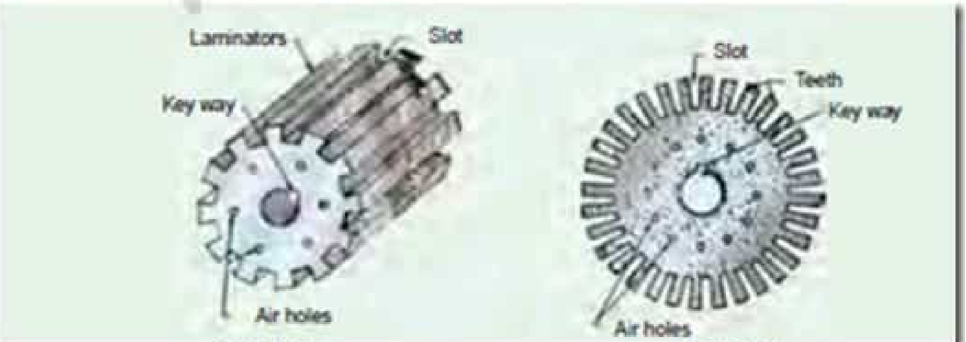


Fig. 26.15 Fig. 26.16

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 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 t

Brushes

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

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

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

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

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

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

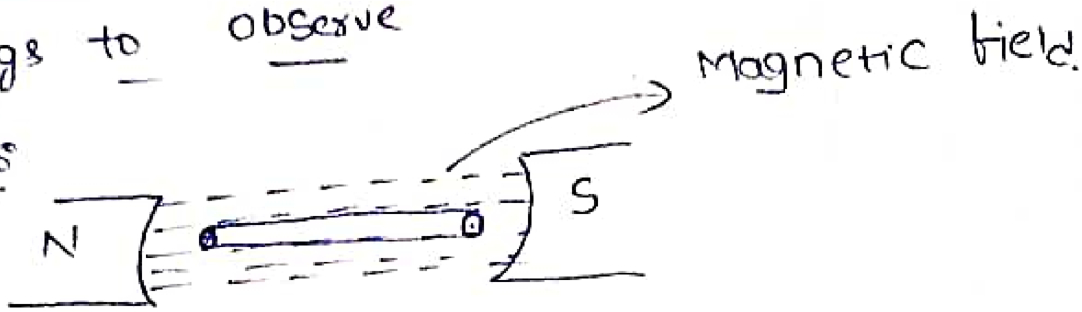
N represents no of turns

'_' 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 linkages between conductor and magnetic field.

Things to observe

at $\theta = 0^\circ$



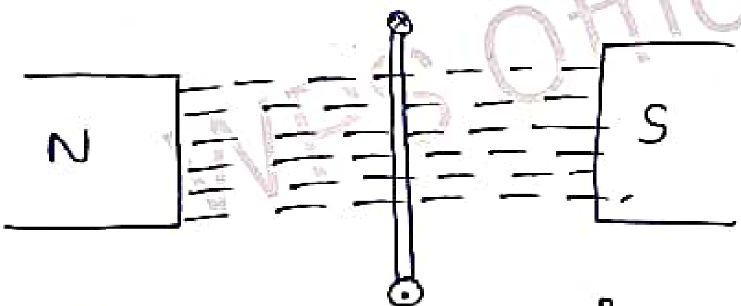
~~at~~ conductor is at 0°

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

no flux linkages (flux cut by the conductor)

$e = 0.$

at $\theta = 90^\circ$

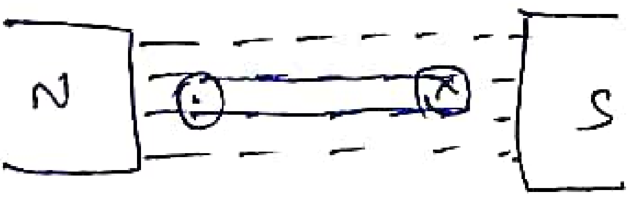


~~at~~ conductor is at 90°

maximum flux linkages with conductor and the

EF induced is High

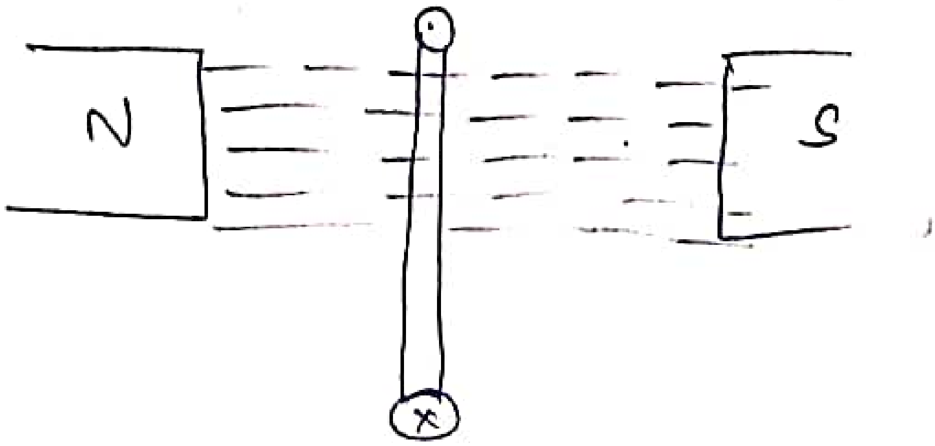
$\theta = 180^\circ$



~~at~~ conductor is at 180°

$e = 0.$

at 270°

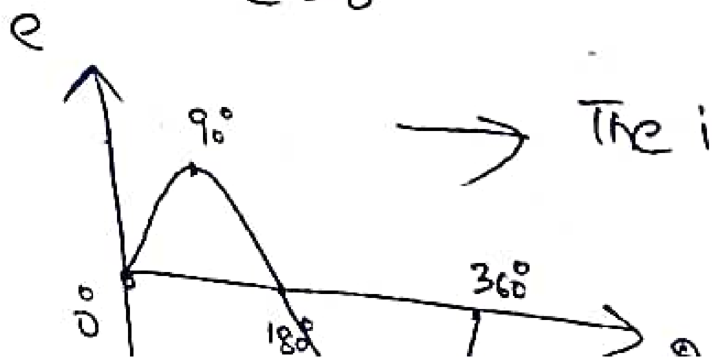


e = Maximum (~~Max~~ highest flux cuts

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

ϕ = 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 Faraday'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 = ϕP

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

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 out z number of conductors in any one of the armature parallel path

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

~~If 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 $A = 2$ $\quad E_g = \frac{\phi Z N P}{120}$

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

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

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

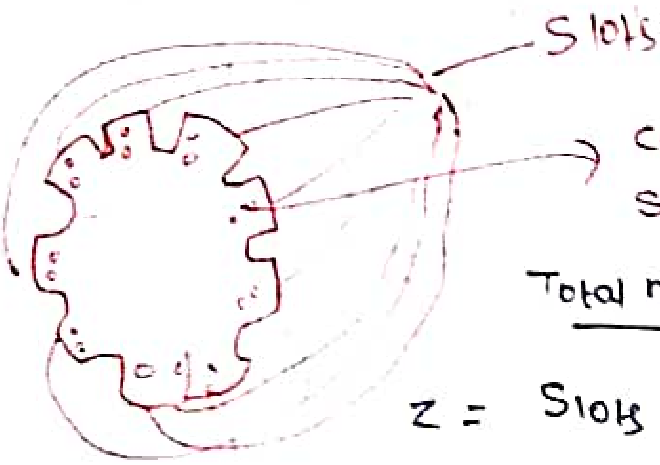
~~of DcGener~~ of DC Generator is having "A" number of Parallel paths, then

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

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

b) 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

Sol :-

$P = 4$

$A = 2$ [wave winding]

$\phi = 0.018$ wb

$N = 1500$

Z = number of slots * number of conductors)

$= 50 \times 20 = 1000$

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

$= 900V$

Pb) 2 - Solve the above problem with lap winding

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); calculate current flowing in generator.

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

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

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Pb2) $P = E_g \cdot I_a$

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

Obs

Observation

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

→ Lap winding is used for low voltage high current applications

Pb) Calculate 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)

~~Z~~ N = no of slots = 38

number of Conductors per slot = 18

$Z = 38 \times 18 = 684$

$\phi = 0.018 wb$; $N = 1000$

$$E_g = \frac{\phi Z N P}{60A} = \frac{0.018 \times 684 \times 1000 \times 4}{60 \times 2}$$

$= 410.4$ V

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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 motor

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

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

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

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

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

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

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

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

<u>Sol</u> :-

$$V_t = E_b + I_a R_a \rightarrow ①$$

$$P = V_t \cdot I_a$$

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

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

$$I_a = 151.2 \, A \rightarrow ②$$

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)

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

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

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

Applications of BLDC [Brushless DC motor]

① These are used in CD-drives
② Satellites & aircrafts
③ Cooling fans in Computers, in future BLDC motors are
④ planned to used for traction purpose.
⑤ Motion-Controlling Robots.

Applications of Induction motors

① Cranes
② Lifts & Elevators
③ Conveyor belts
④ Compressors
⑤ Agriculture pumps.

For these type of applications it is required high starting torch & low starting Current. So, Slip ring induction motors are used for these applications.

Applications for Squirell Case Motors:

For high starting ~~torque~~ high starting Current

① Blowers

② Fans

③ Drilling machines

④ Centrifugal pumps

Applications for Stepper Motor:

① 3D-printing machines

② Textile machine

③ Medical imaging machines.

④ Robots

⑤ Gaming machines

Construction of a DC generator.