UNIT 3: Fundamentals of Electrical Machines

(Lecture 15 to 22 + Tutorial 7 to 8)

Prepared By:

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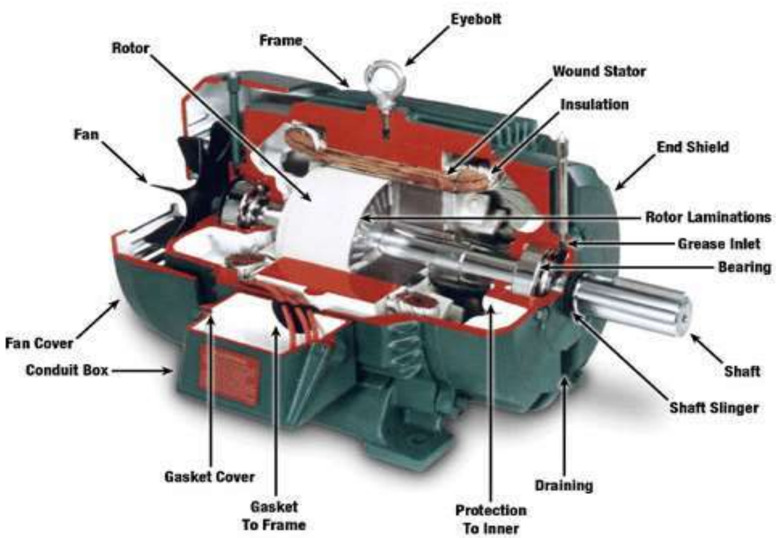
Outcome: Discuss the working principles and applications of transformers and motors

Fundamentals of Electrical machines : Fleming's left hand and right hand rule, mutual inductance and mutual coupling phenomena in transformer, transformer – working, concept of turns ratio and applications, transformer on DC, instrument transformers, auto-transformer, dc machines- working principles, classification, starting, speed control and applications of dc motors, working principle of single and three phase induction motors, applications of ac motors

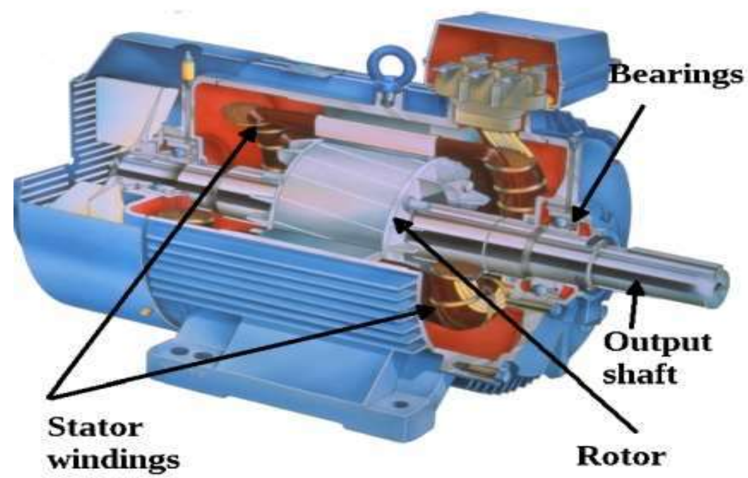
UNIT-III: Fundamentals of Electrical Machines

TRANSFOREMR

DC MACHINE



INDUCTION MOTOR



Need of transformer

- In most cases, appliances are manufactured to work under some specific voltages. Transformers are used to adjust the voltages to a proper level.
- The transformers are the basic components for the transmission of the electricity.
- Transformer is used to increase the voltage at the power generating station(Step up) and used to decrease the voltage(Step down) for house hold purpose.

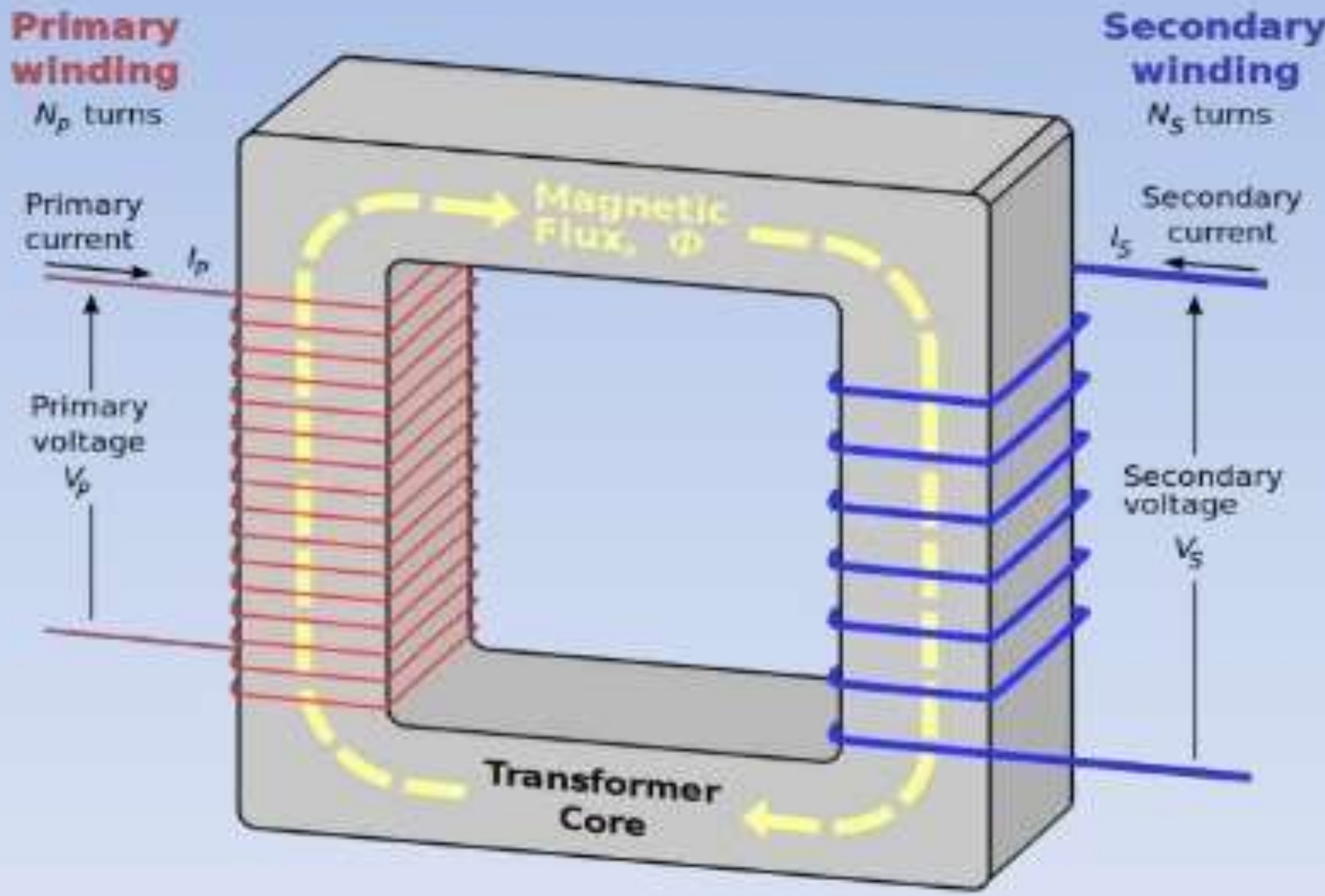
- By increasing the voltages the loss of the electricity in the transmission purpose is minimized.

Definition of Transformer

TRANSFORMER: transformer is a static device which transforms electrical energy from one circuit to another without any direct electrical connection and with the help of mutual induction between two windings. It transforms power from one circuit to another without changing its frequency but may be in different voltage level.

In Brief, A **transformer** is a static electrical device that transfers electrical energy between two or more circuits through electromagnetic induction.

Transformer Construction



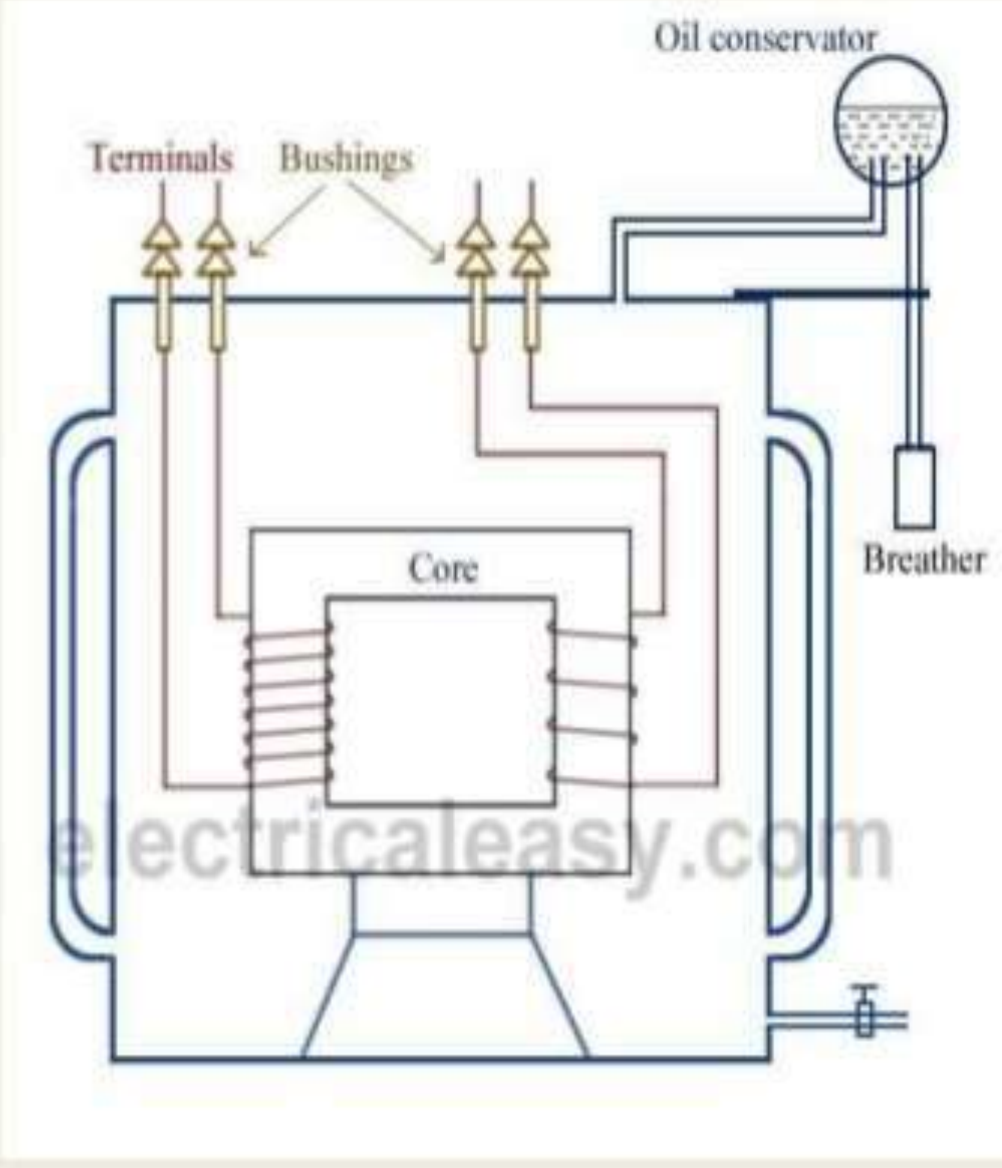
Construction of Transformer

•Basically a transformer consists of two inductive windings and a laminated steel core. The coils are insulated from each other as well as from the steel core.

•core is constructed by assembling laminated sheets of steel, with minimum air-gap between them (to achieve continuous magnetic path).

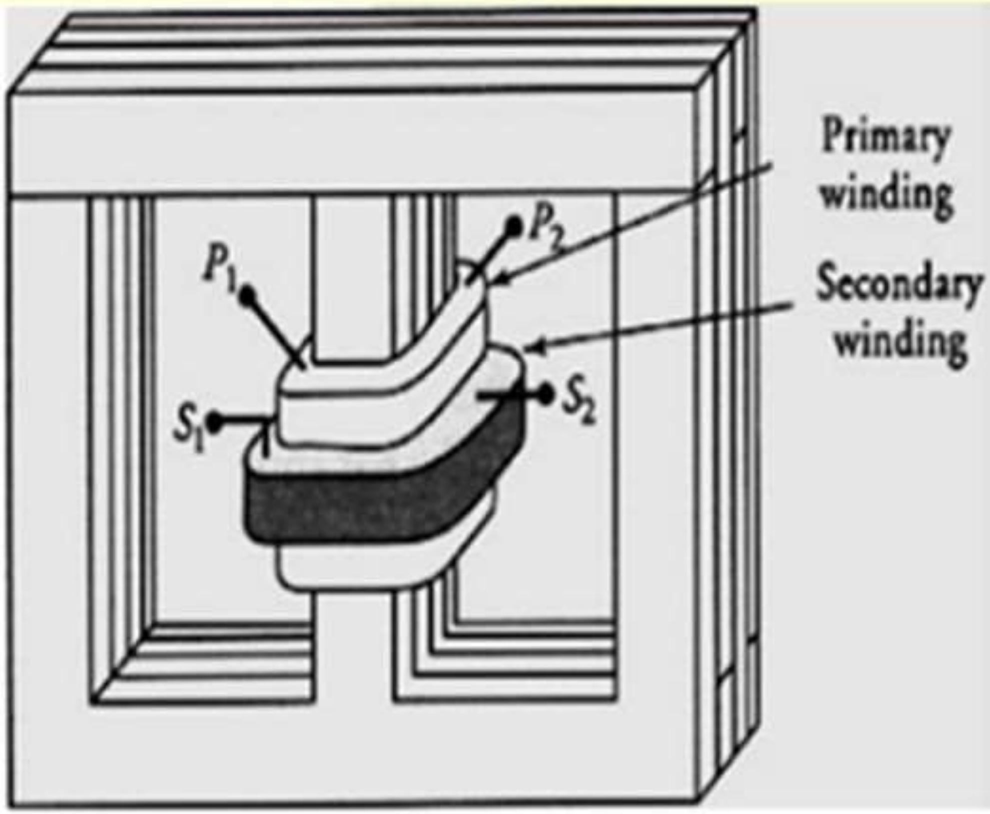
•The silicon steel used is to provide high permeability and low hysteresis loss.

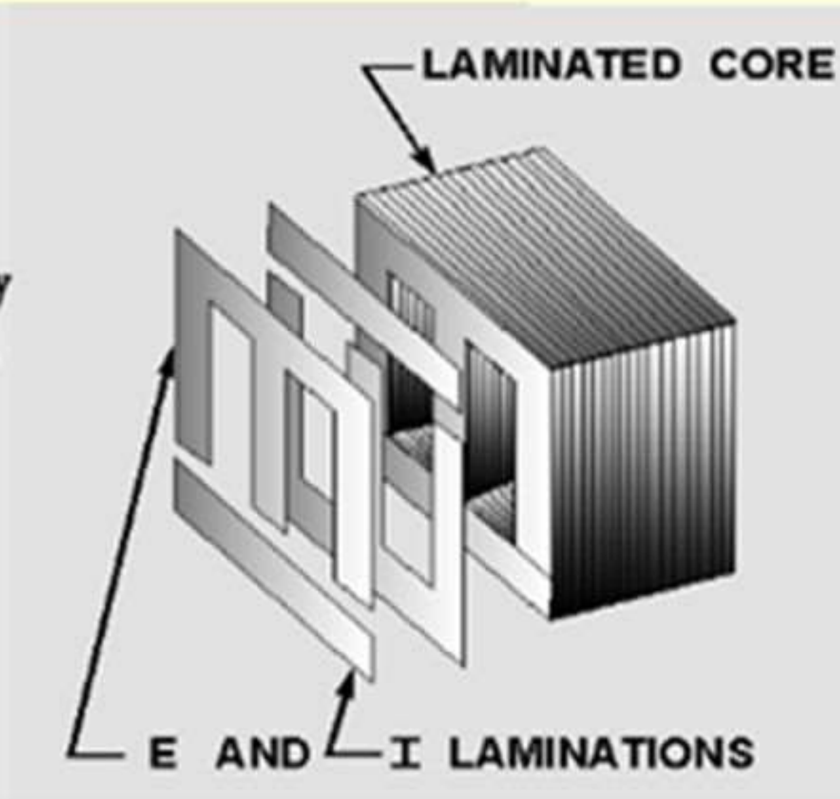
•Laminated sheets of steel are used to reduce eddy current loss.



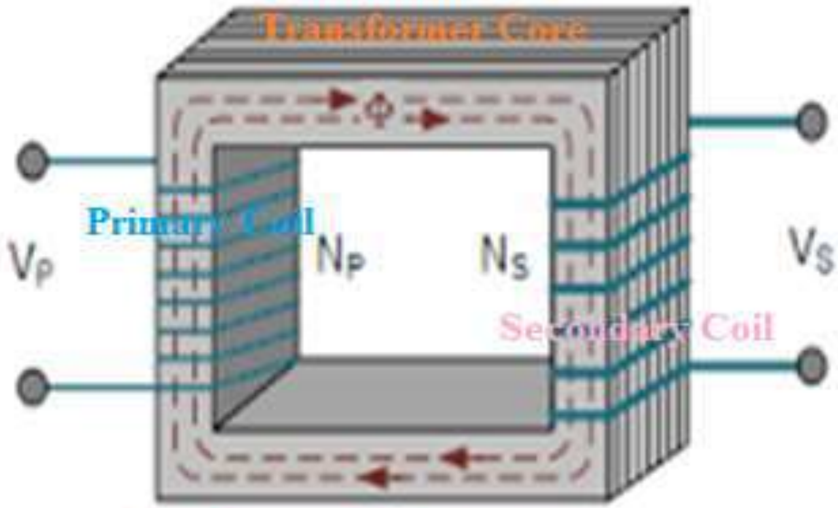
Transformer Construction

Core is made up of laminations to reduce the eddy current losses.
The thickness of laminations is usually 0.4mm.

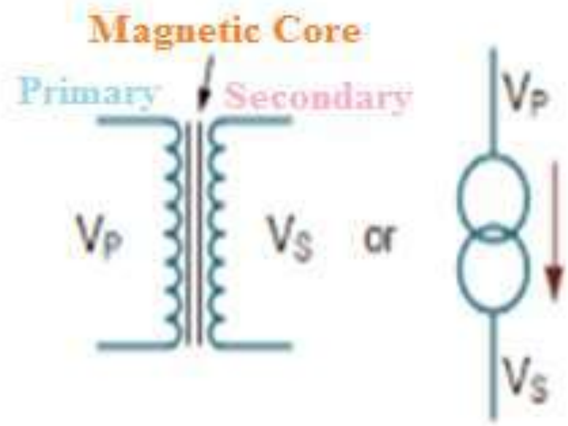




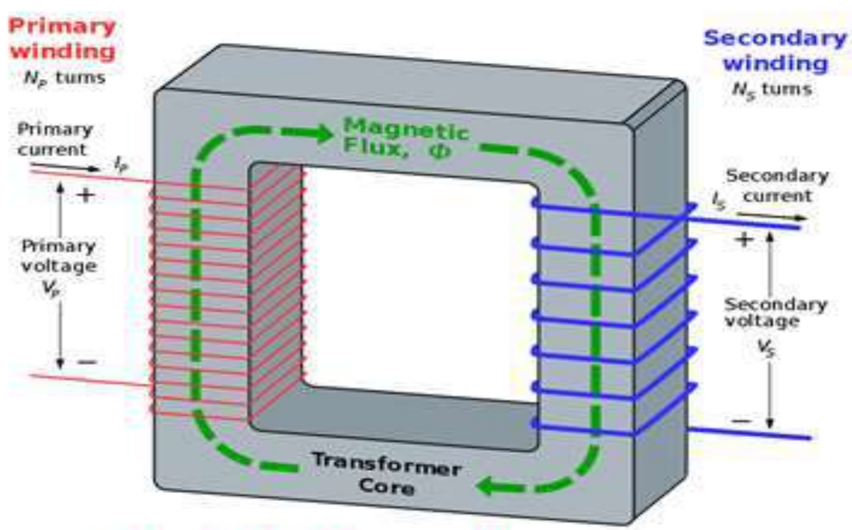
TRANSFORMER SYMBOLS



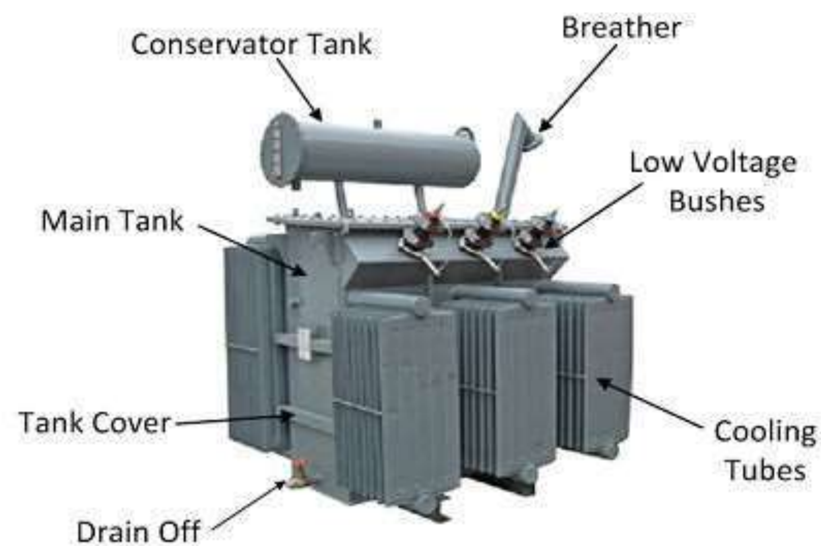
Transformer Construction



Transformer Symbol



Inside Transformer



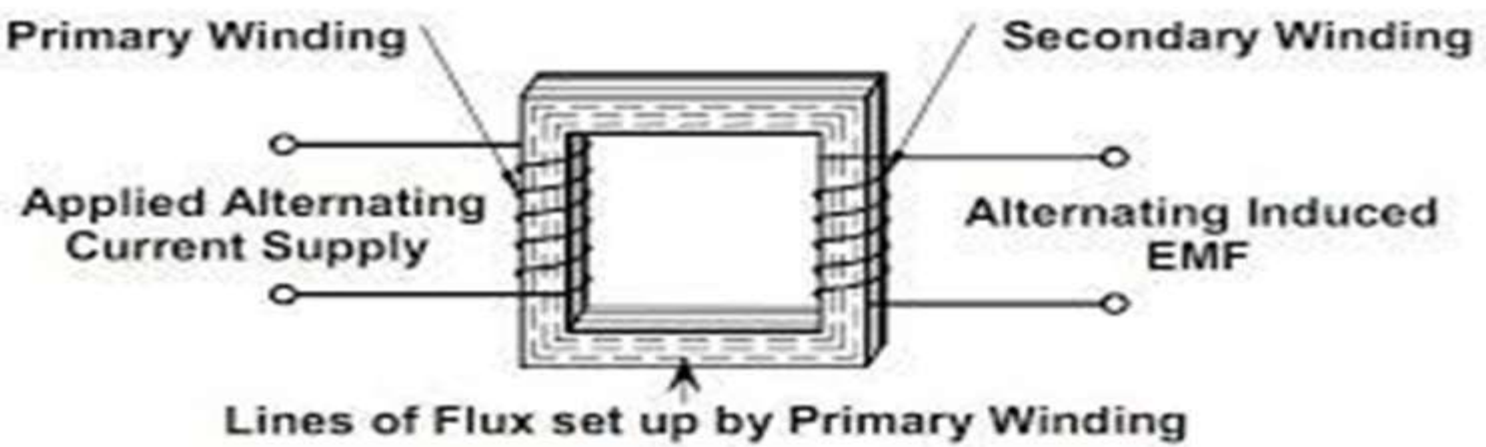
Outside Transformer

Principle of Transformer

- The transformer works on the principle of mutual induction

"The principle of mutual induction states that when the two coils are inductively coupled and if the current in coil change uniformly then the e.m.f. induced in the other coils. This e.m.f can drive a current when a closed path is provide to it."

- When the alternating current flows in the primary coils, a changing magnetic flux is generated around the primary coil.
- The changing magnetic flux is transferred to the secondary coil through the iron core
- The changing magnetic flux is cut by the secondary coil, hence induces an e.m.f in the secondary coil



Quick Quiz (Poll 1)

- What is the principle of Transformer?

A. Fleming’s Left hand rule

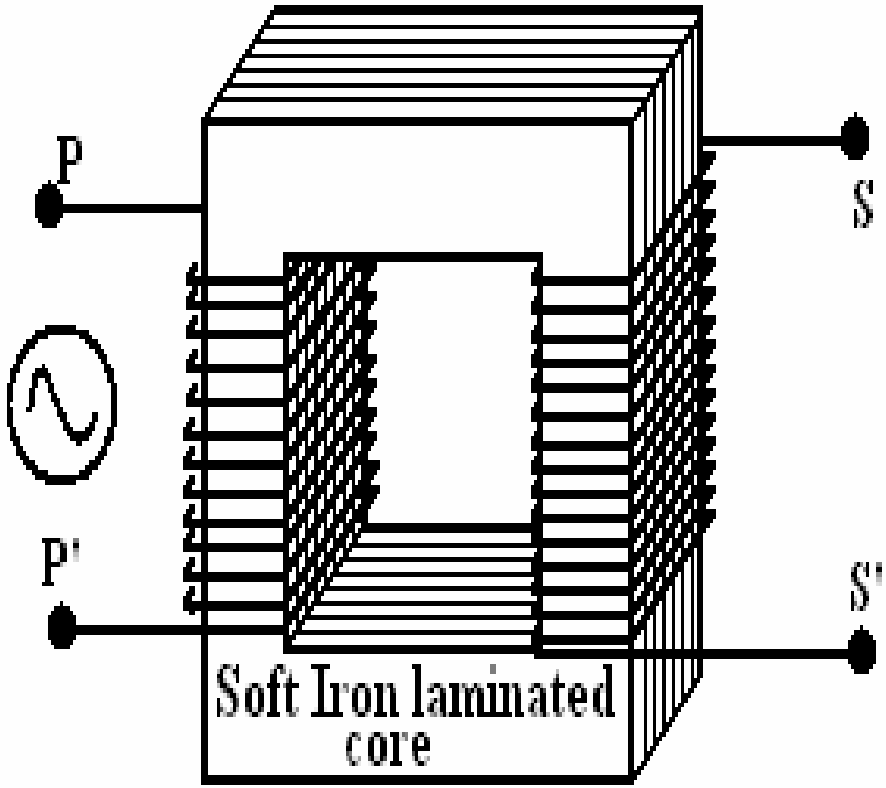
B. Electromagnetic Induction

C. Fleming’s Right hand rule

D. All of the above

Working of a transformer

1. When current in the primary coil changes being alternating in nature, a changing magnetic field is produced
2. This changing magnetic field gets associated with the secondary through the soft iron core
3. Hence magnetic flux linked with the secondary coil changes.
4. Which induces e.m.f. in the secondary.

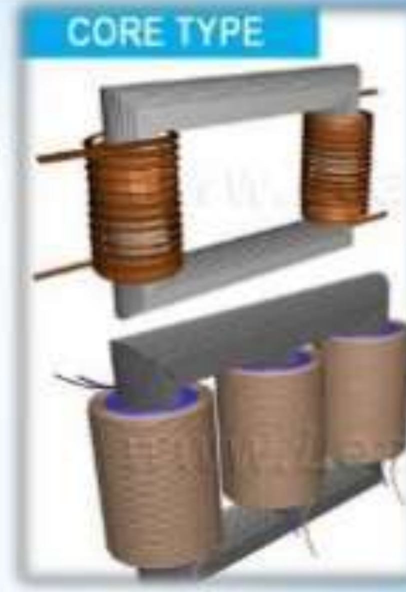


Transformer Cores


* Types of Transformers
Transformer
Basis of Construction
Basis of Winding
Basis of coolant material used
Core type transformer
Shell type transformer
Spiral core transformer
Step up transformer
Step down transformer
Isolation transformer
Oil filled self cooling
Oil filled water cooling
Air blast

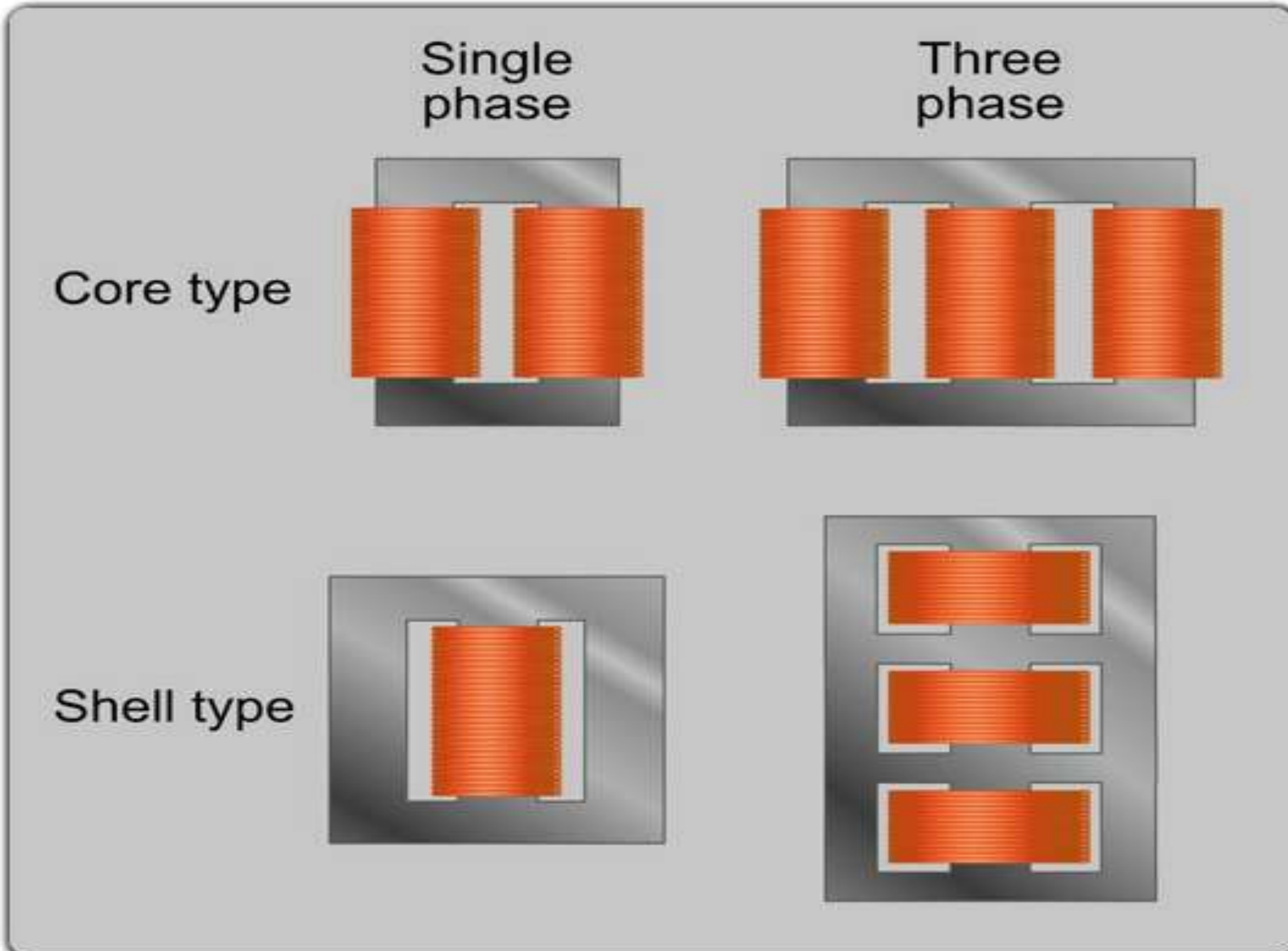
* Basis of construction

Core type transformer: Its core has two limbs .The windings are wounded on two limbs of the core material.



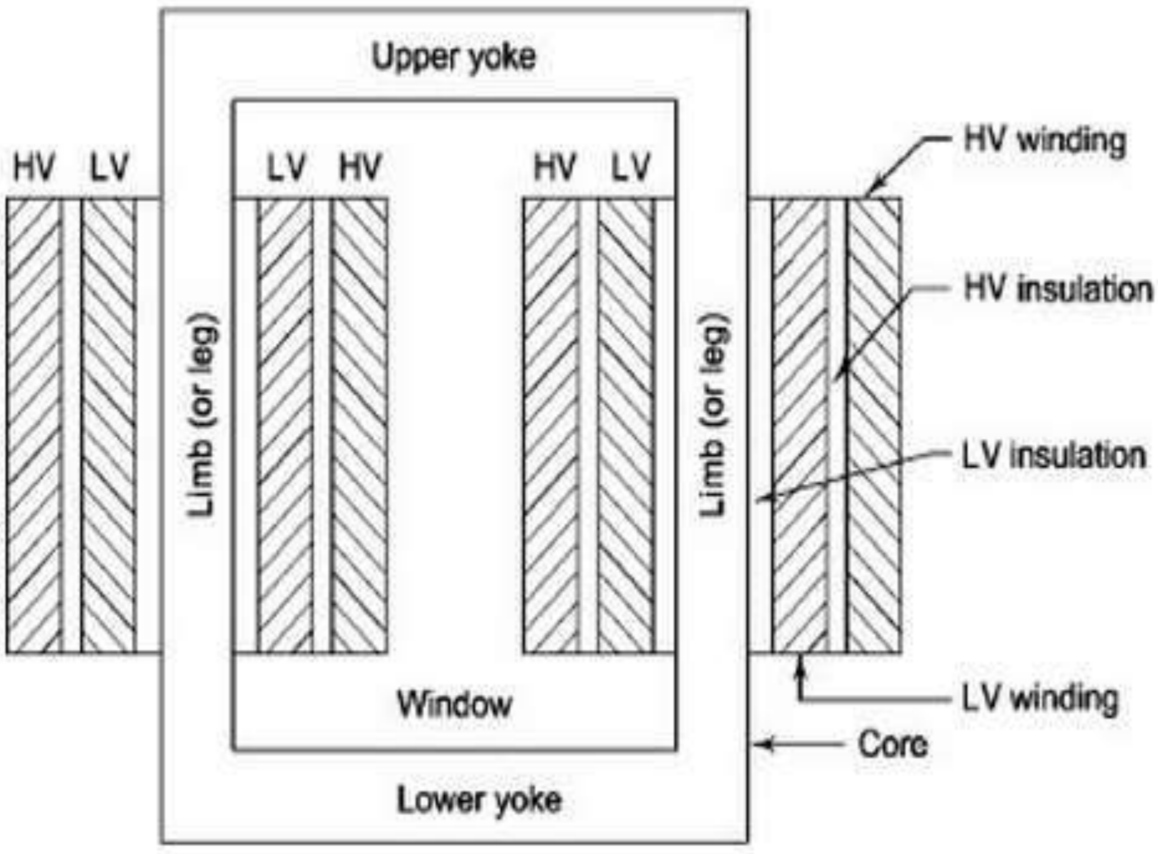
Shell type transformer: Its core has three limbs and two windows. Both the windings are wounded on the central limb.(one over the other)

Spiral core transformer:
The core constructed is similar to wheels of spokes. The windings are wounded these spokes like structure.


Single phase
Three phase
Core type
Shell type

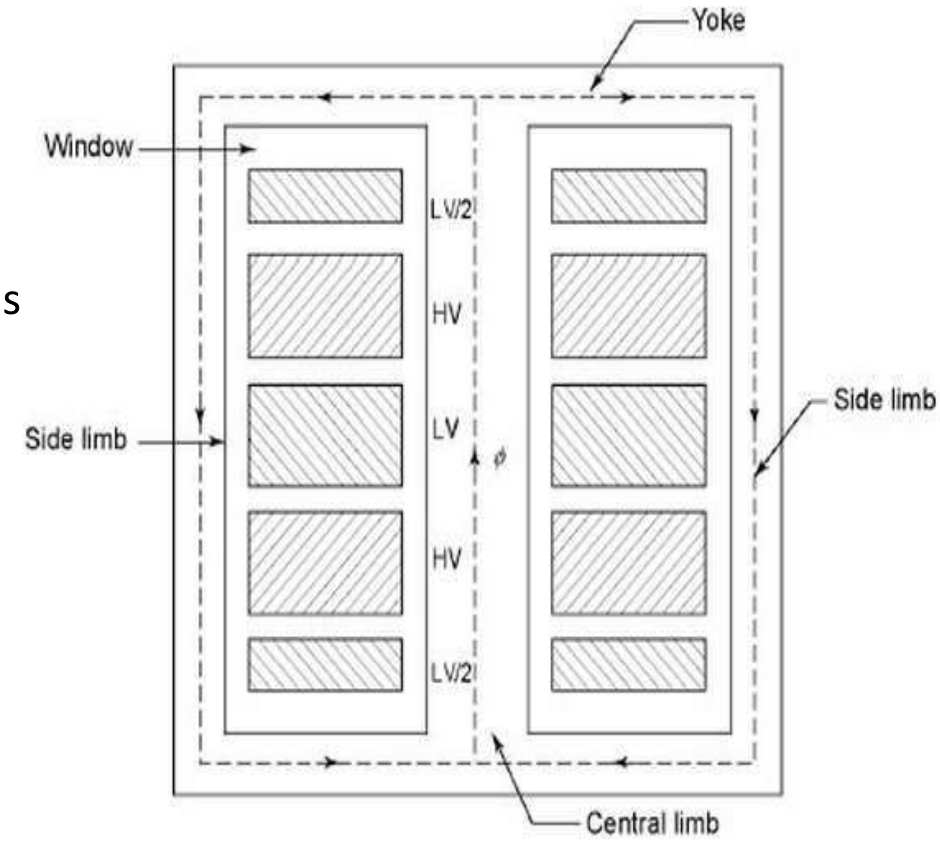
Concentric Windings

This type of winding is used in Core type Transformer. All the turns of LV and HV are concentrated about the same axis.



Sandwich Windings

This type of winding
Is used in shell type
Transformer. Each
HV layer is sandwiched
by two LV layers.



Basis of Windings

- Step up Transformer: The no of windings on Primary side is less than the no. of windings on the secondary side.

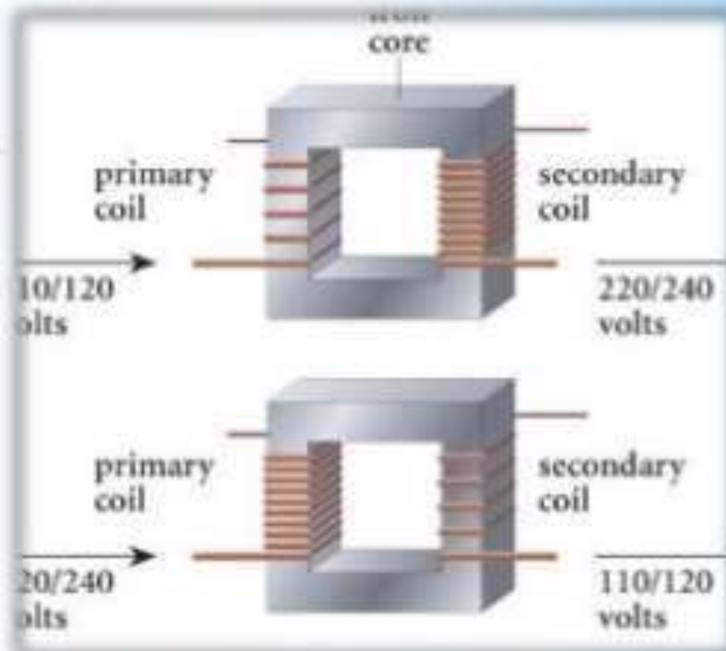
  $$Np < Ns$$

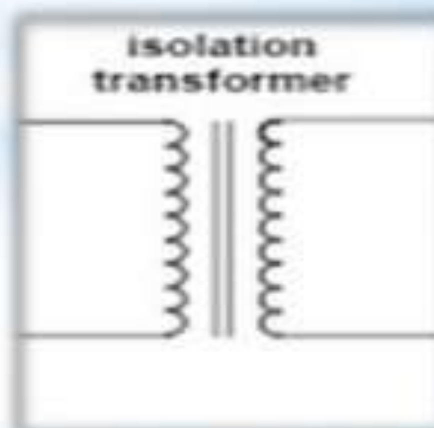
- Step down Transformer: The no. of winding on Primary side are more than the no. of windings on the secondary side.

  $$Np > Ns$$

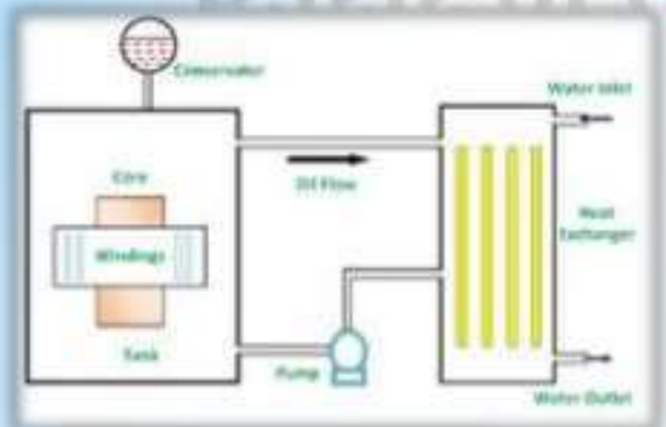
- Isolation Transformer: The no. of winding on Primary side are equal to the no. of windings on the secondary side.

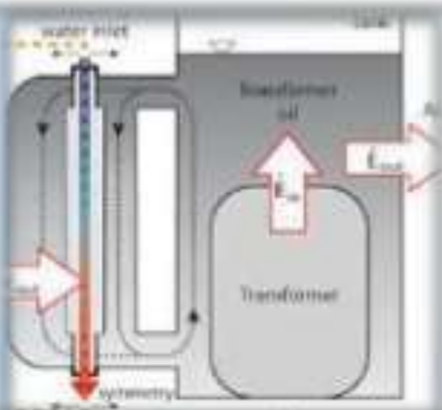
  $$Np = Ns$$

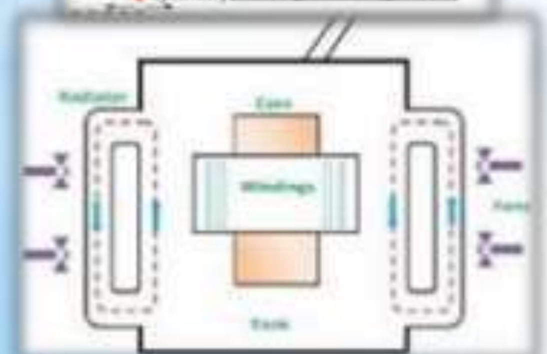




Basis of coolant







- ***Oil filled self cooling:*** Oil filled self cooled type uses small and medium-sized distribution transformers. The assembled windings and core of such transformers are mounted in a welded, oil-tight steel tanks provided with a steel cover.. The oil helps in transferring the heat from the core and the windings to the case from where it is radiated out to the surroundings.
- ***Oil filled water cooled:*** This type is used for much more economic construction of large transformers. The cooling coil is mounted near the surface of the oil, through which cold water keeps circulating. This water carries the heat from the device.
- **Air Blast:** This type is used for transformers that use voltages below 25,000 volts. The transformer is used at houses.

Quick Quiz (Poll 2)

- A transformer transform

A. Current

B. Voltage & current

C. Frequency

D. Voltage

Quick Quiz (Poll 3)

- Transformer cores are laminated in order to

a. simplify its construction

b. minimise eddy current losses

c. reduce cost

d. reduce hysterisis loss

UNIT-III

Fundamentals of Electrical Machines

Lecture 16

Prepared By:
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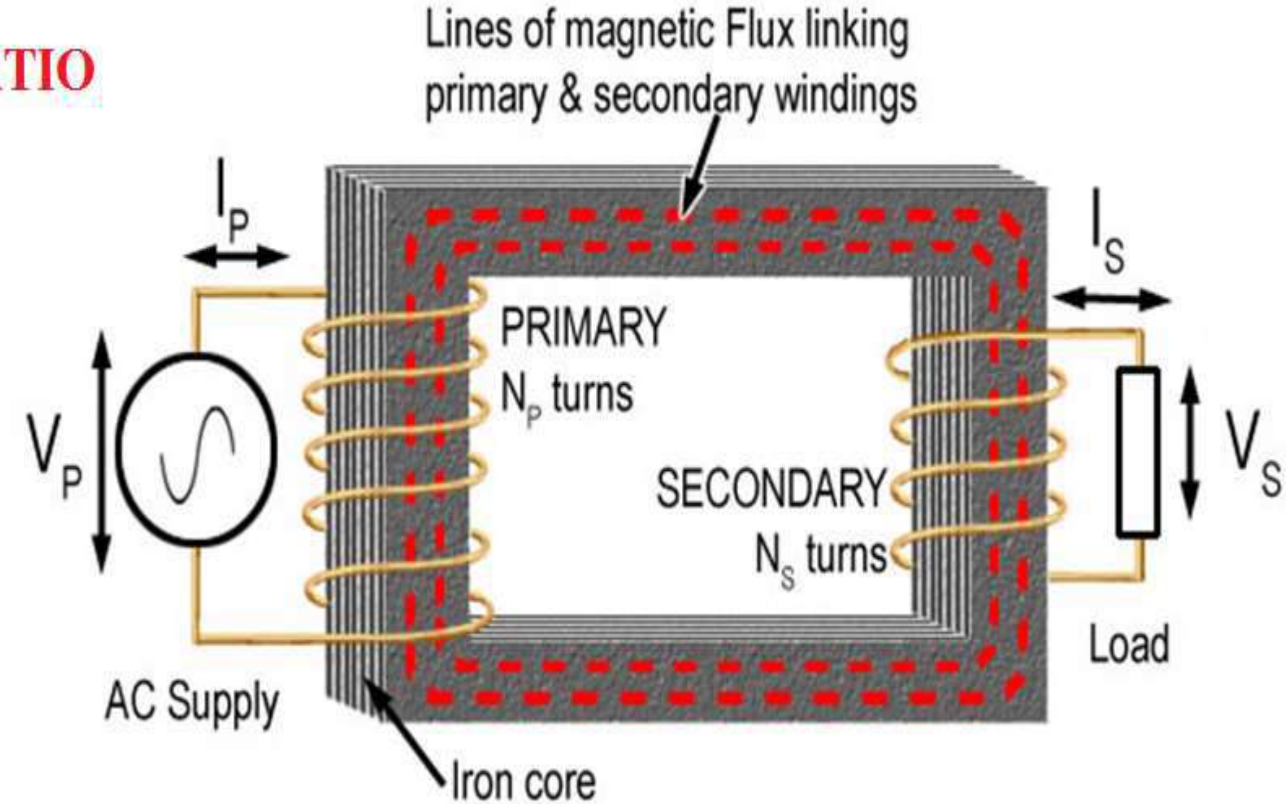
CONCEPT OF TURN RATIO

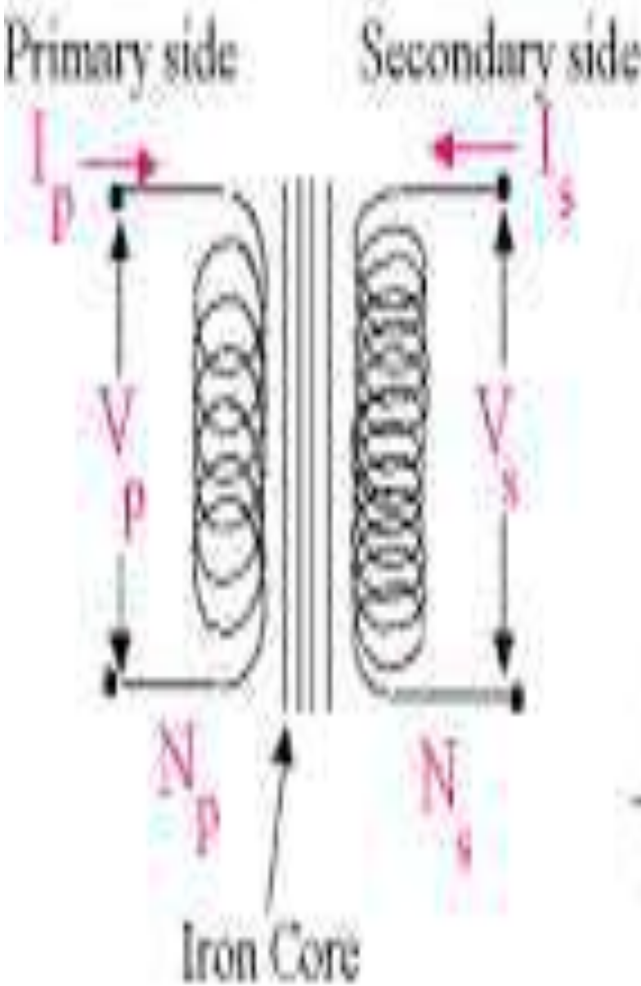
$$\boxed{a = \frac{n_1}{n_2} = \frac{V_1}{V_2} = \frac{I_2}{I_1}}$$

where: a = turns ratio of transformer
n_1 = number of turns on primary
n_2 = number of turns on secondary
V_1 = primary voltage
V_2 = secondary voltage
I_1 = primary current
I_2 = secondary current



$$\frac{\text{The number of primary turns } N_P}{\text{The number of secondary turns } N_S} = \frac{\text{The primary voltage } V_P}{\text{The secondary voltage } V_S}$$

$$\frac{\text{The number of secondary turns } N_S}{\text{The number of primary turns } N_P} = \frac{\text{The primary current } I_P}{\text{The secondary current } I_S}$$



$$\frac{V_s}{V_p} = \frac{N_s}{N_p},$$

But,

$$\frac{I_s}{I_p} = \frac{N_p}{N_s}$$

If the purpose is to increase voltage, the secondary coil must have more turns and therefore a thinner wire. Note that at best the output power equals the input power. Ideally, $P_{out} = P_{in}$, or $V_s I_s = V_p I_p$

Writing as proportions : $\frac{V_s}{V_p} = \frac{I_p}{I_s}$

This is true for an ideal transformer only .

EXAMPLE: A transformer has 400 turns on the primary and 1200 turns on the secondary. If 120 volts of AC current are applied across the primary, what voltage is induced into the secondary?

Given

$E_S = ?$

$E_P = 120\ \text{V}$

$N_S = 1200$ turns

$N_P = 400$ turns

Solution

$$\frac{E_S}{E_P} = \frac{N_S}{N_P}$$

$$\frac{E_S}{120} = \frac{1200}{400}$$

$$E_S = 360\ \text{V}$$

Quick Quiz (Poll 1)

- A transformer having 1000 primary turns is connected to a 250 volt ac supply, for a secondary voltage of 400 volt, the no. of secondary turns should be

a. 1600

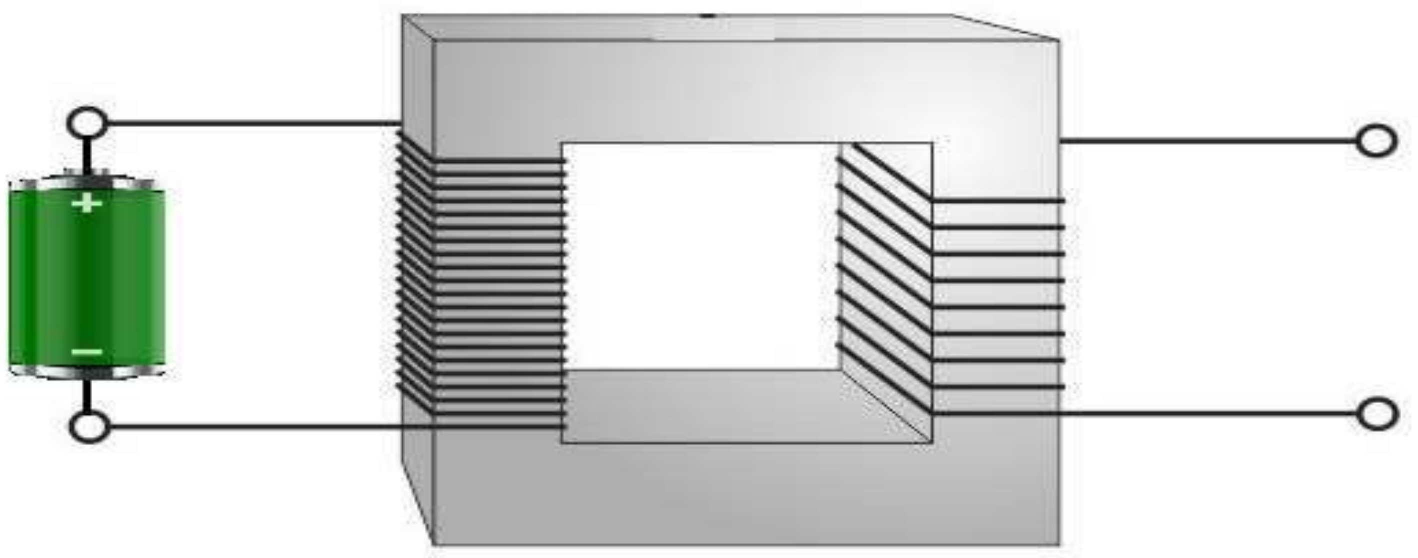
b. 250

c. 400

d. 1250

TRANSFORMER ON DC SUPPLY

What will happen if the Primary of a Transformer is Connected to D.C. Supply????



Transformer doesn't work on a DC supply

According to the principle of Transformer operation
It doesn't work on a DC supply since the rate of change of flux is zero

- A Transformer cannot be operated on the DC source or never connected to DC supply. If a rated dc voltage is applied to the primary of the transformer, the flux produced in the transformer core will not vary but remain constant in magnitude.

- So therefore no emf is induced in the secondary winding except during the moment of switching on the dc supply. As no induced emf is produced current cannot be delivered from the secondary side to the load.

- Therefore heavy current will flow in the transformer primary winding which may result in burning down the transformer primary winding.

LOSSES OF TRANSFORMER

- ***Copper loss in transformer***

*Copper loss is I^2R loss, in primary side it is $I_1^2R_1$ and in secondary side it is $I_2^2R_2$ loss, where I_1 & I_2 are primary & secondary current of transformer and R_1 & R_2 are resistances of primary & secondary winding. As the both primary & secondary currents depend upon load of transformer, so **copper loss in transformer** vary with load.*

- ***Core losses in transformer***

*Hysteresis loss and eddy current loss, both depend upon magnetic properties of the materials used to construct the core of transformer and its design. So these **losses in transformer** are fixed and do not depend upon the load current. So **core losses in transformer** which is alternatively known as **iron loss in transformer** and can be considered as constant for all range of load.*

Applications of Transformers

- Transformers are used in the transmission of electric power over long distances
  - Power dissipation in a electrical wire is P = V I
  - DC voltage would waste too much energy in transmission
  - Transformers allow large AC voltage transmission with small current
- Many household appliances use transformers to convert the AC voltage at a wall socket to the smaller DC voltages needed in many devices

Quick Quiz (Poll 2)

- Transformer are rated in kVA instead of kW because

a. load power factor is often not known

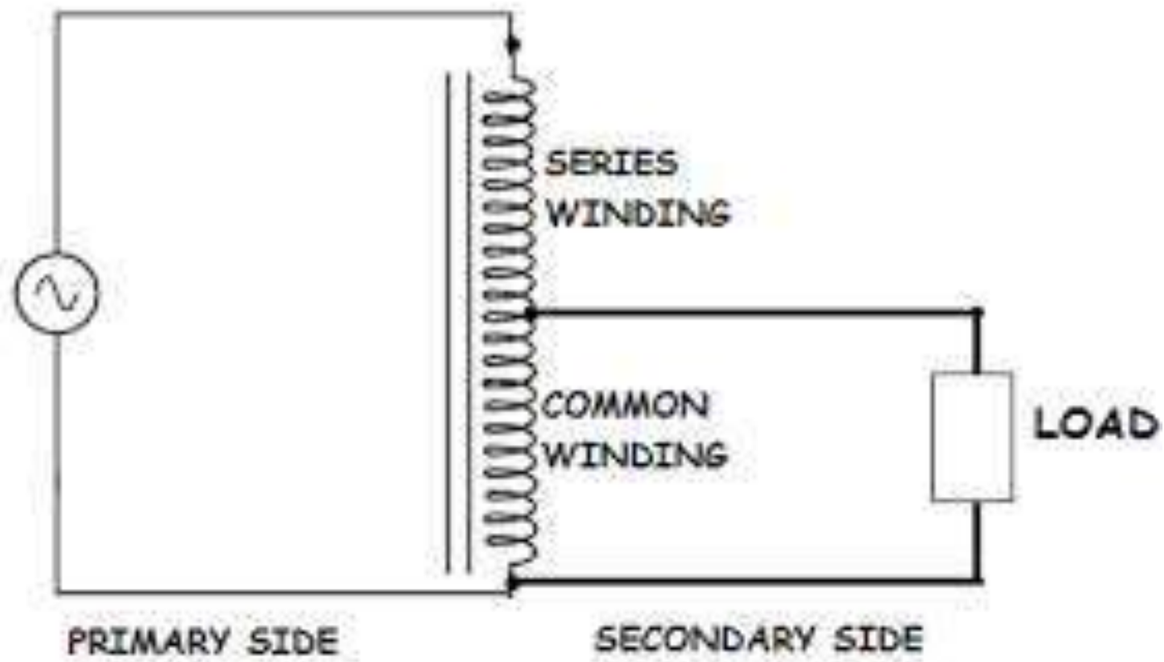
b. kVA is fixed whereas kW depends on load PF

c. total transformer loss depends on the volt ampere

d. it has become customary

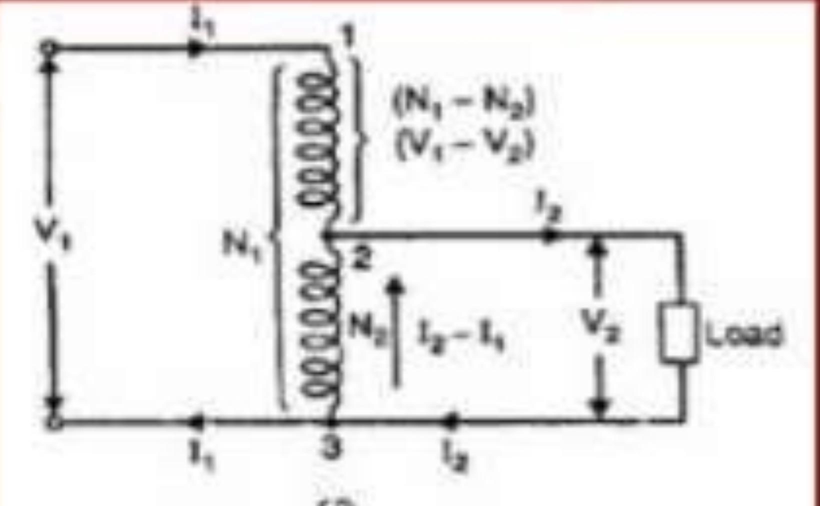
Auto-Transformer

An Auto-transformer is an electrical transformer with only one winding.



Theory of Autotransformer

- N1=primary turn(1-3)
- N2=secondary turn(2-3)
- I1=primary current
- I2=secondary current
- V1=primary voltage
- V2=secondary votage



(i)

From the above fig. We get

$$\frac{V_2}{V_1 - V_2} = \frac{N_2}{N_1 - N_2}$$

$$V_2(N_1 - N_2) = N_2(V_1 - V_2)$$

$$V_2N_1 - V_2N_2 = N_2V_1 - N_2V_2$$

$$V_2N_1 = N_2V_1$$

$$\frac{V_2}{V_1} = \frac{N_2}{N_1} = K$$

Advantages

Some of the **advantages of auto-transformer** are that,

- they are smaller in size,
- cheap in cost,
- low leakage reactance,
- increased kVA rating,
- low exciting current etc.

Disadvantages

- Any undesirable condition at primary will affect the equipment at secondary (as windings are not electrically isolated),
- due to low impedance of auto transformer, secondary short circuit currents are very high,
- harmonics generated in the connected equipment will be passed to the supply.

Instrument Transformers

- The original magnitude can be determined by just multiplying the result with the transformation ratio. Such specially constructed transformers with accurate turns ratio are called as **Instrument transformers**.
- These instruments transformers are of two types –

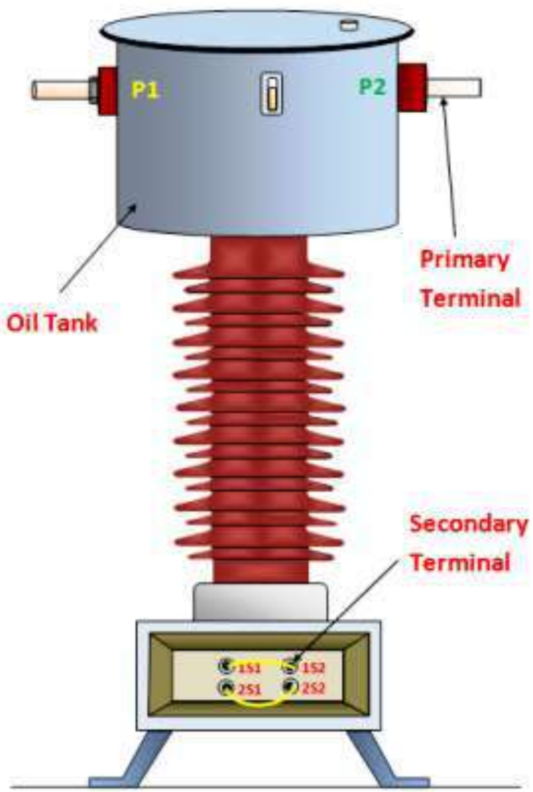
  (i) **Current Transformers (CT)** and

  (ii) **Potential Transformers (PT)**.

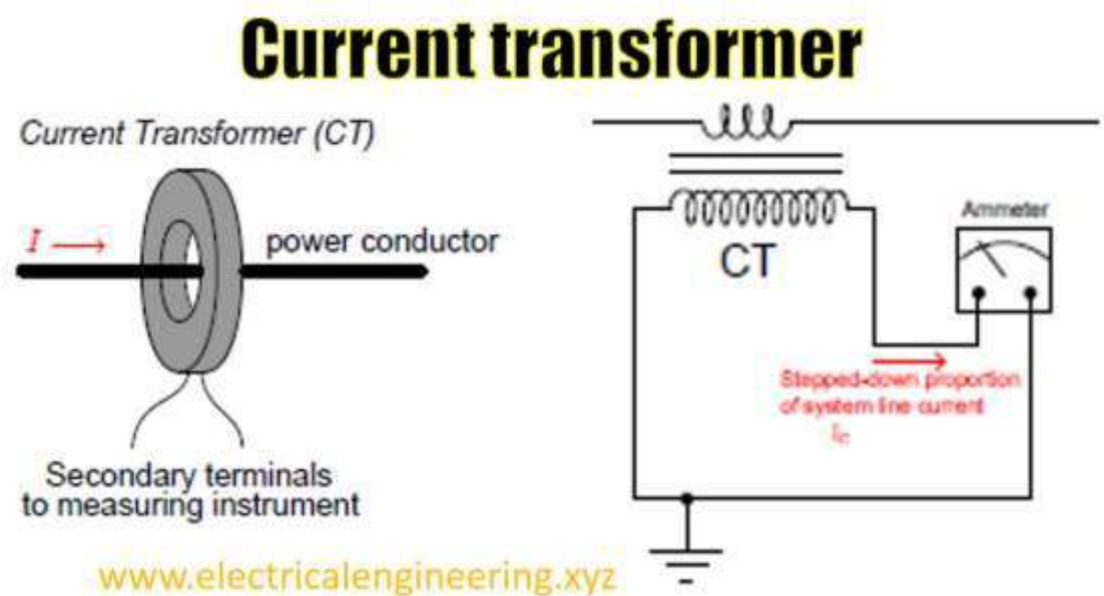
Current Transformers

Construction of C.T.:

- C.T. has a primary coil of one or more turns made of thick wire connected in series with the line whose current is to be measured.
- The secondary consists of a large number of turns made of fine wire and is connected across an ammeter



Live Tank Current Transformer



Potential Transformers

Construction and working of P.T.:

Construction

- A potential transformer has many primary winding turns but few number of secondary winding turns that makes it a step-down transformer.
- A Voltmeter is connected to the secondary winding is usually a voltmeter of 150 V.

Working (Measurement):

- Primary terminals are connected in parallel across the line to which the voltage is to be measured.
- The voltmeter reading gives the transformed value of the voltage across the secondary terminals.

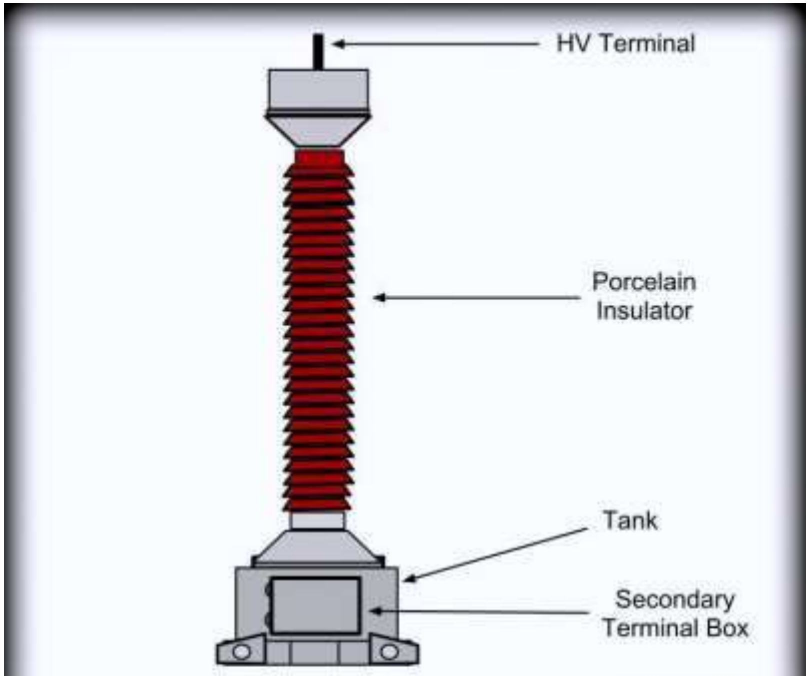
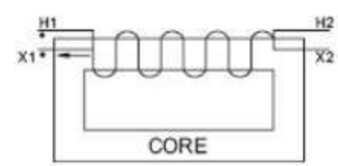


Fig-C: Sketch of Voltage Transformer

Potential Transformer

Voltage Transformer



Voltage Example
Primary 7200 Volts
Ratio 60:1 or 7200:120 Volts

Quick Quiz (Poll 3)

- What are the types of Instrument Transformer?

A. Auto Transformer
B. Current transformer
C. Potential Transformer
D. Both B and C

UNIT-III

Fundamentals of Electrical Machines

Lecture 17

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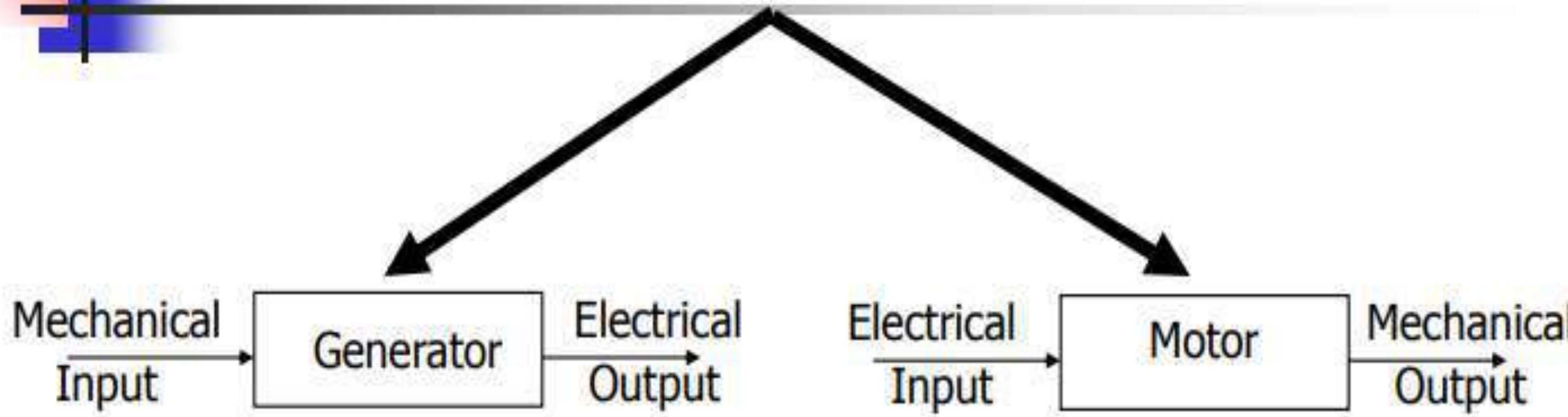
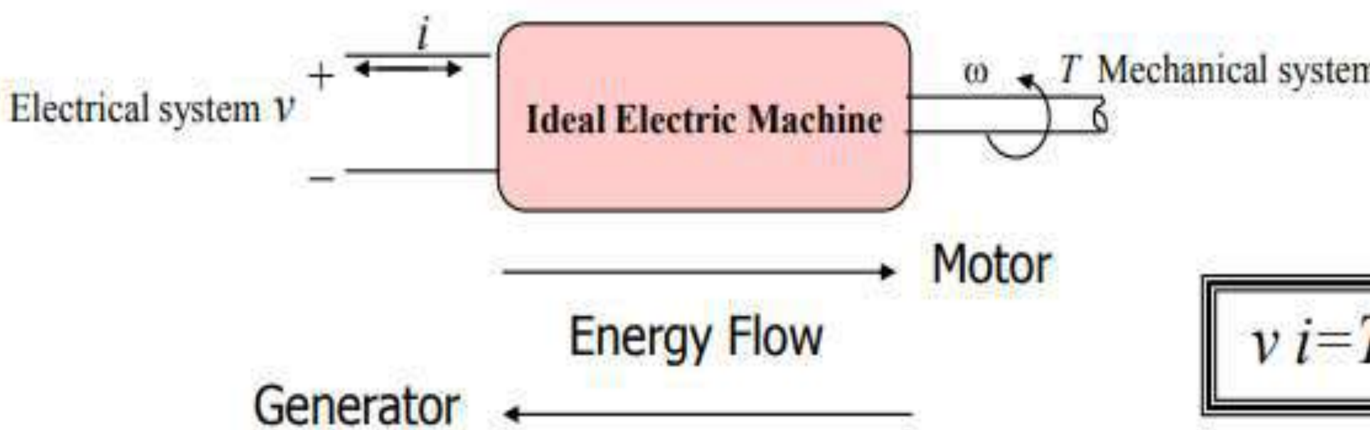
What is an electric motor?

- An electric motor is an electromechanical device that converts electrical energy into mechanical energy.
- All electric motors operate through the interaction of magnetic fields and current-carrying conductors to generate force.

Electric Machine

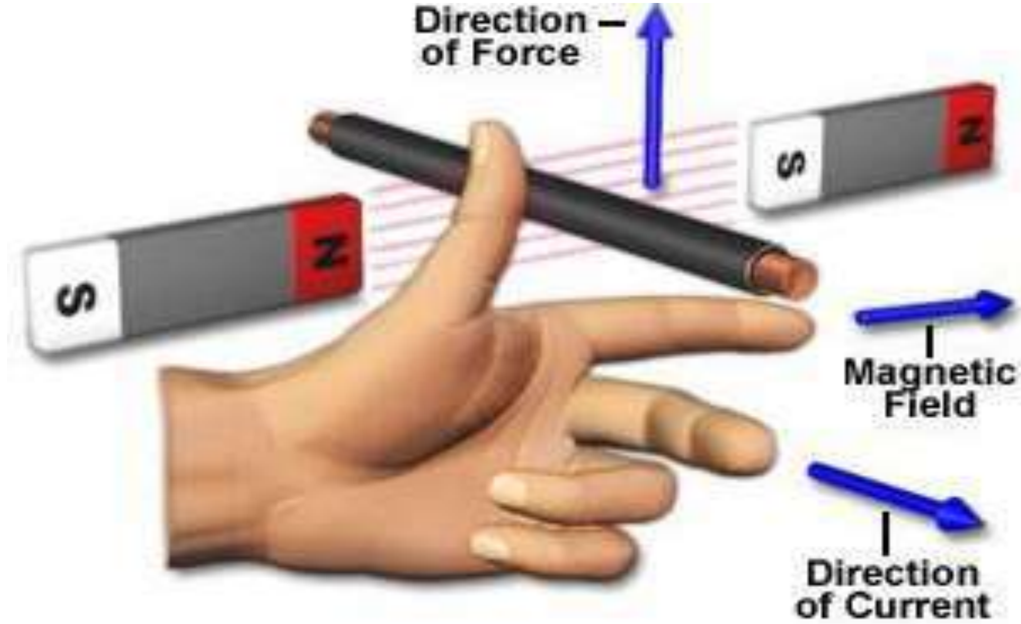


Electromechanical Energy Conversion



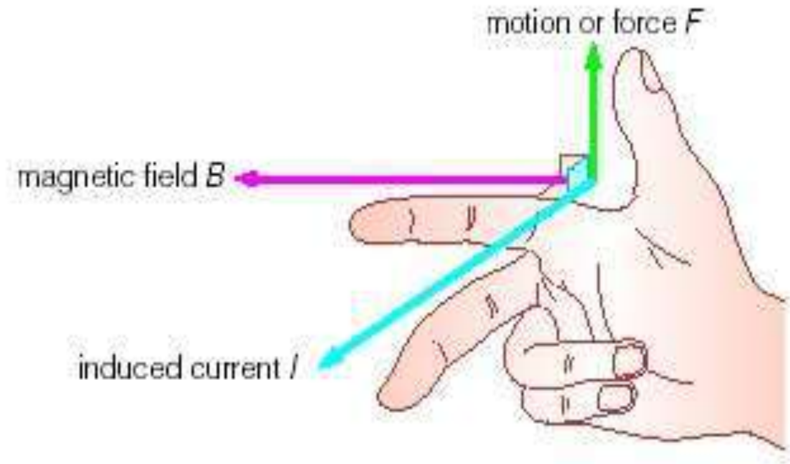
$$\boxed{v\, i = T\, \omega}$$

Flemings left hand rule



- The direction of force exerted on the conductor is given by Fleming's Left Hand Rule.
- Thumb indicates the direction of force experienced by the conductor Index finger represents direction of magnetic field
- Middle finger indicates direction of current
- **This rule is used in motors.**

Flemings Right hand rule



- When a current passes through a conductor, lines of magnetic force (flux) are generated around the conductor.
- The direction of the flux is dependent on the direction of the current flow. The magnetic field produced by the conductor is shown in Figure above.
- This can be found by using Right Hand Thumb Rule.
- This rule states that If the thumb points in the direction of the current, then the curled fingers show the direction of the magnetic field.

Quick Quiz (Poll 1)

- Which of the following rule is used to determine the direction of rotation of D.C motor?

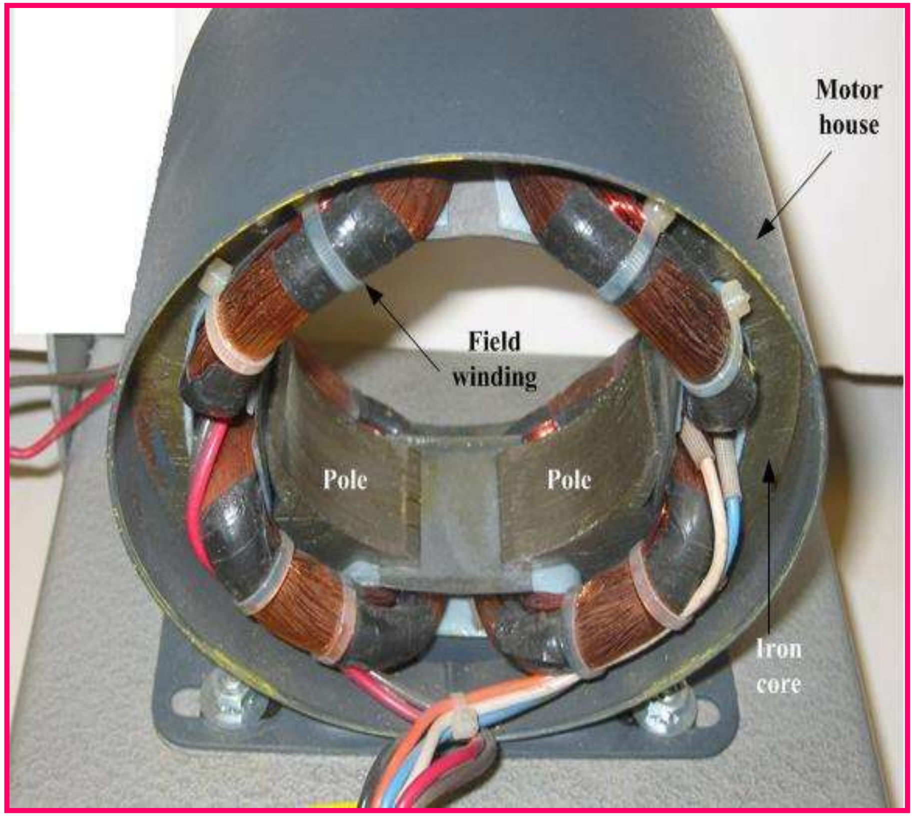
A. Coloumb’s Law

B. Lenz’s Law

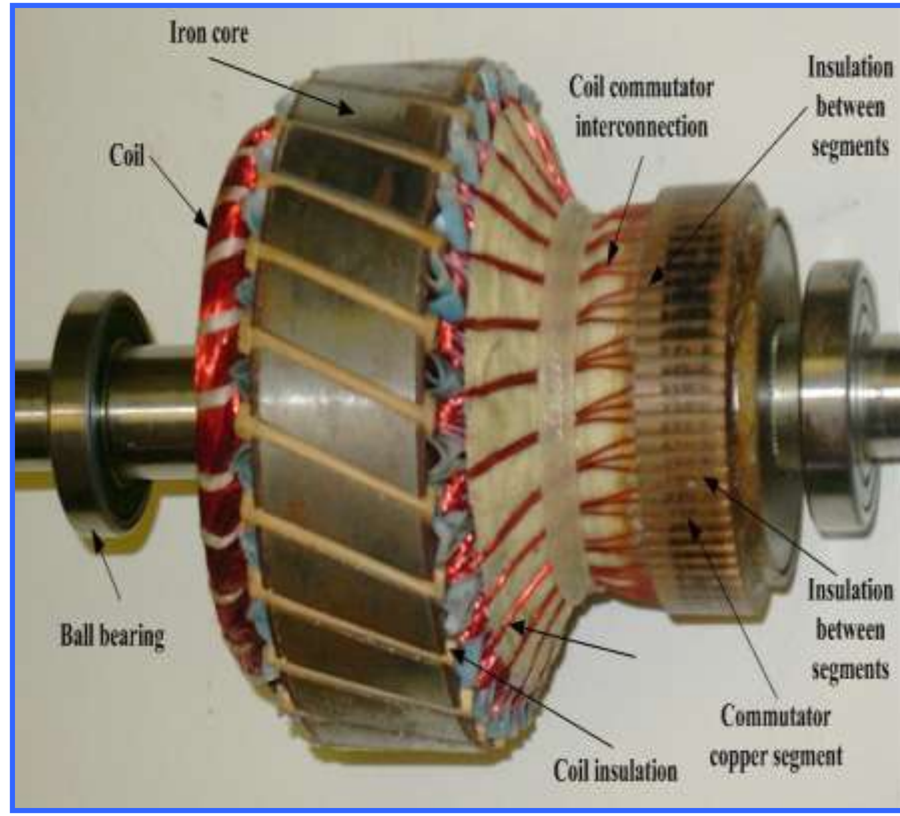
C. Fleming’s Right-hand Rule

D. Fleming’s Left-hand Rule

CONSTRUCTION OF DC MACHINES



DC motor stator

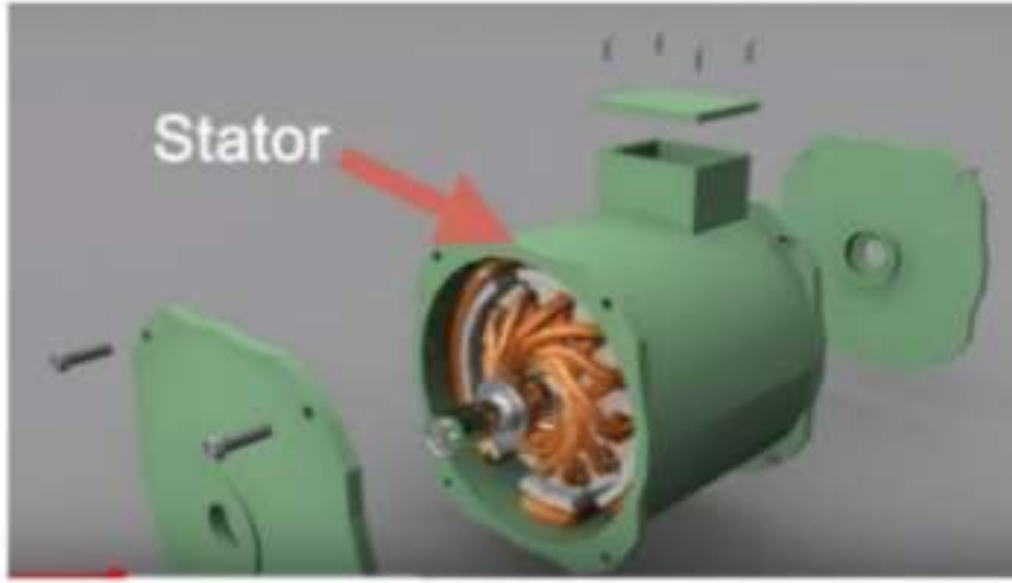


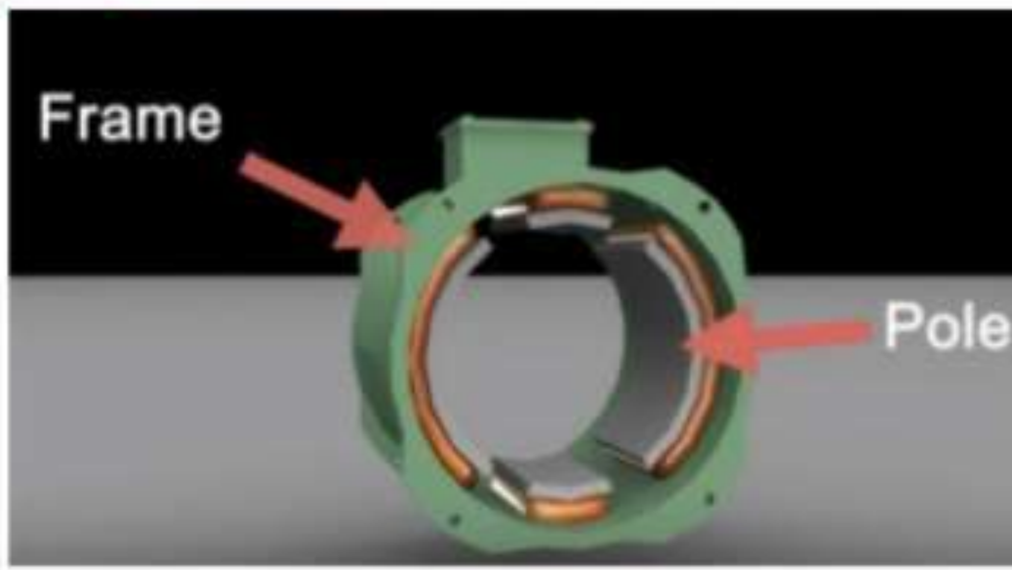
Rotor of a dc motor

Construction

•The outer part of the motor is generally static, which is known as stator.

•Stator consist of a frame, and it contains "Pole Shoes" which are projected inward.

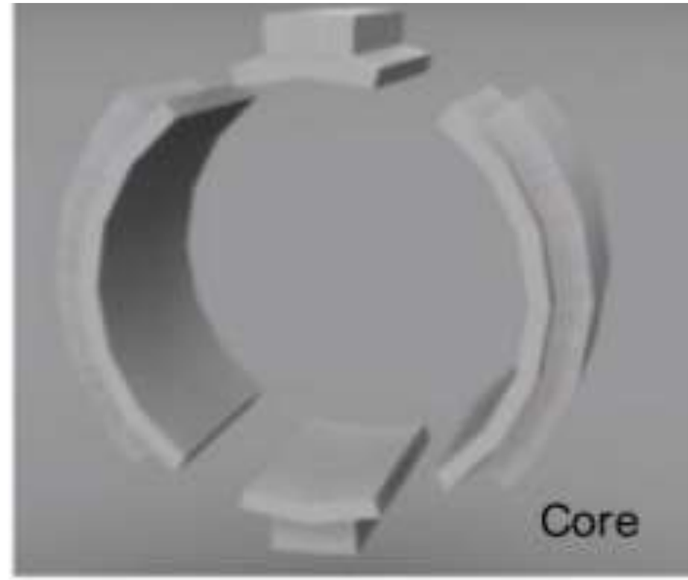


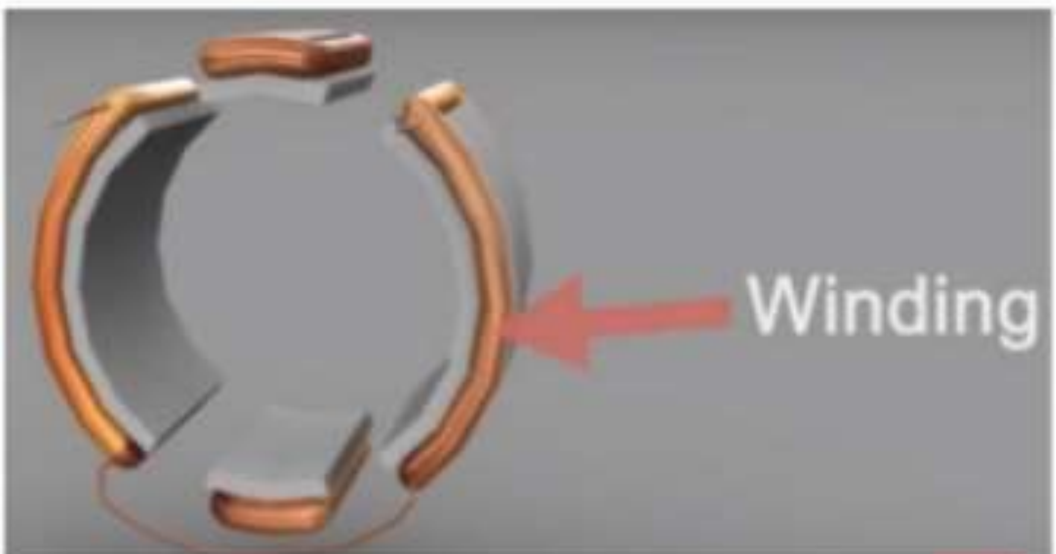


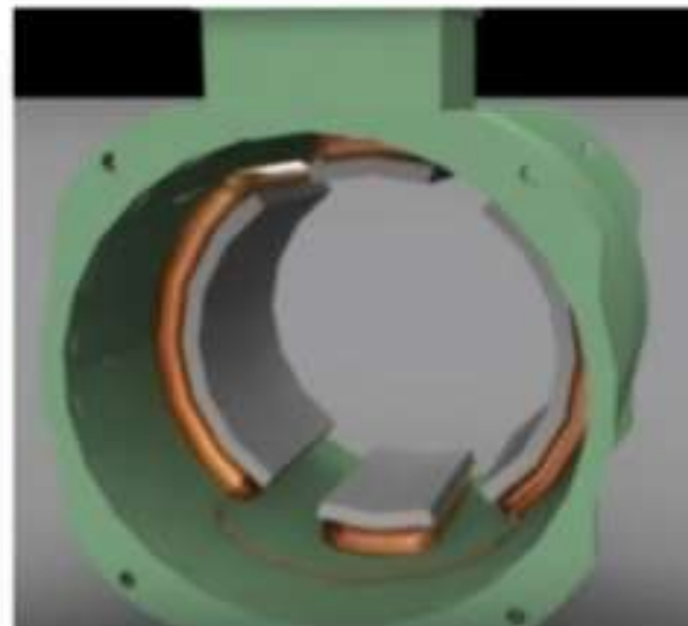
Construction

•Core of these poles are made from silicon steel on which insulated copper wire is wound to make windings.

•These poles are bolted and fixed inside the frame.







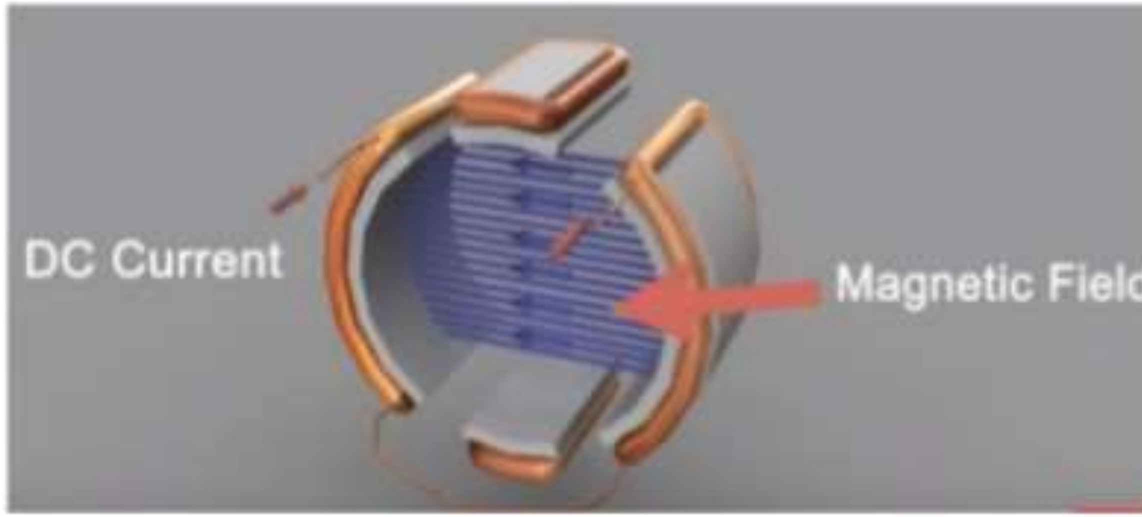
Construction

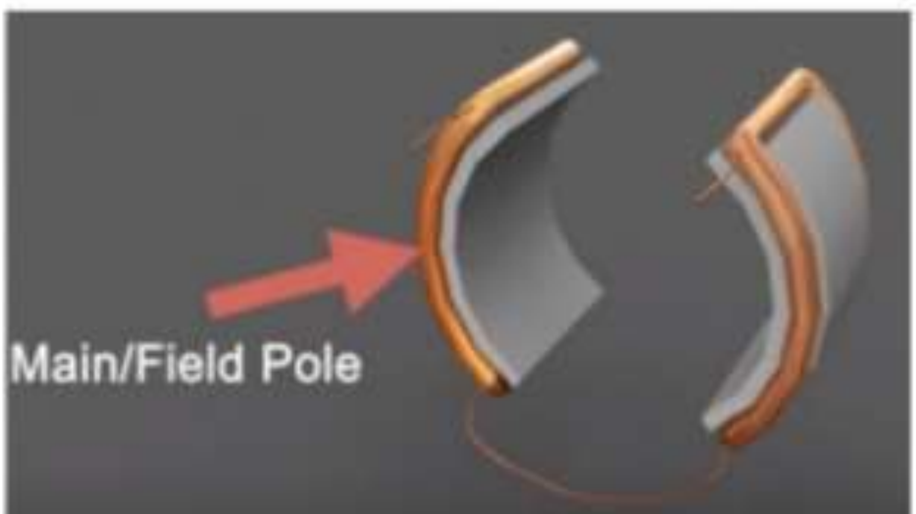
- When DC current is pass through the windings it creates a static magnetic field.

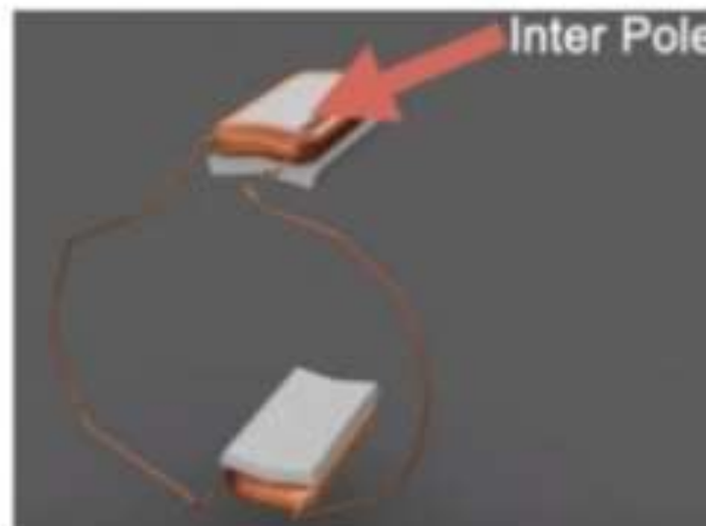
- There are two types of pole in a DC machine.

1. Main/ Field Pole

2. Inter Poles



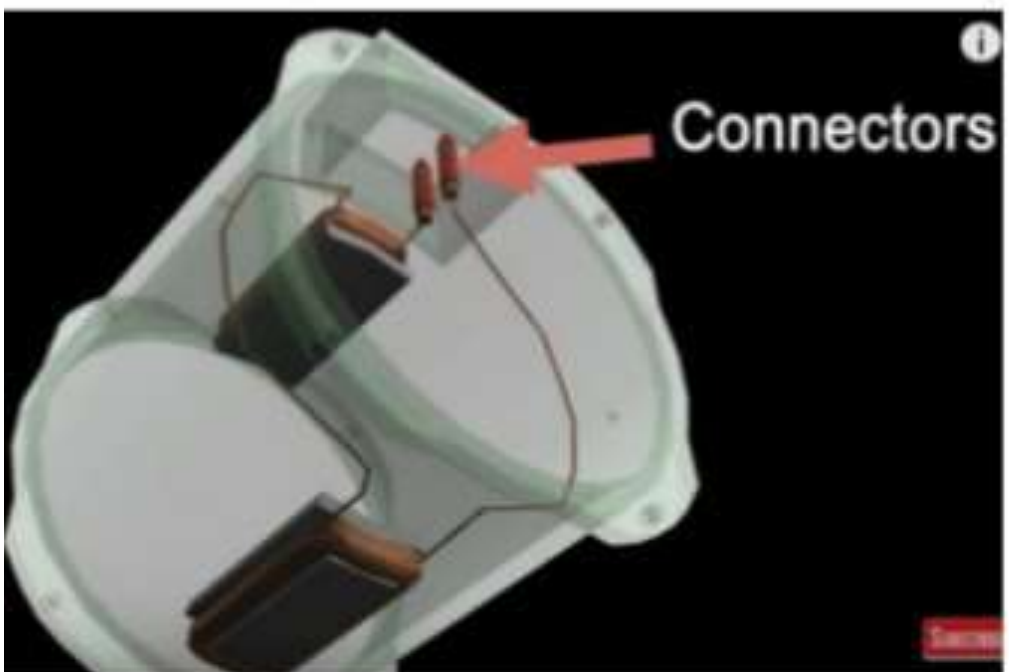


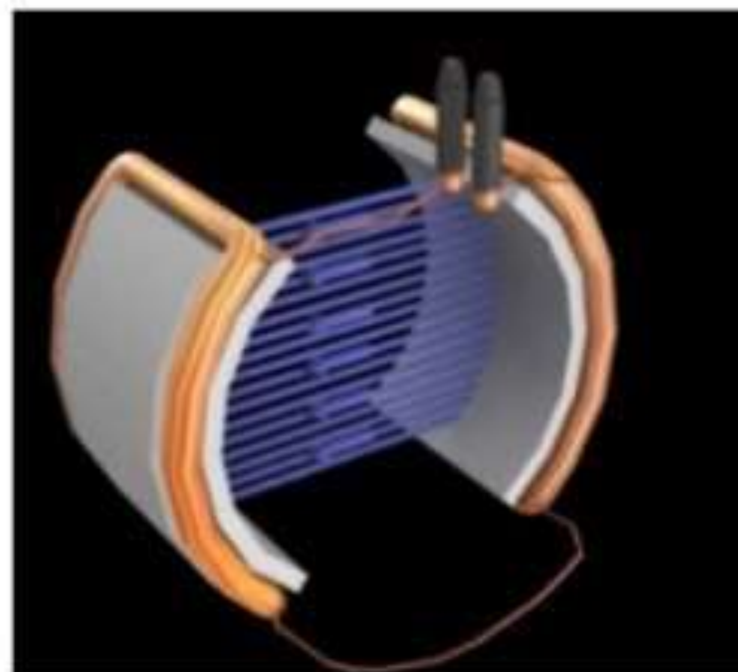


Construction

- The connections of these poles are brought out through connectors in the terminal box, so that we can give electric supply to them and even do the check for the fault.

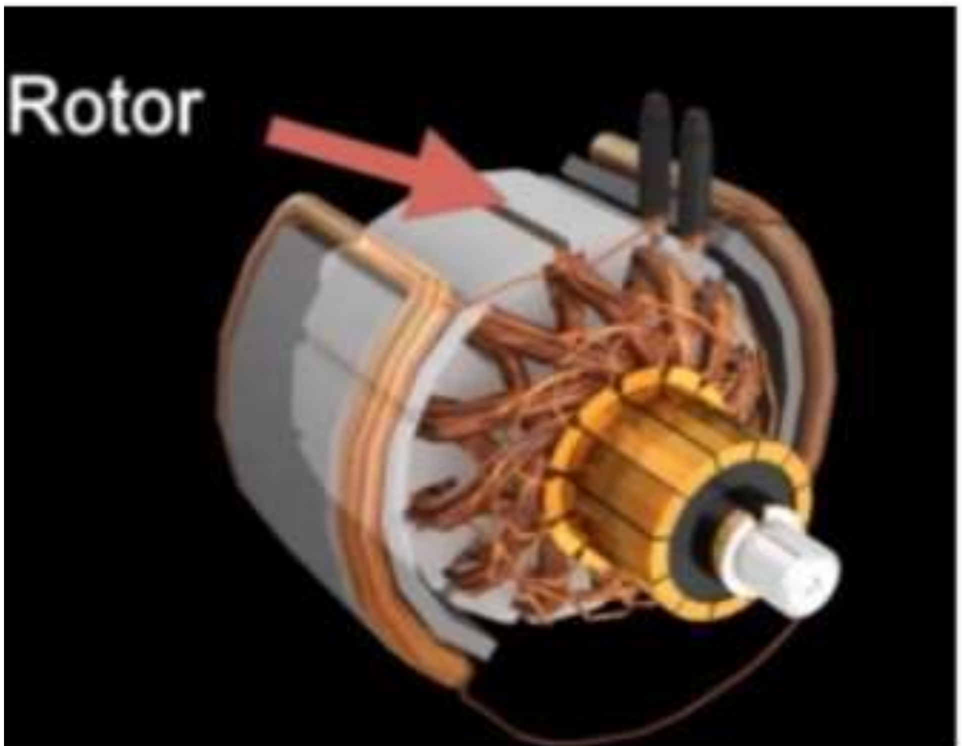
- Main poles create static magnetic field, when current is pass to its winding.





Construction

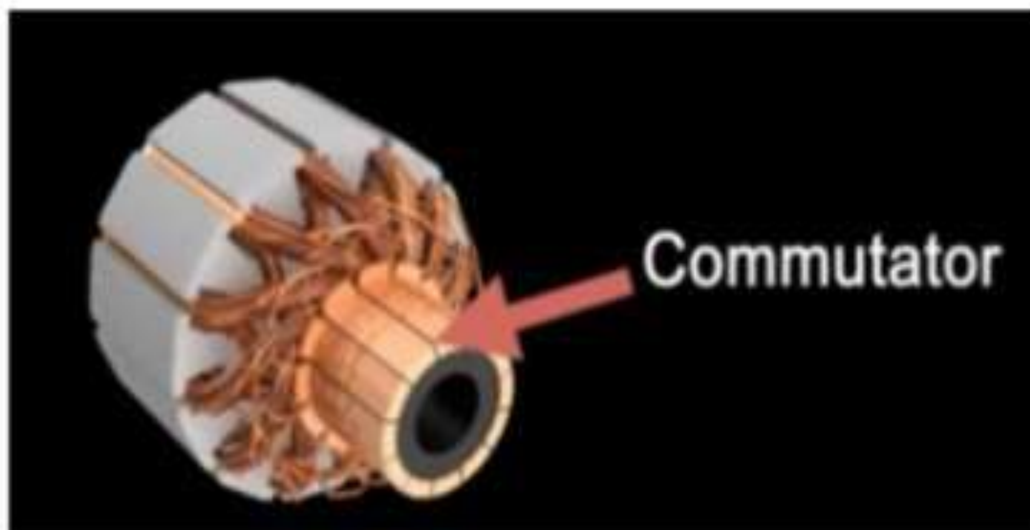
- In this magnetic field rotating part of motor lies, known as Rotor or Armature which is made by number of stampings of highly permeable material i.e. silicon steel, which allows magnetic field to pass through it easily.



Construction

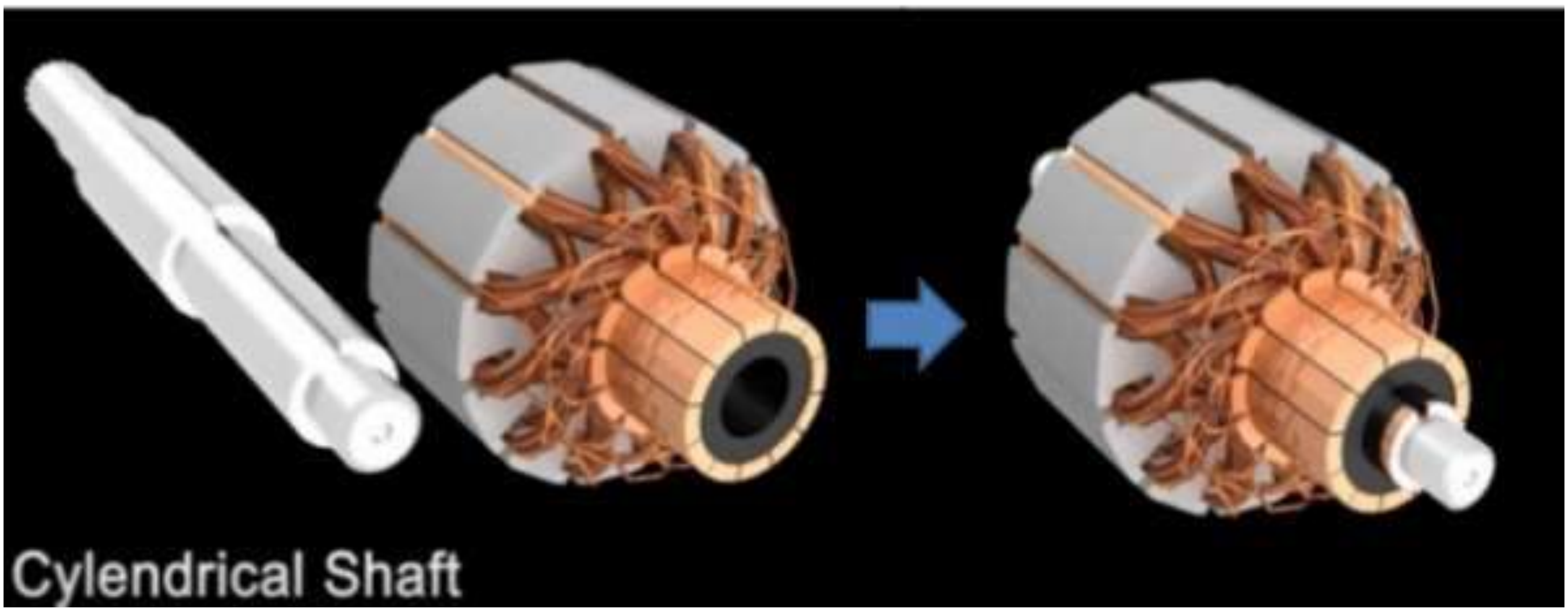
- Slots are cut on the outer periphery of rotor or we can say "armature", which receive coils/windings made up of copper conductor.

- Each coil gets connected to an external DC source by a pair of commutator segments arranged in the form of a Ring.



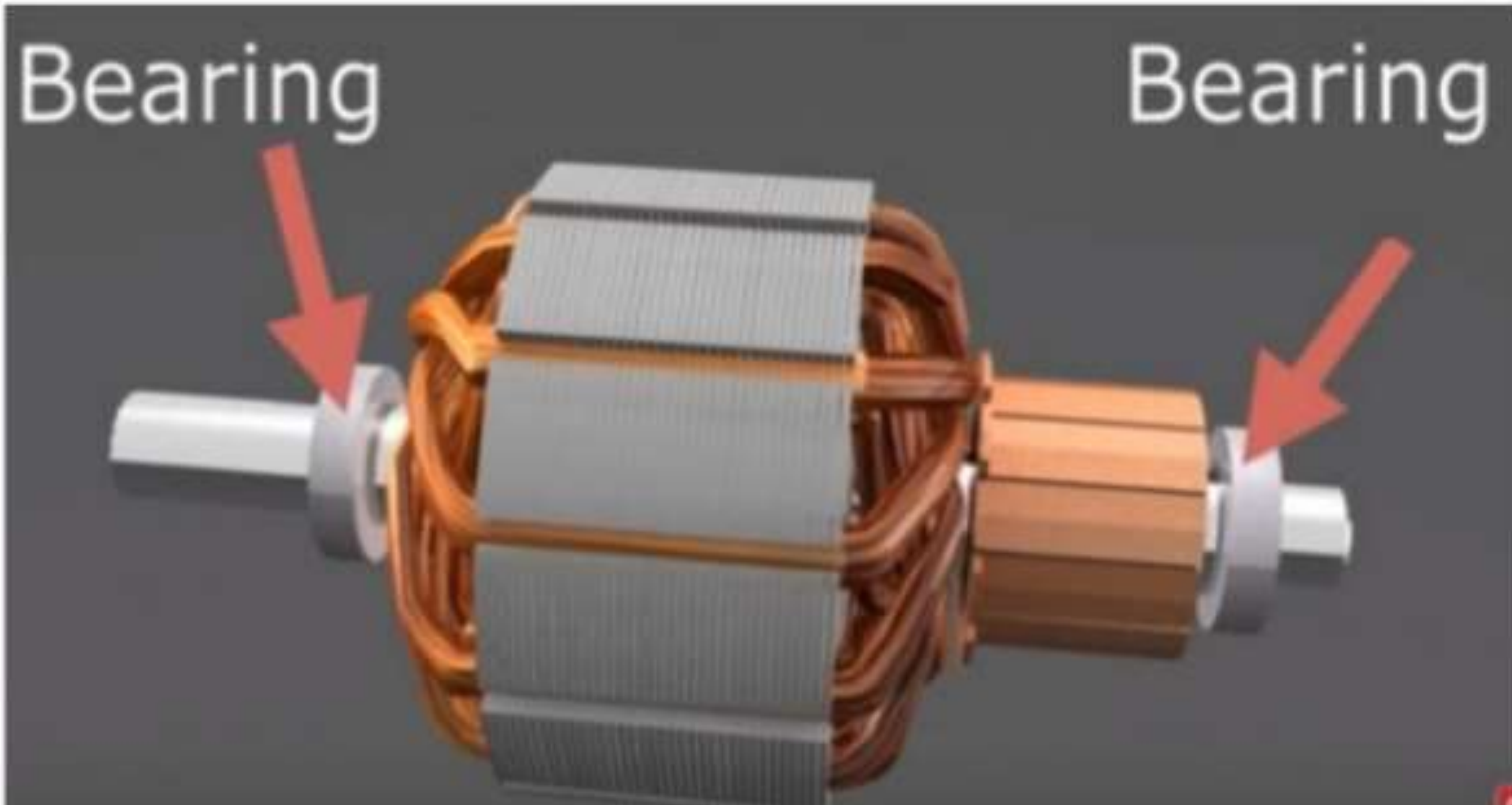
Construction

•This complete assembly is housed over a cylindrical shaft made up of high quality steel.



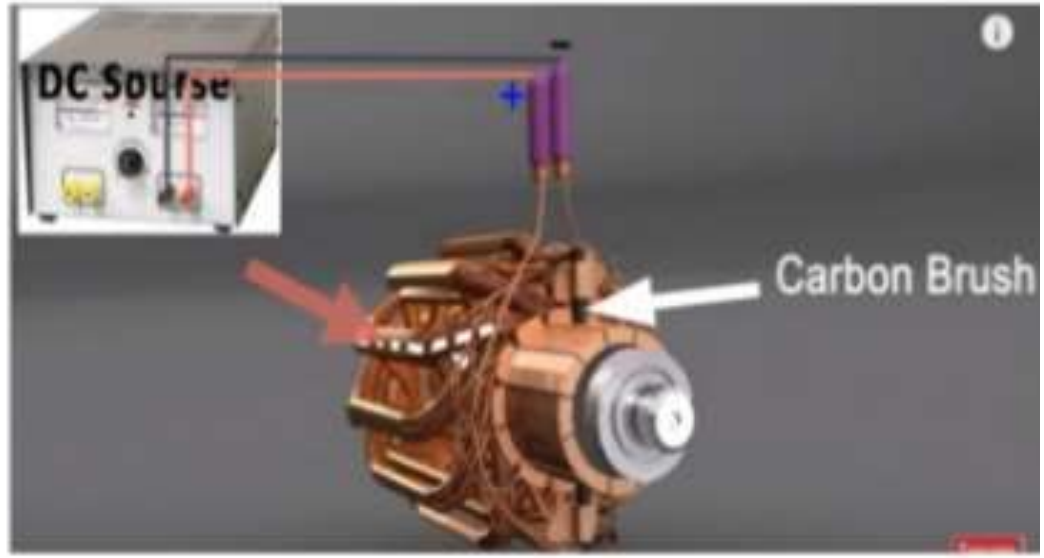
Construction

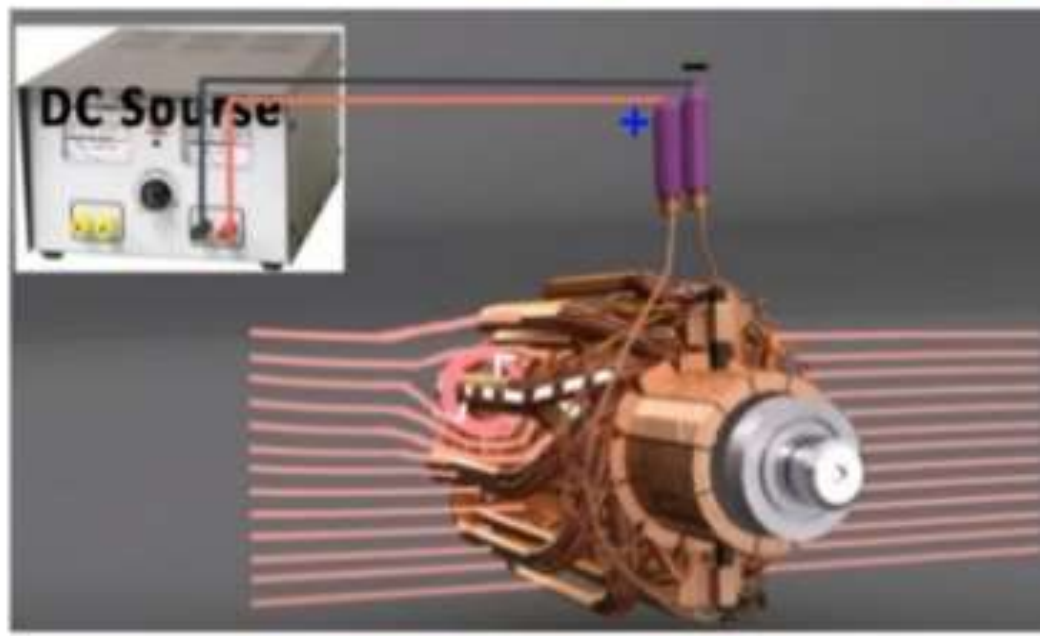
- Because of the bearings at both side of the shaft the rotor is capable of rotate between the field poles.



Working

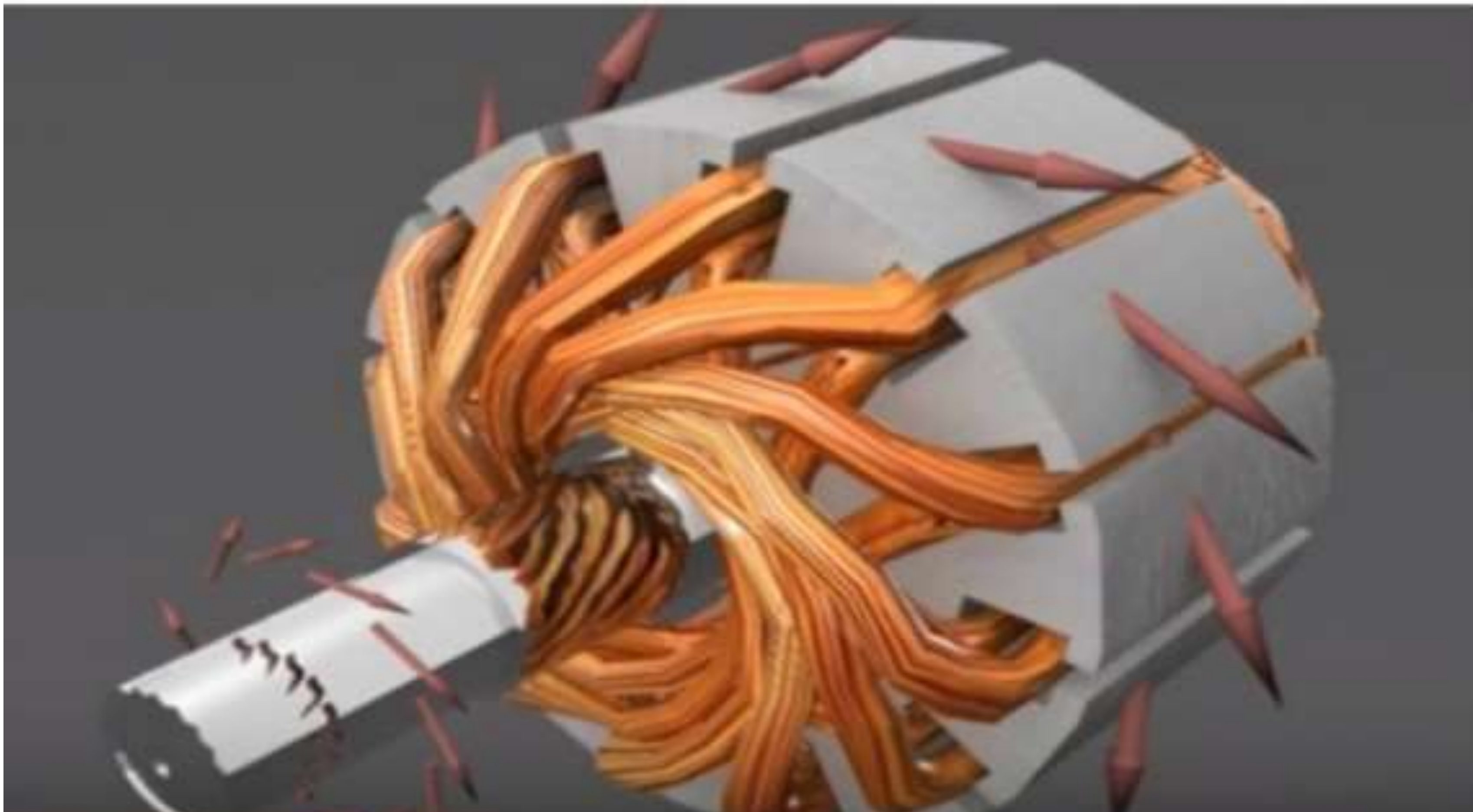
- When electric current is forced to pass through the rotor conductors by a set of carbon brushes through commutator segments, it creates their own magnetic field which tries to distorts the magnetic field, created by the field pole.





- Due to interaction between two magnetic fields i.e magagntic field of main poles and the rotor conductors. Electromagnetic Forces act on the rotor conductors and these forces act tangentially on the rotor surface.

- Therefore a torque is produced at the rotor shaft and the rotor rotates.



Principle of operation

- When current carrying conductor is placed in a magnetic field, it experienced a force.
- In case of DC motor, the magnetic field us developed by the field current i.e. current flowing in field winding and armature winding plays the role of current carrying conductor
- So armature winding experienced a force and start rotating.

Back EMF

- When the armature winding of a dc motor starts rotating in the magnetic flux produced by the field winding, it cuts the lines of magnetic flux.
- Hence according to the faraday's laws of electromagnetic induction, there will be an induced emf in the armature winding.
- As per the Lenz's law, this induced emf acts in opposite direction to the armature supply voltage. Hence this emf is called as the back emf and denoted by E_b.

$$E_b = \frac{NP\varphi Z}{60\ A}$$

Quick Quiz (Poll 2)

- The efficiency of the DC motor at maximum power is

A. 90%

B. 100%

C. Around 80%

D. Less than 50%

Quick Quiz (Poll 3)

- By looking at which particular part of the motor we can Identify a **“DC motor”**?

A Shaft

B Field winding

C Commutator

D Armature winding

UNIT-III

Fundamentals of Electrical Machines

Lecture 18
Prepared By:
Krishan Arora
Assistant Professor and Head

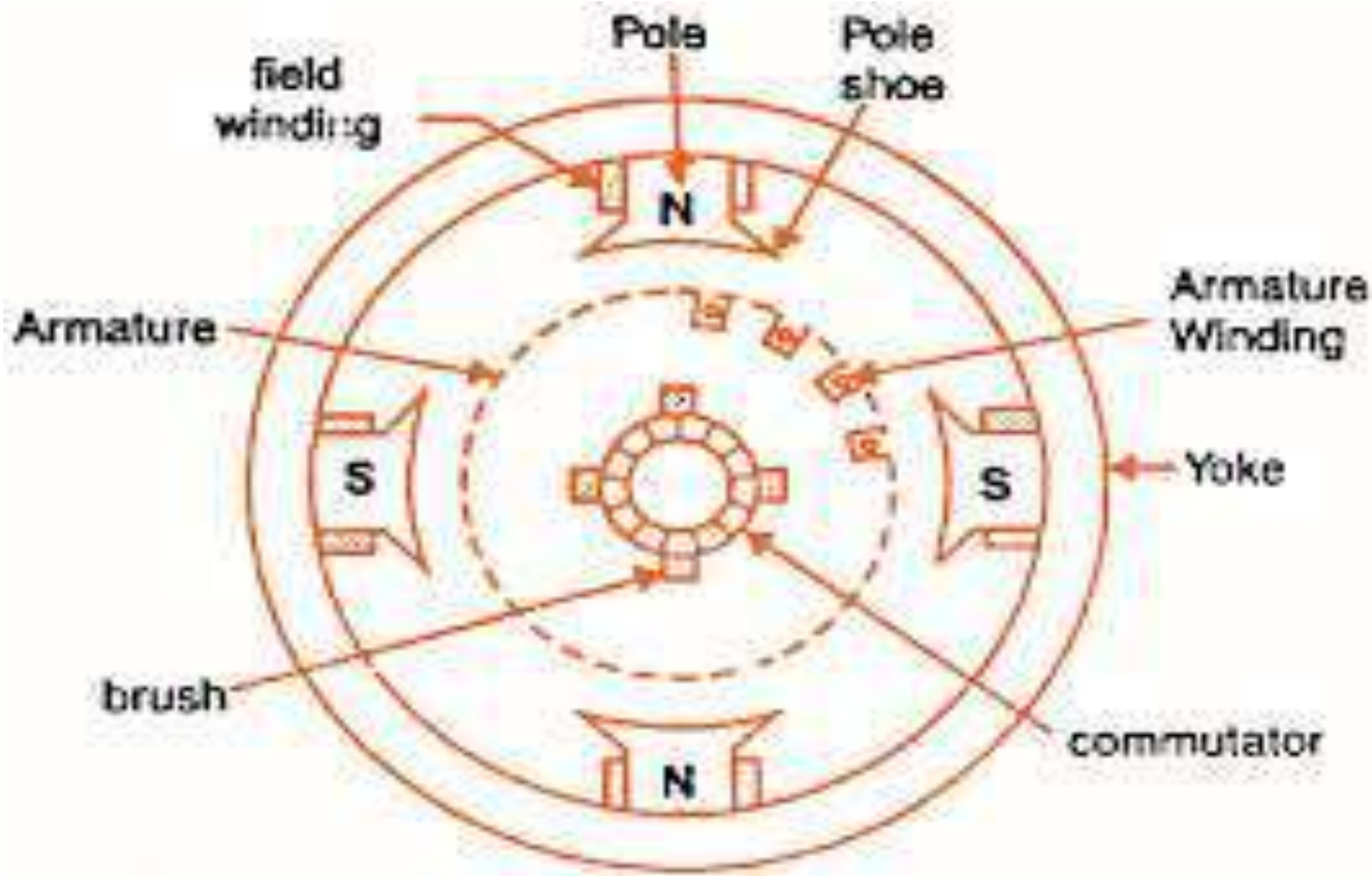
Windings in DC Machine

- In any dc machines, there are two windings:

1. Field winding 2. Armature winding

Out of these, the field winding is stationary which does not move at all and armature winding is mounted on a shaft. So it can rotate freely.

Construction of DC Motor



Revision Quiz (Poll 1)

According to Fleming’s left-hand rule if the index finger points in the direction of the field than the middle finger will point in the direction of

a) Current in the conductor
b) Resultant force on the conductor
c) Movement of the conductor
d) None of the above

Types of DC Motors

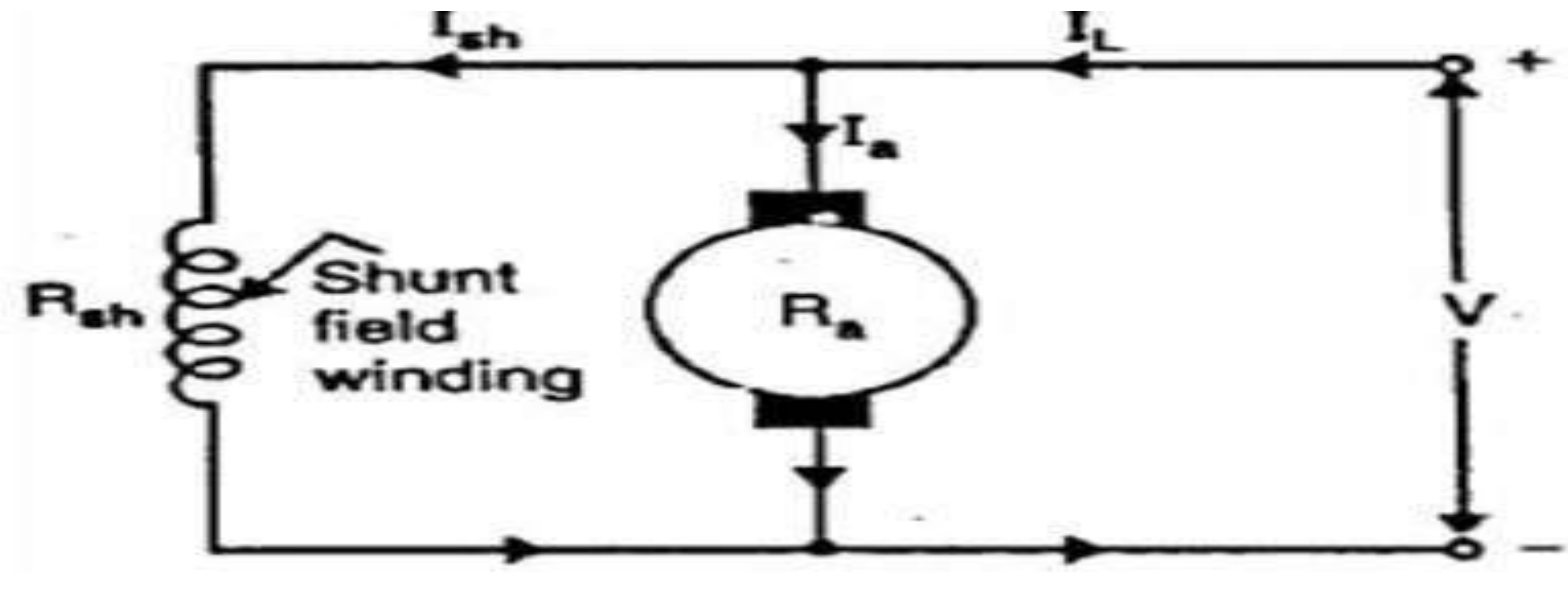
- Depending on the way of connecting the armature and field windings of a d.c. motors are classified as follows:

DC Motor

- **DC series motor**
- **Shunt motor**
- **Compound motor**
  - **Short shunt compound**
  - **Long shunt compound**
- **Separately excited motor**

DC Shunt Motor

In DC shunt type motor, field and armature winding are connected in parallel as shown, and this combination is connected across a common dc power supply.



- The resistance of shunt field winding (R_{sh}) is always much higher than that of armature winding (R_a).
- This is because the number of turns for the field winding is more than that of armature winding.

The field current I_{sh} always remains constant. Since V and R_{sh} both are constant. Hence flux produced also remains constant. Because field current is responsible for generation of flux.

$$\therefore \phi \propto I_{sh}$$

This is why the shunt motor is also called as the constant flux motors.

DC Series Motor

- In DC series motor, the armature and field windings are connected in series with each other as shown in fig.(1).
- The resistance of the series field winding (R_s) is much smaller as compared to that of the armature resistance (R_a).
- The flux produced is proportional to the field current. But in series motor, the field current is same as armature current.

$$\therefore \phi \propto I_a \quad \text{or}$$

$$\therefore \phi \propto I_s$$

- The armature current I_a and hence field current Is will be dependent on the load.
- Hence in DC series motor the flux does not remains constant.

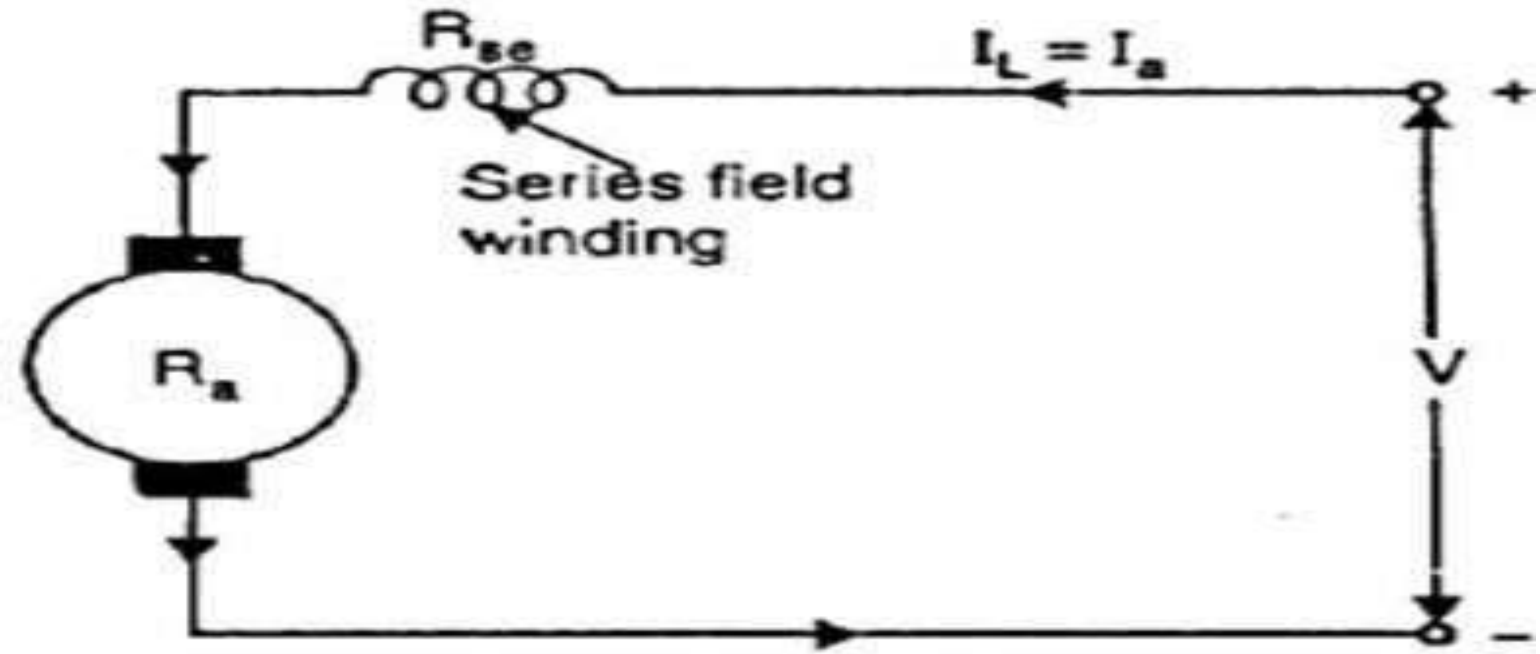


Fig.(1):DC series motor schematic diagram

DC Compound Motor

1. **Long Shunt Compound Motor:**

- As shown in fig.(1), in long shunt dc motor, shunt field winding is connected across the series combination of the armature and series field winding.

2. Short Shunt Compound Motor:

- In short shunt compound motor, armature and field windings are connected in parallel with each other and this combination is connected in series with the series field winding. This is shown in fig.(2).

➢ The long shunt and short shunt compound motors are further classified as **cumulative and differential compound motors**

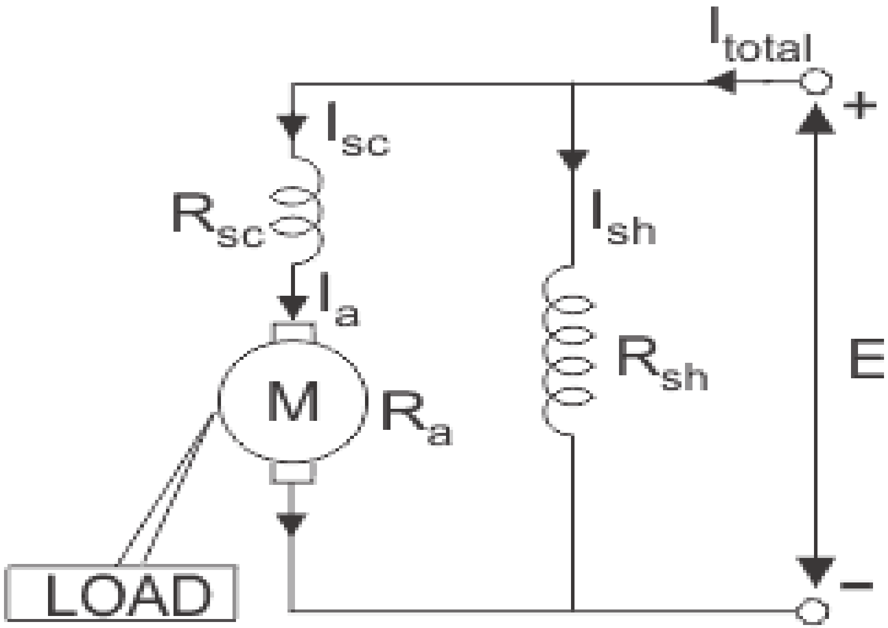


Fig.(1): Long shunt compound dc motor

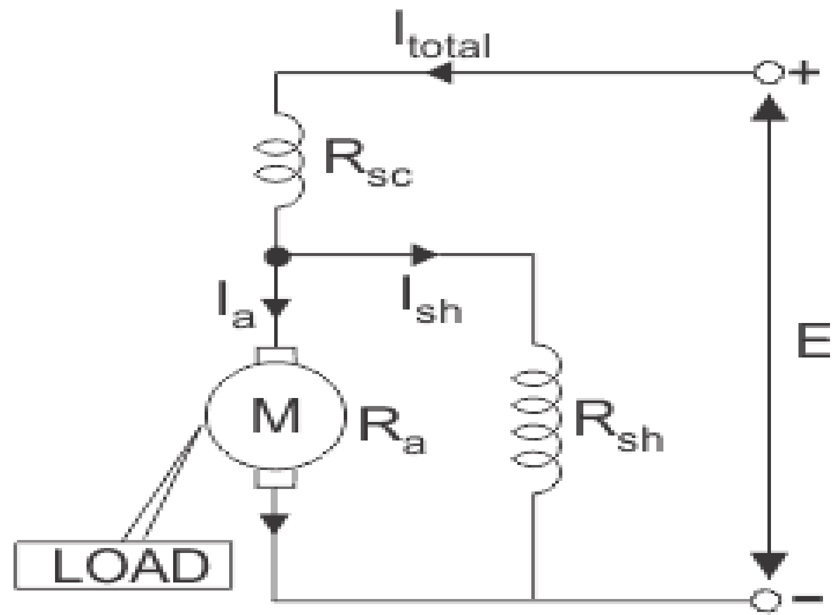


fig.(2):Short shunt compound dc motor

Voltage Equation of a DC Motor

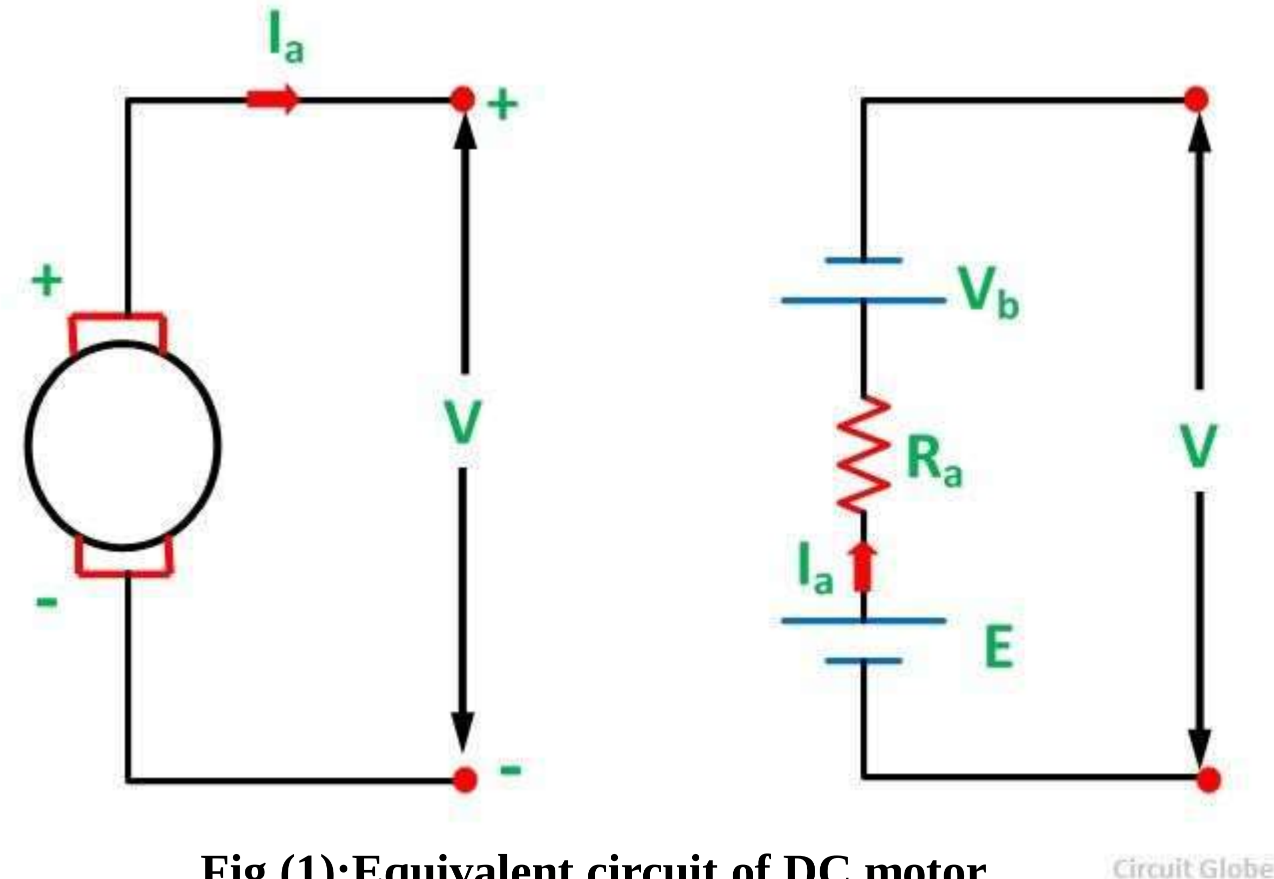


Fig.(1):Equivalent circuit of DC motor

- As shown in fig.(1), the armature supply voltage V has to overcome the opposition posed by the back emf E_b and some other voltage drops such as brush drop and the voltage drop across R_a.
- From fig.(1), we can write that,

$$V = E_b + I_a R_a + V_b \qquad ....(1)$$

- But voltage drop across brushes is negligible.

$$\therefore V = E_b + I_a R_a \qquad ......(2)$$

Torque Equations

- Torque produced by a motor will always be proportional to the air gap flux ø and the current flowing through the armature winding (I_a).
- That means $T \propto ø\, I_a$

1. **Torque equation of DC shunt motor:**

- For DC shunt motor field current = V/ R_{sh} = constant
- Hence the flux ø is constant.

$$\therefore T \propto I_a \qquad \ldots\ldots\ldots(2)$$

- Hence in dc shunt motor, torque is proportional to only to the armature current.

2. Torque equation DC series motor:

- For DC series motor, the field current is equal to the armature current i.e. $I_{field} = I_a$.
- Hence $T \propto I_a\ I_a$

$$\therefore T \propto I_a^2 \qquad \ldots\ldots\ldots(3)$$

- Hence in dc series motor, torque is proportional to the square of armature current.

Quick Quiz (Poll 2)

- Which DC motor is preferred for constant speed?

a) Series motor
b) Compound motor
c) Shunt motor
d) Differential motor

Quick Quiz (Poll 3)

- If T_a be the armature torque and I_a be the armature current then which of the following relation is valid for DC series motor before saturation?
- $T_a \propto I_a$
- $T_a \propto I_a^2$
- $T_a \propto 1/I_a$
- $T_a \propto 1/I_a^2$

UNIT-III

Fundamentals of Electrical Machines

Lecture 19

Prepared By:
Krishan Arora
Assistant Professor and Head

Types of DC Motors

- Depending on the way of connecting the armature and field windings of a d.c. motors are classified as follows:

DC Motor

- DC series motor
- Shunt motor
- Compound motor
  - Short shunt compound
  - Long shunt compound
- Separately excited motor

Important Equations

Voltage Equation

$$V = E_b + I_a R_a + V_b \qquad \text{.......(1)}$$

- But voltage drop across brushes is negligible.

$$\therefore V = E_b + I_a R_a \qquad \text{......(2)}$$

Torque equation of DC shunt motor:

- $\therefore T \propto I_a$ ....(3)

Torque equation DC series motor:

- $T \propto I_a I_a \quad = T \propto I_a^2$ ....(4)

Revision Quiz (Poll 1)

- Which part will surely tell that given motor is DC motor and not an AC type?

  a) Winding
  b) Shaft
  c) Commutator
  d) Stator

Speed Equations

- We know that the expression for the back emf is, $E_b = \frac{NP\varphi Z}{60\ A}$
- But P, Z and 60A are constants. Therefore we can write that,

$$E_b \propto ø\ N \qquad \ldots\ldots(1)$$

- Therefore the speed can be expressed as,

$$N \propto E_b / ø \qquad \ldots\ldots.(2)$$

$$N = k\ E_b / ø \qquad \ldots\ldots\ldots(3)$$

- But $V = E_b + I_a\ R_a$

$$\therefore E_b = V - I_a\ R_a \qquad \ldots\ldots\ldots..(4)$$

- Substituting eq.(4) into eq.(2) we get,

$$N \propto (V - I_a\ R_a) / ø \qquad \ldots\ldots.(5)$$

- Since $ø \propto I_{field}$, we can write,

$$N \propto (V - I_a\ R_a) / I_{field} \qquad \ldots\ldots.(6)$$

Speed Control of DC Motor:

- The speed equation of dc motor is

$$N \propto \frac{Eb}{\emptyset} \propto \frac{(V - IaRa)}{\emptyset}$$

- But the resistance of armature winding or series field winding in dc series motor are small.
- Therefore the voltage drop $IaRa$ or $Ia(Ra + R_s)$ across them will be negligible as compare to the external supply voltage V in above equation.
- Therefore $N \propto \frac{V}{\emptyset}$, since V>>>> $IaRa$
- Thus we can say

1. Speed is inversely proportional to flux $\emptyset$.
2. Speed is directly proportional to armature voltage.
3. Speed is directly proportional to applied voltage V.

So by varying one of these parameters, it is possible to change the speed of a dc motor

Thus speed can be controlled by:

- <u>Flux control method:</u> By Changing the flux by controlling the current through the field winding.

- <u>Armature control method:</u> By Changing the armature resistance which in turn changes the voltage applied across the armature

Flux Control Method

Advantages:

- It provides relatively smooth and easy control
- Speed control above rated speed is possible
- As the field winding resistance is high the field current is small. Power loss in the external resistance is small . Hence this method is economical

Disadvantages:

- Flux can be increased only upto its rated value
- High speed affects the commutation, motor operation becomes unstable

Armature Voltage Control Method

- The speed is directly proportional to the voltage applied across the armature .
- Voltage across armature can be controlled by adding a variable resistance in series with the armature

Potential Divider Control

If the speed control from zero to the rated speed is required , by rheostatic method then the voltage across the armature can be varied by connecting rheostat in a potential divider arrangement

Need of Starter:

We know that, $V = E_b + I_a R_a$............for a dc shunt motor

and $V = E_b + I_a(R_a + R_s)$....for a dc series motor

Hence the expression for I_a are as follows:

$$I_a = \frac{V-E_b}{R_a} \text{...................... for dc shunt motor}$$

$$I_a = \frac{V-E_b}{(R_a+R_s)} \text{..................for dc series motor}$$

At the time of starting the motor, speed N=0 and hence the back emf E_b=0. Hence the armature current at the time of starting is given by,

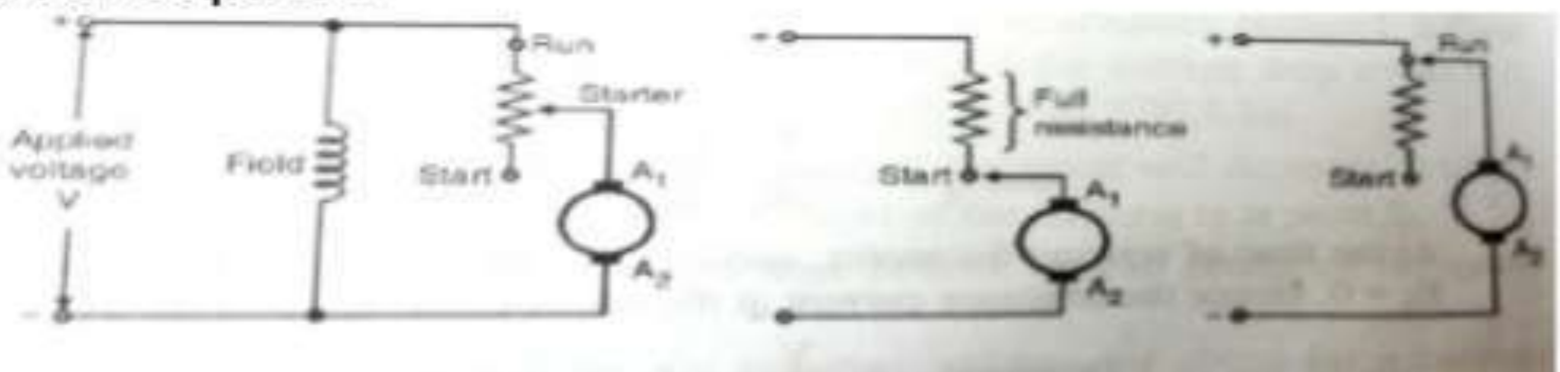
$$I_{a(starting)} = \frac{V}{R_a} \text{............for dc shunt motor}$$

$$I_{a(starting)} = \frac{V}{(R_a+R_s)} \text{......for dc series motor}$$

- Since the the values of R_a and R_s are small, the starting currents will be tremendously large if the rated voltage is applied at the time of starting.
- The starting current of the motor can be 15 to 20 times higher than the full load current.
- Due to high starting current the supply voltage will fluctuate.
- Due to excessive current, the insulation of the armature winding may burn.
- The fuses will blow and circuit breakers will trip.
- For dc series motors the torque $T \propto {I_a}^2$. So an excessive large starting torque is produced. This can put a heavy mechanical stress on the winding and shaft of the motor resulting in the mechanical damage to the motor.
- So to avoid all these effects we have to keep the starting current of motor below safe limit. This is achieved by using starter.

Principle of starter:

- Starter is basically a resistance which is connected in series with the armature winding only at the time of starting the motor to limit the starting current.
- The starter of starter resistance will remain in the circuit only at the time of starting and will go out of the circuit or become ineffective when the motor speed upto a desire speed.



(a) Principle of starter (b) At the time of starting (c) Under normal operating condition

- At the time of starting, the starter is in the start position as shown in fig. so the full starter resistance appears in series with the armature. This will reduce the starting current.
- The starter resistance is then gradually cut off. The motor will speed up, back emf will be developed and it will regulate the armature current. The starter is not necessary then.
- Thus starter is pushed to the Run position as shown in fig under the normal operating condition. The value of starter resistance is zero in this position and it does not affect the normal operation.

Types of starter:

1. Three point starter
2. Four point starter

Applications of DC Motor

1. Shunt motor applications:

i. Various machine tools such as lathe machines, drilling machines, milling machines etc.

ii. Printing machines

iii. Paper machines

iv. Centrifugal and reciprocating pumps

v. Blowers and fans etc.

2. Series motor applications:

i. Electric trains
ii. Diesel-electric locomotives
iii. Cranes
iv. Hoists
v. Trolley cars and trolley buses
vi. Rapid transit systems
vii. Conveyers etc.

3. Cumulative compound motor applications:

i. Elevators
ii. Rolling mills
iii. Planers
iv. Punches
v. Shears

4. Differentials compound motors applications:

- The speed of these motors will increase with increase in the load, which leads to an unstable operation.
- Therefore we can not use this motor for any practical applications

Quick Quiz (Poll 2)

No-load speed of which of the following motor is highest?

a) Differentially compound motor
b) Cumulative compound motor
c) Series Motor
d) Shunt Motor

Quick Quiz (Poll 3)

In which of the following application DC series motor is used?

a) Centrifugal Pump
b) Motor Operation in DC and AC
c) Water pump drive
d) Starter for car

UNIT-III

Fundamentals of Electrical Machines

Lecture 20
Prepared By:
Krishan Arora
Assistant Professor and Head

Previous Lecture topics

- Speed Equation

$$N \propto (V - I_a R_a) / ø$$

- Speed Control Methods

- Starters
- Need of Starters

Revision Quiz (Poll 1)

The reason for using starter while starting of DC motor is

a) To restrict armature current as there is no back E.M.F at starting
b) Motors are not self-starting
c) Restrict starting torque
d) None of the above

Reversal of Direction of Rotation:

- The direction of the magnetic flux in the air gap depends on the direction of the field current.
- And the direction of the force exerted on the armature winding depends on the direction of flux and the direction of armature current.
- Thus in order to reverse the direction of dc motor, we have to reverse the direction of force.
- This can be achieved either by changing the terminals of the armature or the terminals of the field winding.

Specifications of DC Motor

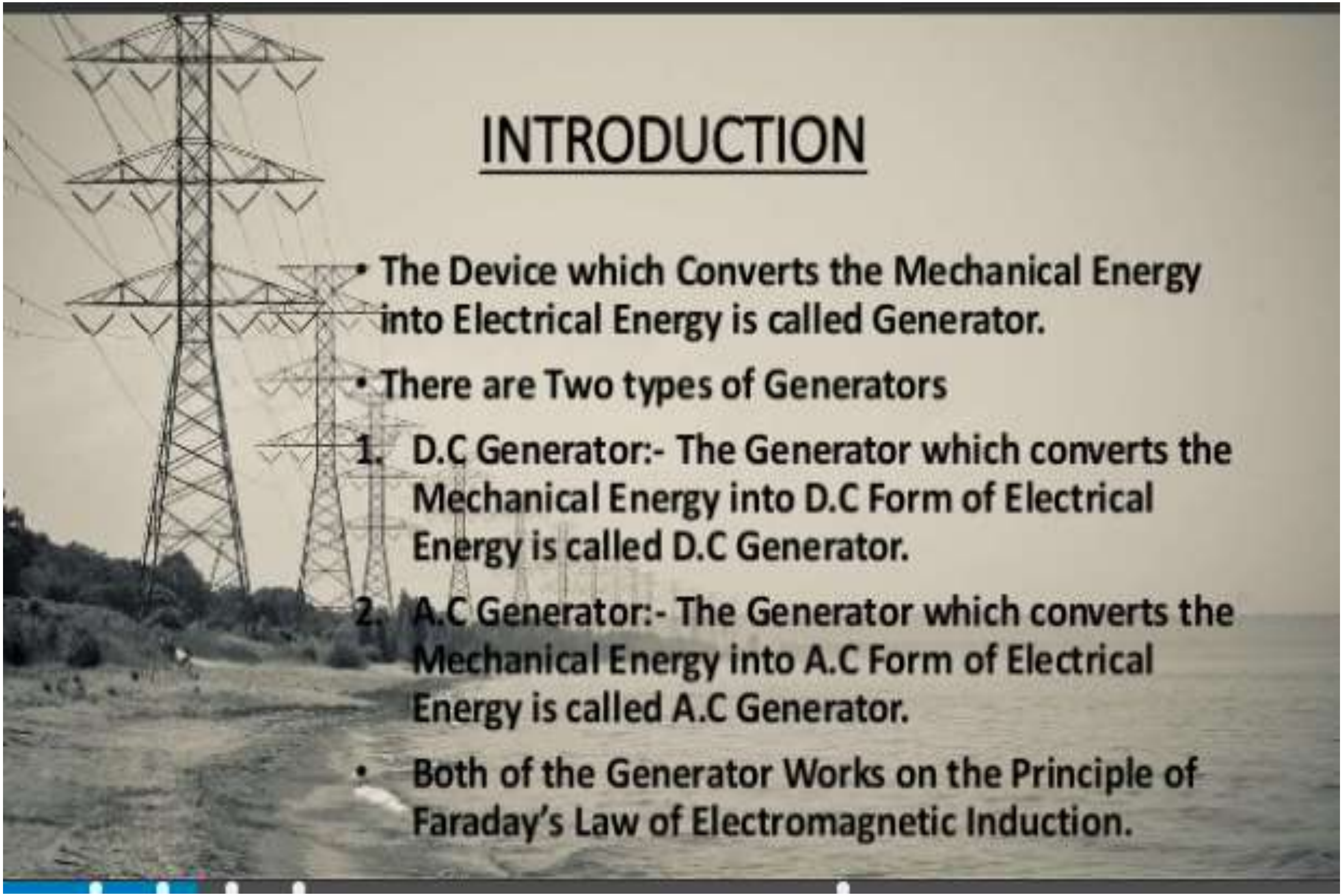
- Some of important specifications of a DC motor:

1. Output power in horse power(H.P.)
2. Rated voltage
3. Type of field winding
4. Excitation voltage
5. Base speed in RPM
6. Current
7. Frame size
8. Rating

Typical specifications of DC series motor

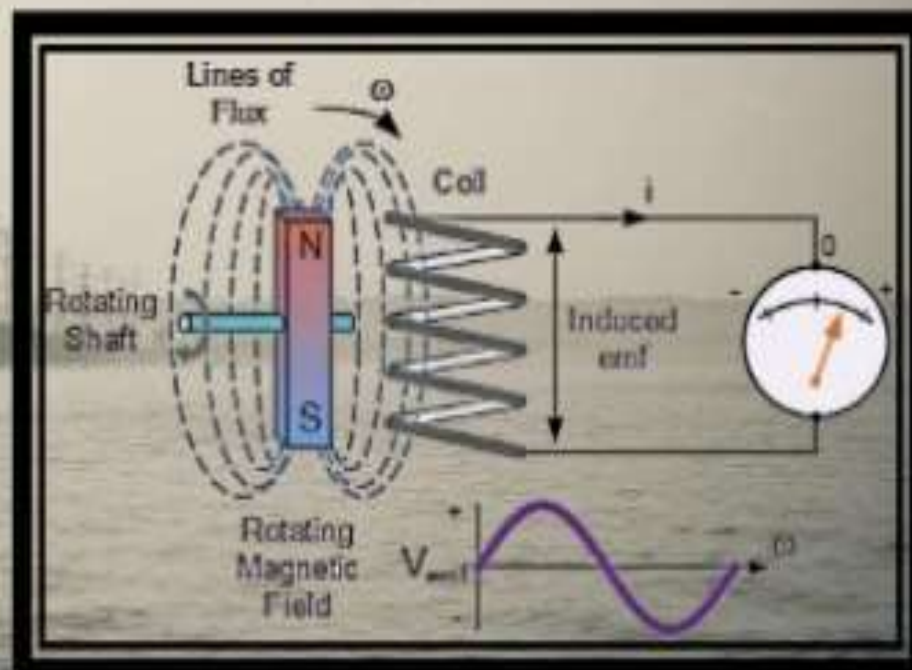
Sr. No.	Specifications/Rating	Value
1.	Output power in horse power	3HP
2.	Rated voltage	230V
3.	Type of field winding	Series
4.	Excitation voltage	230V
5.	Insulation	B
6.	Base speed	1000RPM
7.	Current	11Amp
8.	Frame size	132
9.	Rating	Continous
10.	S.R.Number	840858

DC Generators



PRINCIPLE OF OPERATION

- In 1831, Michael Faraday, an English physicist gave one of the most basic laws of electromagnetism called **Faraday's law of electromagnetic induction**.

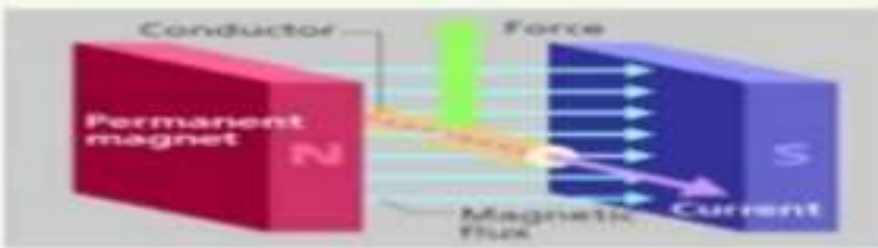


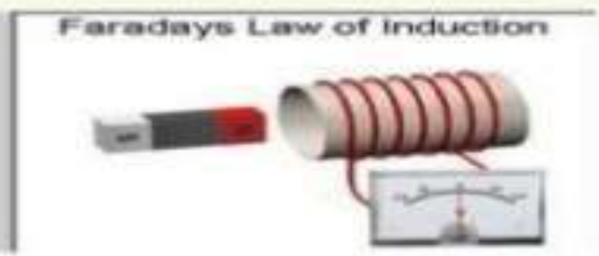
PRINCIPLE OF OPERATION

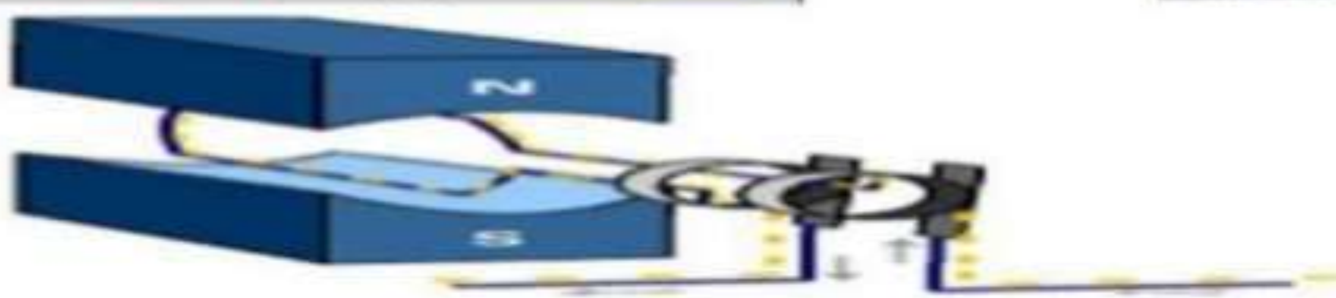
❖ **FARADAYS LAWS**

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

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

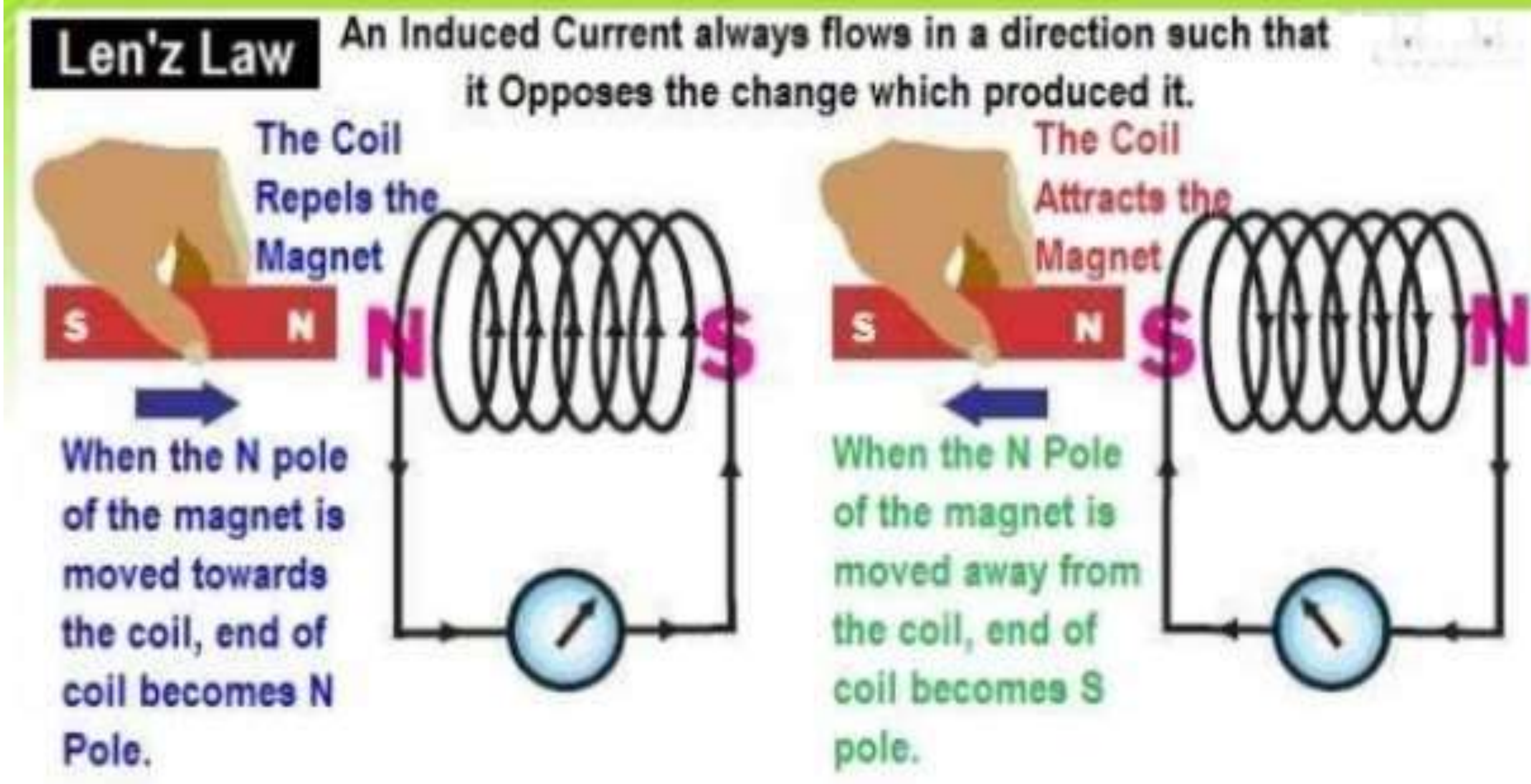




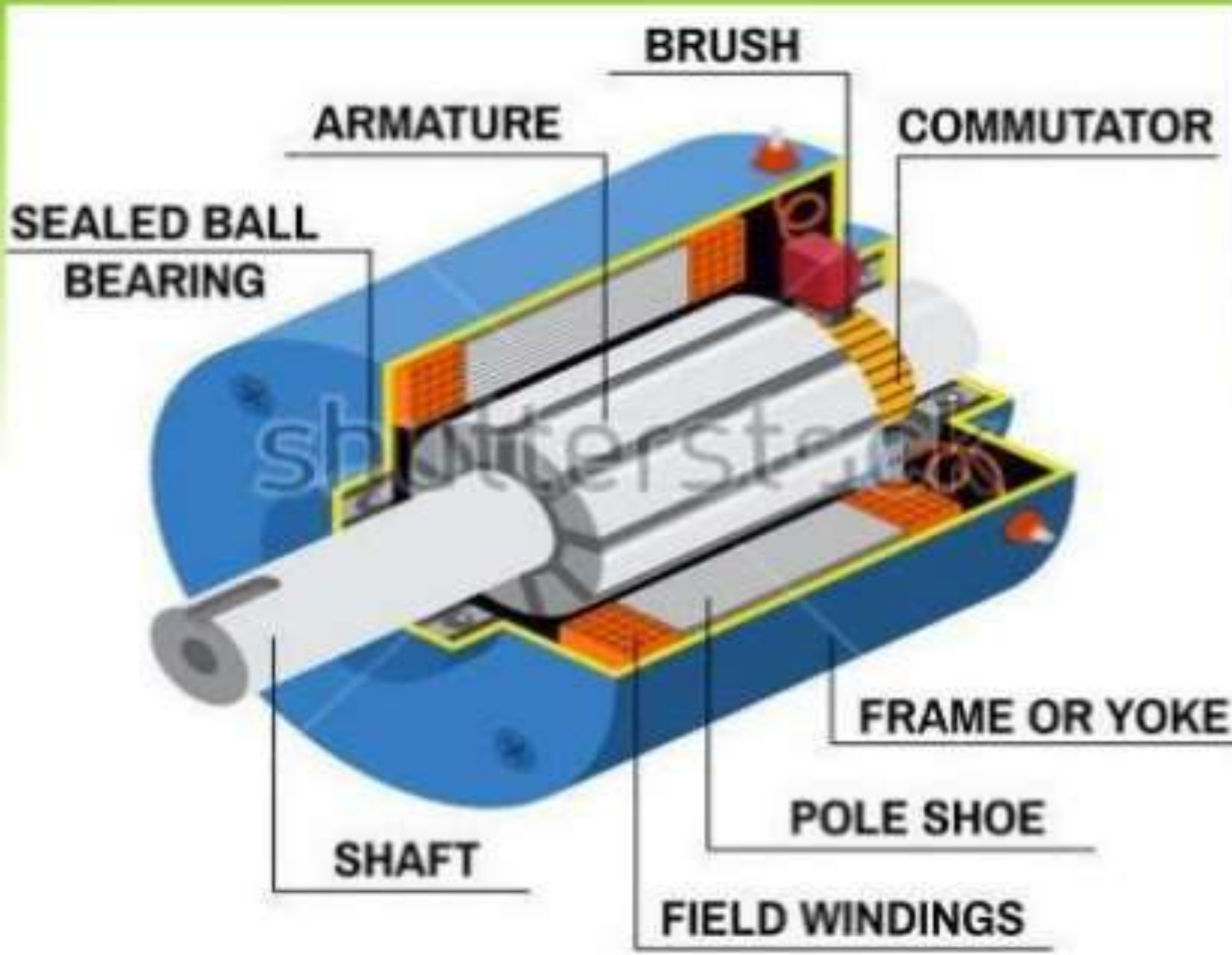


$$e = -\frac{d\Phi}{dt}$$

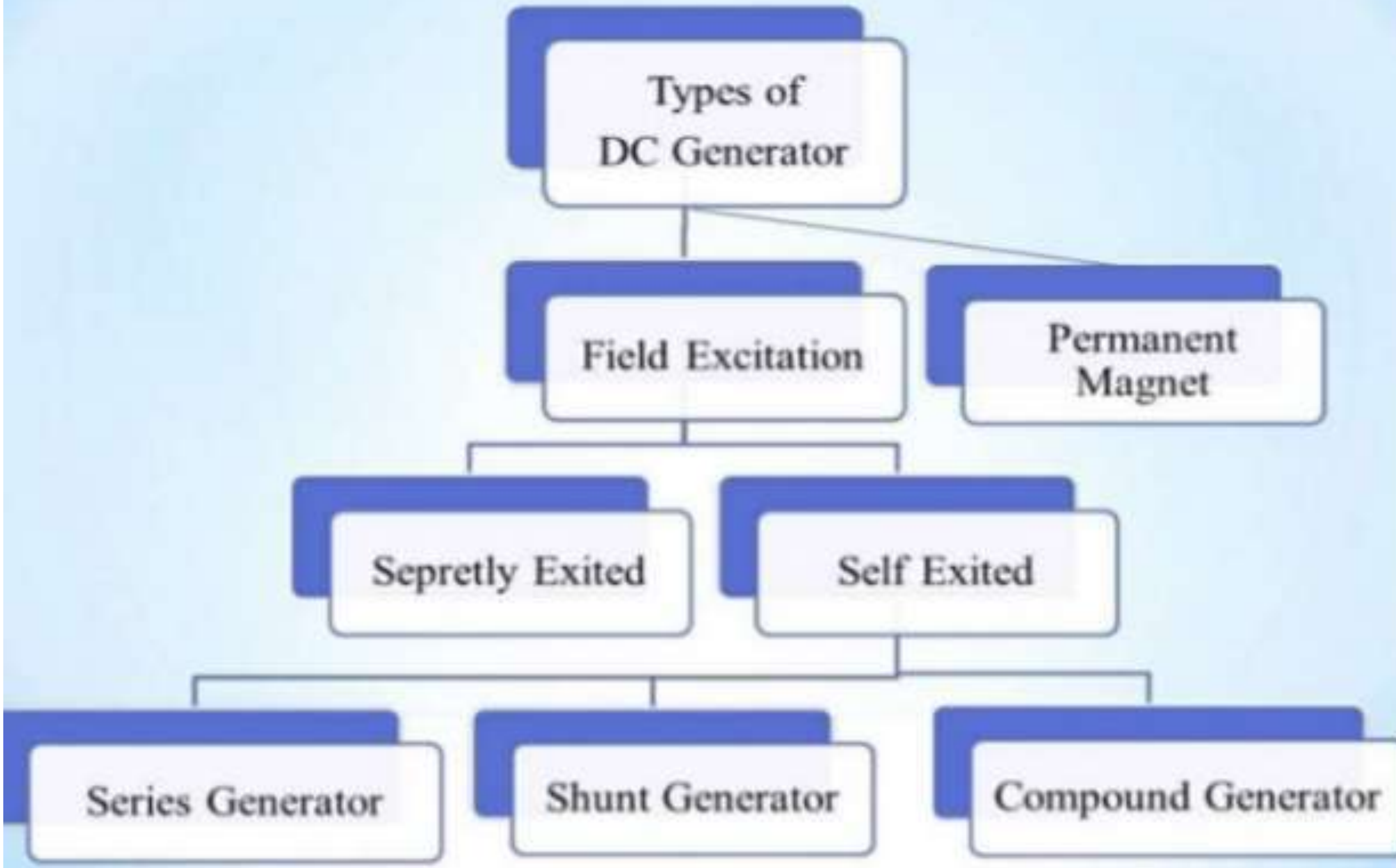
PRINCIPLE OF OPERATION



DC GENERATOR

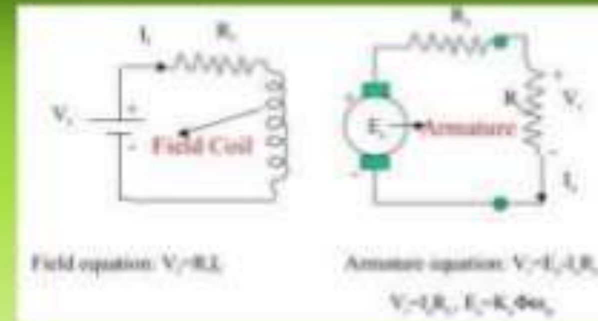


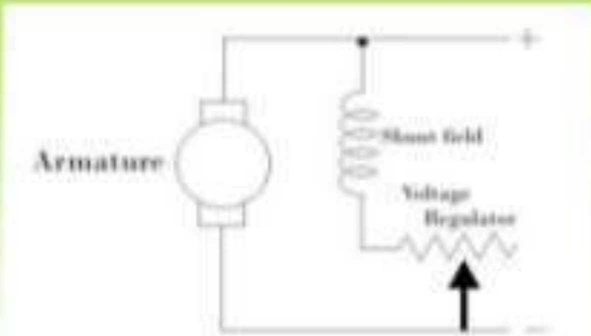
TYPES OF DC GENERATOR.



ACCORDING TO THE WAY OF FIELD EXCITATION

1. **Saparately Excited DC Generator**
   – The field winding is excited from dedicated DC supply i.e : Battery

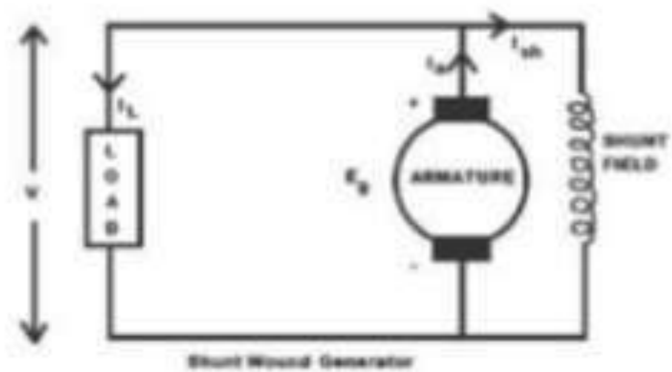




2. **Self Excited DC Generator**
   - The field winding is excited from the armature. No need separate DC supply.

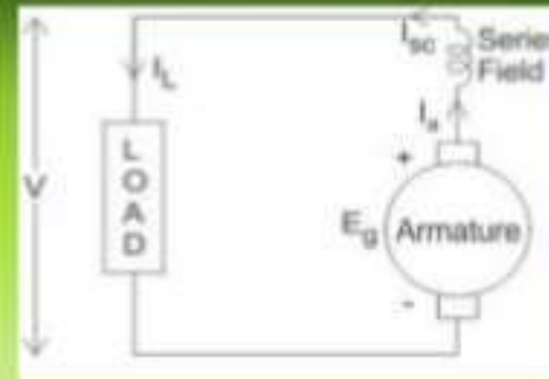
ACCORDING TO THE CONNECTION OF FIELD WINDING WITH RESPECT TO ARMATURE WINDING

1. **Shunt Generator**
   - The field winding is connected in parallel with armature winding
   - Application : Lighning load, Battery charging, Use for giving excitation to the alternator



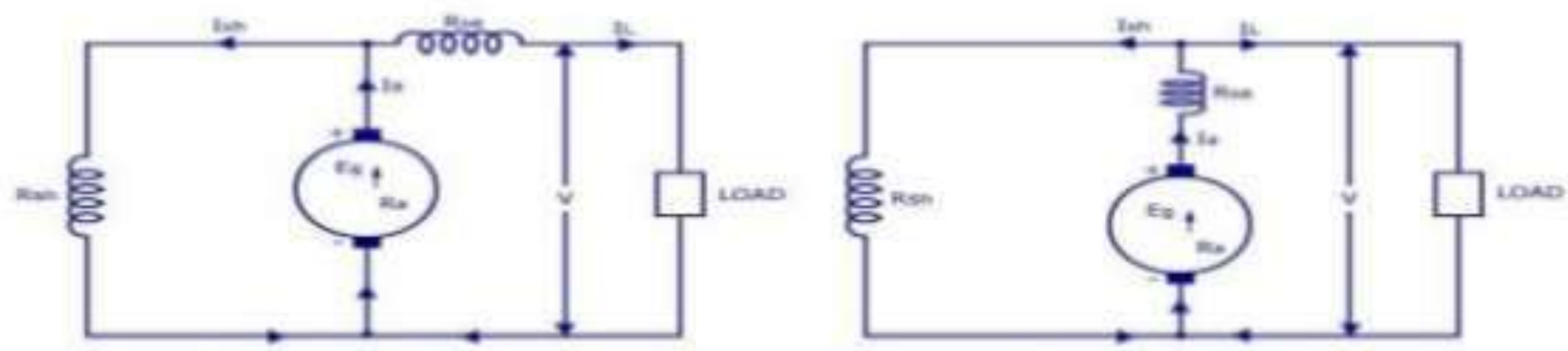
2. **Series Generator**

- Field winding is connected in series with the armature.
- Application : For arc lamp, As constant current generator,
  As booster on DC generator



3. **Compound Generator**

- Both series and shunt winding are used to get combined characteristic of two types of generator.
- Application : Use for driving a motor, for small distance operation (power supply for hotel, office & home)



Short Shunt Compound (a)

Long Shunt Compound (b)

- Short Shunt : Only shunt field winding is in parallel with armature winding.
- Long Shunt : Shunt field winding is in parallel with both series field & armature winding.

Applications of DC Generator

Shunt Generators:

a. in electro plating

b. for battery recharging

c. as exciters for AC generators.

Series Generators :

A. As boosters

B. As lighting arc lamps

Quick Quiz (Poll 2)

- The armature of DC generator is laminated to

a) Reduce Hysteresis loss
b) Insulate the Core
c) Reduce eddy current loss
d) Provide air cooling passage

Quick Quiz (Poll 3)

- The thickness of lamination in D.C machine is approx

a) 5 mm
b) 0.5 mm
c) 0.005 mm
d) 5 mm

UNIT-III

Fundamentals of Electrical Machines

Lecture 21
Prepared By:
Krishan Arora
Assistant Professor and Head

INDUCTION MOTORS

An induction motor or asynchronous motor is an AC electric motor in which the electric current in the rotor needed to produce torque is obtained by electromagnetic induction from the magnetic field of the stator winding

Depending on the rotor construction, induction motor can be classified into two categories:

- Squirrel-cage induction motor.
- Slip-ring induction motor or wound rotor induction motor.

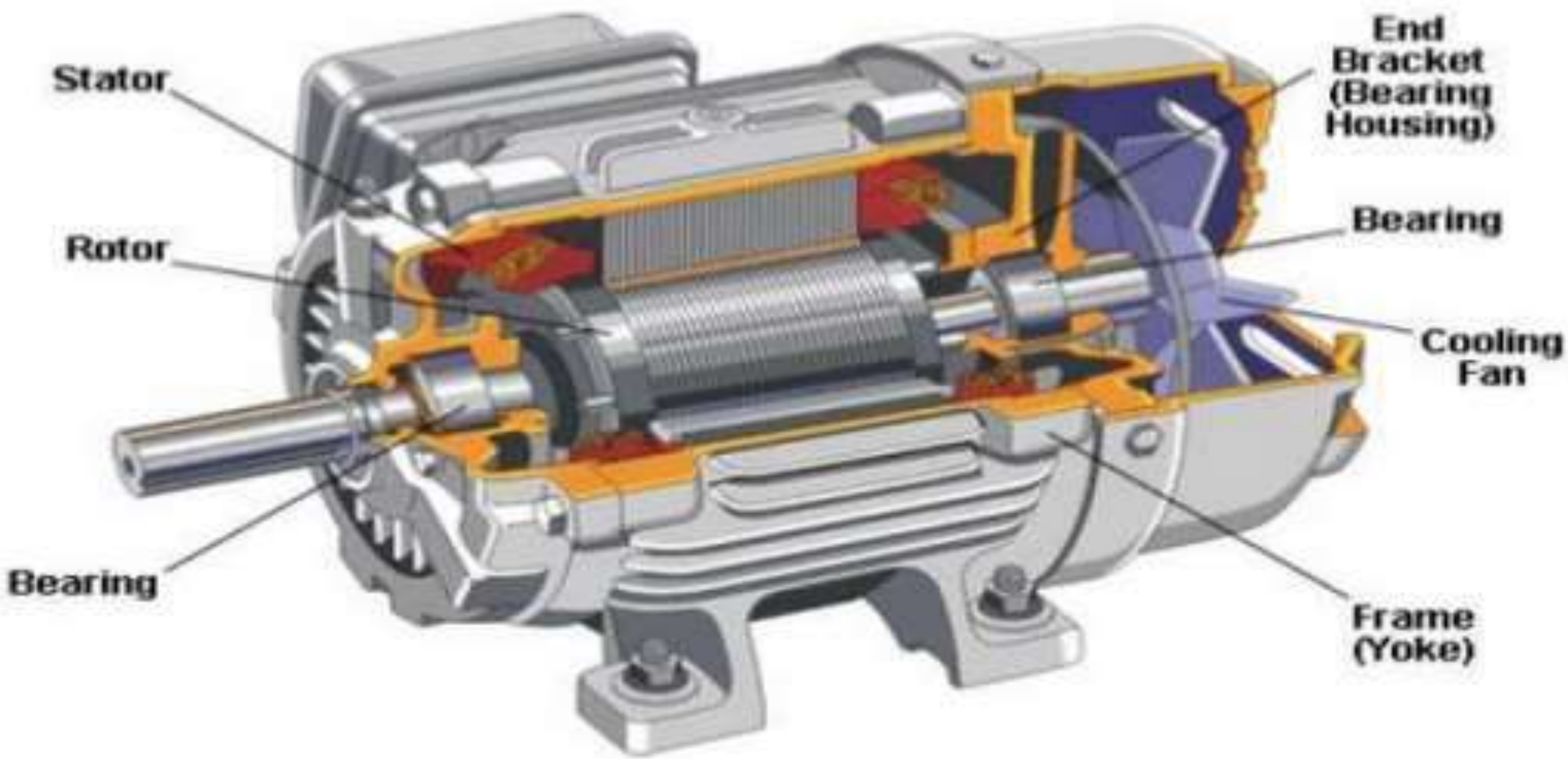
Depending on the number of phases it can be classified as:

- Single-phase induction motor
- Three-phase induction motor

Single Phase Induction Motor

- The single-phase induction machine is the most frequently used motor for refrigerators, washing machines, clocks, drills, compressors, pumps, and so forth.
- The single-phase motor stator has a laminated iron core with two windings arranged perpendicularly.
  - One is the main and
  - The other is the auxiliary winding or *starting winding*

Parts of AC Motor

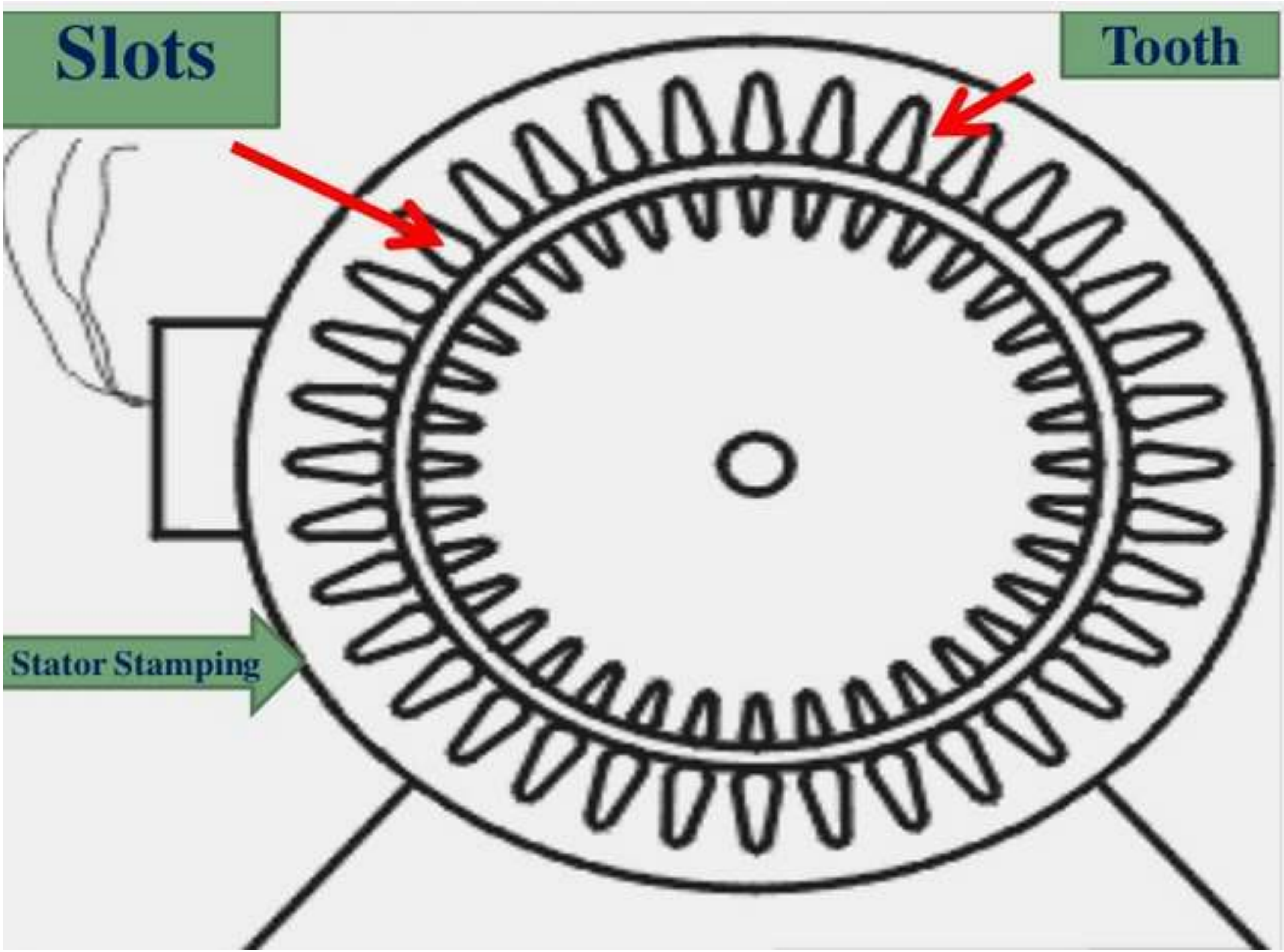


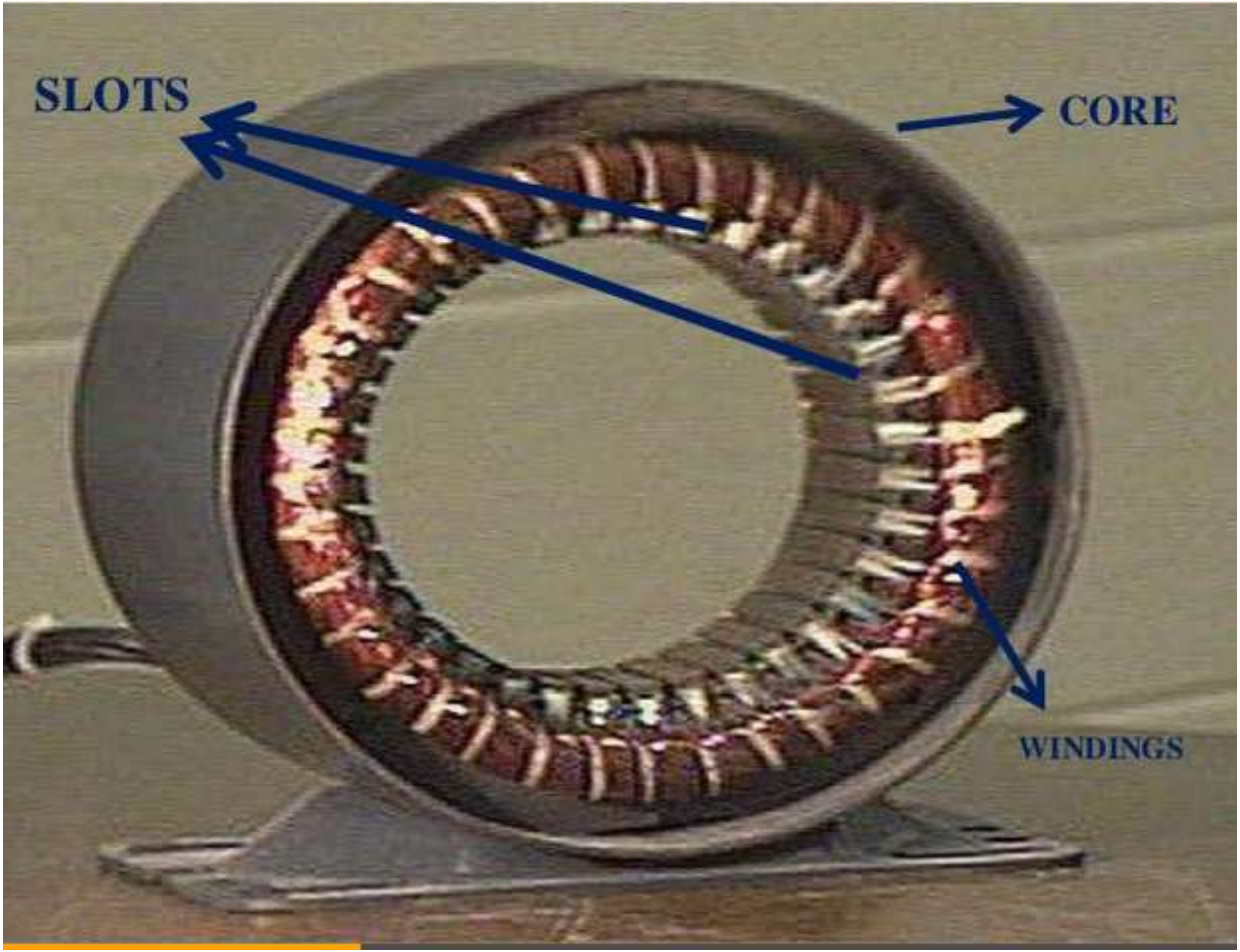
- It consists of two parts:

  1. ***Stator*** - It is the stationary part of the motor.

  2. ***Rotor*** - It is the rotating part of the motor.

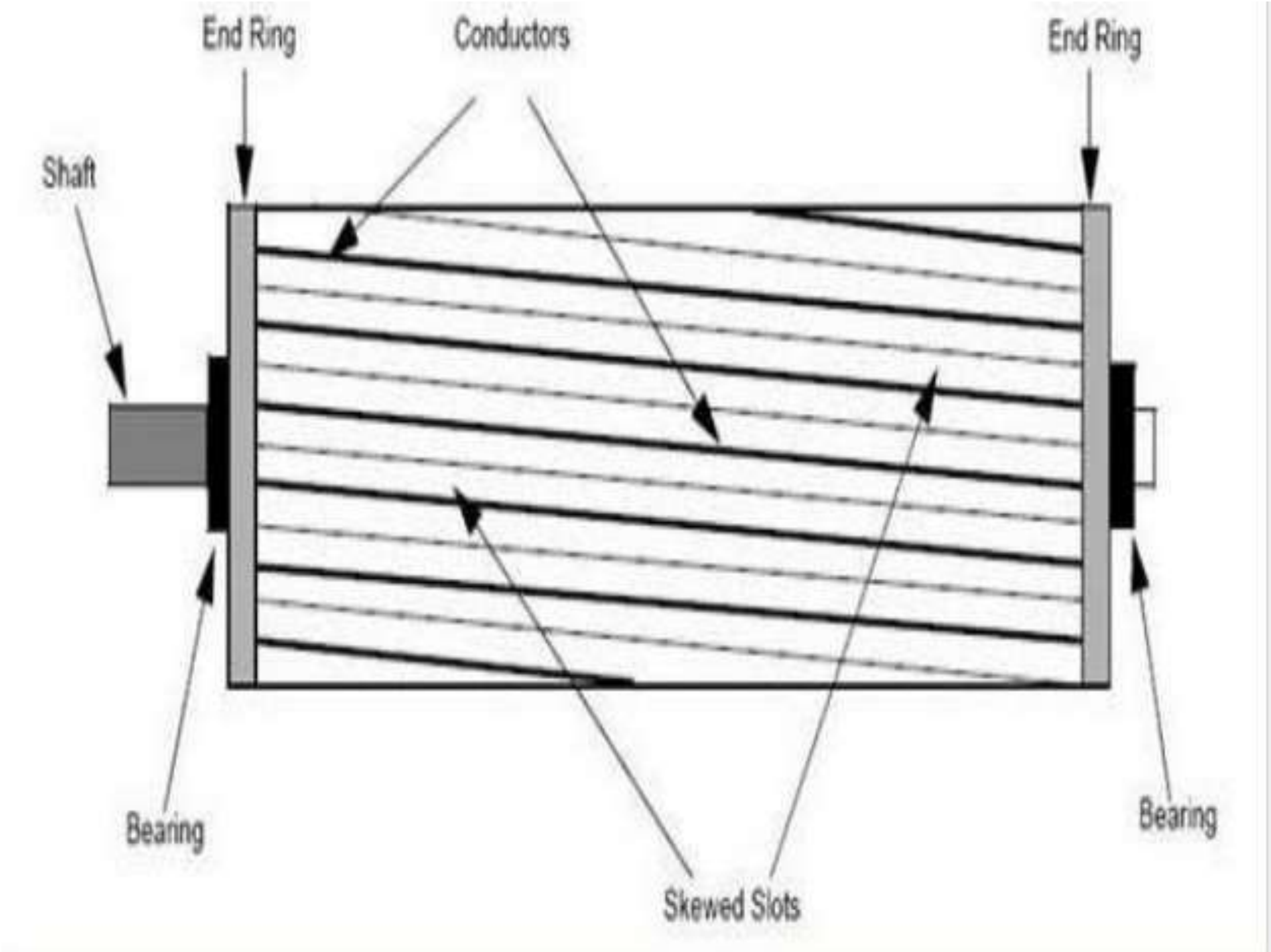
STATOR


Slots
Tooth
Stator Stamping

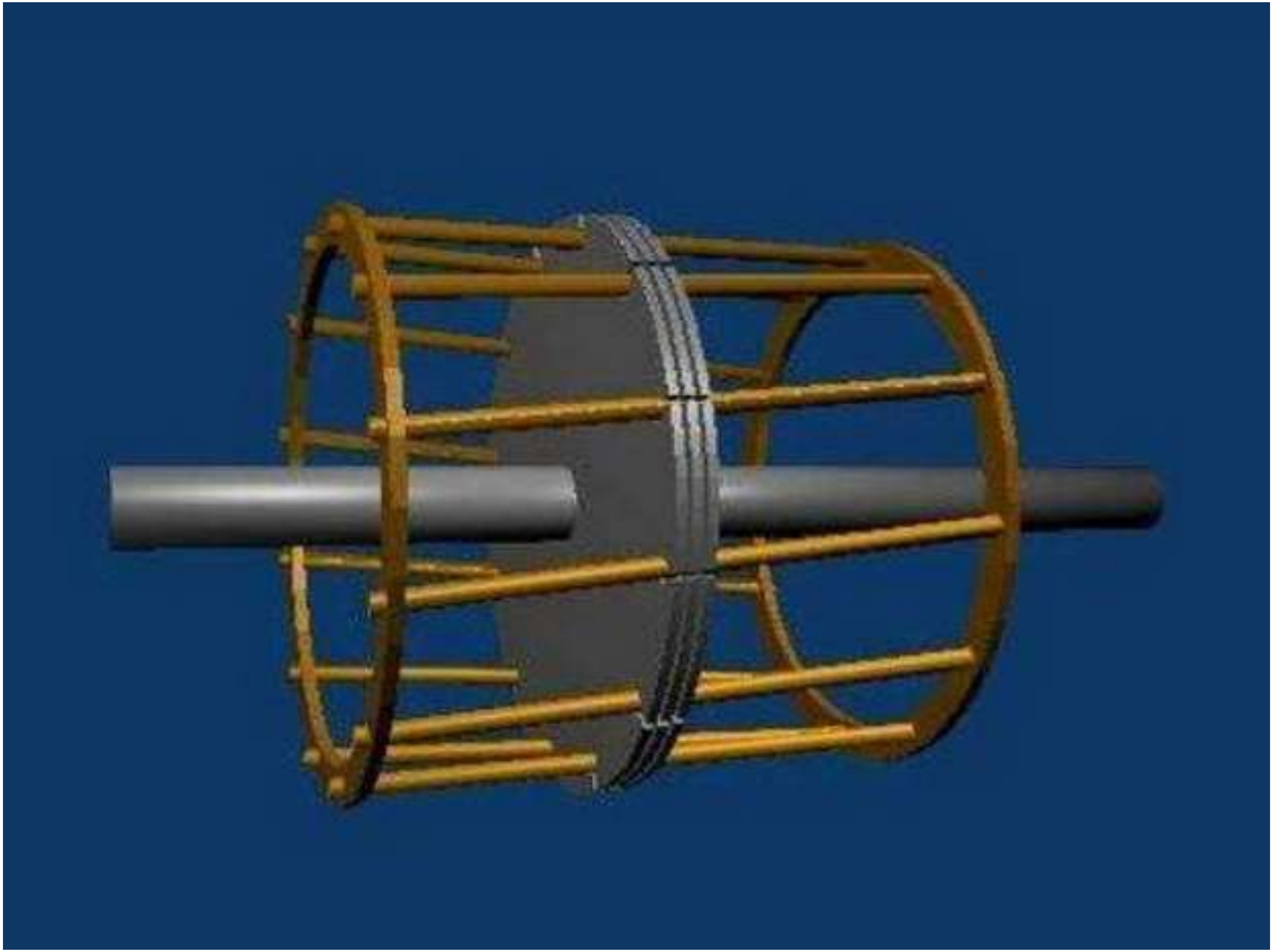

SLOTS
CORE
WINDINGS

ROTOR

SQUIRREL CAGE ROTOR


End Ring
Conductors
End Ring
Shaft
Bearing
Bearing
Skewed Slots

- It consists of a laminated cylindrical core having semi closed circular slots at the outer periphery.
- Copper or aluminum bar conductors are placed in these slots and short circuited at each end by copper or aluminum rings called short circuiting rings.
- The rotor winding is permanently short circuited and it is not possible to add any external resistance.



PHASE WOUND ROTOR

- It is also called ***SLIP RING ROTOR***

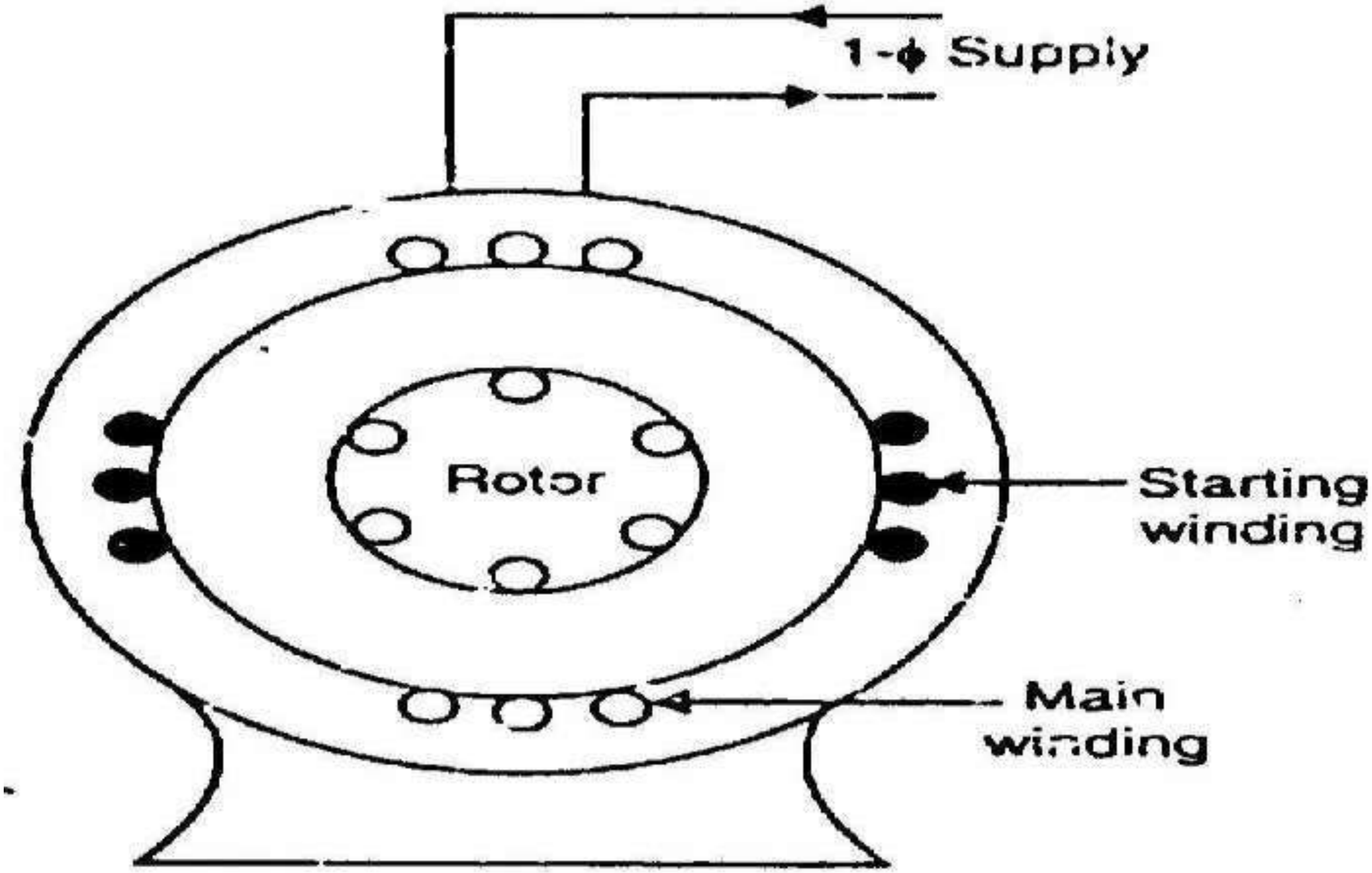
- Consists of a laminated core having semi closed slots at the outer periphery and carries a 3-phase insulated winding.

- The rotor is wound for the same number of poles as that of stator.

- The three finish terminals are connected together forming a star point and the three star terminals are connected to three slip rings fixed on the shaft.

Making Single-Phase Induction Motor Self-Starting

- The single-phase induction motor is not self starting and it is undesirable to resort to mechanical spinning of the shaft or pulling a belt to start it.
- To make a single-phase induction motor self-starting, we should somehow produce a revolving stator magnetic field. This may be achieved by converting a single-phase supply into two-phase supply through the use of an additional winding.
- When the motor attains sufficient speed, the starting means (i.e., additional winding) may be removed depending upon the type of the motor.


1-ϕ Supply
Rotor
Starting winding
Main winding

Quick Quiz (Poll 1)

- The torque developed by a single-phase motor at starting is

a) less than the rated torque
b) More than the rated torque
c) zero
d) None of the above

Single Phase Induction Motor

- **The single-phase induction motor operation can be described by two methods:**
  - **Double revolving field theory; and**
  - **Cross-field theory.**
- **Double revolving theory is perhaps the easier of the two explanations to understand**
- **Learn the double revolving theory only**

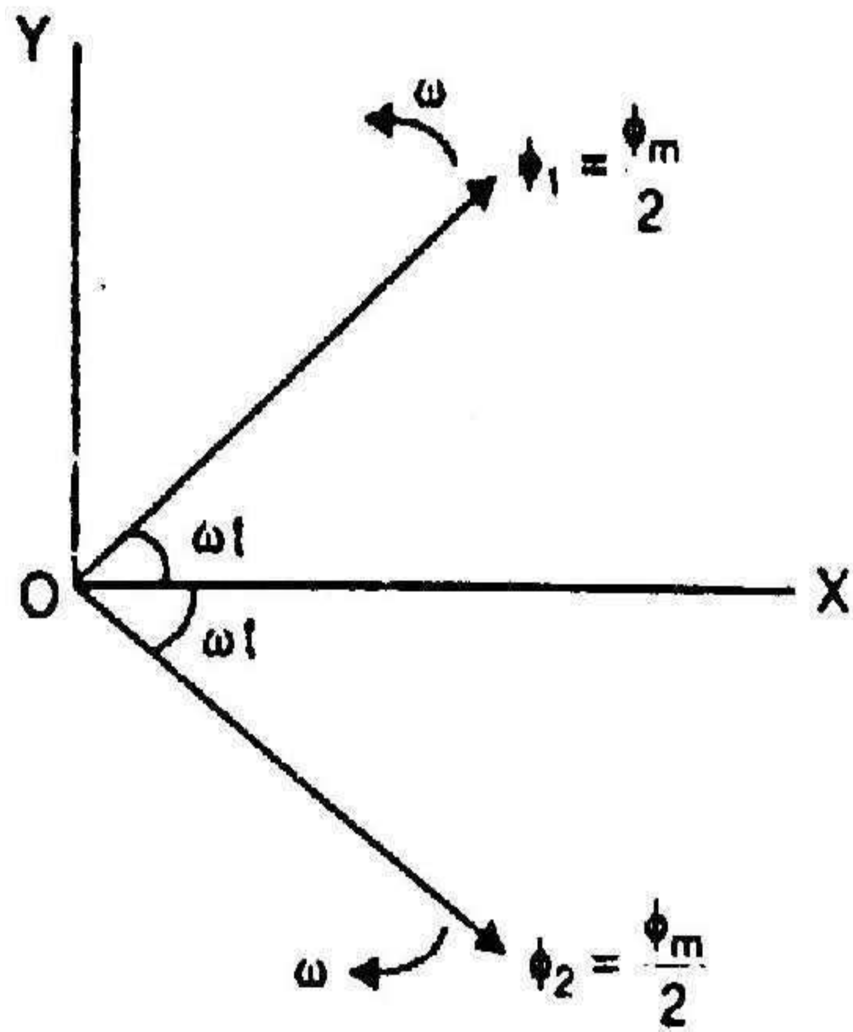
Single Phase Induction Motor

Double revolving field theory

- **A single-phase ac current supplies the main winding that produces a pulsating magnetic field.**
- **Mathematically, the pulsating field could be divided into two fields, which are rotating in opposite directions.**
- **The interaction between the fields and the current induced in the rotor bars generates opposing torque**

Single Phase Induction Motor

- **Under these conditions, with only the main field energized the motor will not start**
- However, if an external torque moves the motor in any direction, the motor will begin to rotate.
- **Single-phase motor main winding generates two rotating fields, which oppose and counter-balance one another.**



Applications

- Fans
- Hair driers
- Washing machines
- Vacuum Cleaners
- Mixers
- Refrigerators
- Food Processors

Quick Quiz (Poll 2)

- If any two phases for an induction motor are interchanged

A. The motor will run in the reverse direction

B. The motor will continue to run in the same direction

C. The motor will stop

D. The motor will Burn

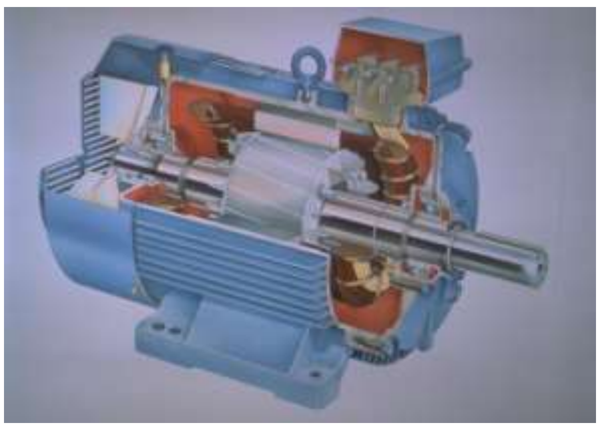
Quick Quiz (Poll 3)

A centrifugal switch is used to disconnect starting winding when motor has

a) Picked up 10% speed
b) Picked up 20% speed
c) Picked up 5 – 10% speed
d) Picked up 50 – 70% speed

UNIT-III

Fundamentals of Electrical Machines



Lecture 22

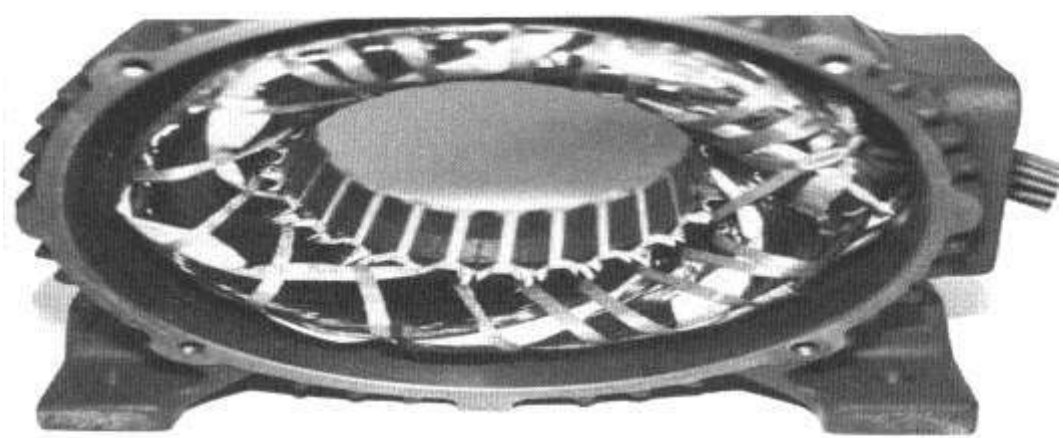
Prepared By:
Krishan Arora
Assistant Professor and Head

Introduction

- Three-phase induction motors are the most common and frequently encountered machines in industry
  - simple design, rugged, low-price, easy maintenance
  - wide range of power ratings: fractional horsepower to 10 MW
  - run essentially as constant speed from no-load to full load
  - Its speed depends on the frequency of the power source
    - not easy to have variable speed control
    - requires a variable-frequency power-electronic drive for optimal speed control

Construction

- An induction motor has two main parts
  - a stationary stator
    - consisting of a steel frame that supports a hollow, cylindrical core
    - core, constructed from stacked laminations (why?), having a number of evenly spaced slots, providing the space for the stator winding

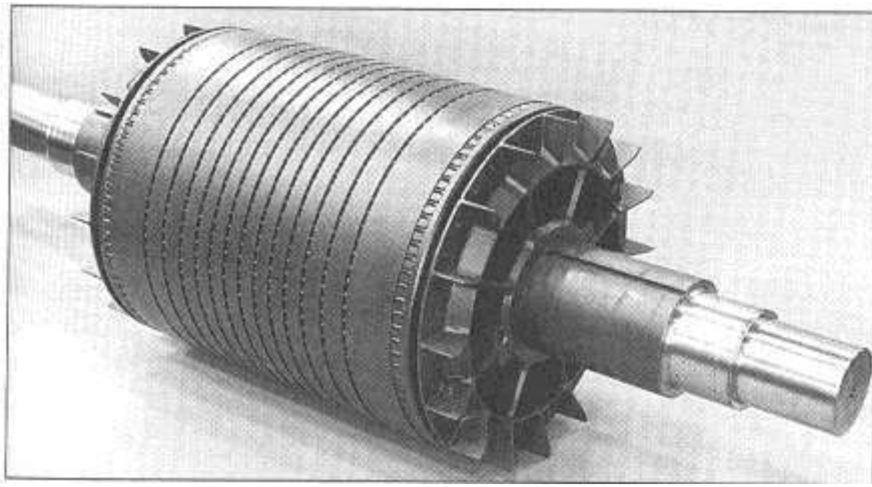


Stator of IM

Construction

  - a revolving rotor
    - composed of punched laminations, stacked to create a series of rotor slots, providing space for the rotor winding
- Two basic design types depending on the rotor design
  - squirrel-cage: conducting bars laid into slots and shorted at both ends by shorting rings.
  - wound-rotor: complete set of three-phase windings exactly as the stator. Usually Y-connected, the ends of the three rotor wires are connected to 3 slip rings on the rotor shaft. In this way, the rotor circuit is accessible.

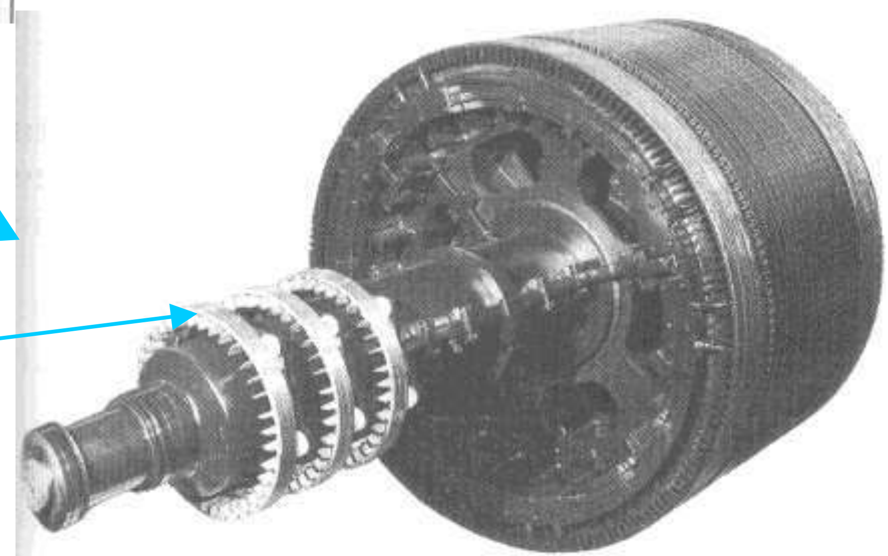
Construction



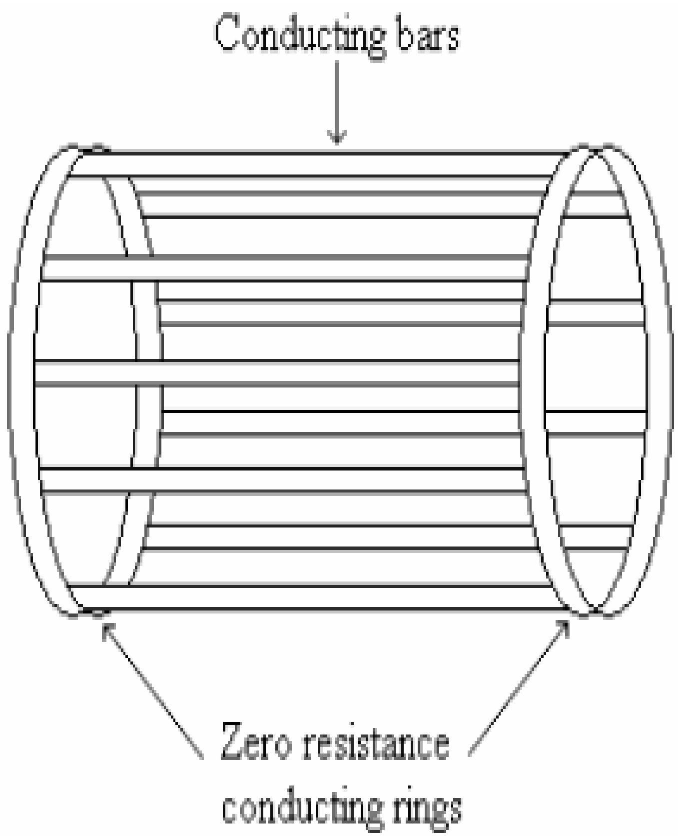
Squirrel cage rotor

Wound rotor

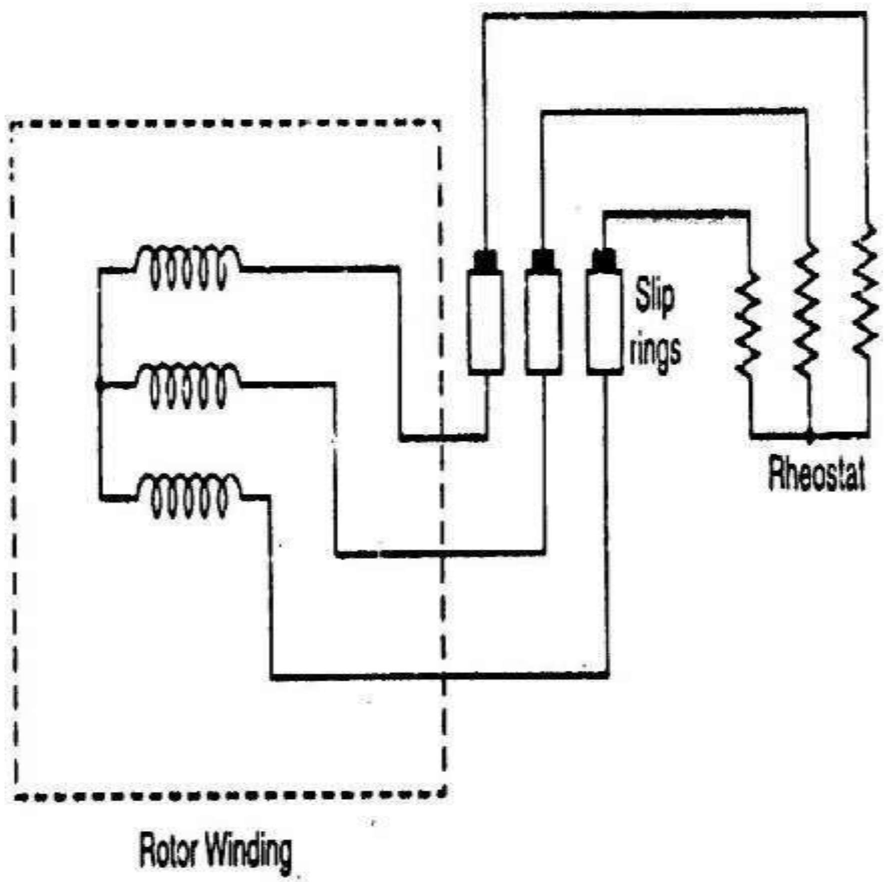
Notice the slip rings



Images

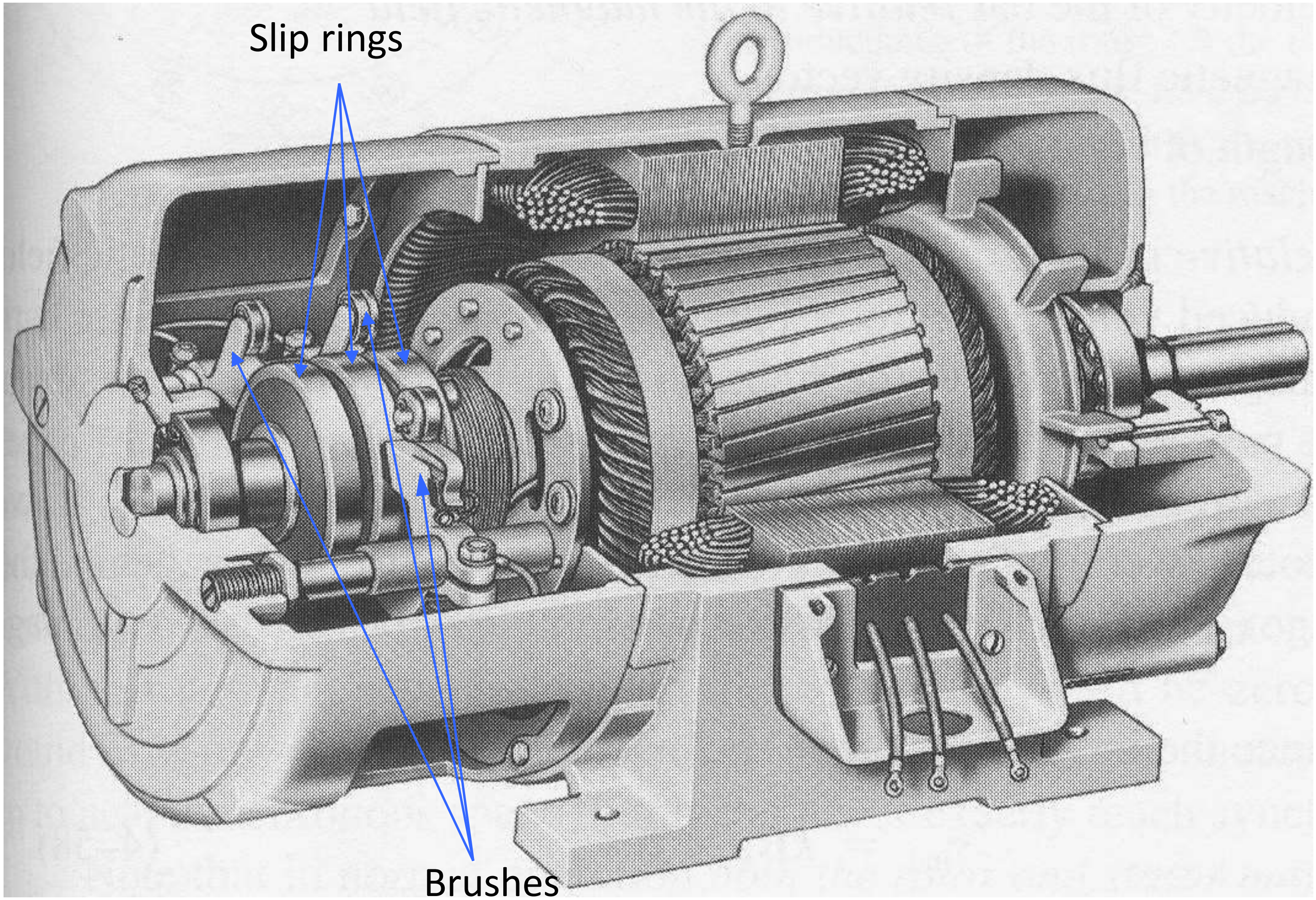


Conducting bars
Zero resistance
conducting rings



Slip
rings
Rheostat
Rotor Winding

Construction



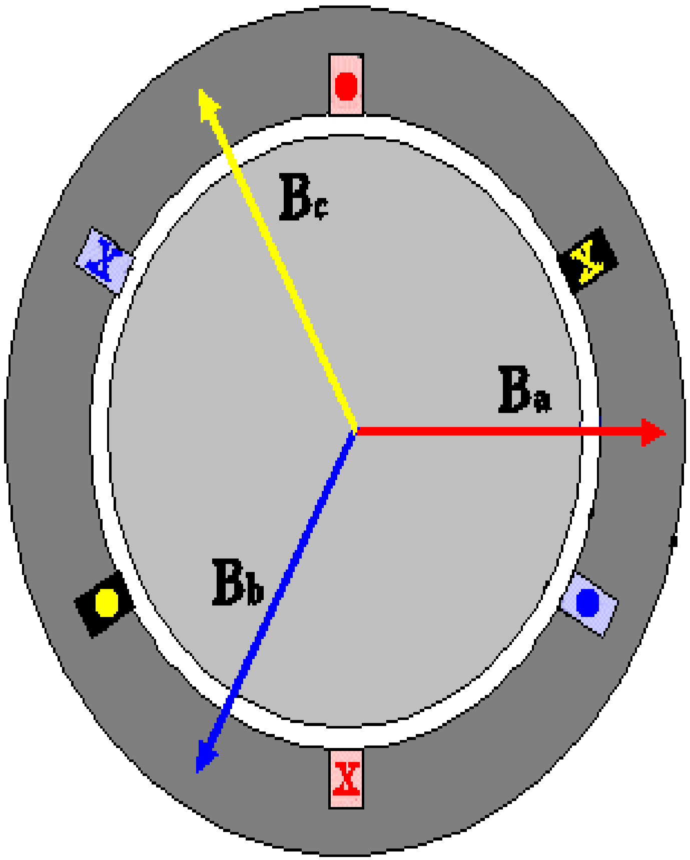
Cutaway in a typical wound-rotor IM. Notice the brushes and the slip rings

Rotating Magnetic Field

- Balanced three phase windings, i.e. mechanically displaced 120 degrees form each other, fed by balanced three phase source
- A rotating magnetic field with constant magnitude is produced, rotating with a speed

$$n_{sync} = \frac{120 f_e}{P} \quad rpm$$

Where f_e is the supply frequency and
P is the no. of poles and n_{sync} is called the synchronous speed in *rpm* (revolutions per minute)



Synchronous speed

P	50 Hz	60 Hz
2	3000	3600
4	1500	1800
6	1000	1200
8	750	900
10	600	720
12	500	600

Quick Quiz (Poll 1)

- Induction motors have the advantage of

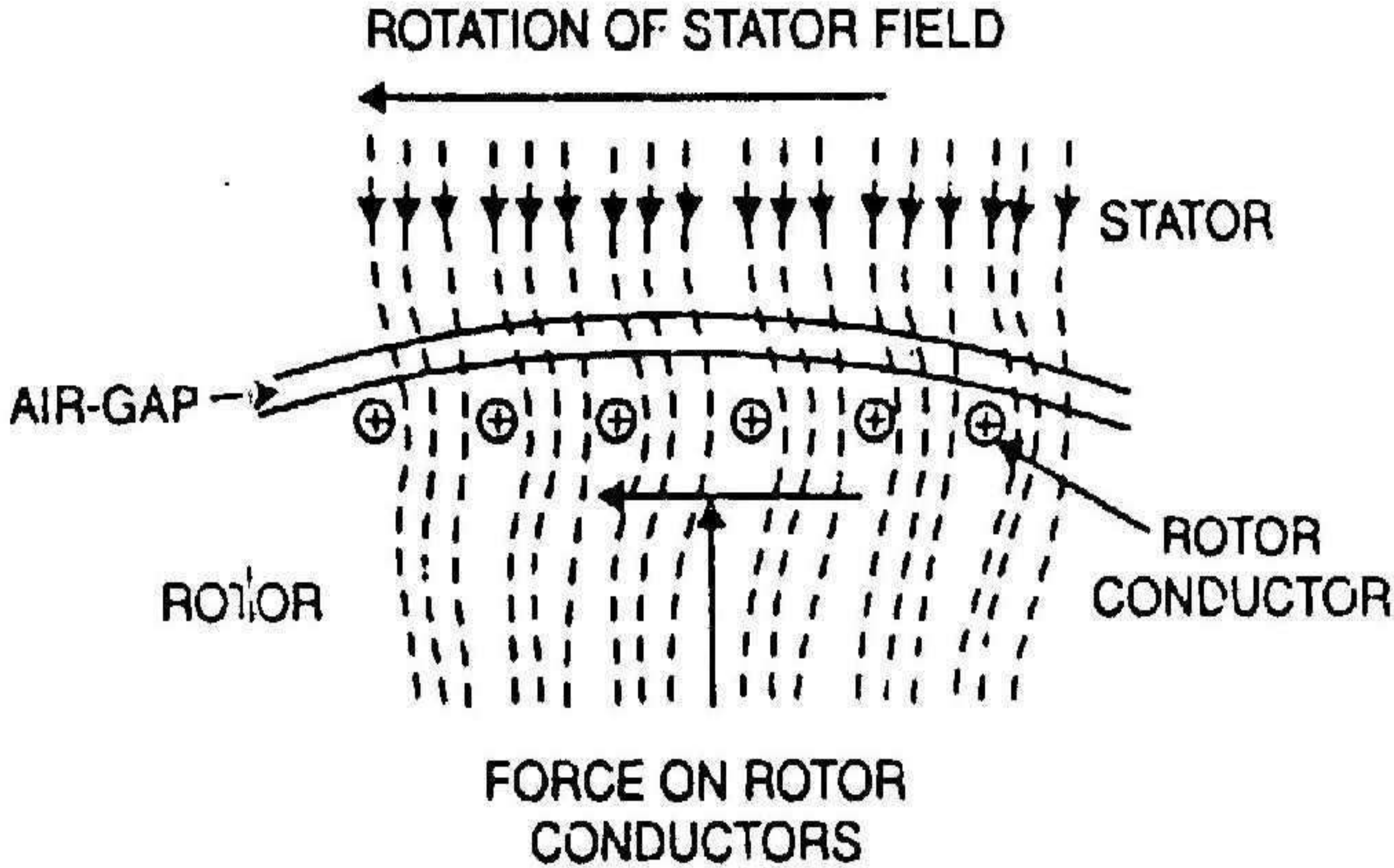
A. Less Maintenance
B. Less cost
C. Simple in construction
D. All of the above

Principle of operation

- This rotating magnetic field cuts the rotor windings and produces an induced voltage in the rotor windings
- Due to the fact that the rotor windings are short circuited, for both squirrel cage and wound-rotor, and induced current flows in the rotor windings
- The rotor current produces another magnetic field
- A torque is produced as a result of the interaction of those two magnetic fields

$$\tau_{ind} = kB_R \times B_s$$

Where τ_{ind} is the induced torque and B_R and B_S are the magnetic flux densities of the rotor and the stator respectively


ROTATION OF STATOR FIELD
STATOR
AIR-GAP
ROTOR
ROTOR CONDUCTOR
FORCE ON ROTOR CONDUCTORS

Induction motor speed

- So, the IM will always run at a speed lower than the synchronous speed
- The difference between the motor speed and the synchronous speed is called the *Slip*

$$\boxed{n_{slip} = n_{sync} - n_m}$$

Where n_{slip}= slip speed

n_{sync}= speed of the magnetic field

n_m = mechanical shaft speed of the motor

The Slip

$$s = \frac{n_s - n_r}{n_s} \quad OR \quad n_r = n_s(1 - s)$$

Where; n_s = synchronous speed (rpm)
n_r = mechanical speed of rotor (rpm)
s = slip

Slip may be expressed as a percentage by multiplying the above eq. by 100, notice that the slip is a ratio and doesn't have units

Rotor Frequency

- The frequency of the voltage induced in the rotor is given by

$$f_r = \frac{P \times n}{120}$$

Where f_r = the rotor frequency (Hz)

P = number of stator poles

n = slip speed (rpm)

$$f_r = \frac{P \times (n_s - n_m)}{120}$$

$$= \frac{P \times sn_s}{120} = sf_e$$

Induction Motors and Transformers

- Both IM and transformer works on the principle of induced voltage
  - Transformer: voltage applied to the primary windings produce an induced voltage in the secondary windings
  - Induction motor: voltage applied to the stator windings produce an induced voltage in the rotor windings
  - The difference is that, in the case of the induction motor, the secondary windings can move
  - Due to the rotation of the rotor (the secondary winding of the IM), the induced voltage in it does not have the same frequency of the stator (the primary) voltage

- **Advantages of Three-Phase Induction Motor**: These **motors** are self-starting and use no capacitor, start winding, centrifugal switch or other starting device.

APPLICATIONS

- **Three-phase** AC **induction motors** are widely used in industrial and Commercial **applications**.

APPLICATION OF three phase INDUCTION MOTOR

- **Squirrel cage induction motor**
- Squirrel cage induction motors are simple and rugged in construction, are relatively cheap and require little maintenance. Hence, squirrel cage induction motors are preferred in most of the industrial applications such as in
- Lathes
- Drilling machines
- Agricultural and industrial pumps
- Industrial drives.

Quick Quiz (Poll 2)

- A 50 Hz, 3-phase induction motor has a full load speed of 1440 r.p.m. The number of poles in the motor is

a) 2 pole

b) 4 pole

c) 6 pole

d) 8 pole

Explanation

- **P = 120f/N**
- = 120 x 50/ 1400
- **= 4.28**
- **The number of poles should be even and the whole number. Therefore the number of poles must be 4.**

Quick Quiz (Poll 3)

- A three phase, 50 Hz, 4 pole induction motor has a full load speed of 1440 rpm. The full load slip will be

a) 3%

b) 5%

c) 4%

d) 2%

Explanation

- $\mathbf{N_s = 120f/P}$
  $= 120 \times 50/4$
  $= 1500$

  and slip is equal to
  $\mathbf{s = N_s - N_r/N_s}$
  $= 1500 - 1440/1500$
  $=$ **4%**

Tutorial 7

Example 1

- A transformer has a primary coil and a secondary coil with the number of loops are 500 and 5000. Input voltage is 220 V. What is the output voltage?

Solution

- Primary coil (N_P) = 500 loops
- Secondary coil (N_s) = 5000 loops
- Primary voltage (V_P) = 220 Volt
- Secondary voltage (V_S) = ?

- <u>Solution :</u>
- $V_s / N_s = V_p / N_p$
- $V_s / 5000 = 220 / 500$
- $V_s / 5000 = 0.44$
- $V_s = (0.44)(5000)$
- $V_s = 2200$ Volt

Example 2

- A transformer has primary coil with 1200 loops and secondary coil with 1000 loops. If the current in the primary coil is 4 Ampere, then what is the the current in the secondary coil.

Solution

- <u>Solution :</u>
- $I_S/I_P = N_P/N_S$
- The current in the secondary coil :
- $I_S/4 = 1200/1000$
- $I_S/4 = 1.2$
- $I_S = 1.2\ (4)$
- $I_S = 4.8$ Ampere

Example 3

- The secondary voltage is 220 Volt and primary voltage is 110 volt, then a comparison of the secondary coil and primary coil is…

Solution

<u>Given :</u>

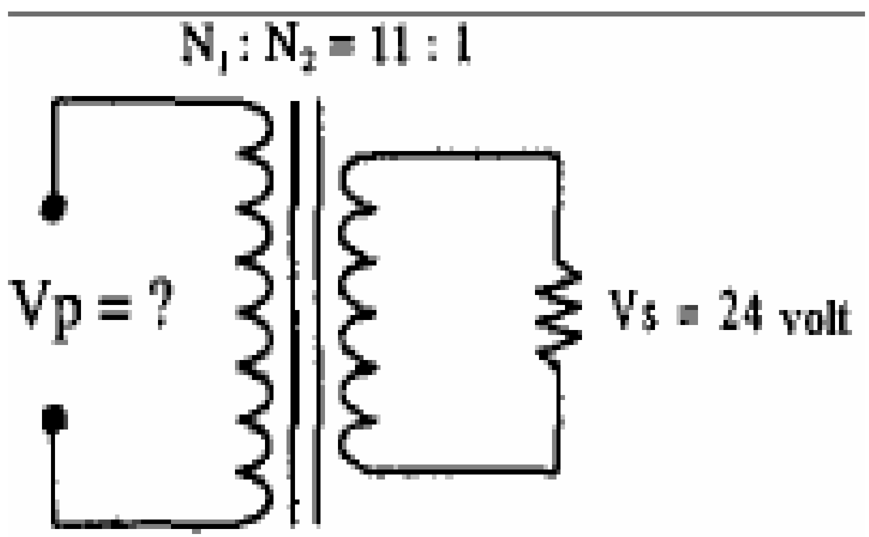
- Secondary voltage (V_S) = 220 Volt
- Primary voltage (V_P) = 110 Volt

Required N_S/N_P

- <u>Solution :</u>
- $V_S/V_P = N_S/N_P$
- $220/110 = N_S/N_P$
- $22/11 = N_S/N_P$
- $2/1 = N_S/N_P$
- $12/6 = N_S/N_P$

Example 4

- Based on figure below, what is the primary voltage of the transformer.



Solution

<u>Given :</u>

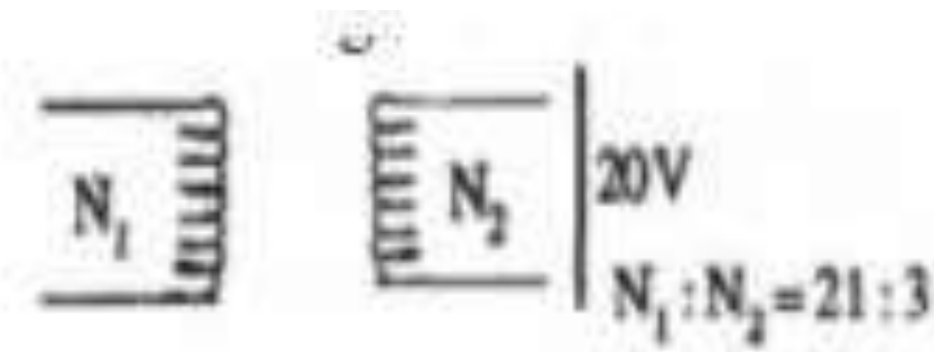
- Secondary voltage (V_S) = 24 Volt
- Primary loops (N_P or N_1) = 11 N
- Secondary loops ($N_{S\ or}$ N_2) = 1 N = N

  Primary voltage (V_P) = ?

- <u>Solution :</u>
- $V_s / N_s = V_p / N_p$
- $24 / 1 = V_p / 11$
- $24 = V_p / 11$
- $V_p = (24)(11)$
- V_p = 264 Volt

Example 5

- Based on figure below, what is the input voltage of the transformer



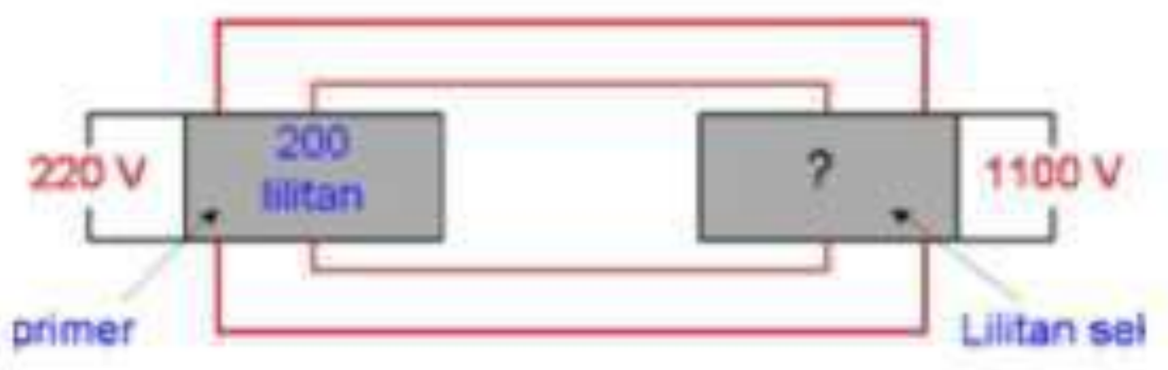
Solution

<u>Given :</u>

- Primary coil (N_1) = 21 N
- Secondary coil (N_2) = 3 N
- Secondary voltage (V_2) = 20 Volt
- Primary voltage (V_1) = ?
- <u>Solution :</u>
- $V_2 / N_2 = V_1 / N_1$
- $20 / 3 \text{ N} = V_1 / 21 \text{ N}$
- $20 / 1 = V_1 / 7$
- $20 = V_1 / 7$
- $V_1 = (7)(20)$
- $V_1 = 140$ Volt

Example 6

- According to figure below, what is the amount of the secondary loops of the transformer.

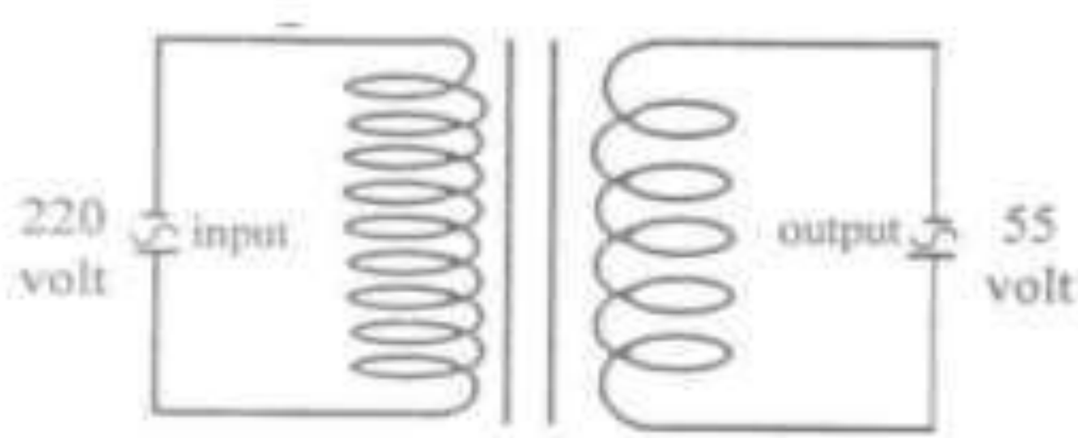


Solution

- $V_s / N_s = V_p / N_p$
- 1100 Volt / N_s = 220 Volt / 200 loops
- 1100 / N_s = 220 / 200
- 1100 / N_s = 1.1
- N_s = 1100 / 1.1
- N_s = 1000 loops

Example 7

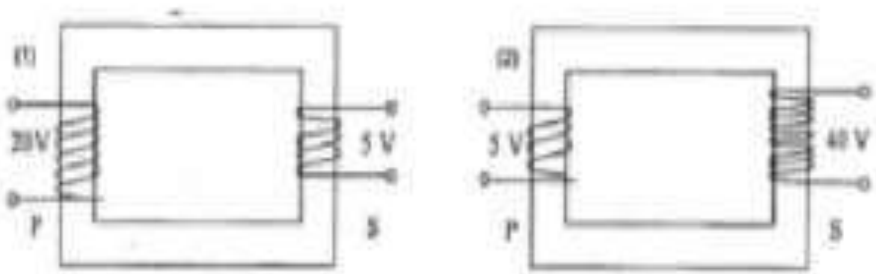
- If the primary coil has 800 loops, then determine the secondary coil.



Solution

- $V_s / N_s = V_p / N_p$
- $55 / N_s = 220 / 800$
- $55 / N_s = 22 / 80$
- $N_S = (80)(55) / 22$
- $N_S = 4400 / 22$
- $N_S = 200$ loops

Quick Quiz 1



Based on the above figure, which of the following statements about the figure above is correct.

A. Figure 1 is a step-up transformer and figure 2 is a step-down transformer

B. Figure 1 is a step-down transformer and figure 2 is a step-up transformer

C. Figure 1 and 2 are a step-down transformer

D. Figure 1 and 2 are a step-up transformer

Quick Quiz 2

Quantities	Transformers	
	P	Q
Primary voltage	110 V	220 V
Secondary voltage	200 V	110 V
Primary current	4 A	1 A
Secondary current	2 A	2 A
Power	400 W	220 W

The correct statement about transformer P and Q is…

A. P is a step-down transformer because of $I_s < I_p$

B. P is a step-up transformer because of $V_p < V_s$

C. Q is a step-up transformer because of $V_p > V_s$

D. Q is a step-up transformer because $I_s > I_p$

Quick Quiz 3

- Turns ratio of the transformer is directly proportional to _______________

  a) Resistance ratio
  b) Currents ratio
  c) Voltage ratio
  d) Not proportional to any terms

Quick Quiz 4

- Which of the following statement is correct regarding turns ratio?

  a) Current ratio and turns ratio are inverse of each other
  b) Current ratio is exactly same to the voltage ratio
  c) Currents ratio is exactly same to the turns ratio
  d) Voltage ratio and turns ratio are inverse of each other

Tutorial 8

DC Machines and AC Machines

Example 1

A 208-V, 10hp, four pole, 60 Hz, Y-connected induction motor has a full-load slip of 5 percent. What is the synchronous speed of this motor?

Explanation

$$n_{sync} = \frac{120 f_e}{P} = \frac{120(60)}{4} = 1800\ rpm$$

Example 2

- A 3-phase induction motor is wound for 4 poles and is supplied from 50 Hz system. Calculate
- (i) Synchronous speed
- (ii) Rotor speed when slip is 4%
- (iii) rotor frequency when motor runs at 600 rpm.

Explanation

Solution. (*i*) $N_s = 120\,f/P = 120 \times 50/4 = 1500$ rpm

(*ii*) rotor speed, $N = N_s(1 - s) = 1500\,(1 - 0.04) = \mathbf{1440\ rpm}$

(*iii*) when rotor speed is 600 rpm, slip is

$$s = (Ns - N)/N_s = (1500 - 600)/1500 = 0.6$$

rotor current frequency, $f' = sf = 0.6 \times 50 = \mathbf{30\ Hz}$

Example 3

- A slip ring induction motor runs at 290 rpm at full load, when connected to 50 Hz supply. Determine the number of poles and slip?

Explanation

- N = 290 rpm
- Ns has somewhere near it ,say 300 rpm
- If Ns is assumed as 300 rpm then

  300 = 120 X 50/P

Hence P = 20

S = (300-290)/300

= 3.33%

Example 4

- A three phase, 50 Hz, 4 pole slip ring induction motor has a star connected rotor. The full load speed of the motor is 1460 rpm. Determine the synchronous speed and percentage slip.

Explanation

- (i) Ns = 120f/p = 120 x 50 /4 = 1500 rpm;

- (ii) slip = (Ns – N) / Ns = (1500 – 1460)/ 1500 = 0.0266
- Percentage slip = 2.66 %

Example 5

- A 4 pole, 3 phase induction motor operates from a supply whose frequency is 50 Hz, Calculate
- (i) the speed at which magnetic field of stator is running
- (ii) the speed of the rotor when slip is 0.04

Explanation

Solution. (*i*) Stator field revolves at synchronous speed, given by

$$N_s = 120f/P = 120 \times 50/4 = \mathbf{1500\ r.p.m.}$$

(*ii*) rotor (or motor) speed, $N = N_s(1 - s) = 1500(1 - 0.04) = \mathbf{1440\ r.p.m.}$

Example 6

- The stator of 3 phase induction motor has 3 slots per pole per phase. If supply frequency is 50 Hz, then Calculate
- (i) number of stator pole produced and total number of slots on the stator
- (ii) speed of the rotating stator flux

Explanation

Solution. (*i*)	$P = 2n = 2 \times 3 =$ **6 poles**
Total No. of slots	$=$ 3 slots/pole/phase $\times$ 6 poles $\times$ 3 phases $=$ **54**
(*ii*)	$N_s = 120\,f/P = 120 \times 50/6 =$ **1000 r.p.m.**

MCQ 1

- A 3-phase 440 V, 50 Hz induction motor has 4% slip. The frequency of rotor e.m.f. will be
- (a) 200 Hz
- (b) 50 Hz
- (c) 2 Hz
- (d) 0.2 Hz

Answer

- Ans: c

MCQ 2

- 5 H.P., 50Hz, 3-phase, 440 V, induction motors are available for the following r.p.m. Which motor will be the costliest ?
- (a) 730 r.p.m.
- (b) 960 r.p.m.
- (c) 1440 r.p.m.
- (d) 2880 r.p.m.

Answer

- (a) 730 r.p.m.

Armature winding

There are 2 types of winding

Lap and Wave winding

Lap winding

- **A = P**
- The armature windings are divided into no. of sections equal to the no of poles

Wave winding

- **A = 2**
- It is used in low current output and high voltage.
- 2 brushes

Example

- A DC motor takes an armature current of 110 Amp. at 480 volts. The armature circuit resistance is 0.2 ohm. The machine has 6-poles and the armature is lap connected with 864 conductors. The flux per pole is 0.05 Wb. Calculate the speed of DC motor.

Explanation

Solution. $E_b = 480 - 110 \times 0.2 = 458$ V, $\quad \Phi = 0.05$ W, $Z = 864$

Now, $$E_b = \frac{\Phi\, ZN}{60}\left(\frac{P}{A}\right) \text{ or } 458 = \frac{0.05 \times 864 \times N}{60} \times \left(\frac{6}{6}\right)$$

$$\therefore \qquad N = 636 \text{ r.p.m.}$$

Example

- A 250 V, 4 pole wave wound dc series motor has 782 conductors on its armature. It has armature and series field resistance of 0.75ohm. The motor takes a current of 40 Amp. Calculate the speed when flux per pole is 25mWb.

Explanation

Solution. $$E_b = \Phi ZN\,(P/A)$$

Now, $$E_b = V - I_a R_a = 50 - 40 \times 0.75 = 220\ \text{V}$$

$\therefore$ $$220 = 25 \times 10^{-3} \times 782 \times \text{N} \times 0.75 = 220\ \text{V}$$