BEE Unit 5: Introduction to Electric Machines

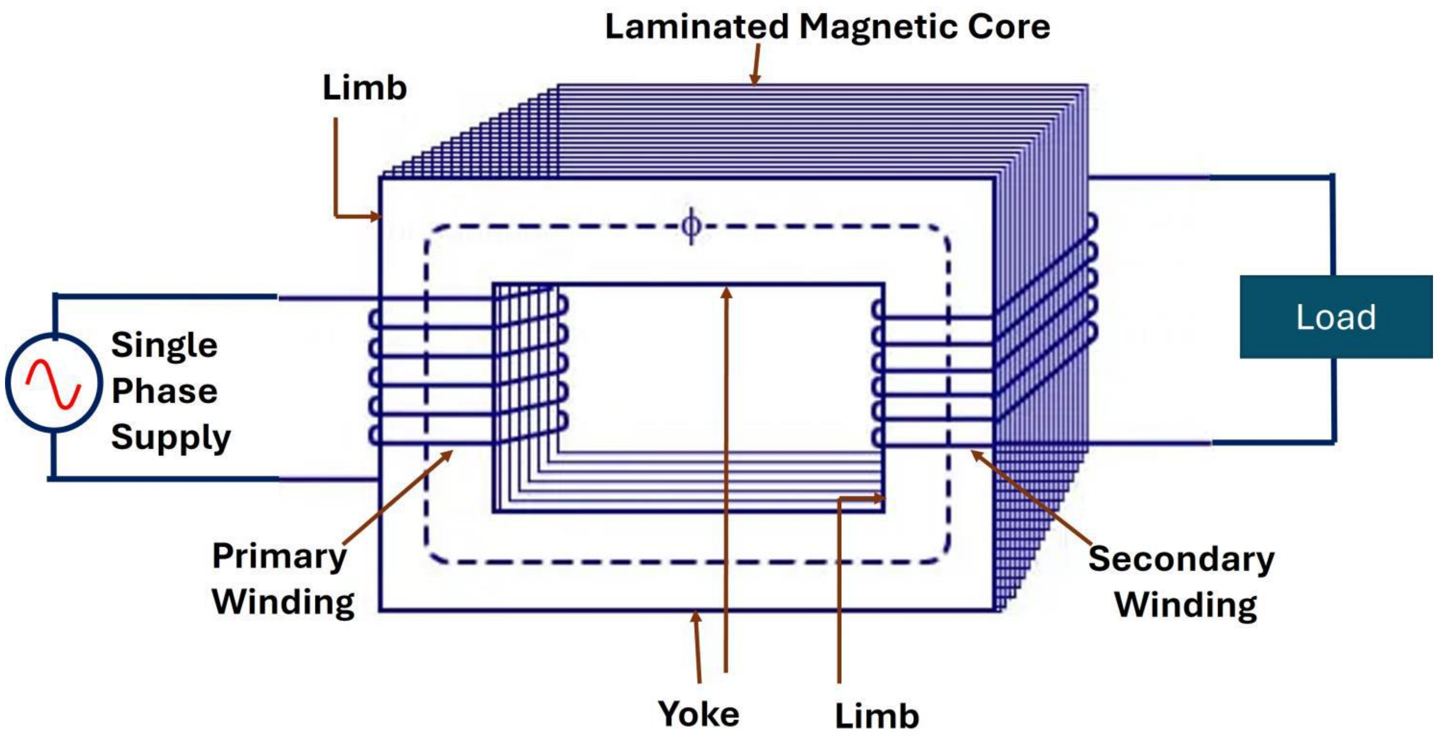
Draw

Unit V	Introduction to Electric Machines	(06 Hours)
Single Phase Transformer: Construction, working principle, EMF equation, transformation ratio, rating, types, losses, regulation and efficiency at different loading conditions. **Electrical Motors :** a) **D.C. Motors**: Construction, working principle, types, voltage equation, characteristics and Applications. b) **Three Phase Induction Motor**: Working principle using rotating magnetic field theory, types and applications. c) **Single Phase Induction Motor**: Construction, working principle of single phase Induction motor. Applications of split phase, capacitor start and capacitor run motors.		
#Exemplar	Mobile charger, electric substations, UPS, Lathe machine, compressor, lifts, hoists, ceiling fan etc	

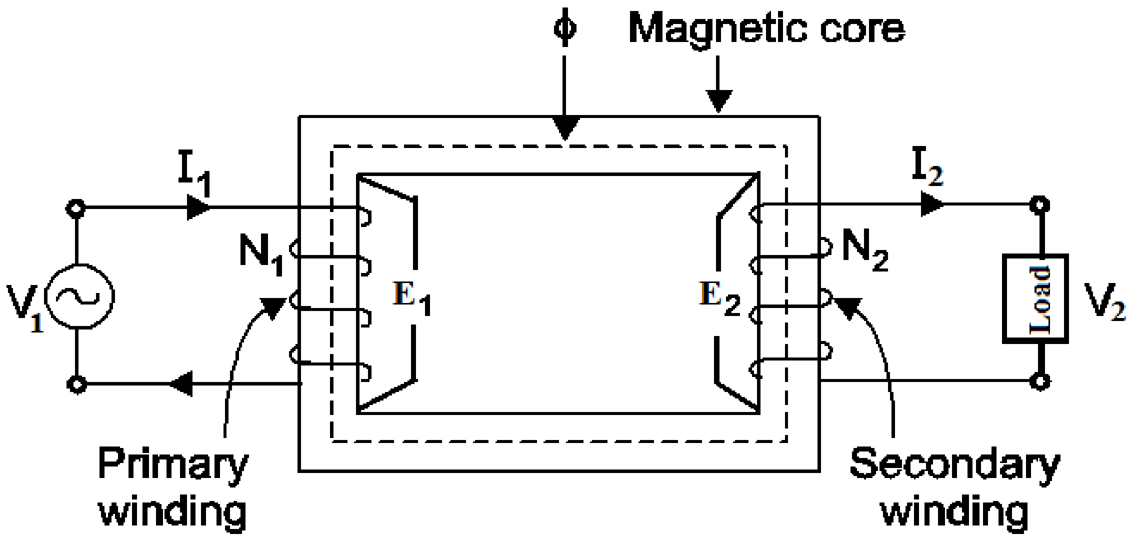
Lecture Plan..

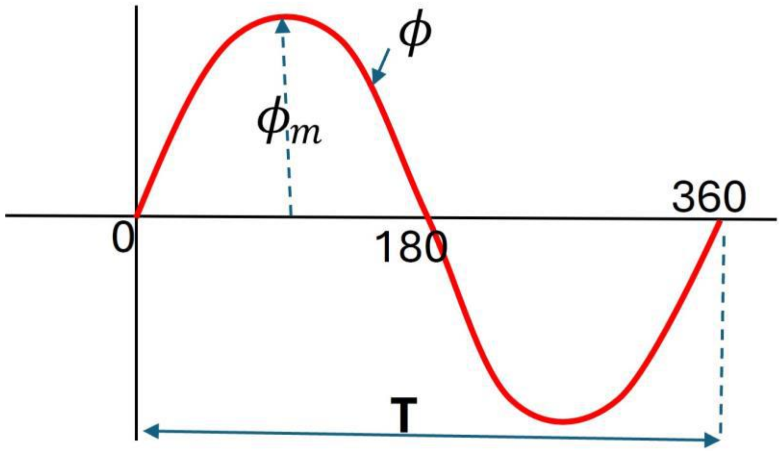
- **Lecture 25: Single Phase Transformer**
  - Construction, working principle, EMF equation, transformation ratio, rating, types
- **Lecture 26:**
  - Losses, regulation and efficiency at different loading conditions, Numericals to find efficiency of transformer at different power factor and different loading
- **Lecture 27: DC Motor**
  - Construction, working principle, voltage equation,
  - Types-Shunt, series and compound, electrical and mechanical characteristics, applications
- **Lecture 28: Three phase Induction Motor**
  - Working principle using rotating magnetic field theory,
  - Types- squirrel cage and slip ring and applications
- **Lecture 29: Single Phase Induction Motor**
  - Construction, working principle of single-phase Induction motor.
- **Lecture 30:**
  - applications of split phase, capacitor start, and capacitor run motors.

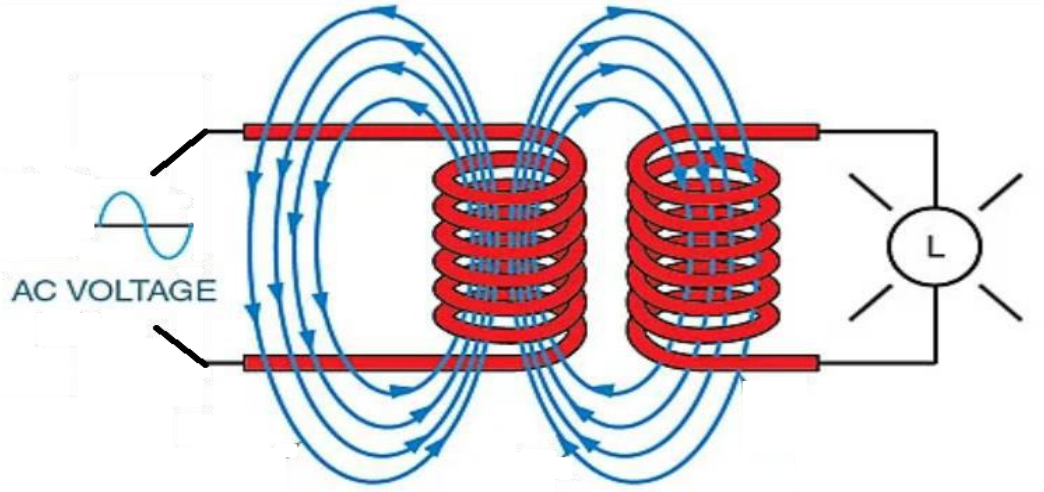
Single Phase Transformer: Construction



Working Principle and EMF Equation







$$e_{avg} = \frac{d\phi}{dt} = \frac{Final\ Flux - Initial\ Flux}{Time\ Required}$$

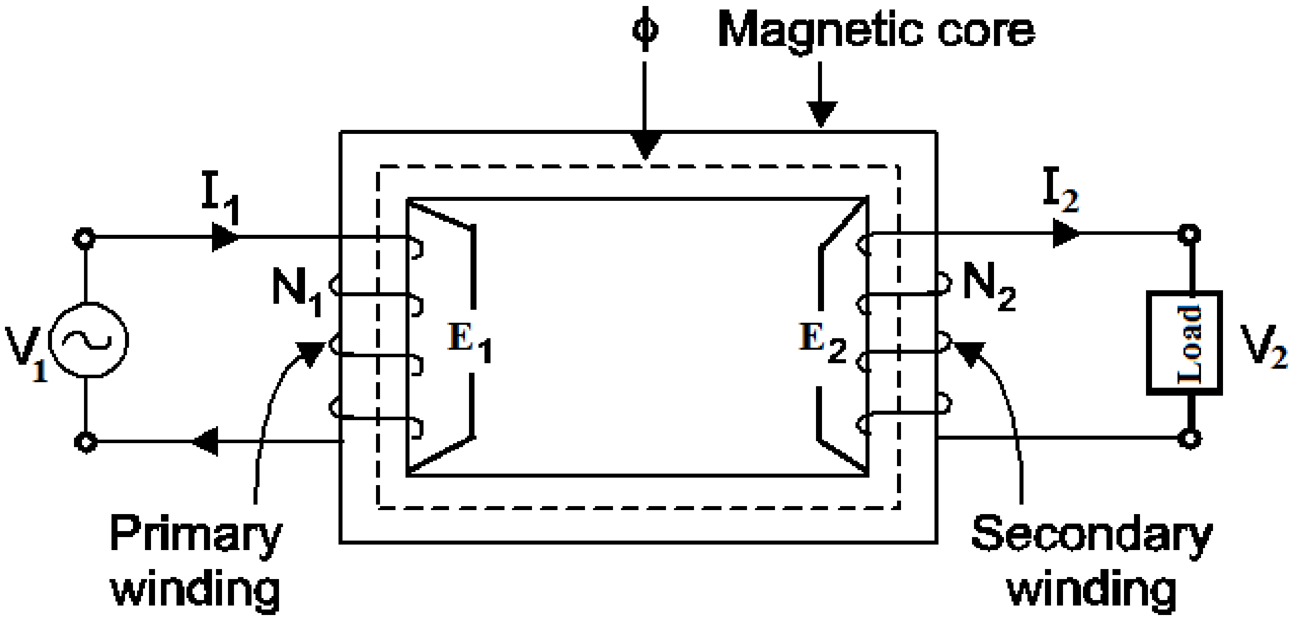
$$e_{avg} = \frac{d\phi}{dt} = \frac{\phi_m - 0}{(T/4)} = 4\phi_m f$$

$$E = 1.11x4\ \phi_m f\ = 4.44\ \phi_m f$$

Primary Induced EMF $\boldsymbol{E_1 = 4.44\ \phi_m f\ N_1}$

Secondary Induced EMF $\boldsymbol{E_2 = 4.44\ \phi_m f\ N_2}$

Transformation Ratio and Rating



$$K = \frac{E_2}{E_1} = \frac{N_2}{N_1} = \frac{V_2}{V_1} = \frac{I_1}{I_2}$$

Step up transformer, $N_2 > N_1$

Step down transformer, $N_2 < N_1$

One to One transformer, $N_2 = N_1$

Transformer Rating :

It is the output given by transformer at rated voltage and rated frequency under usual service conditions without exceeding the standard limits of temperature rise.

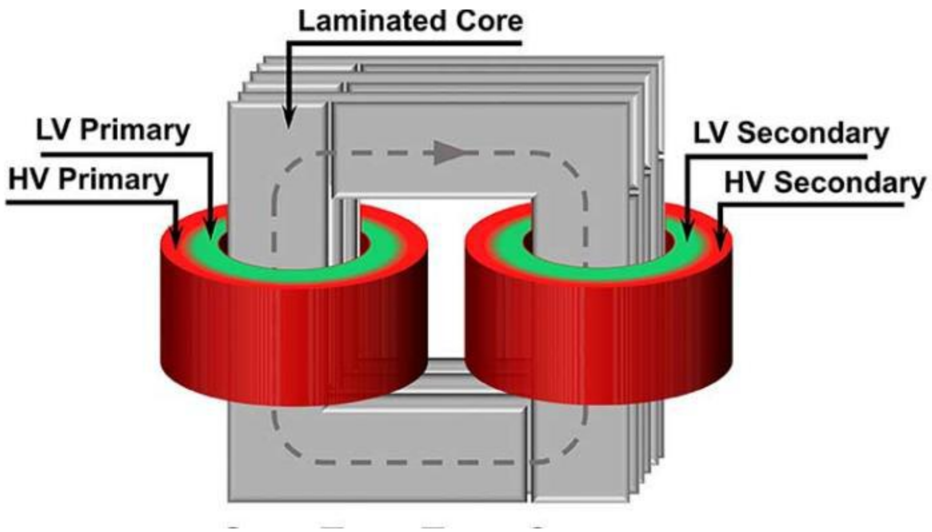
$$General\ Rating: \quad \frac{V_1}{V_2}\ \ and\ kVA$$

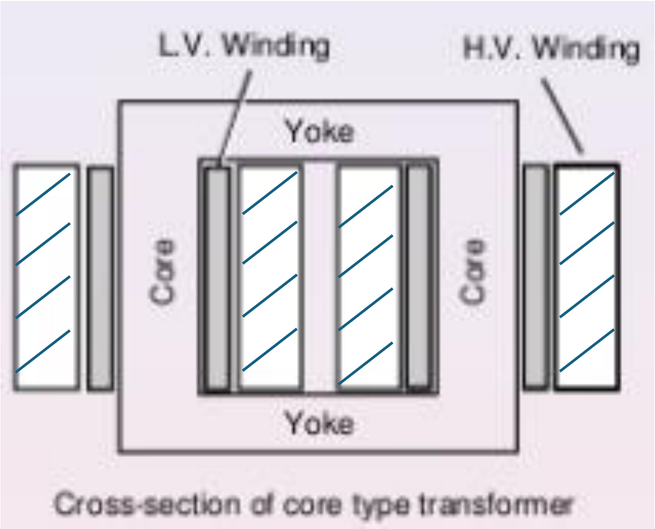
$$kVA\ Rating = \frac{V_1 I_1}{1000} = \frac{V_2 I_2}{1000}$$

$$I_1 = \frac{kVAx1000}{V_1} \qquad I_2 = \frac{kVAx1000}{V_2}$$

Types of Transformer:

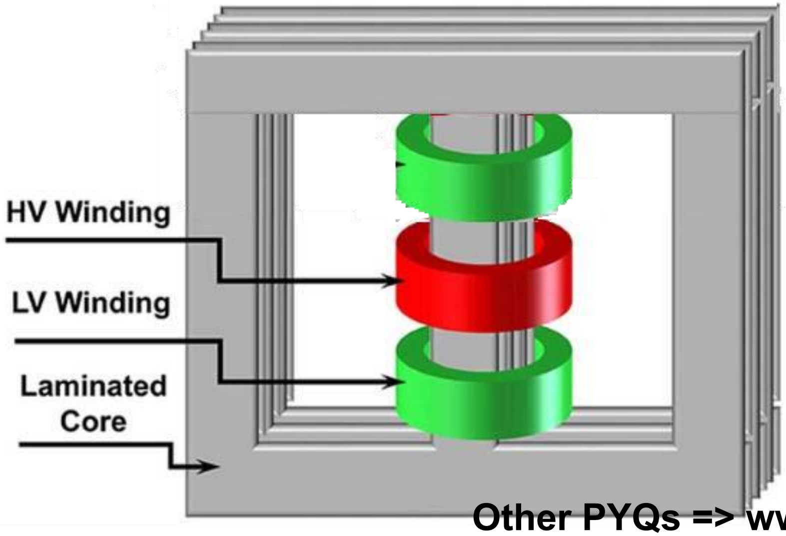
Core Type

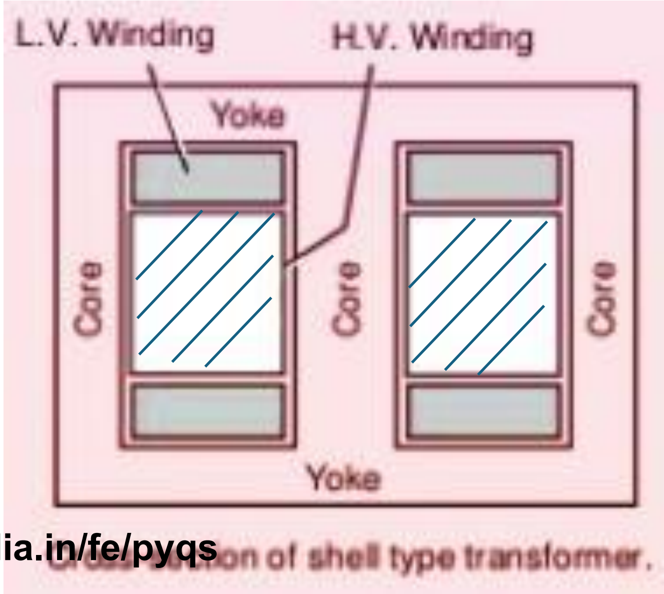




Cross-section of core type transformer

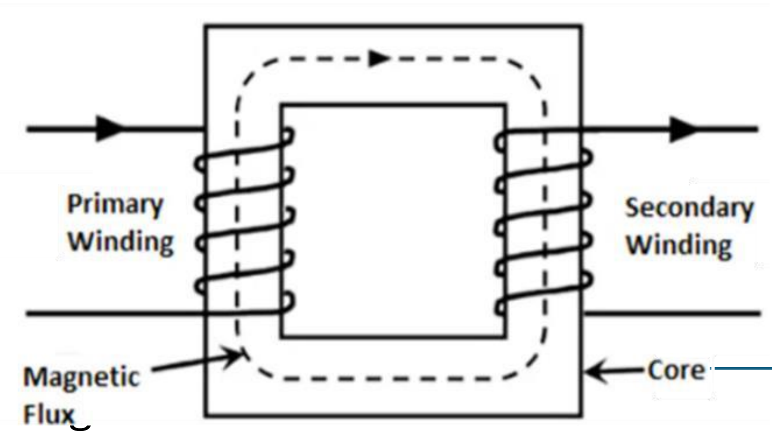
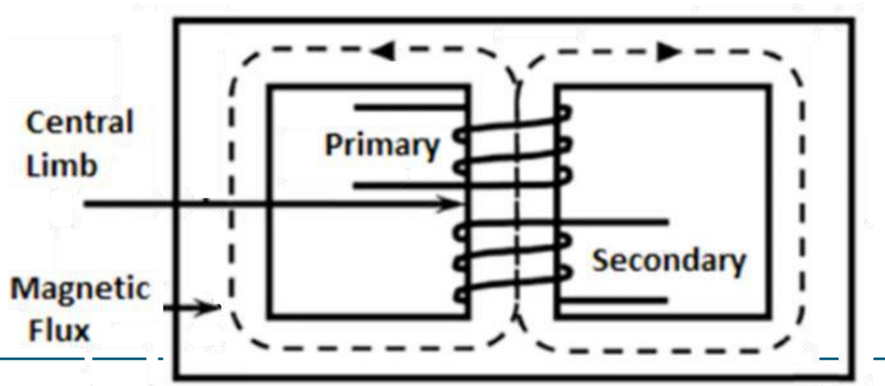
Shell Type



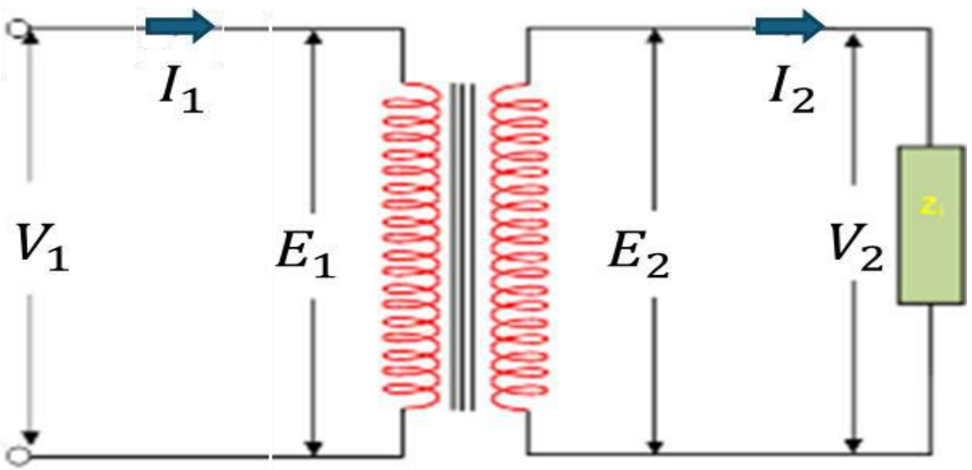


on of shell type transformer.

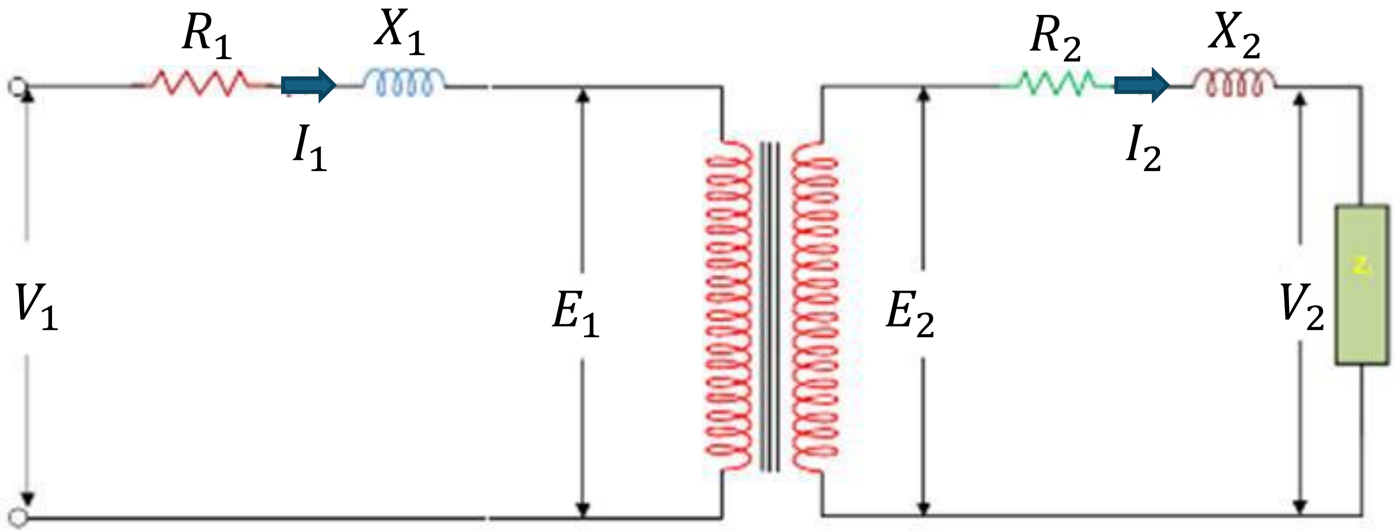
Comparison: Core and Shell Type Transformer

	Core Type Transformer	Shell Type Transformer
		
1	One	Two Magnetic Paths
2	Winding surrounds core	Core Surrounds winding
3	Natural cooling better	Natural cooling poor
4	Easy repair and maintenance	Difficult repair and maintenance
5	Concentric and Cylindrical winding	Sandwich or disc winding
6	High Voltage applications	High Power applications

Ideal and Practical Transformer



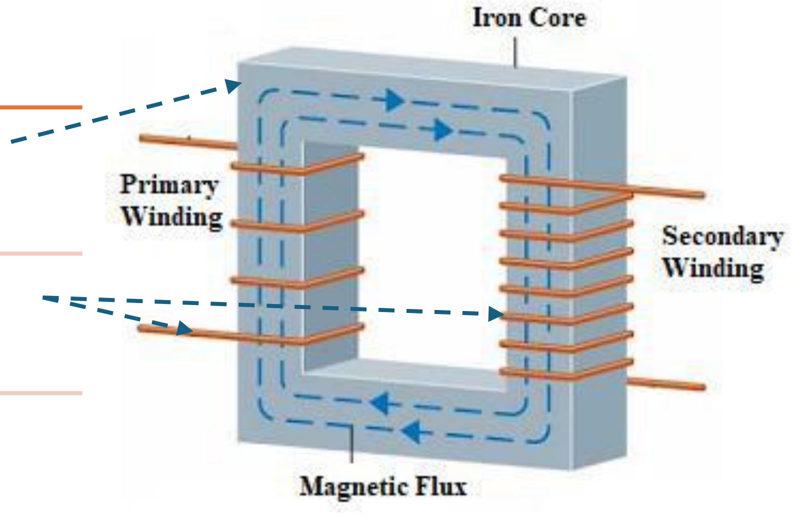
Ideal Transformer



Practical Transformer

Ideal Transformer	Practical Transformer
No ohmic Resistance	Ohmic Resistance ✓
No Magnetic Leakage	Magnetic Leakage ✓
Core has Infinite permeability	Core has finite permeability
No losses	Losses ✓

Practical Transformer

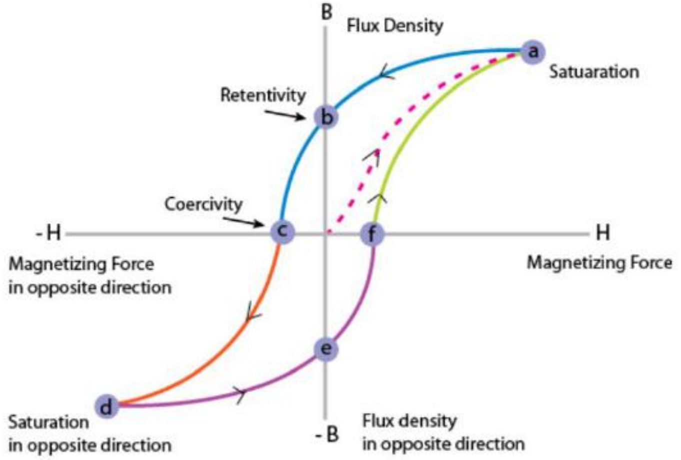


Losses

- Iron Loss/ Core Loss/ Constant Loss
- Copper Loss/ Winding Loss/ Variable Loss

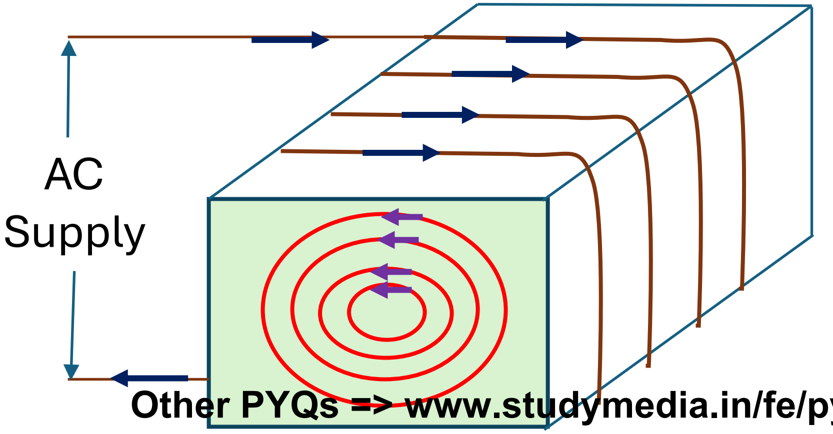
Iron Loss

Hysteresis Loss



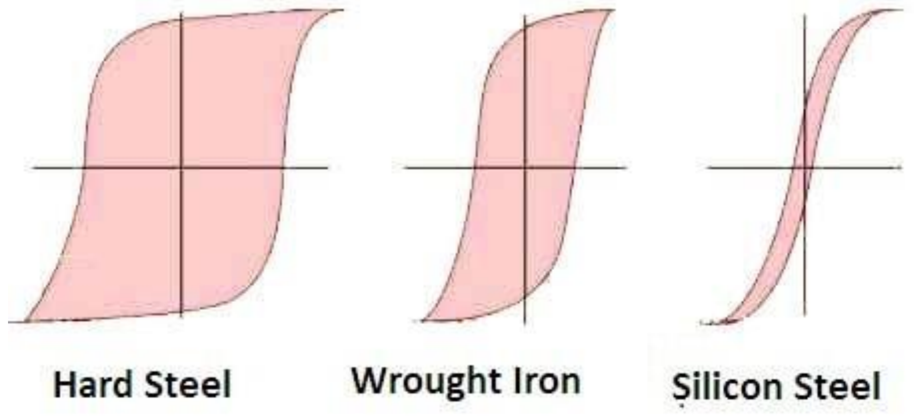
$$P_h = K_h \, B_m^{\;1.6} \, f \, v \; Watts$$

Eddy Current Loss

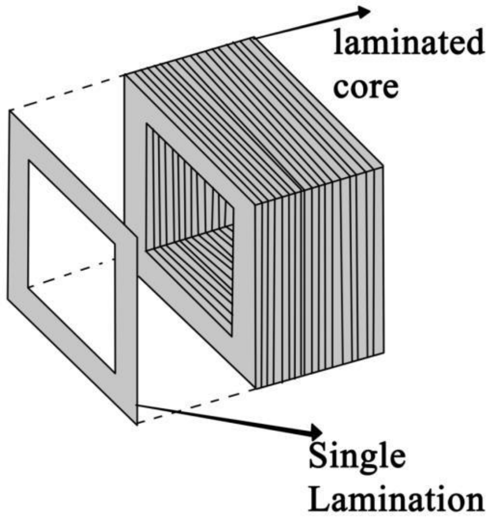


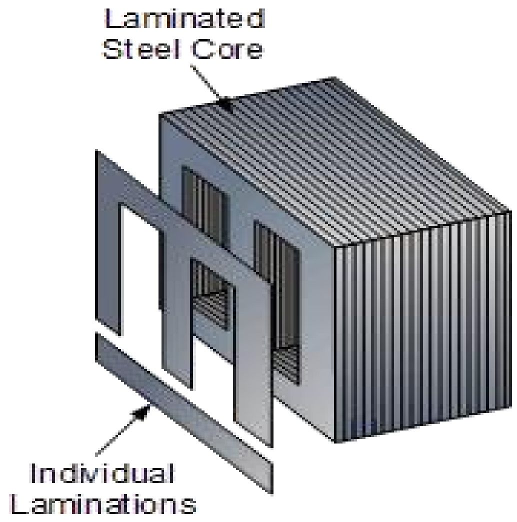
$$P_e = K_e \, B_m^{\;2} \, f^2 \, t^2 \, v \; Watts$$

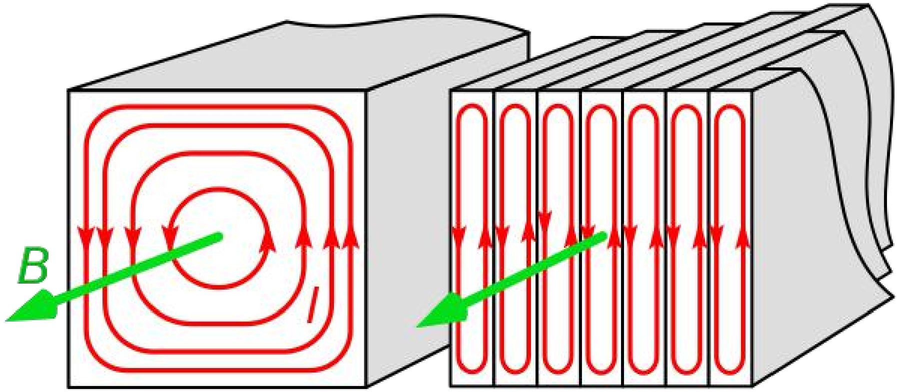
Reduction of Iron losses

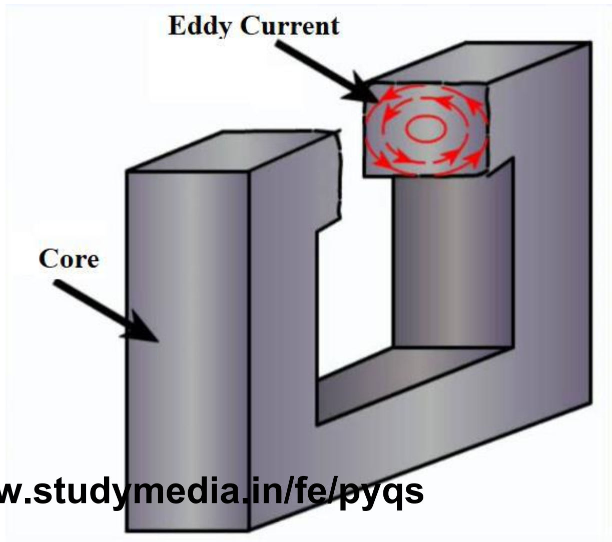


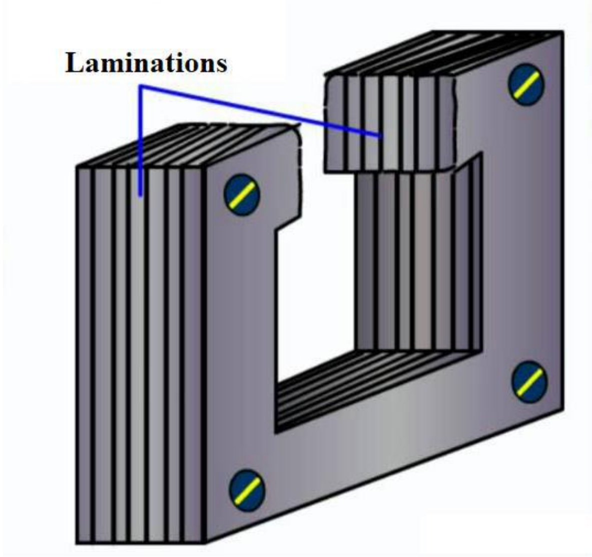
Hysteresis Loops



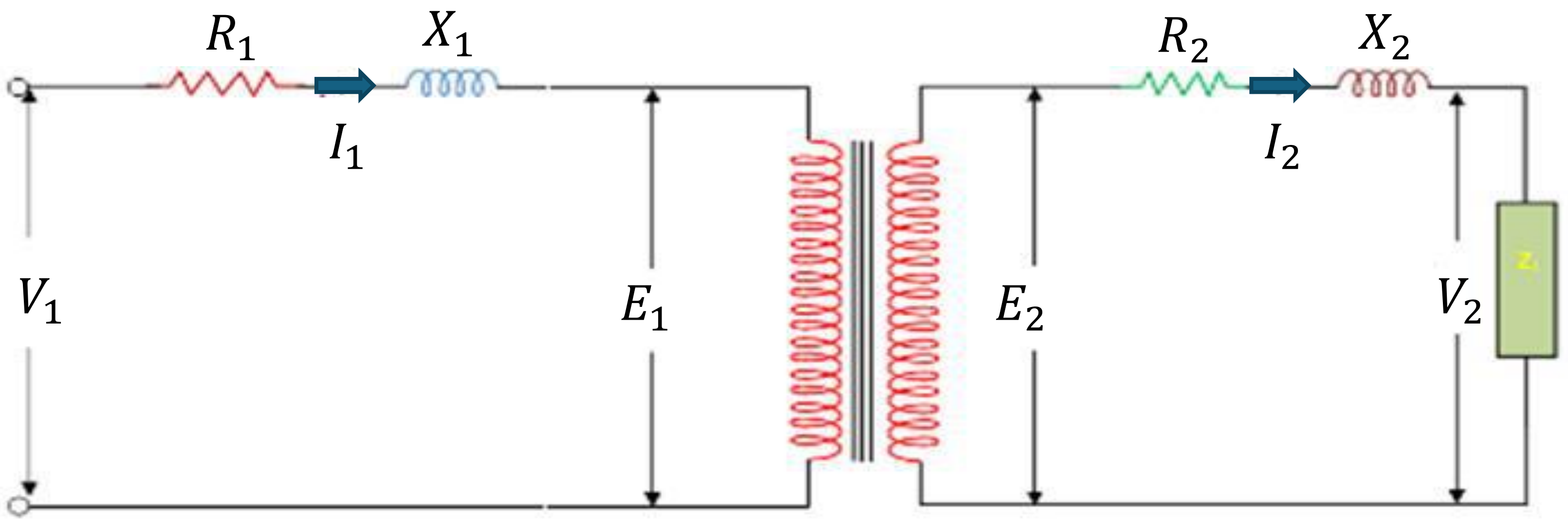








Copper losses



These losses occurs in the primary and secondary windings due to resistance of primary and secondary winding.

Let I_1 and I_2 : the primary and secondary current.

R_1 and R_2 : the primary and secondary winding resistance.

Hence, **Total copper loss** $= I_1^2 R_1 + I_2^2 R_2$ **Watt**

Efficiency

Total Losses= Iron Loss (P_i)+Copper Loss (P_{cu})

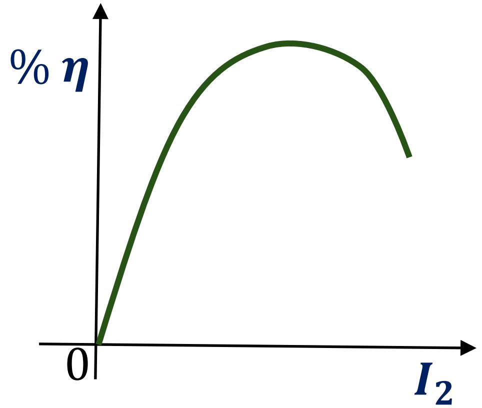
$$\% \eta = \frac{Output\ Power}{Input\ Power} x100 = \frac{Output\ Power}{Output\ Power + Losses} x100$$

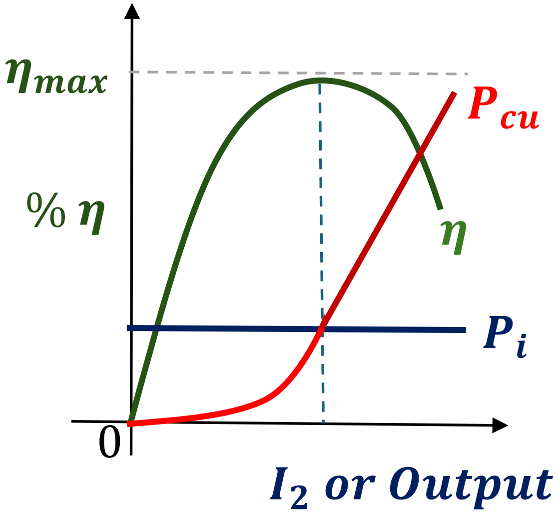
$$\% \eta = \frac{V_2 I_2\ Cos\phi}{V_2 I_2\ Cos\phi + P_i + P_{cu}} x100$$

$Maximum\ Efficiency\quad \eta_{max}$

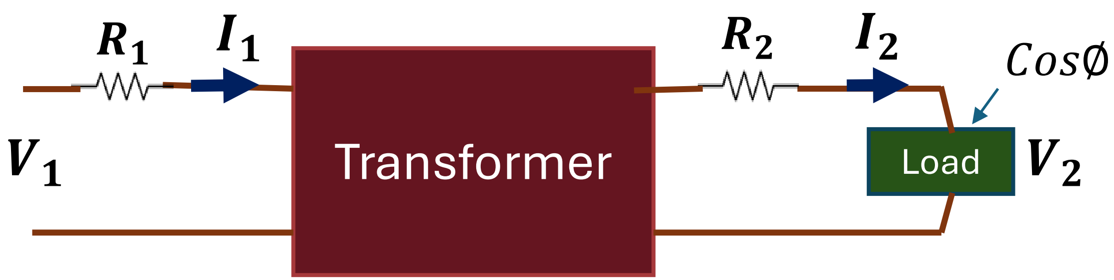
$P_i = P_{cu}$

$Iron\ Loss = Copper\ Loss$





Efficiency at different loading and power factor



$$Losses = Pi + Pcu$$

$$P_{cu} = {I_1}^2 R_1 + {I_2}^2 R_2$$

$$P_{cu(FL)} = {I_{1(FL)}}^2 R_1 + {I_{2(FL)}}^2 R_2$$

$$\%\,\eta = \frac{V_2 I_2 \, Cos\phi}{V_2 I_2 \, Cos\phi + P_i + P_{cu}} x100$$

$$\%\,\eta = \frac{x \, V_2 I_{2(FL)} \, Cos\phi}{x \, V_2 I_{2(FL)} \, Cos\phi + P_i + x^2 P_{cu(FL)}} x100$$

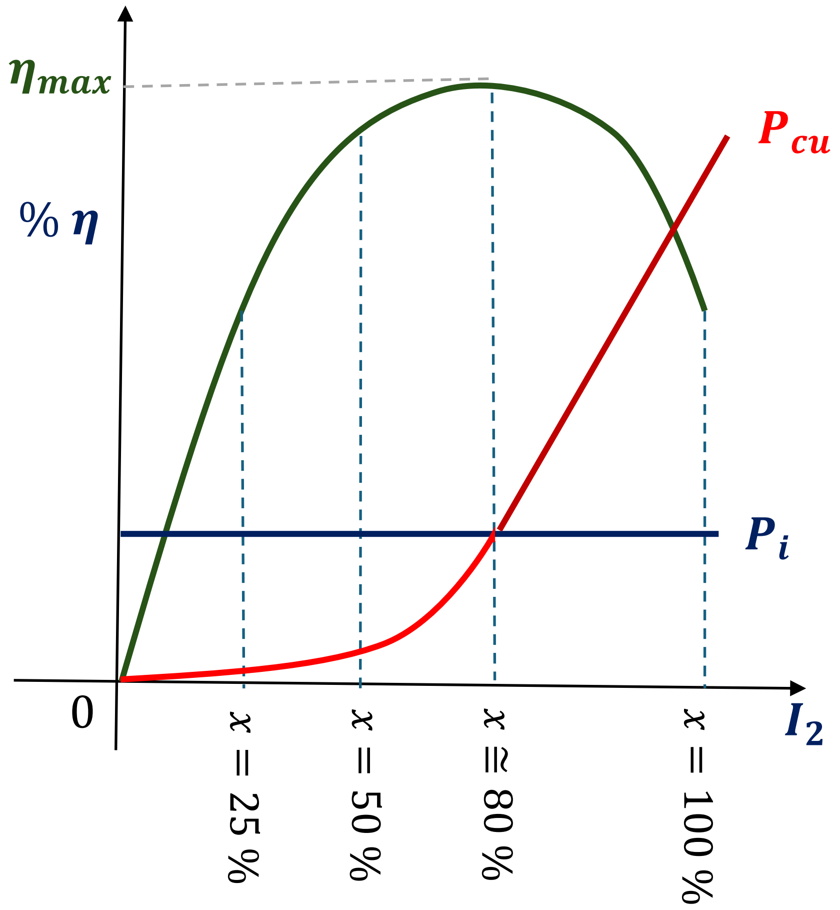
$$\%\,\eta = \frac{x \, kVA * 1000 * Cos\phi}{x \, kVA * 1000 * Cos\phi + P_i + x^2 P_{cu(FL)}} x100$$

$$where, x = \%\, age\ of\ loading$$

$$I_{1(FL)} = \frac{kVAx1000}{V_1}$$

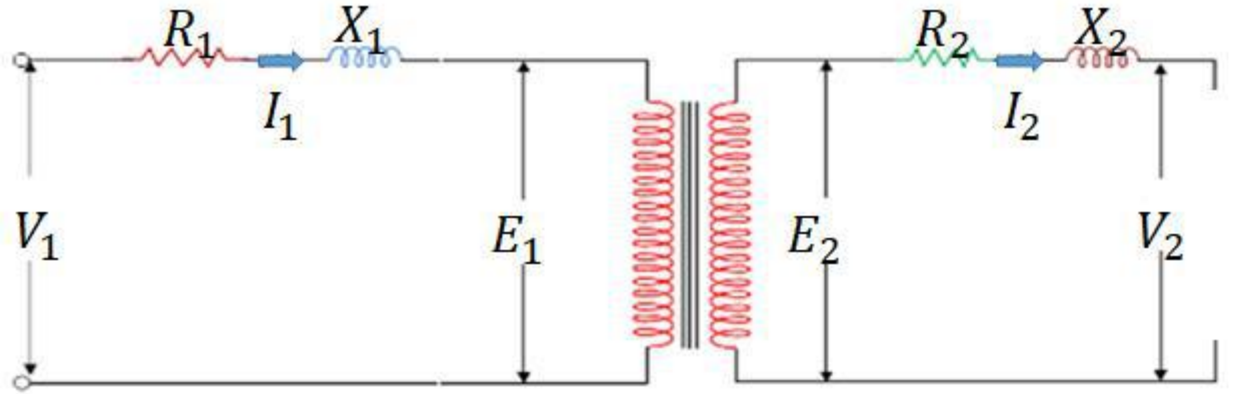
$$I_{2(FL)} = \frac{kVAx1000}{V_2}$$

$$kVA, \quad \frac{V_1}{V_2}$$



Other PYQs => www.studymedia.in/fe/pyqs

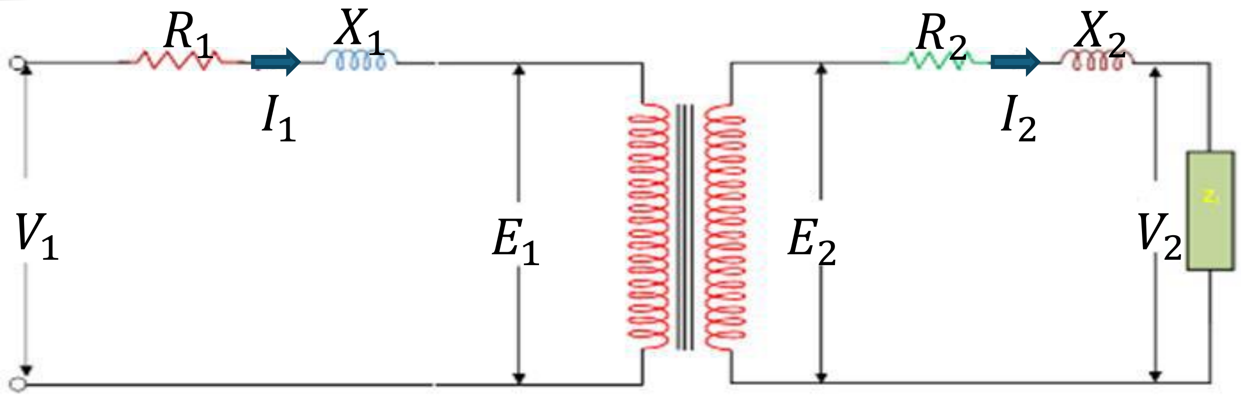
Regulation



No Load

$$V_2 = E_2 - I_2(R_2 + jX_2) \qquad V_2 = E_2 - 0(R_2 + jX_2)$$

$$V_2 = E_2$$

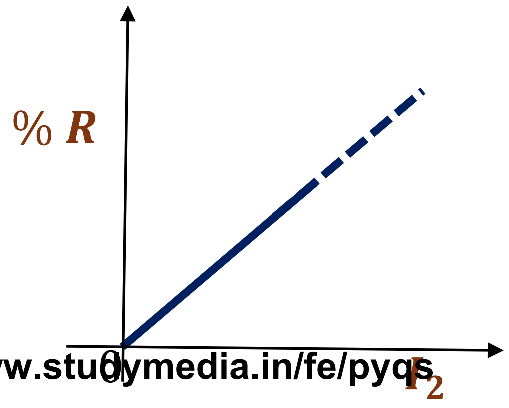


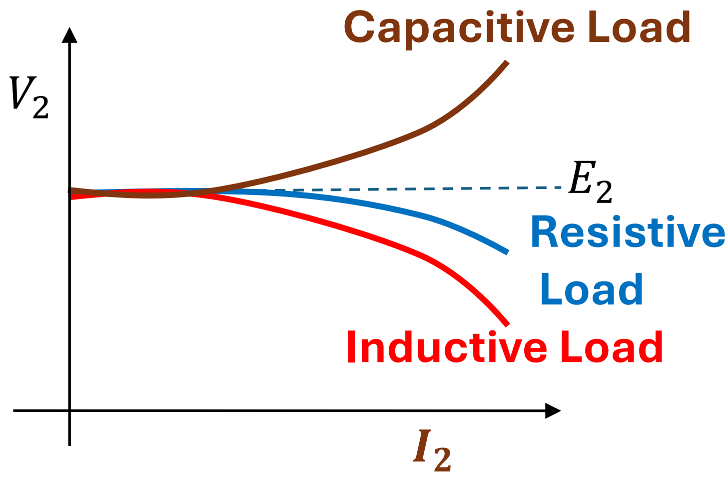
At Load

$$V_2 = E_2 - I_2(R_2 + jX_2)$$

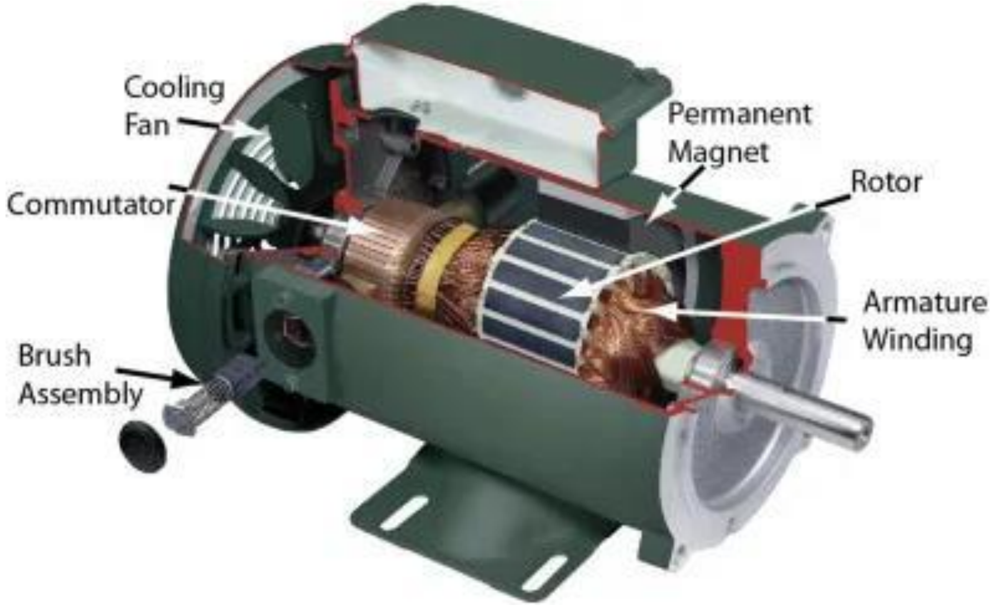
$$\% \boldsymbol{Regulation} = \frac{\boldsymbol{V_{NL} - V_{FL}}}{\boldsymbol{V_{NL}}} \boldsymbol{x100}$$

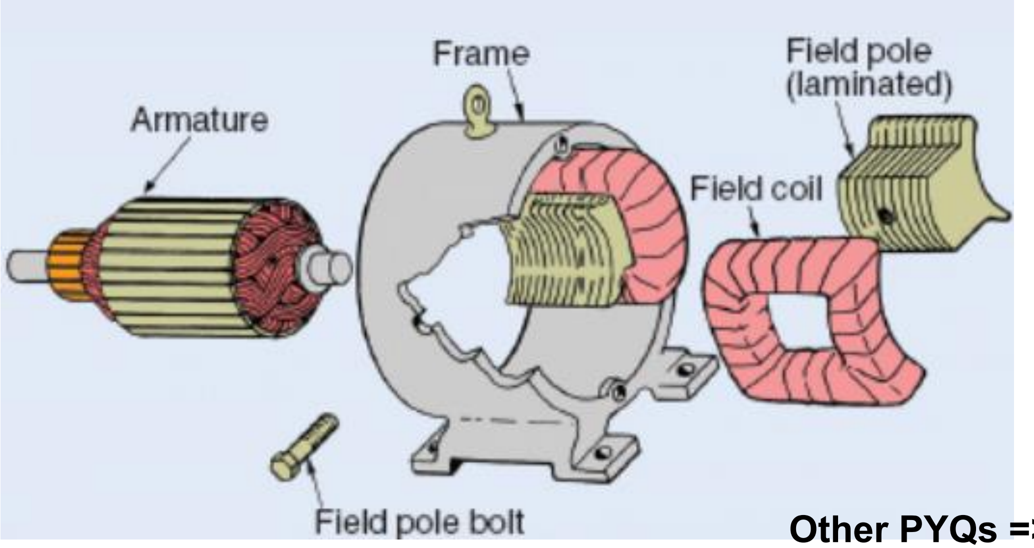
$$\% \boldsymbol{Regulation} = \frac{\boldsymbol{E_2 - V_2}}{\boldsymbol{E_2}} \boldsymbol{x100}$$

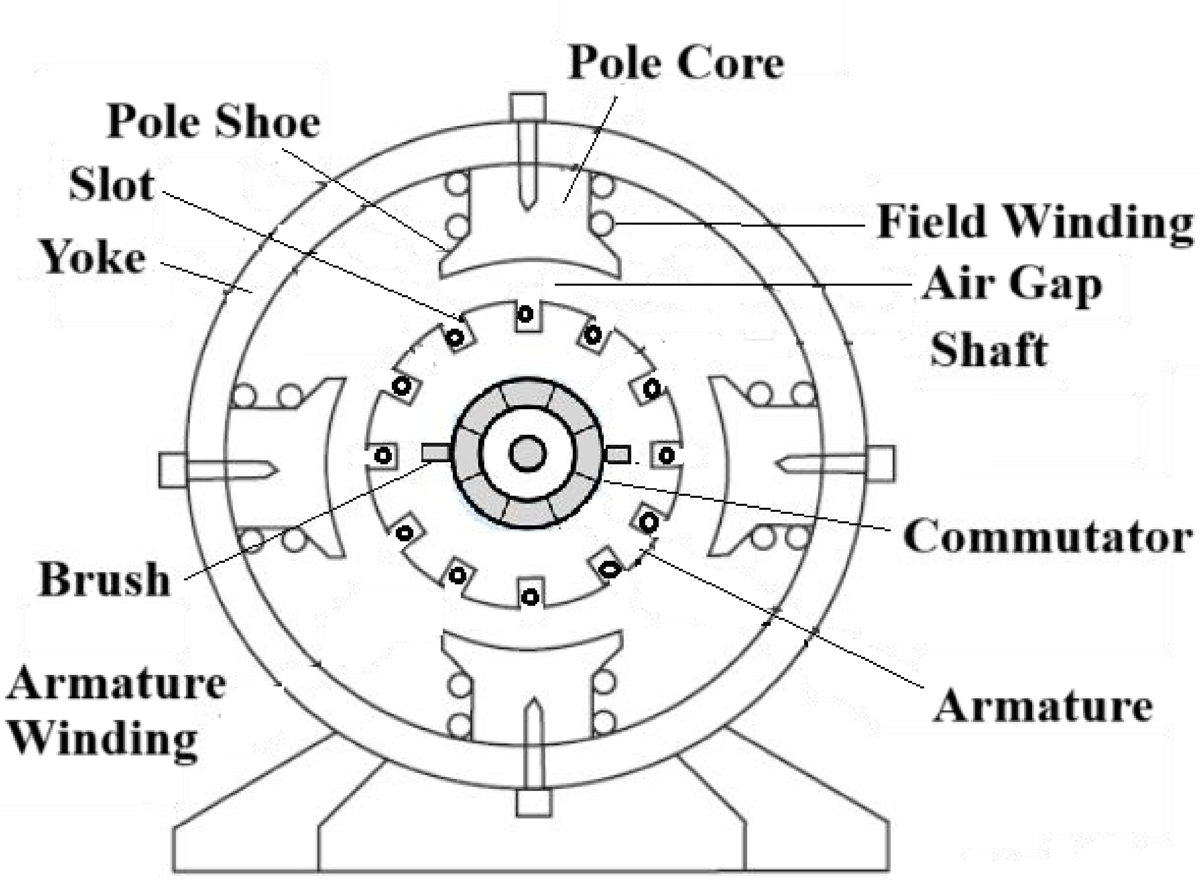




DC Machine (Motor) Construction





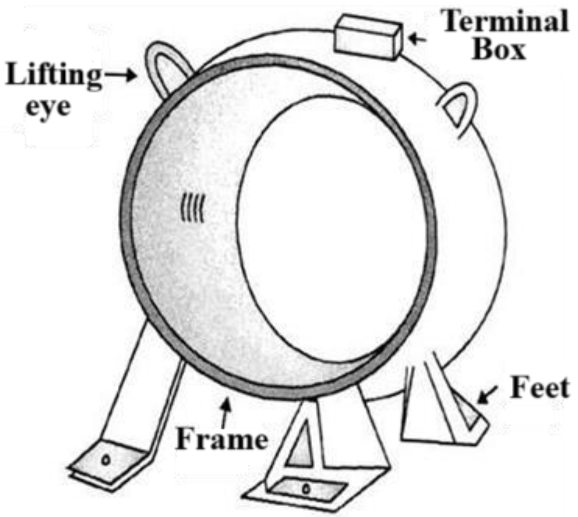


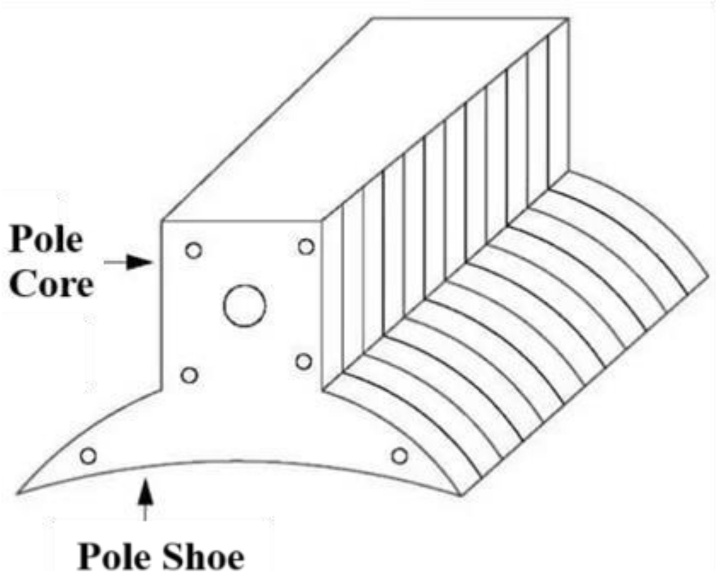
Cross sectional view

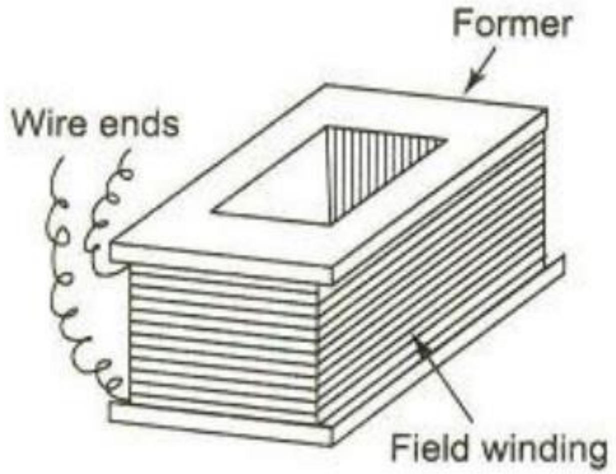
Other PYQs => www.studymedia.in/fe/pyqs

Yoke:

The outer frame of a dc machine is called as yoke.
It is a stationary part 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. For small motors the Yoke are made of cast iron. But for larger, cast steel or rolled steel is used.







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. Cast steel or cast iron material is used.

Pole shoes serve two purposes:

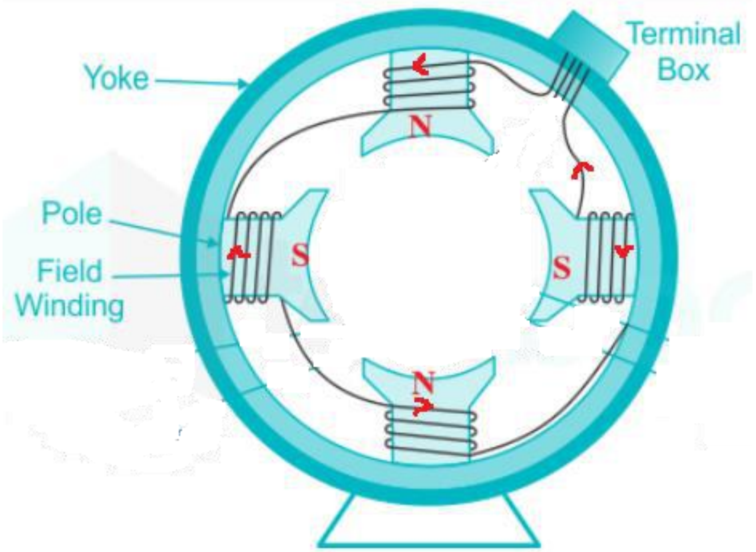
(i) they support field coils and (ii) spread out the flux in air gap uniformly.

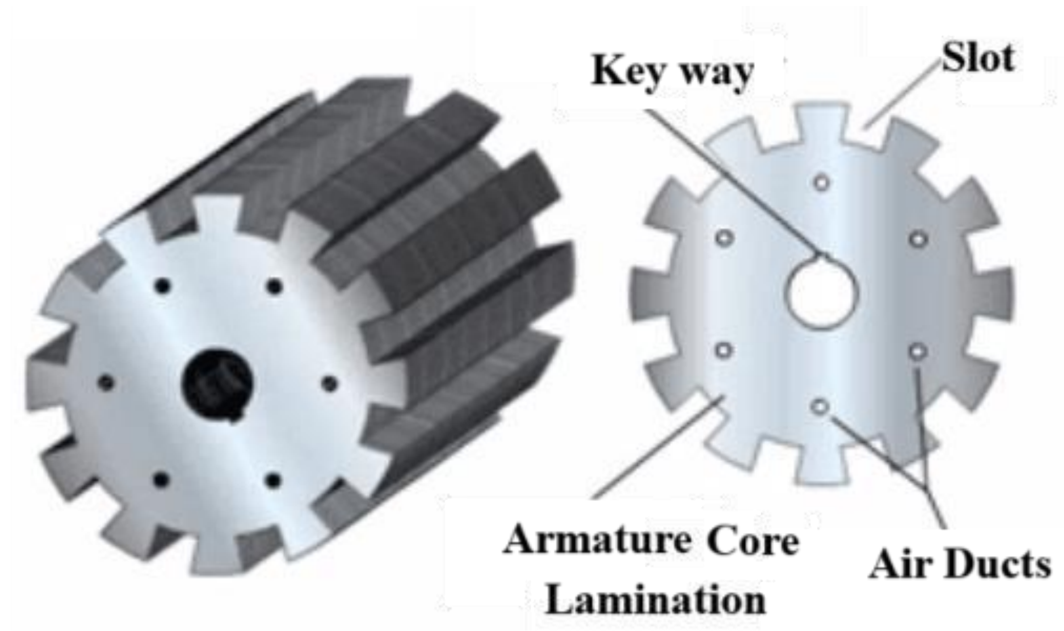
Field windings:

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.





Armature core:

Armature core is the rotor of a dc machine.

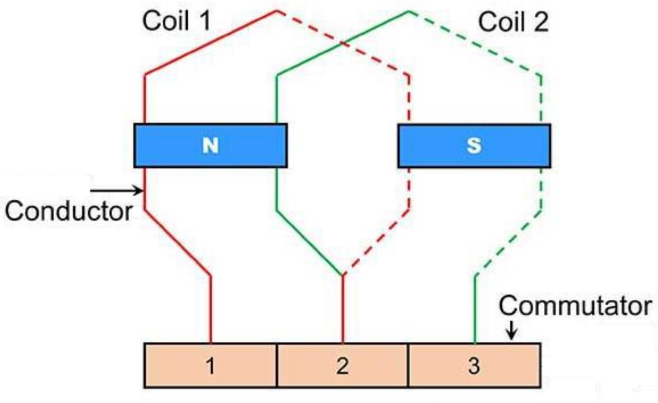
It is cylindrical in shape with slots to carry armature winding. The armature is built up of thin laminated circular steel disks for reducing eddy current losses.

Armature core is made of silicon steel laminations which are insulated from each other by insulating varnish coating. These laminations are used to reduce eddy current losses.

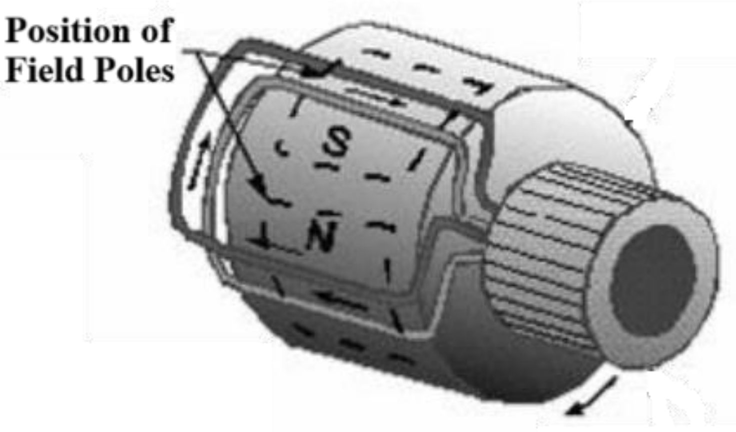
It may be provided with air ducts for the axial air flow for cooling purposes.

Armature winding:

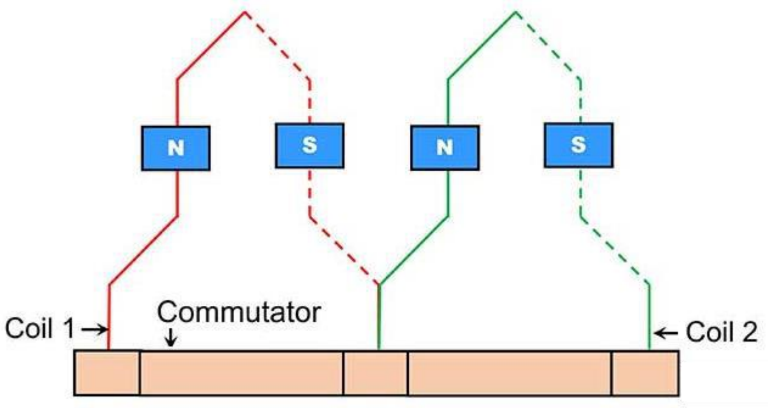
It is usually a former wound copper coil which rests in armature slots. The armature conductors are insulated from each other and also from the armature core. Armature winding can be wound by one of the two methods; **lap winding or wave winding.**



Lap Winding



- Windings are overlapped
- No. of parallel paths are always same as no. of poles
- No. of brush sets equal to no. of parallel paths
- Large current low voltage
- Current rating > 500 Amp

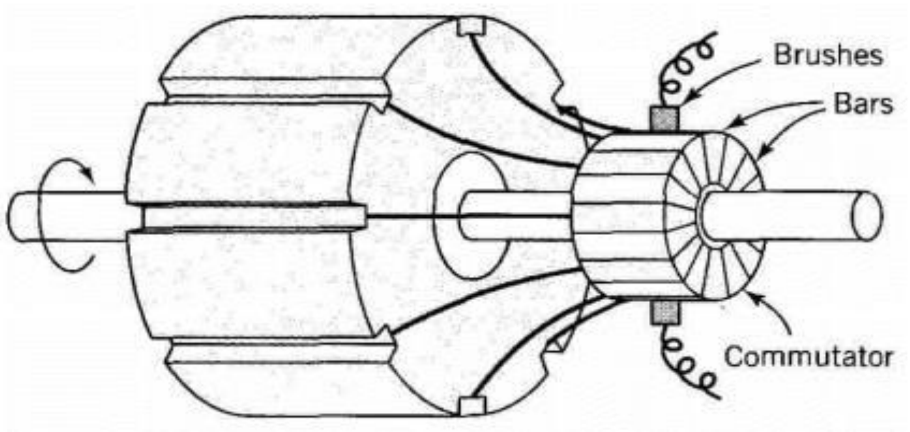


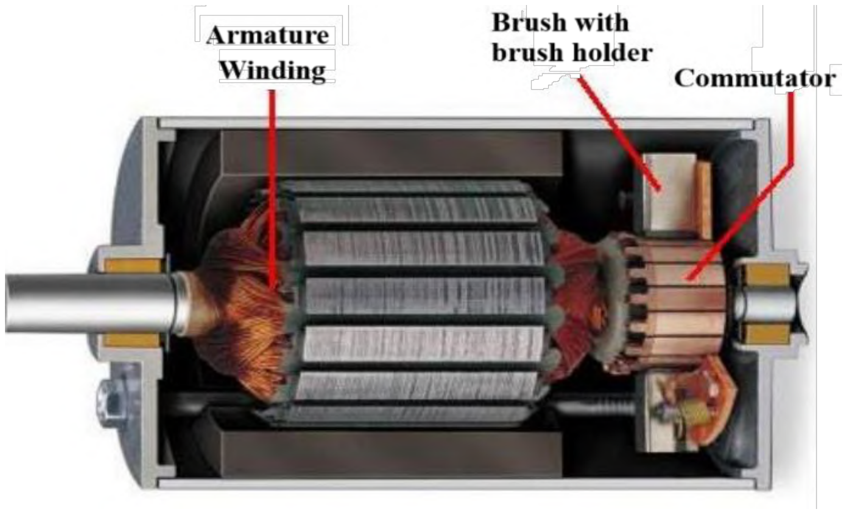
Wave Winding

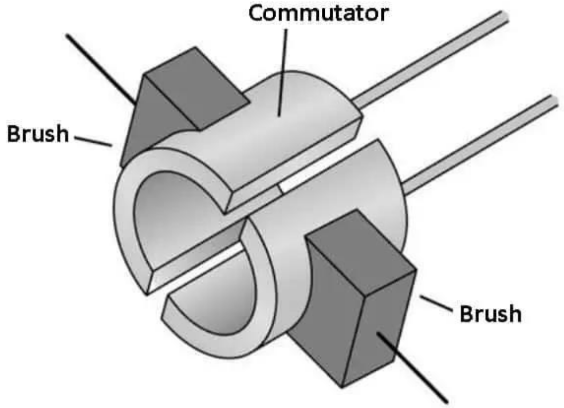
- Windings are in the form of Progressive wave
- No. of parallel paths are always two
- No. of brush sets are always two
- High voltage low current
- Current rating < 500 Amp

Commutator:

In the case of DC motor, the commutator is used to convert DC to AC. Physical connection to the armature winding is made through a commutator-brush arrangement. Commutator helps in providing current to the armature conductors. A commutator consists of a set of copper segments which are insulated from each other. 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.





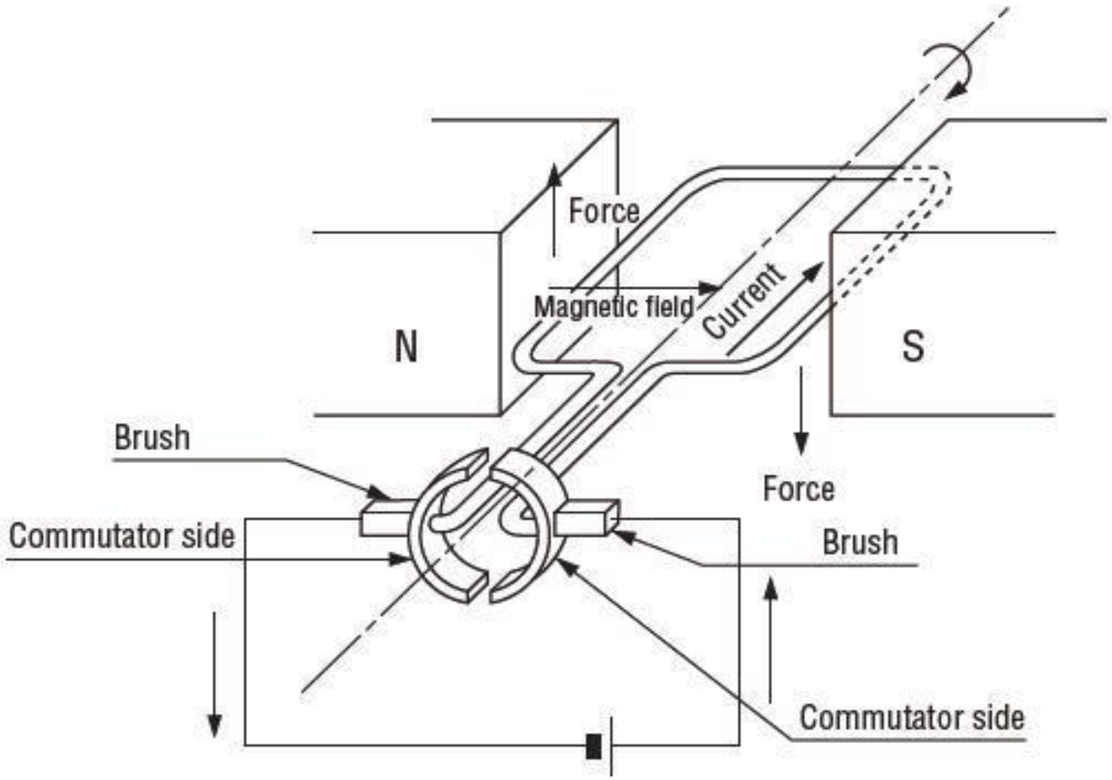


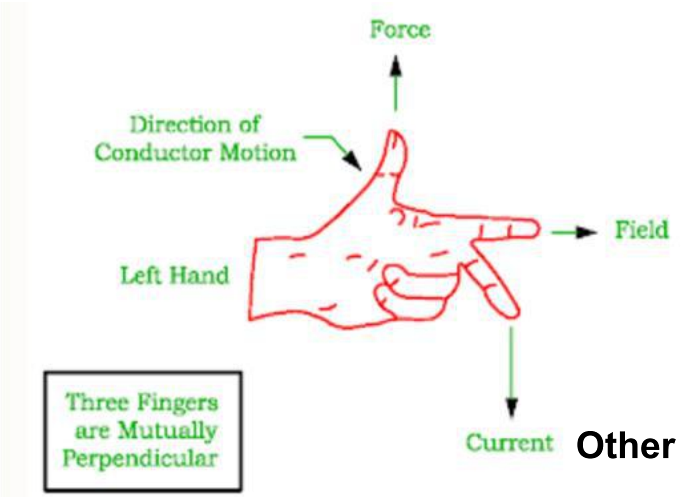
Brushes:

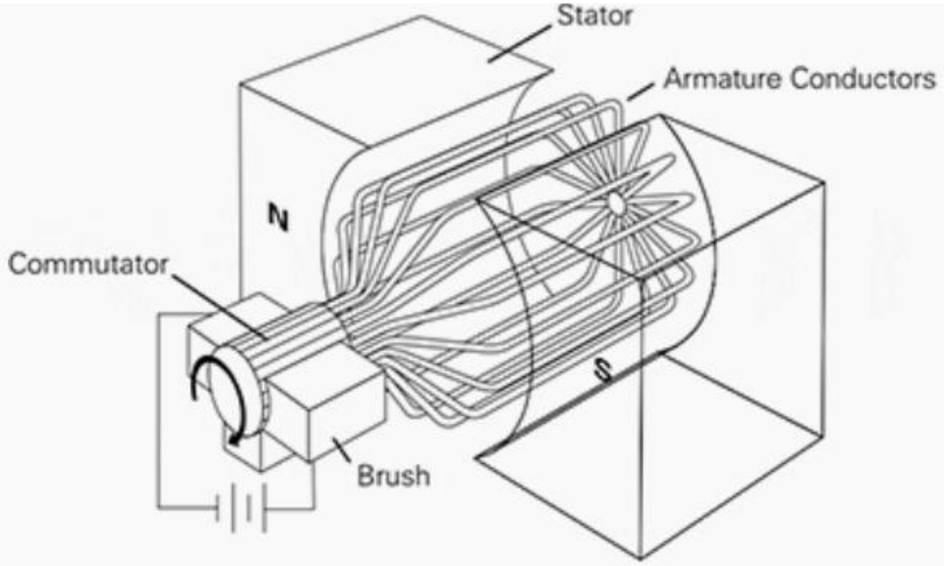
Brushes are a stationary part.

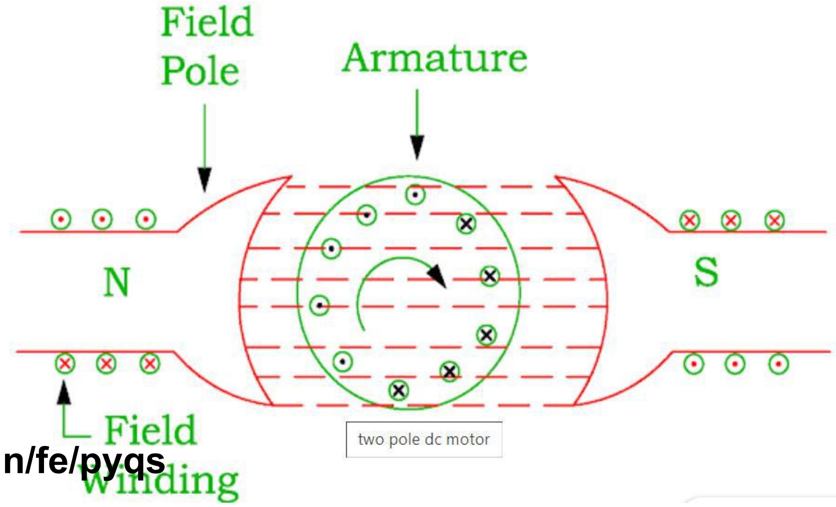
Brushes are usually made from carbon or graphite. They rest on commutator segments and slide on the segments when the commutator rotates keeping the physical contact to collect or supply the current.

DC Motor working principle



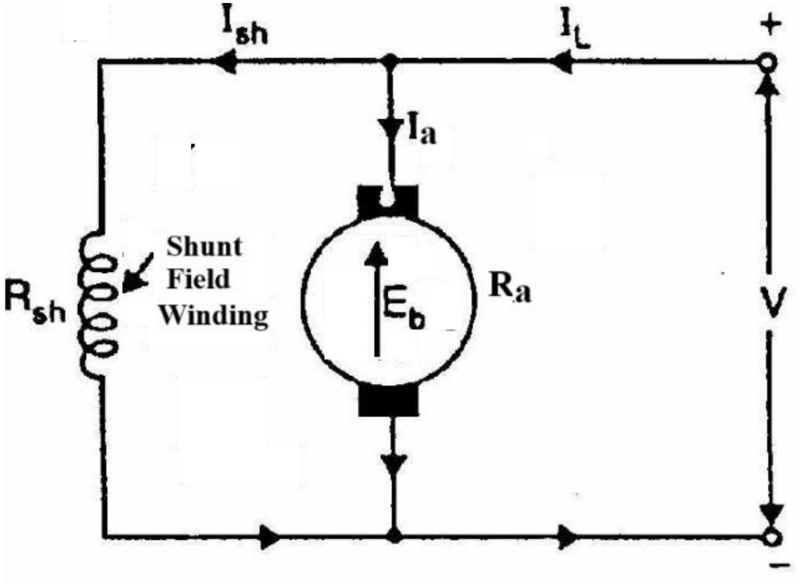






DC Motor types and characteristics

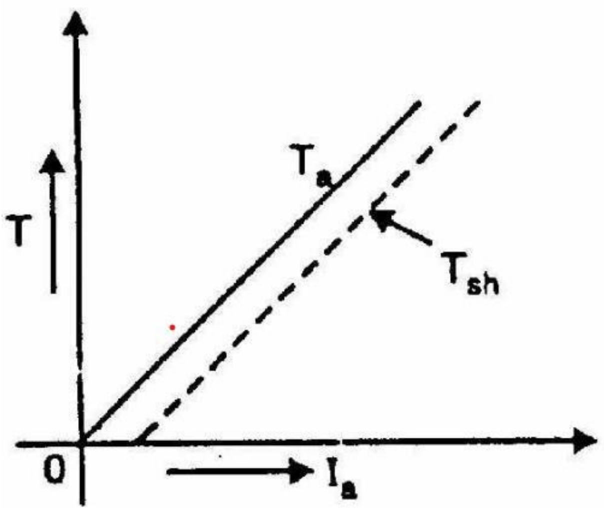
DC Shunt Motor



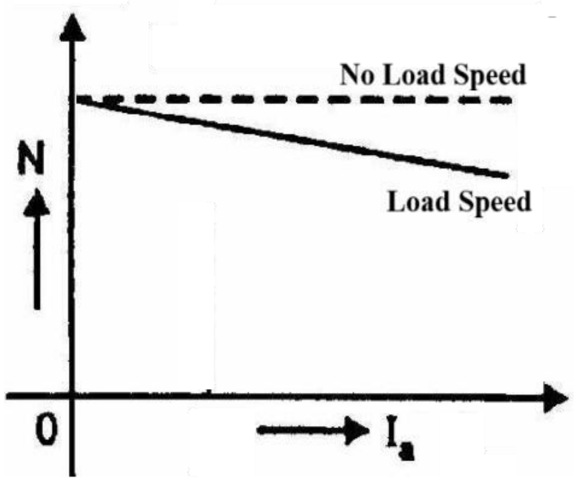
Voltage Equation $V = E_b + I_a R_a$

Torque relation $T_a \propto \emptyset\, I_a \propto I_a$

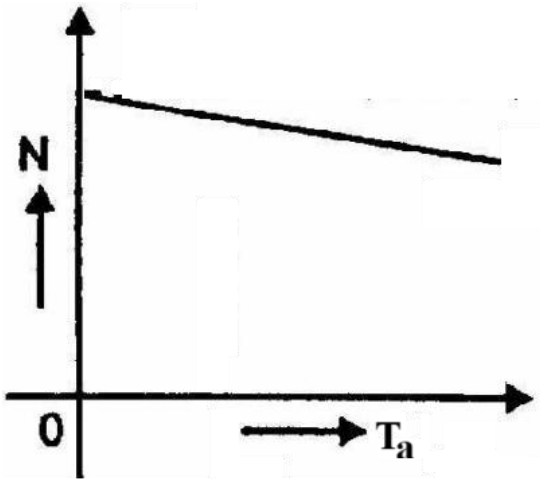
Speed relation $N \propto \dfrac{E_b}{\emptyset} \propto \dfrac{V - I_a R_a}{\emptyset}$



Torque Vs Armature Current

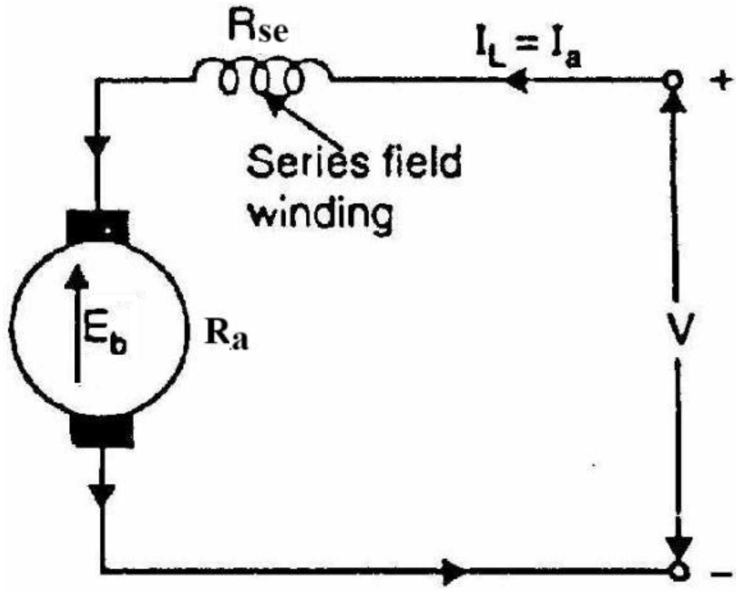


Speed Vs Armature Current



Speed Vs Armature Torque

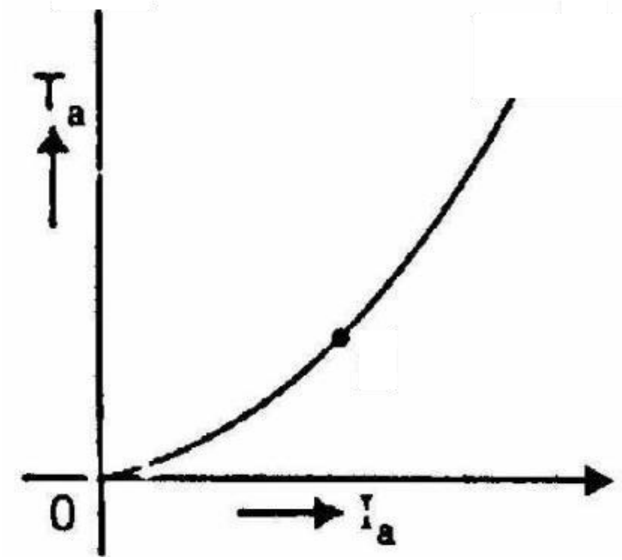
DC Series Motor



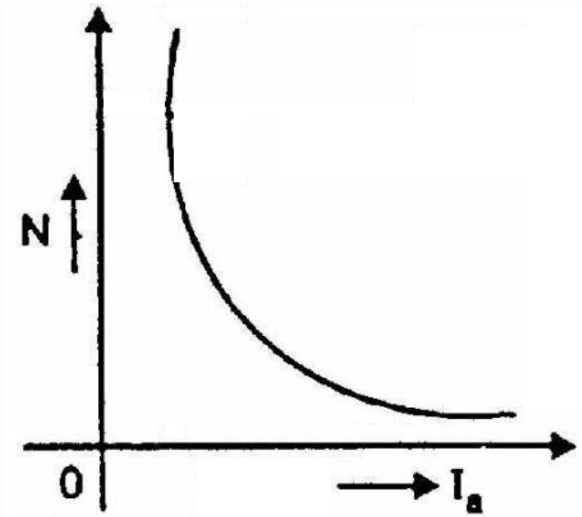
Voltage Equation $V = E_b + I_a(R_a + R_{se})$

Torque relation $T_a \propto \emptyset\, I_a \propto {I_a}^2$

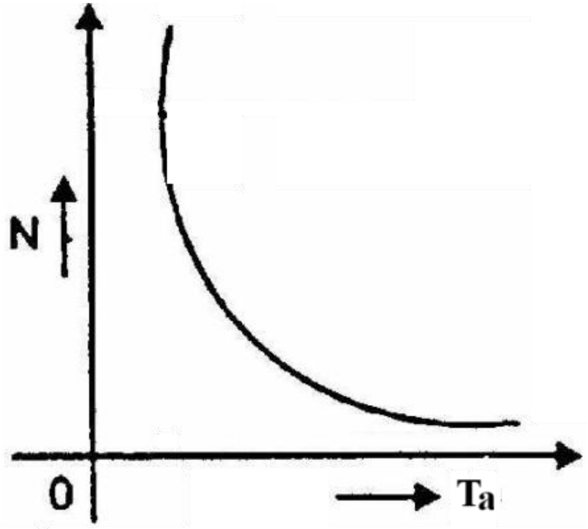
Speed relation $N \propto \dfrac{E_b}{\emptyset} \propto \dfrac{V - I_a(R_a + R_{se})}{I_a}$



Torque Vs Armature Current



Speed Vs Armature Current



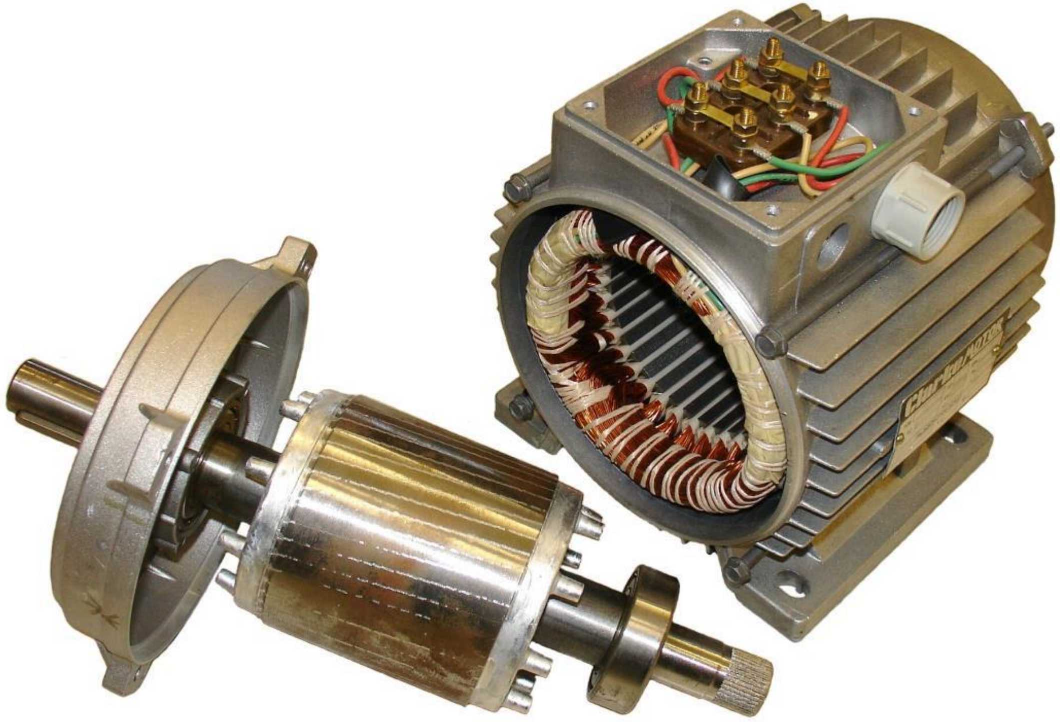
Speed Vs Armature Torque

Applications

DC Shunt Motor
Moderate starting torque, constant speed
Fans
Centrifugal Pumps
Lathe Machine
Drilling Machine
Milling Machine
Blowers
Machine tools

DC Series Motor
High starting torque, No load condition not possible Variable speed
Lifts
Cranes
Hoists
Elevators
Electric traction
Electric Locomotives
Trolleys and Conveyors

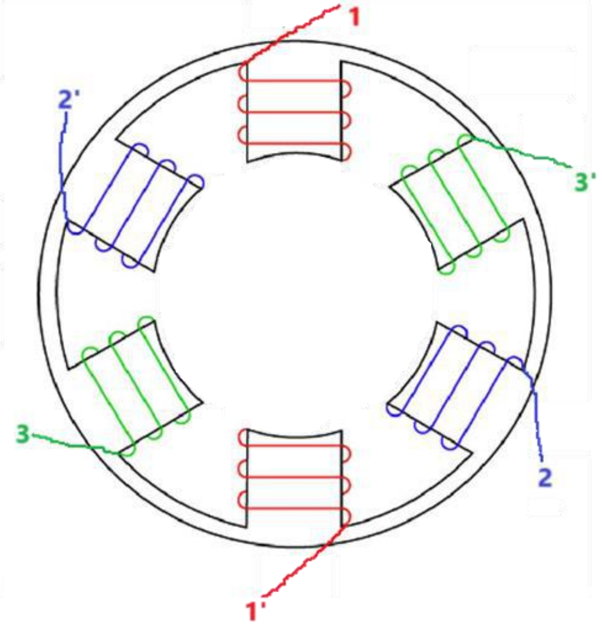
Three phase Induction Motor

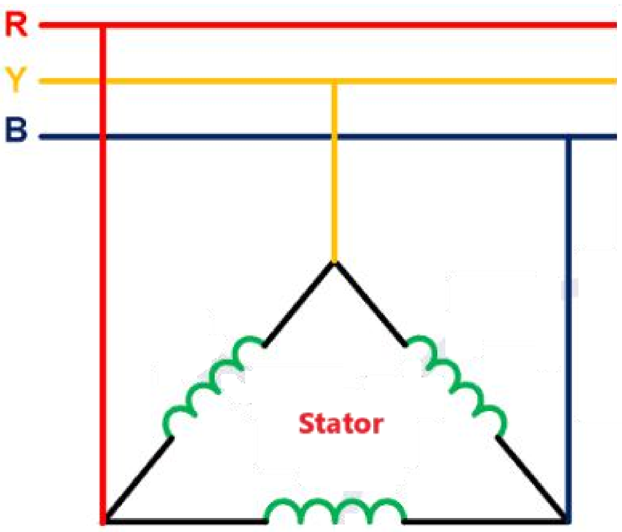


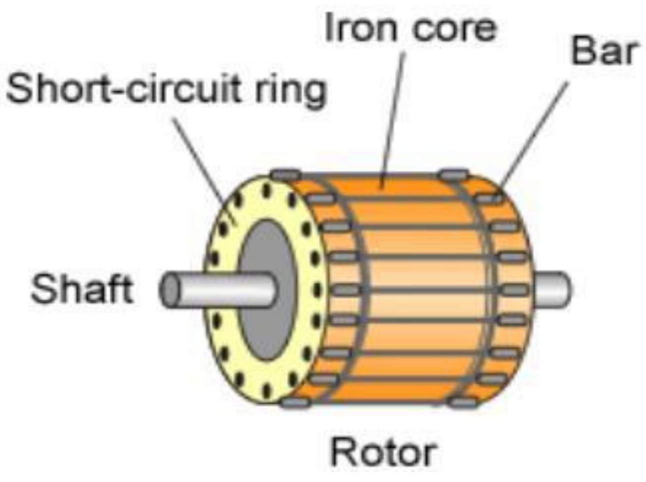
Advantages

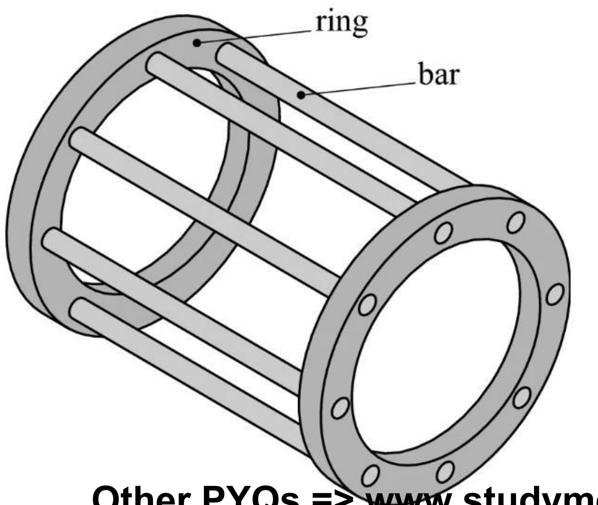
- Three-phase induction motors are the most common and frequently used machines in industry
- Simple design, rugged, low-price, easy maintenance
- Wide range of power ratings: fractional H.P. to 10 MW
- Run essentially as constant speed from zero to full load
- Robust; No brushes. No contacts on rotor shaft (Squirrel Cage)
- High Power/Weight ratio compared to DC motor, Lower Cost/Power
- Speed is frequency dependent

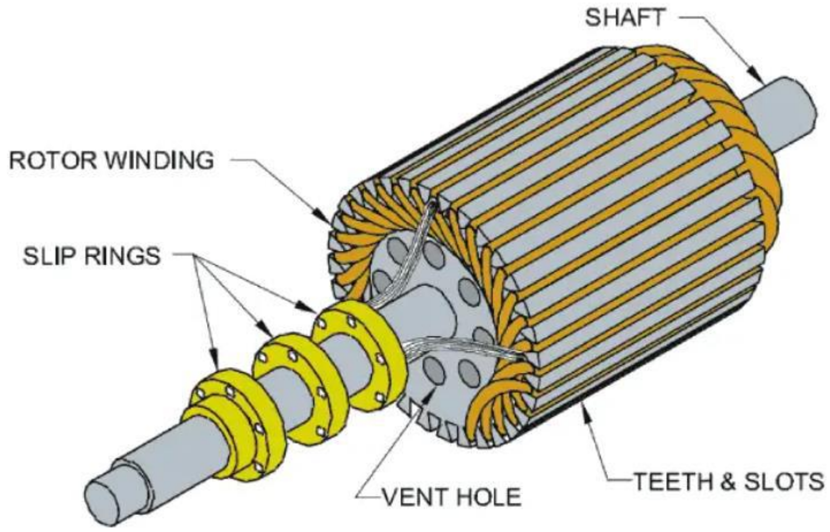
Stator and rotor

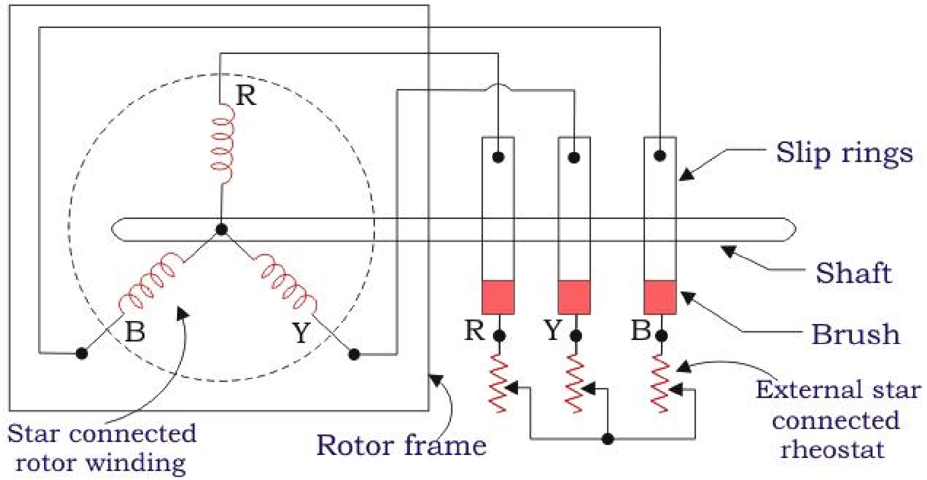




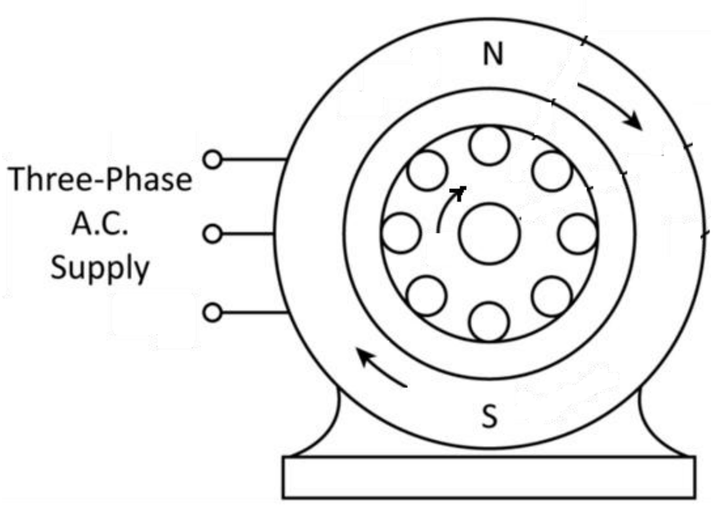


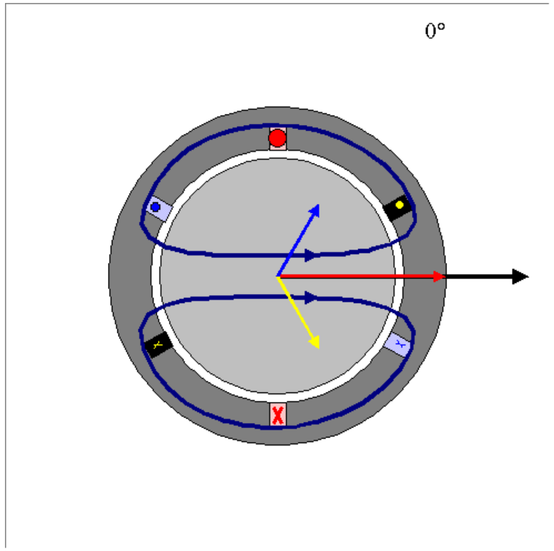


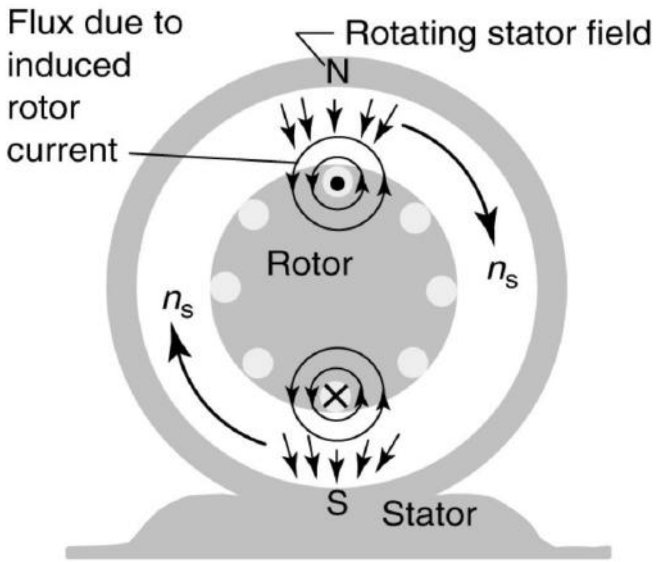


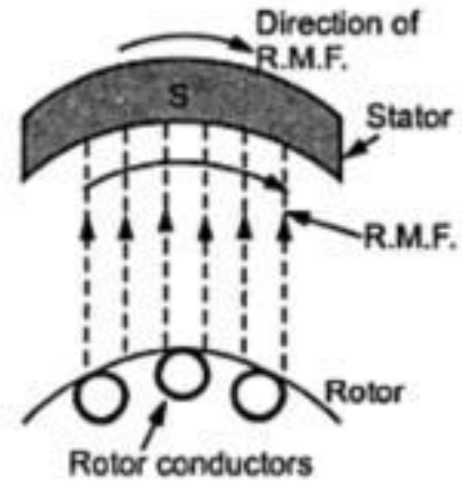


Working Principle

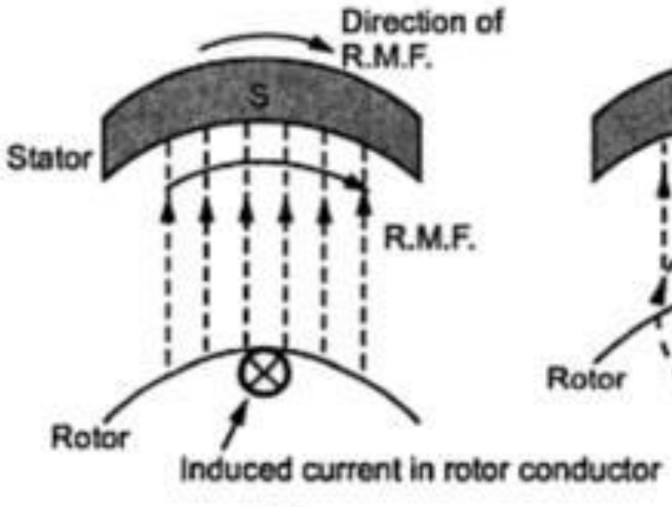








(a)



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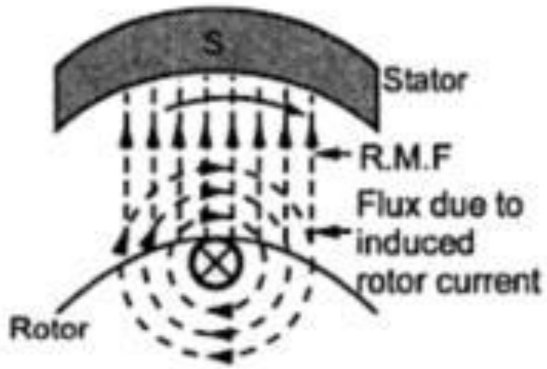

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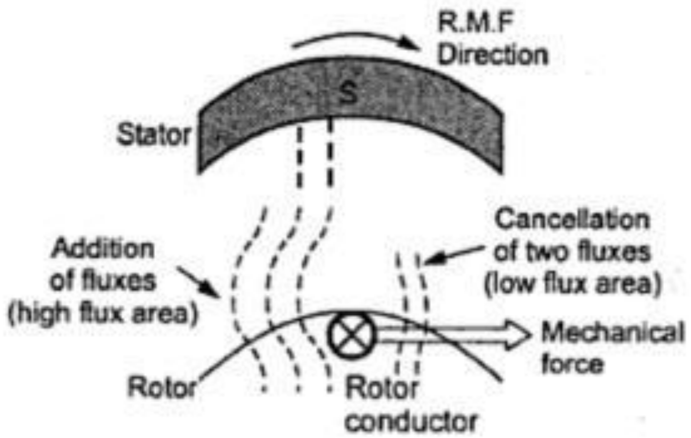


Comparison Squirrel Cage and Slip ring induction motor

Feature	Squirrel Cage	Slip RIng
Construction	Construction is simple	Construction is complicated.
Rotor	Rotor bars made up of aluminum	Three phase winding like stator
End/Slip Rings	Rotor bars (rotor conductors) are short-circuited with the end rings.	The three-phase windings are connected to the slip rings
External Resistance	External resistance can not be added in rotor circuit because the rotor bars are permanently short-circuited.	External resistance can be added in the rotor circuit to limit starting current as well as increase the torque.
Starting Torque	Lower starting torque compared to wound rotor motors	Higher starting torque
Speed Control	Speed control using rotor resistance is not possible as the rotor bars are shorted	Easier speed control by varying the external resistance connected to the rotor winding
Efficiency	Higher efficiency under normal operating conditions	Lower efficiency due to the additional losses in the external resistors and brushes.
Maintenance	maintenance-free as there are no brushes or slip rings.	Requires periodic maintenance of slip rings and brushes.
Cost	Generally lower cost due to simpler construction.	Higher cost due to the additional components and maintenance requirements.

Applications

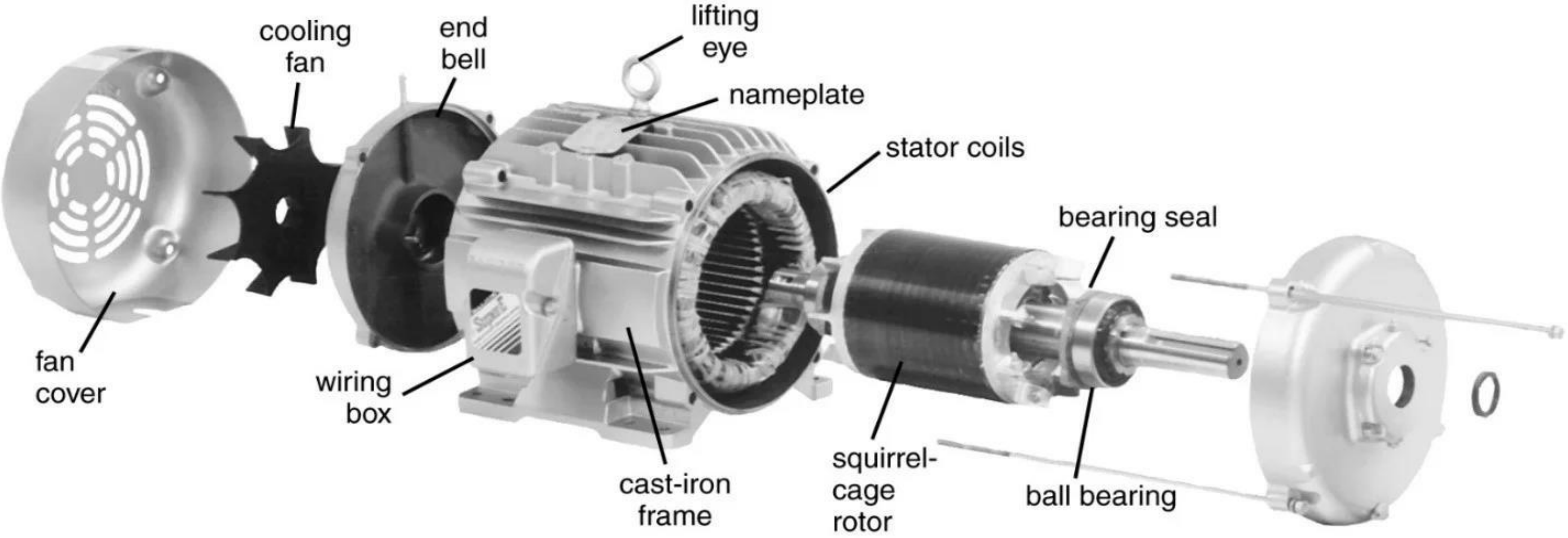
Squirrel Cage
Moderate starting torque, constant speed
Fans
Blowers
Pumps
lathe machine
drill machine
Industrial Drives
Floor Mills

Slip RIng
High starting torque, Variable speed
Lifts
Cranes
Hoists
Elevators
conveyors
Printing Presses
Hoists
Large ventilating fans
Mining
Wind turbine

Single Phase Induction Motor

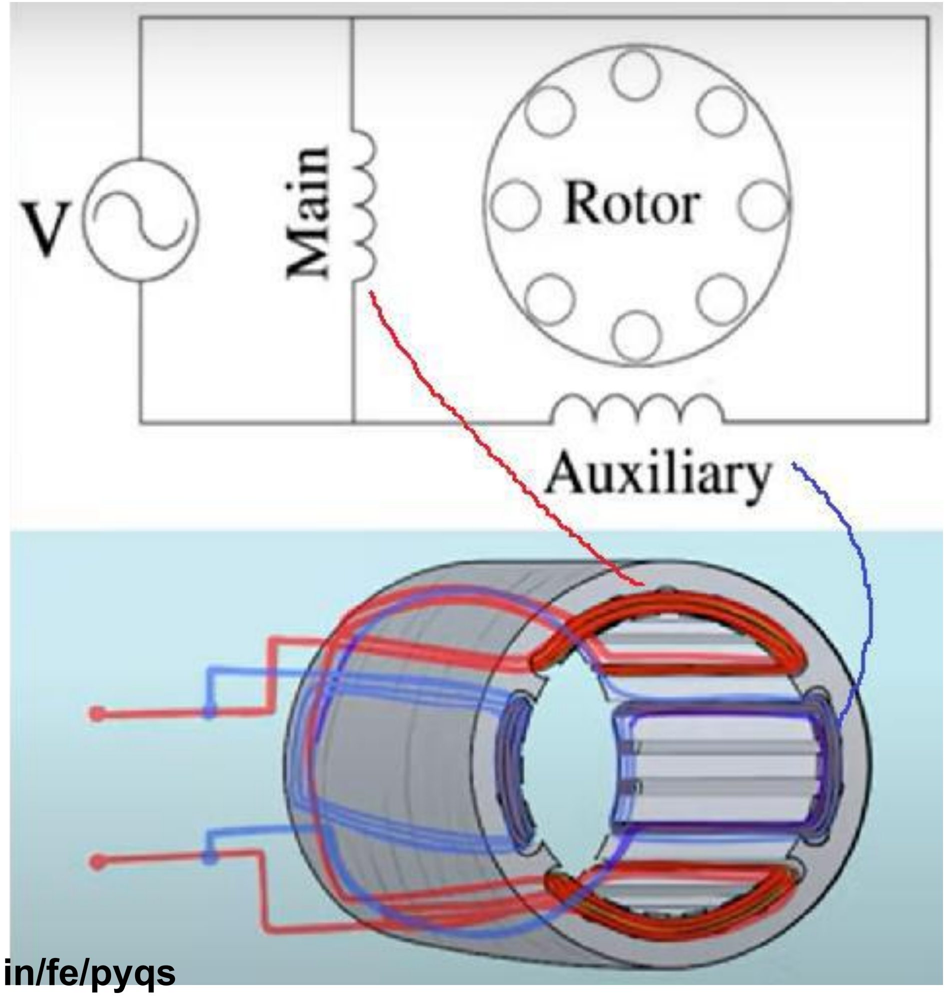
- The single phase induction motor remains one of the most widely used motors for domestic, commercial, and small industrial applications where only single-phase power is available.
- The single phase induction motor stands out as one of the most common and essential devices.
- Simple, easy to build, robust, low cost and maintenance

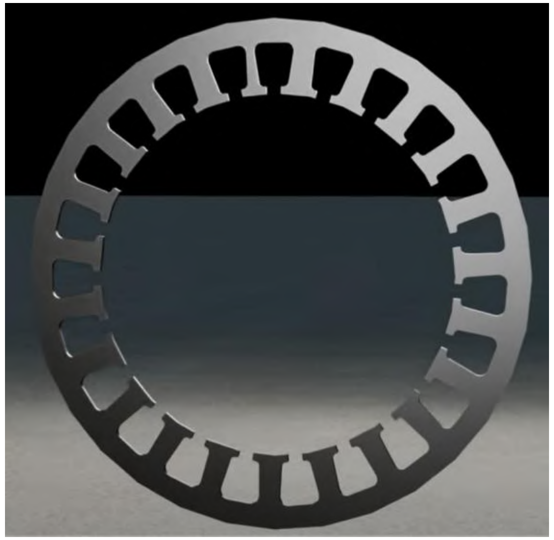
Parts of Single Phase Induction Motor

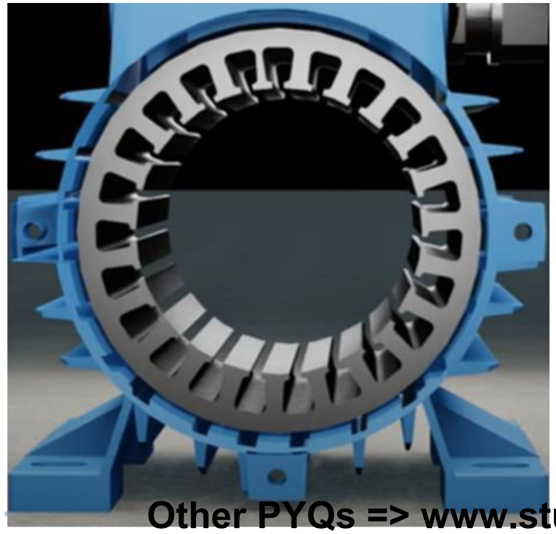


Stator and stator winding : As the name indicates, it is the stationary part of the induction motor and made of silicon steel strips of thickness, varying from 0.3 to 1.35 mm. These strips are combined, which are called laminated strips, and the combination is known as laminated core. These laminated stampings/strips are slotted to receive the winding. The stator core is laminated to reduce the eddy current loss.

In a single-phase induction motor, there are two windings made up of coppers are used in the stator. Out of these two windings, one winding is the main winding and the second is auxiliary winding.



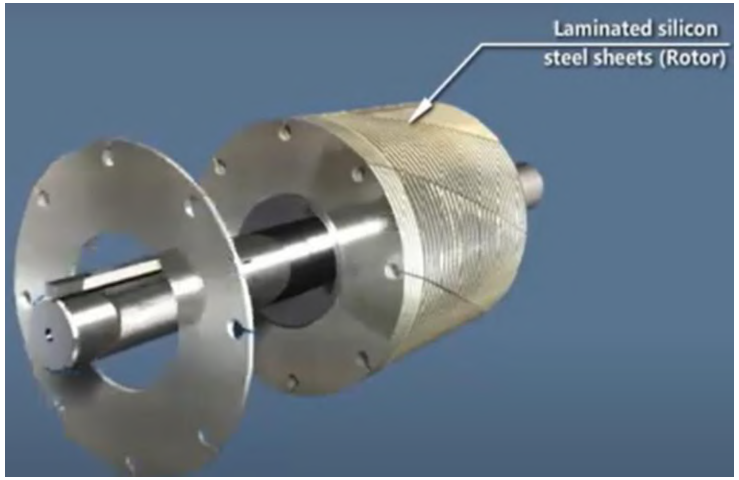


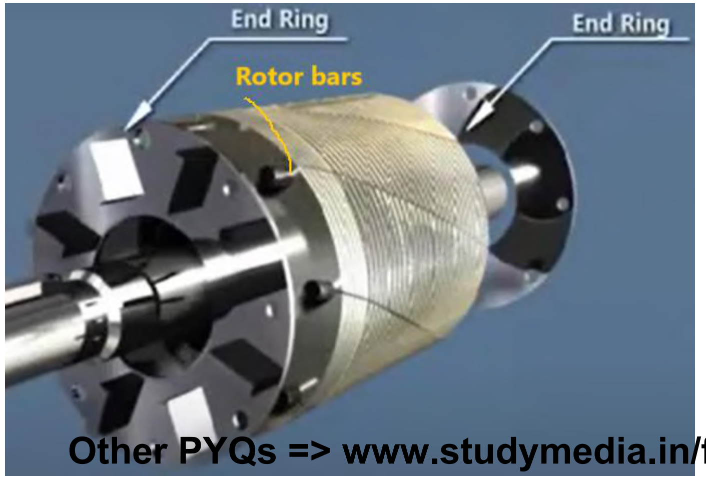


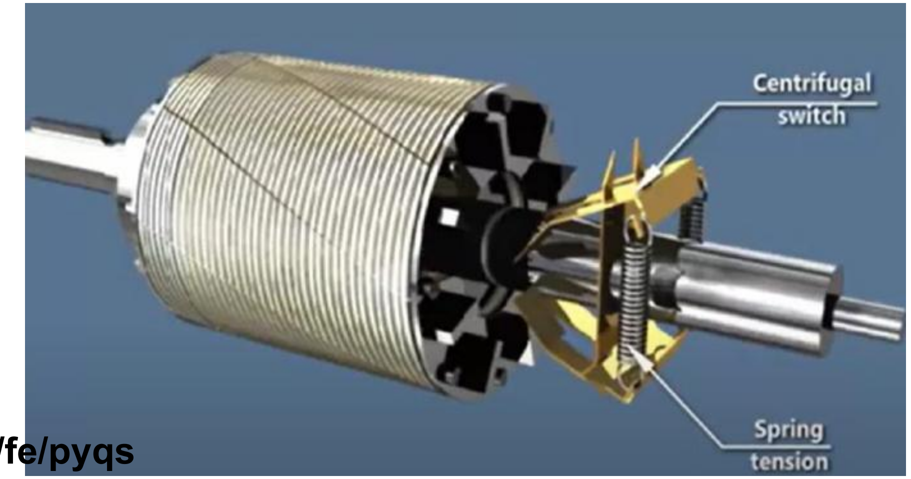
Rotor: The rotor is the rotating part of the motor and made of silicon steel strips. The thickness of these strips varies from 0.3 to 1.35 mm, as in the case of stator. These strips are clamped together to form rotor core, called laminated core. This laminated core is slotted to totally closed type, to receive rotor winding.

In large capacity motors thick aluminum bars are inserted and are short-circuited with end rings. Now a day, melted aluminum is filled in these slots, which works as short-circuited winding. This winding is known as squirrel cage winding. The rotor bars are braced to the end-rings to increase the mechanical strength of the motor.

Centrifugal Switch: As the name indicates, it is a switch, which switches on and switches off on the principle of centrifugal forces. When the motor is at standstill position, the switch contacts remain closed, keeping the starting winding in the circuit and it cut-off the starting winding out of circuit when the motor attains more than the 80 % of the rated speed. When the motor is switched off, the starting winding is again inserted into the circuit by switching on the centrifugal switch.







Working Principle

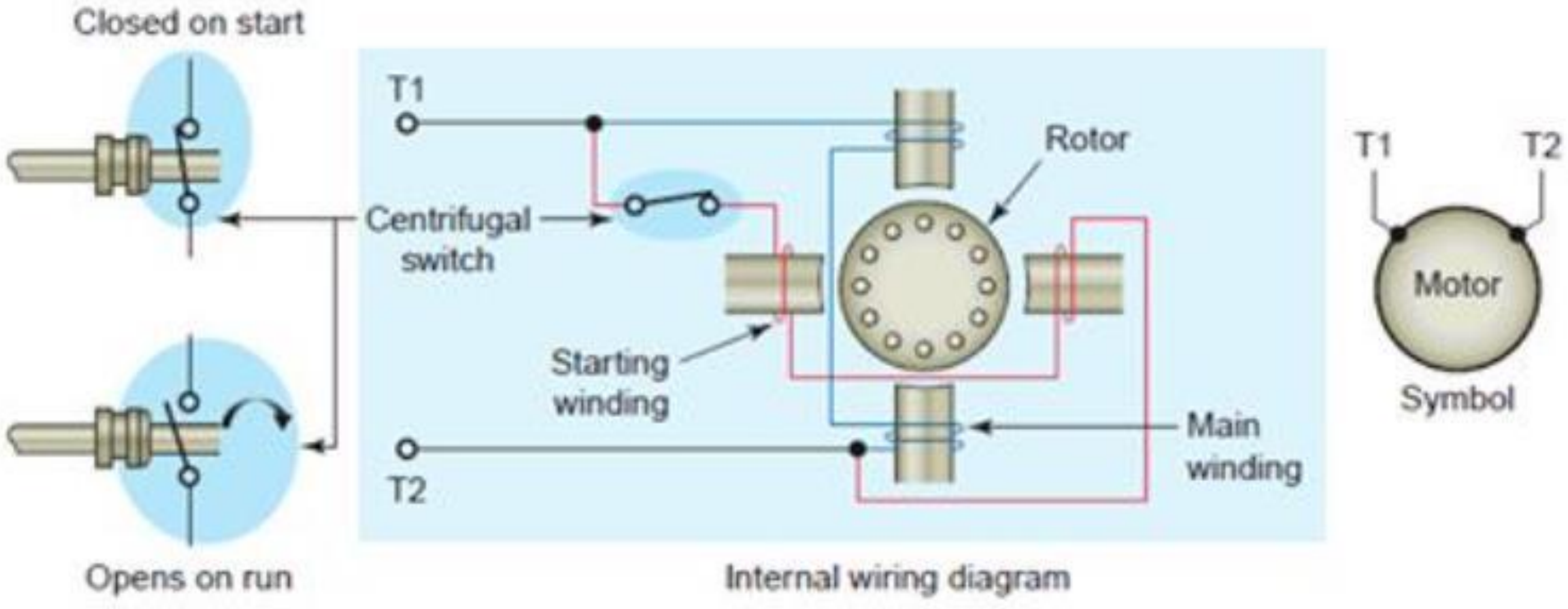
- The working principle of a Single-Phase induction motor is based on Faraday's law of electromagnetic induction.
- AC supply is given to stator windings which is single phase, the current flowing through the winding will produce a magnetic field which is called stator magnetic field.
- The flux lines of this magnetic field will inter react with the rotor conductors
- An emf and current will be induced in the rotor. The induced current will give rise to another magnetic field which is called rotor magnetic field.
- The interaction of the two magnetic fields or magnetic fluxes, one from stator and second from rotor will produce torque.
- But after each half cycle the direction of induced current is change and hence the direction of force (torque) is changed after each half cycle.
- Pulsating flux acting on stationary squirrel cage rotor can't produce rotation and therefore 1-phase induction motor is not self starting.

Working Principle....

- Various techniques are therefore used to derive a quasi-rotating magnetic field for enabling self-starting capability in single phase induction motors.
- To make it self-starting, it can be temporarily converted into a two-phase motor while starting. This can be achieved by introducing an additional 'starting winding' also called as auxillary winding.
- Hence, stator of a single phase motor has two windings: (i) Main winding and (ii) Starting winding (auxillary winding). These two windings are connected in parallel across a single phase supply and are spaced 90 electrical degrees apart. Phase difference of 90 degree can be achieved by connecting a capacitor in series with the starting winding.

Working Principle....

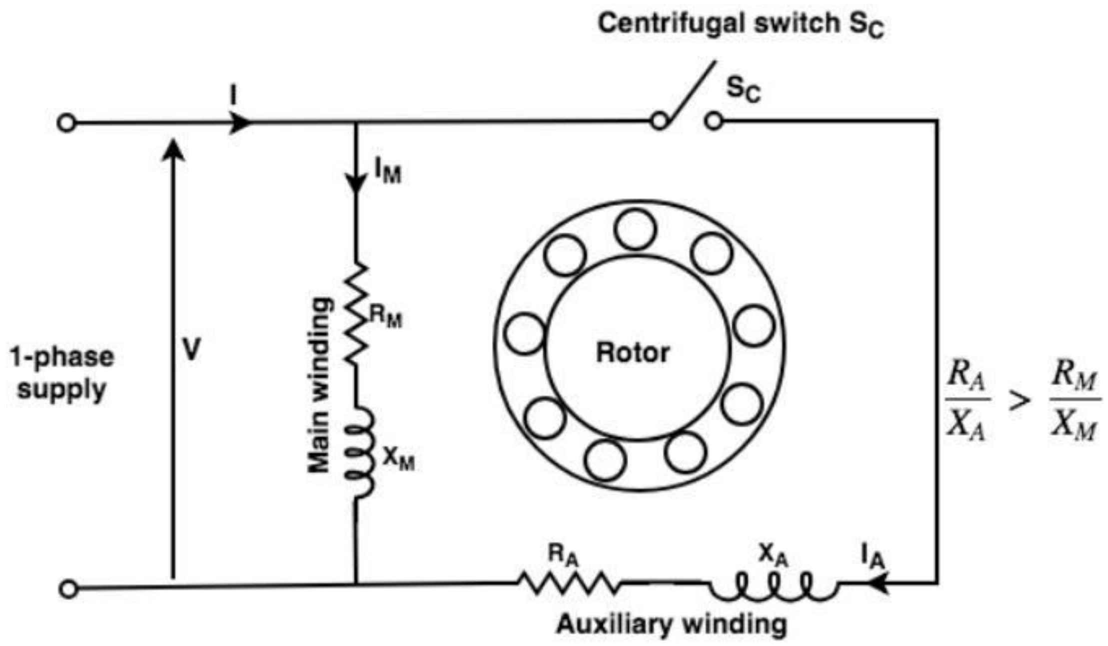
- Hence the motor behaves like a two-phase motor and the stator produces revolving magnetic field which causes rotor to run. Once motor gathers speed, say upto 80 or 90% of its normal speed, the starting winding gets disconnected form the circuit by means of a centrifugal switch, and the motor runs only on main winding.



Applications

Split Phase Induction Motor:

Split-phase motors are most suitable for easily started loads where the frequency of starting is limited, and these are very cheap. The starting torque of a resistance-start induction motor is about 1.5 times full-load torque. The maximum or pull-out torque is about 2.5 times full-load torque.



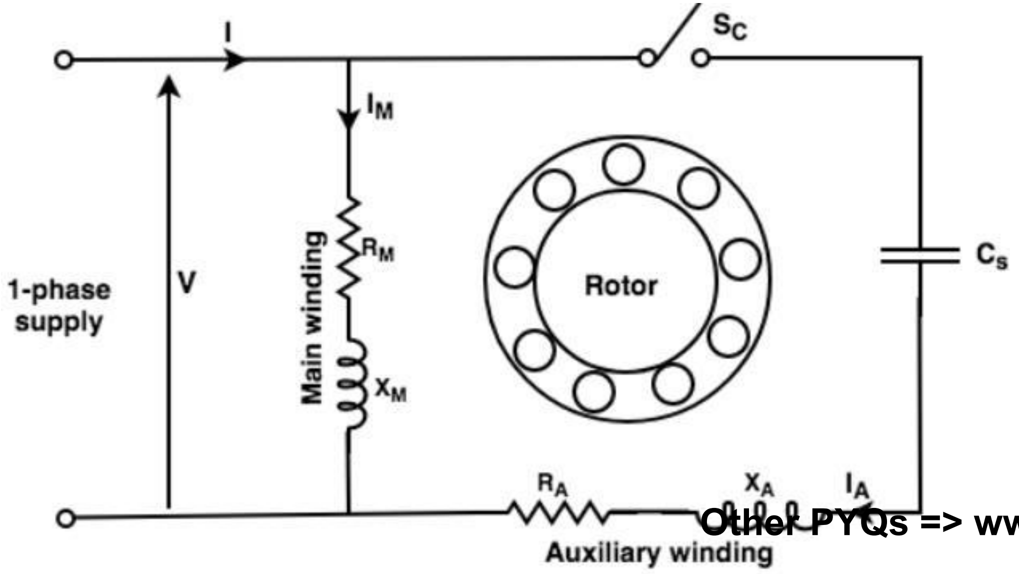
- Washing machines
- Air conditioning fans
- food mixers, grinders
- floor polishers
- blowers, centrifugal pumps
- small drills, lathes
- office machinery

Capacitor motors:

Capacitor motors are the motors that have a capacitor in the auxiliary winding circuit to produce a greater phase difference between the current in the main and auxiliary windings. There are three types of capacitor motors

1. Capacitor-start motor:

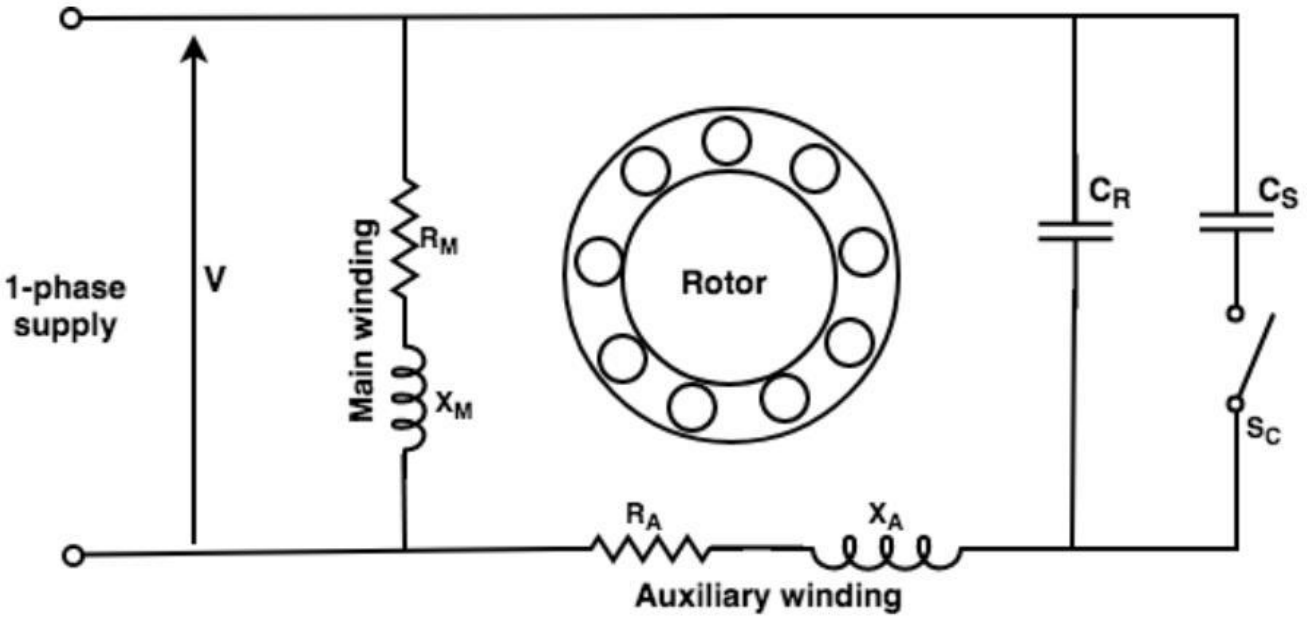
- Develops a much higher starting torque, i.e. 3.0 to 4.5 times the full-load torque.
- To obtain a high starting torque, the value of the starting capacitor must be large, and the resistance of starting winding must be low.
- Electrolytic capacitors of the order of 250 μF are used.



- pumps and compressors
- conveyors

Capacitor Start –Capacitor run Motor

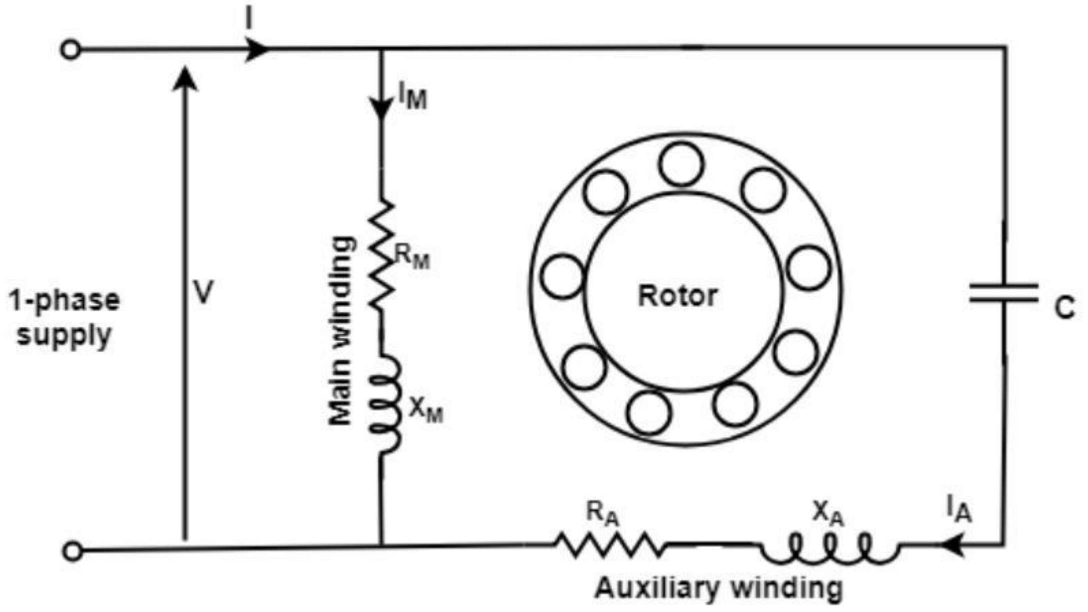
- Two capacitors Cs and C_R are used.
- During starting, these two capacitors are connected in parallel.
- In running condition Cs gets disconnected with the help of centrifugal switch, C_R remains in the circuit
- Improvement in power factor



- Used for loads of higher inertia that requires frequent start.
- Used in pumping equipment.
- Used in refrigeration, air compressors, etc.

Permanent-split Capacitor (PSC) motor:

- Has only one capacitor C which is connected in series with the starting winding.
- The capacitor C is permanently connected in series with the starting winding.
- No centrifugal switch is required.
- has higher efficiency higher power-factor because of a permanently-connected capacitor.
- Low starting torque.
- Paper-spaced oil-filled type capacitors are to be used.



- used for fans and blowers in heaters.
- used in air conditioners.
- used to drive refrigerator compressors.
- used to operate office machinery.
- Ceiling fans

Questions

- Describe construction and working principle of single-phase transformer
- Derive and EMF equation of single-phase transformer
- What is kVA rating of transformer. Explain, why the rating of transformer is expressed in KVA.
- How primary and secondary currents can be calculated from KVA rating.
- Compare core type and shell type transformer
- Explain different losses taking place in transformer. State where these losses takes place and how these losses can be minimized.
- Define is efficiency and regulation of transformer. State the formulae's.
- Explain construction of DC motor with the help of cross-sectional view.
- Explain the working principle of DC motor.
- Draw circuit diagram for DC shunt and series motor. Write the voltage equations.
- Draw torque-armature current, speed- torque and speed-armature current characteristics of DC series and shunt motor
- State applications of DC shunt and series motors

Questions

- Explain the working principle of three phase Induction motor
- Compare squirrel cage and slip ring induction motor
- State the applications of squirrel cage and slip ring induction motor
- What are the main parts of single-phase induction motor
- Explain the working principle of single-phase Induction motor
- Why the single-phase induction motor is not self starting. What arrangement is used to make it self starting motor.
- State applications of resistive split phase, capacitor start, capacitor start-capacitor run and permanent capacitor type single phase induction motor.
- Numericals on single phase transformer
    - Transformation ratio & EMF equation
    - Efficiency at different loading and different power factor