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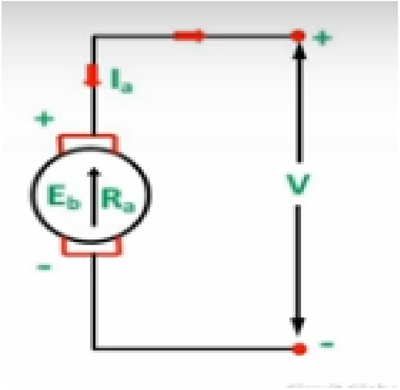
- Back Emf
- Significance of Back Emf
- Torque
- Speed
- Types of motors and applications

Back EMF of DC Motor

- When the armature of a d.c. motor rotates, the windings or conductors on the armature also rotate in the magnetic field. According to the " Faraday's Laws of Electromagnetic Induction " e.m.f. is induced in the conductors, whose direction is in opposition to the applied voltage.
- Since the e.m.f. induced in the armature winding is in the opposite direction, hence it is referred to as back e.m.f. of the motor.
- This back e.m.f. tries to oppose applied voltage V, but it has to drive armature current I_A against the opposing of back emf Eb.
- Recall: Eb= $V - I_A R_A$
- $$V = Eb + I_A R_A$$

Implies, $I_A = \frac{V-E}{R_A}$



Significance of Back emf in a DC Motor

- The back emf makes the DC motor self-regulating machine, i.e., the back emf develops the armature current according to the need of the motor. The armature current of the motor is calculated as:

$$I_A = \frac{V - E}{R_A}$$

At the start, the armature is not moving, and the back EMF is ZERO. The armature current is very high

- The back emf opposes the supply voltage. The supply voltage induces the current in the coil which rotates the armature. The electrical work required by the motor for causing the current against the back emf is converted into mechanical energy. And that energy is induced in the armature of the motor. Thus, we can say that **energy conversion in the DC motor is possible only because of the back emf.**
- The mechanical energy induced in the motor is the product of the back emf and the armature current, i.e., $E_b I_a$.

Explained in torque section

Explanation Slide

Need of Starters for DC Motors:

Since at the time of starting the DC Motor, the dc motor has no back emf.

Thus the armature current is controlled by the resistance of the circuit. The resistance of the armature is low, and when the **full voltage is applied** at the standstill condition of the motor (when rotor does not start to rotate), the armature current becomes very high which damage the parts of the motor.

Since at the time of starting the DC Motor, the starting current is very large. At the time of starting of all DC Motors, except for very small motors, an extra resistance must be connected in series with the armature. This extra resistance is added so that a safe value of the motor is maintained and to limit the starting current until the motor has attained its stable speed.

QUICK QUIZ (POLL)

What will happen if the back emf of a DC motor vanishes suddenly?

a) The motor will stop

b) The motor will continue to run

c) The armature may burn

d) The motor will run noisy

Back EMF of DC Motor

- From Faraday's law of electromagnetic Induction, the induced emf is given by:

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

Ø= Flux/pole

Z= total number of armature conductors

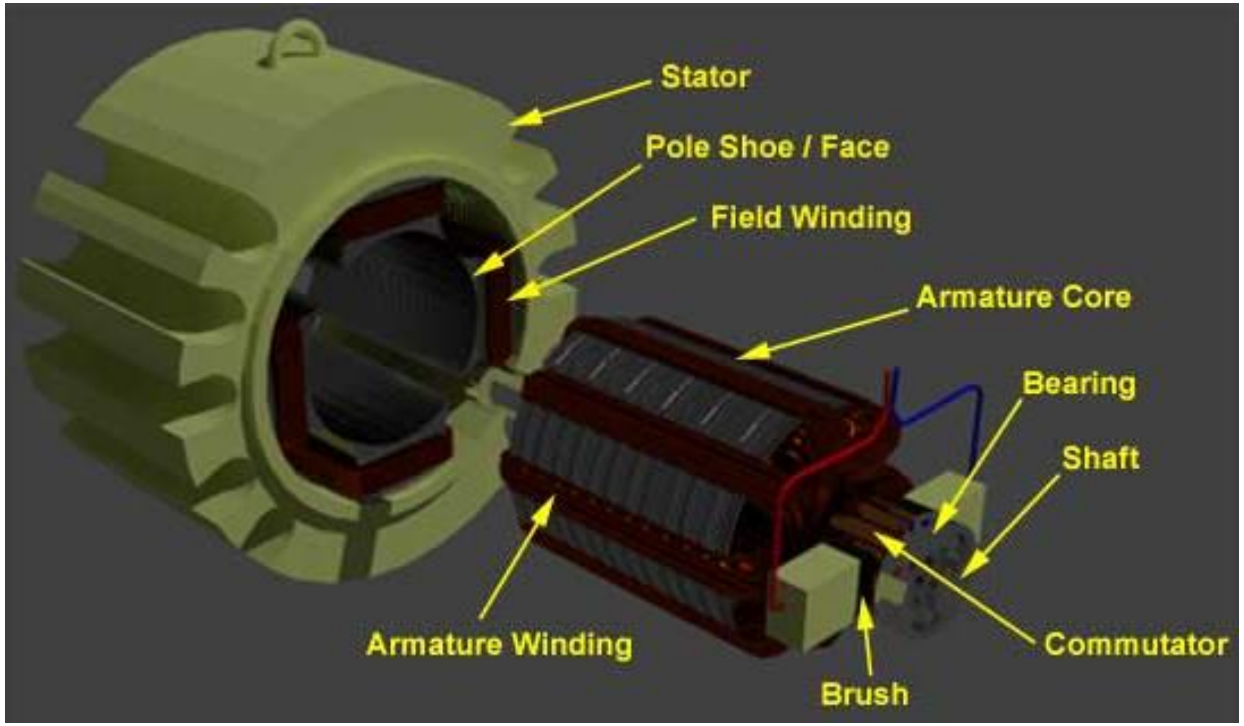
P= number of poles

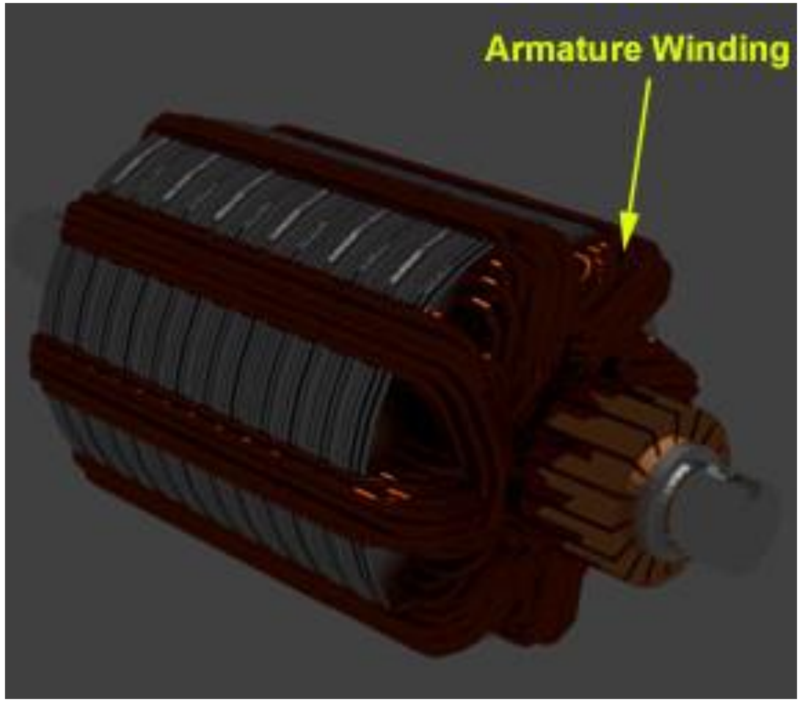
A= number of parallel paths in armature

N= armature rotation in revolutions per minute (rpm)

So, we can write:

$$V = E_b + I_A R_A \qquad (1)$$


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


Armature Winding

Speed Regulation of DC Motor

- For a given machine A, Z and P are fixed., so the expression for back emf becomes:

$$E_b = \frac{NP\emptyset Z}{60A} = kN\emptyset$$

So, we can write eq. (1) as:

$$V = kN\emptyset + I_A R_A$$

Implies, $N = \frac{V - I_A R_A}{k\emptyset}$

Thus the speed of the d.c motor can be regulated by:

1. Applied voltage
2. Armature Resistance
3. Flux

QUICK QUIZ (POLL)

Speed of DC motor can be controlled by varying

A. Applied voltage.

B. Its flux.

C. Resistance of armature.

D. All of these.

Torque developed by DC Motor

- From eq. (1), we know that:

$$V = E_b + I_A R_A$$

Multiply both sides by I_A

$$V I_A = E_b I_A + I_A^2 R_A$$

- Here, $V I_A$ represents total electric power supplied to the armature.
- $I_A^2 R_A$ represents the losses due to the armature resistance.
- The difference between the two quantities represents the electrical power that is converted to a mechanical power by the armature.

Torque developed by DC Motor

- Recall:

$$VI_A = E_bI_A + I_A^2R_A$$

- Now, if τ is the torque in Newton-metres exerted on the armature to develop the mechanical power (E_bI_A) at the speed of N rotations per minute (rpm), then:

Mechanical Power developed, $P_m = \tau\omega = \frac{2\pi N}{60}\tau$

Implies, $E_bI_A = \frac{2\pi N}{60}\tau$

Or, $\frac{NP\emptyset Z}{60A} I_A = \frac{2\pi N}{60}\tau$

For a given machine, A, Z and P are fixed. So, we can write:

$$\tau = k\emptyset I_A$$

QUICK QUIZ (POLL)

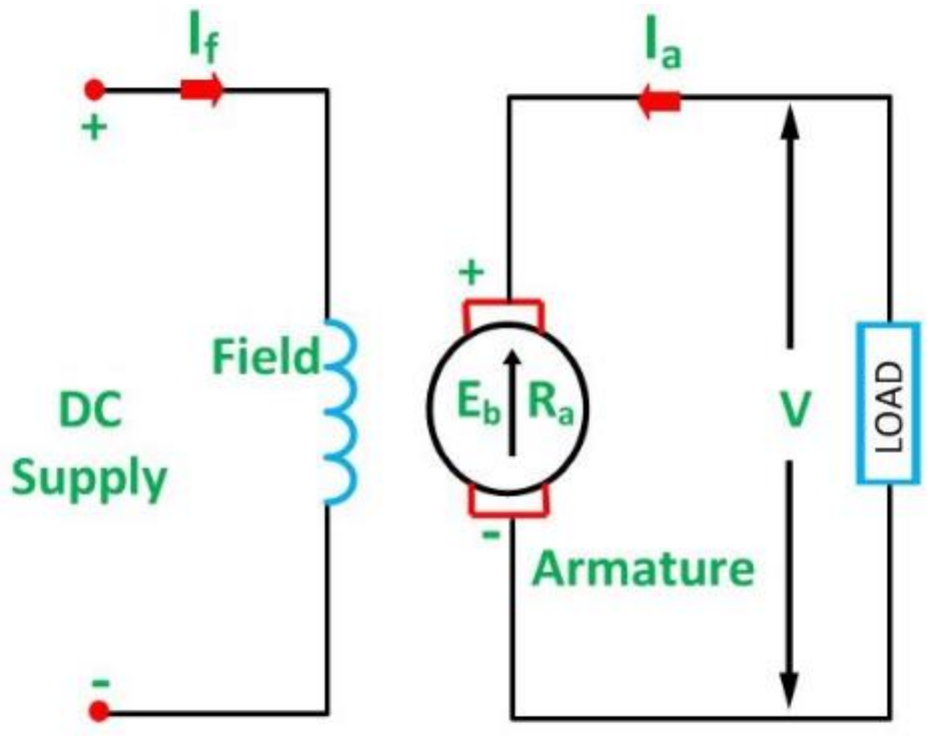
The current drawn by the armature of DC motor is directly proportional to _________________

a) Torque
b) Speed
c) The voltage across the terminals
d) Cannot be determined

DC Machine as a Motor

- The current I_A flows in the opposite direction to that of the generated emf, and the terminal voltage V is more than the emf E due to the armature circuit voltage drop. Thus we have:

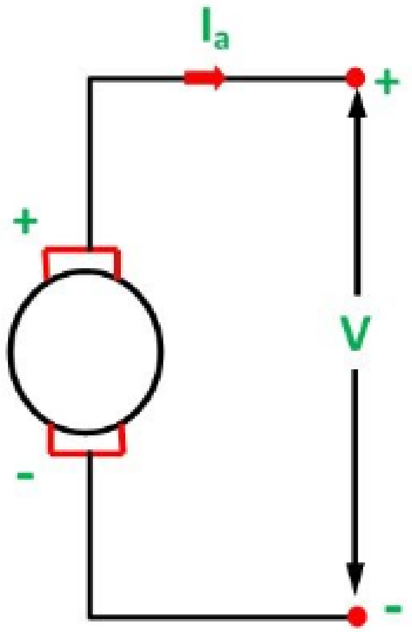
$$V = E + I_A R_A$$



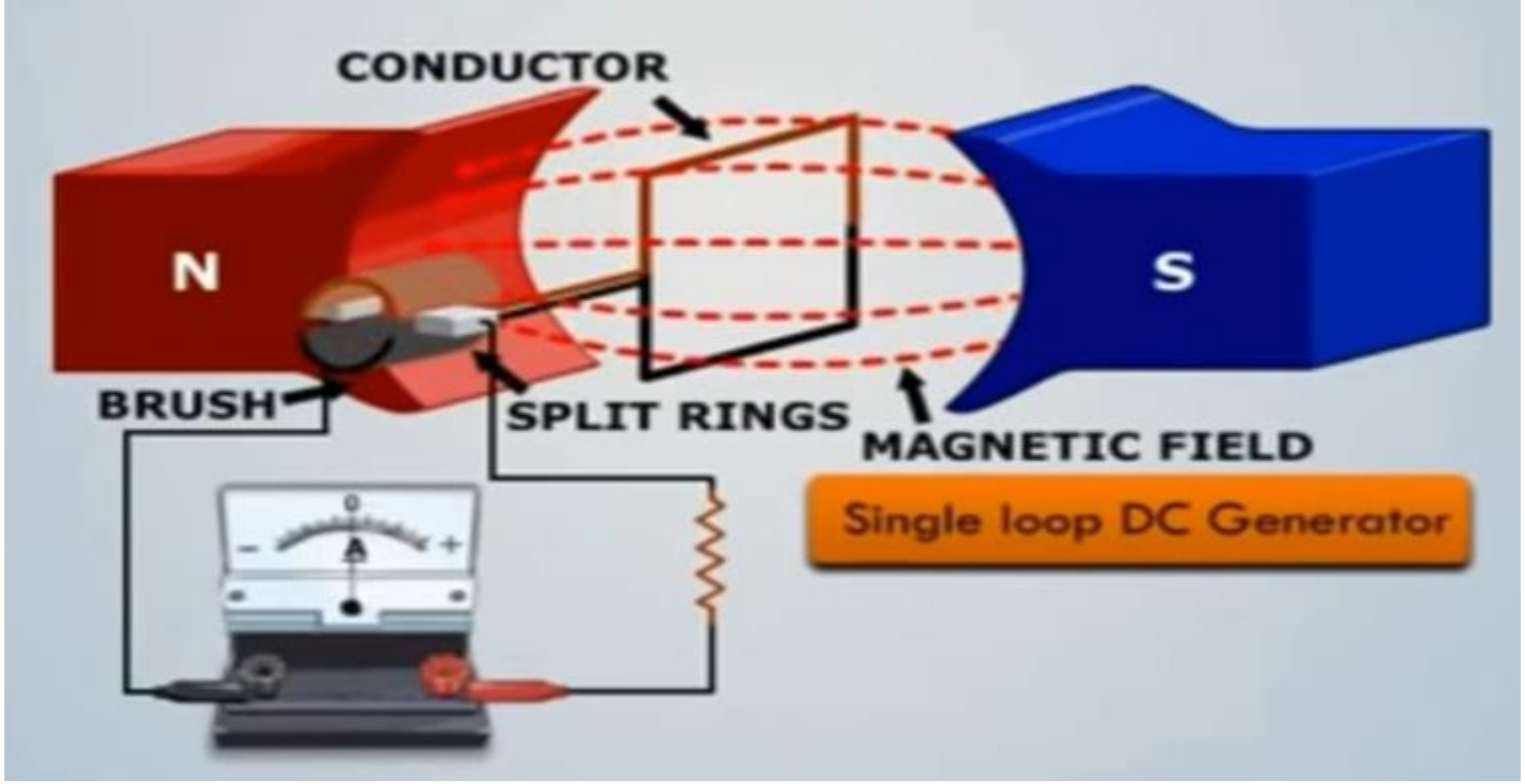
DC Machine as a Generator

- The current I_A flows in the same direction as the generated emf, and the terminal voltage V is less than the emf E due to the armature circuit voltage drop. Thus we have:

$$V = E - I_A R_A$$

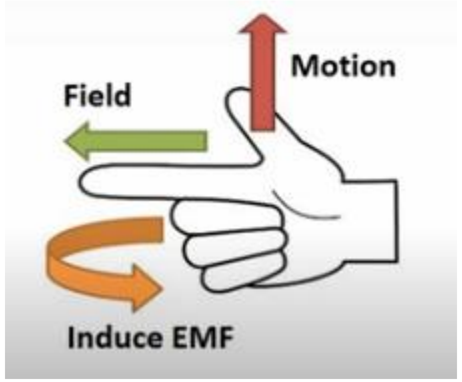


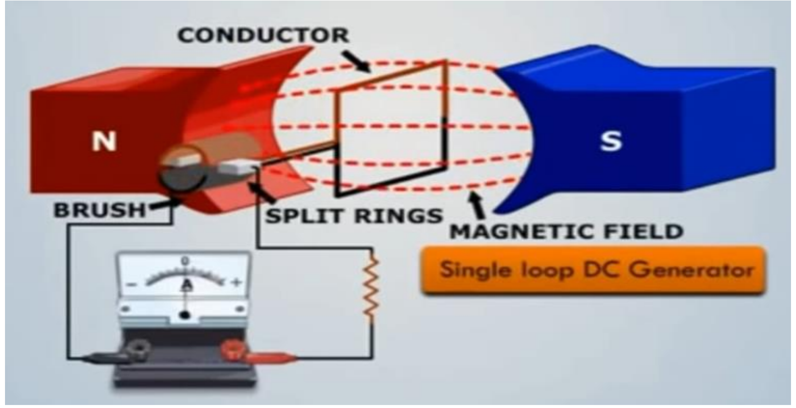
Working Principle of a DC Generator



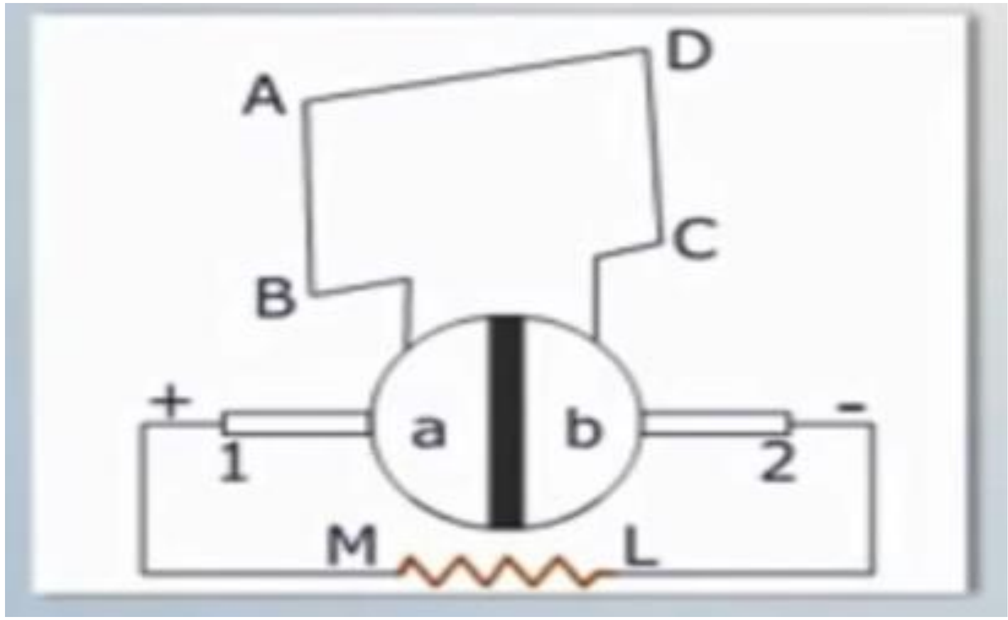
Working Principle of a DC Generator

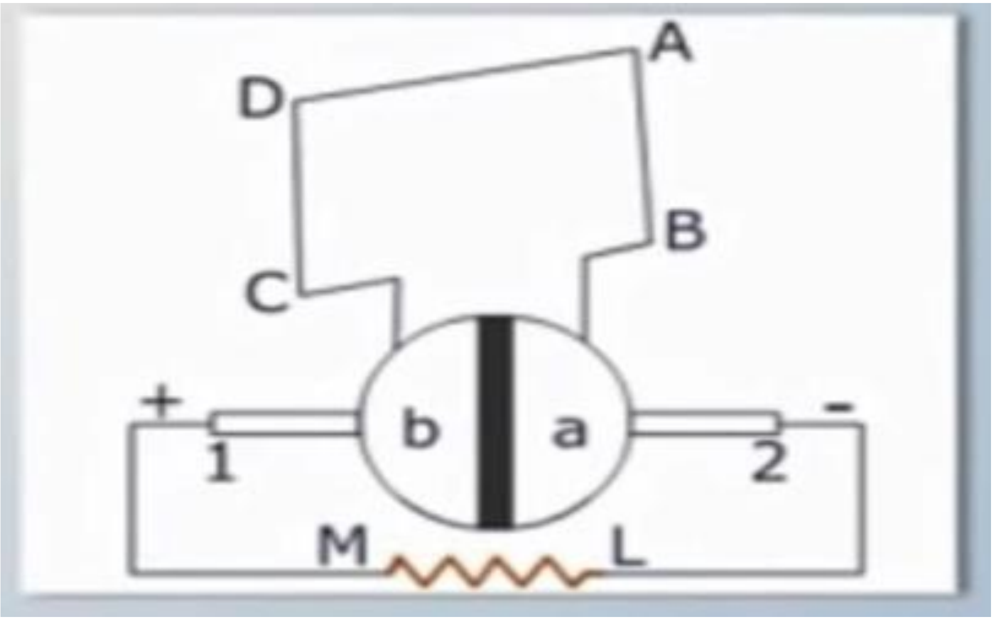
- Based on the principle of Faraday's law of electromagnetic induction.
- This law states that: when a conductor moves in a magnetic field it cuts magnetic lines of force, which induces an electromagnetic force (EMF) in the conductor.
- The magnitude of this induced EMF depends upon the rate of change of flux (magnetic line force) linkage with the conductor.
- This EMF will cause a current to flow if the conductor circuit is closed.
- The direction of this induced emf can be found out using Fleming's Right Hand Rule.





Commutation in a DC Generator

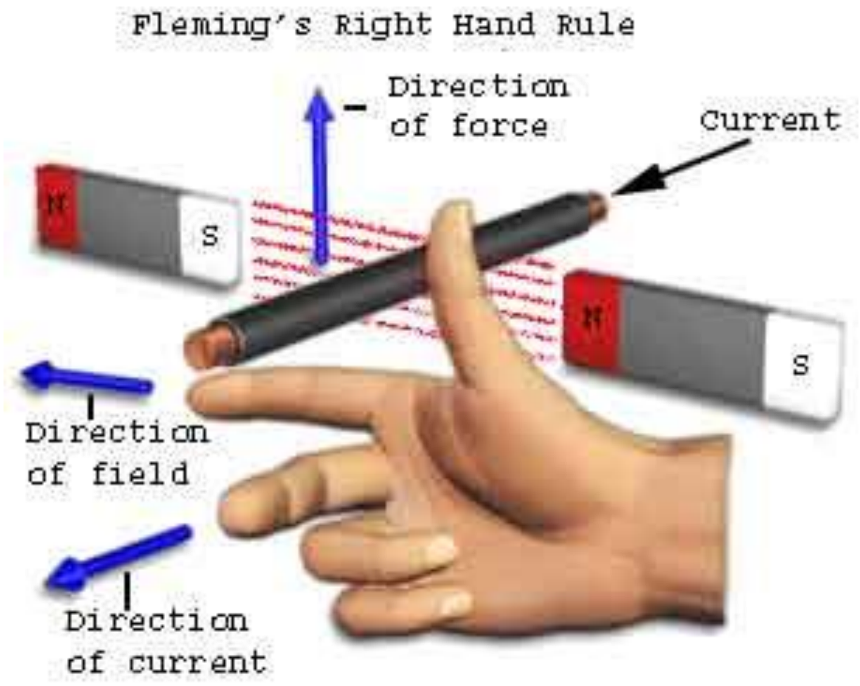




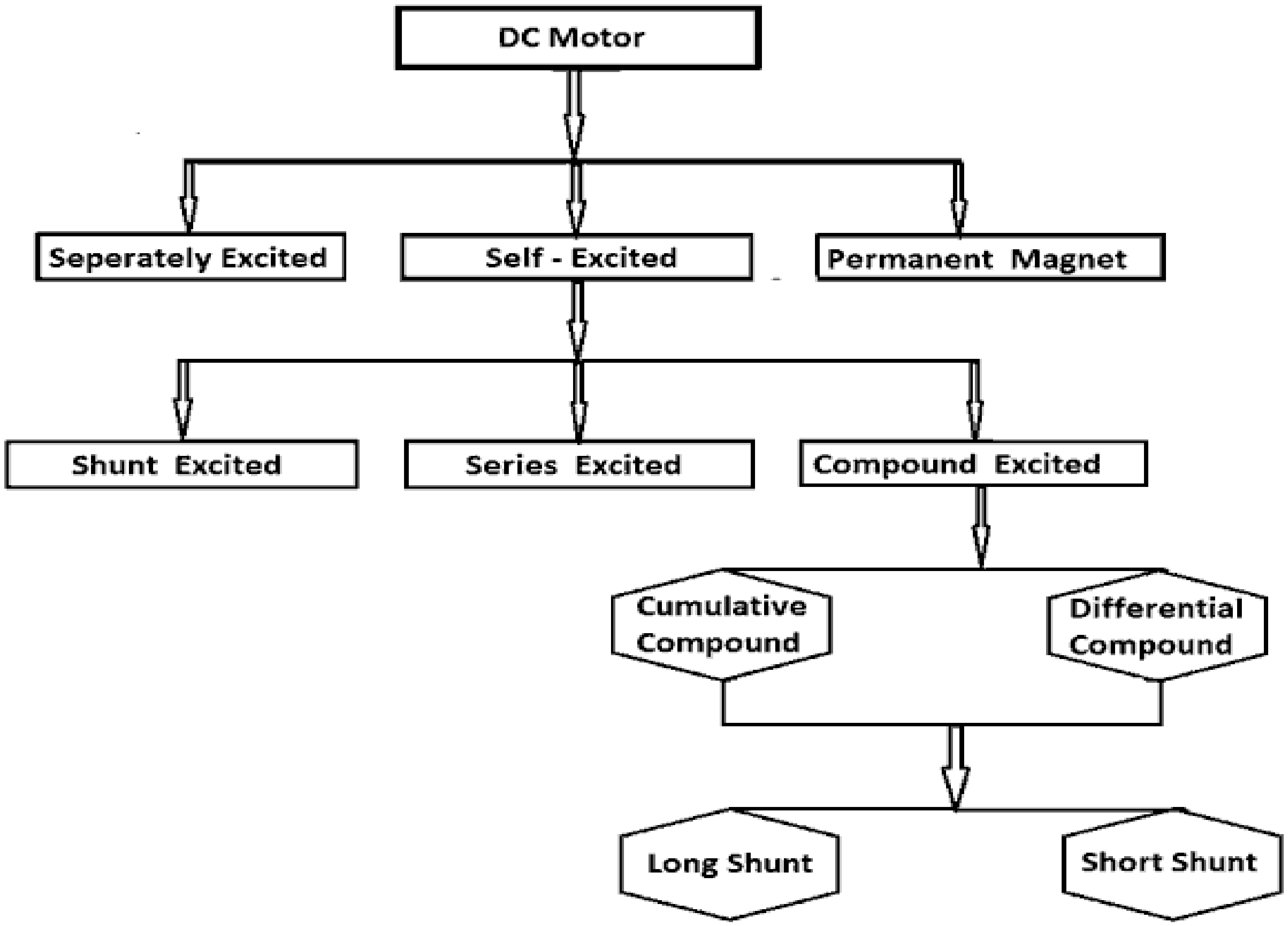
Fleming's Right Hand Rule

Statement:

The thumb, fore finger and middle finger of the right hand are stretched to be perpendicular to each other. If the thumb represents the direction of the movement of conductor, fore-finger represents direction of the magnetic field, then the middle finger represents direction of the induced current.



Classification of DC Motors

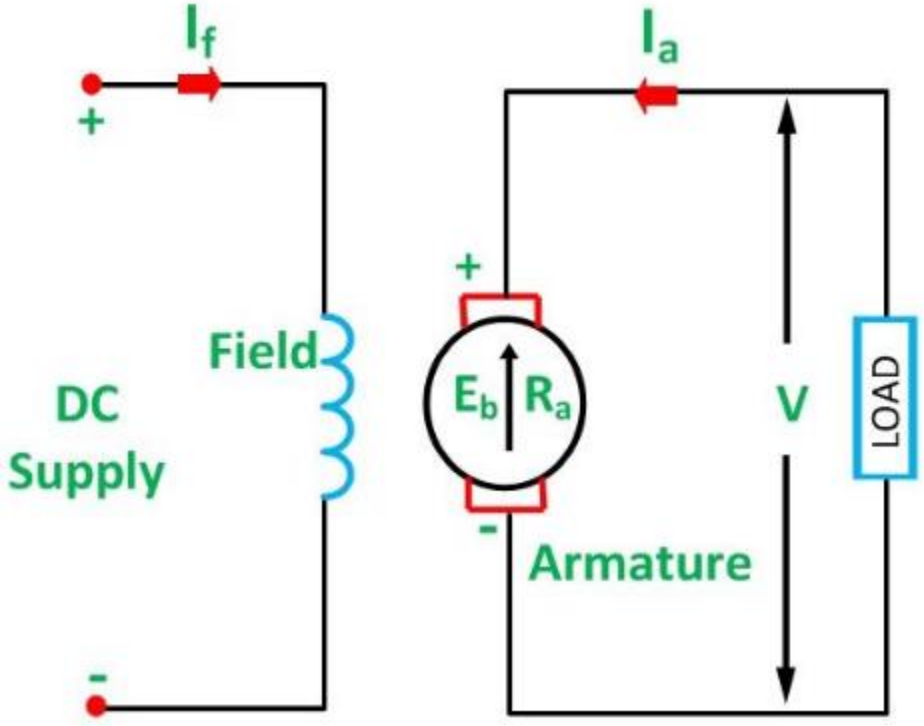


Separately Excited DC Motor

- As the name signifies, the field coils or field windings are energized by a separate DC source.

Applications:

- Separately excited DC motors are often used in trains and automotive traction applications.



QUICK QUIZ POLL

- How many supplies required in **Separately** excited DC motor:

A) 1 DC Supplies

B) 2 DC Supplies

C) 1 AC Supplies

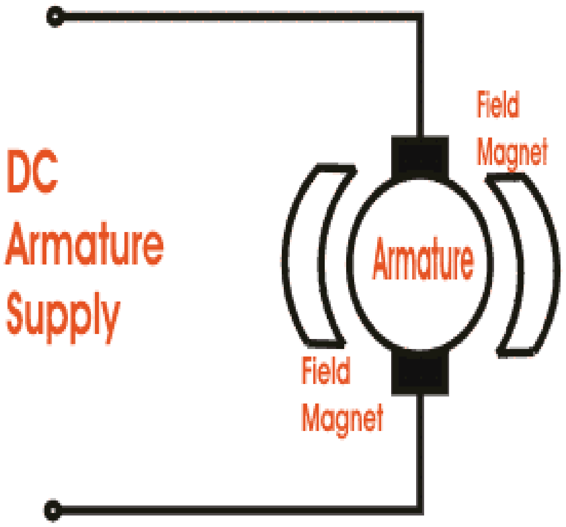
D) 2 AC Supplies

Permanent Magnet DC Motor

- consists of an armature winding as in case of an usual motor, but does not contain the field windings.
- Magnetic field strength is fixed.

Applications:

1. used in toy industries.
2. electric toothbrushes, portable vacuum cleaners
3. portable electric tool such as drilling machines.



QUICK QUIZ (POLL)

The magnetic field strength remains constant in

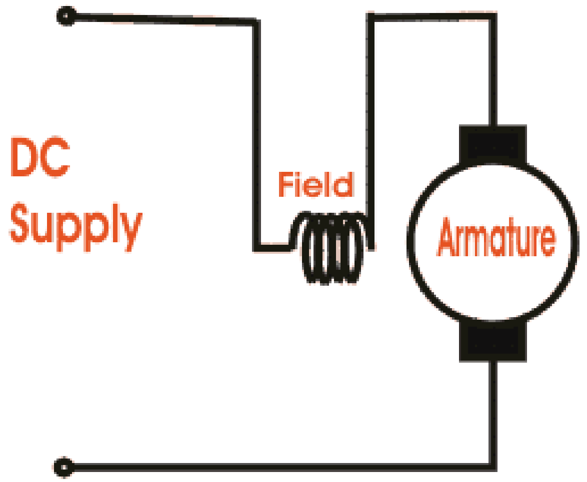
A. Shunt dc motor
B. series dc motor
C. PMDC Motor
D. Compound dc motor

Series DC Motor (Self-Excited)

- The armature and field winding are connected in series.
- Field resistance should be low, otherwise armature current would decrease. That results in lower value of torque.
- This is achieved by using field windings of thick wire and lesser number of turns.

Important Properties:

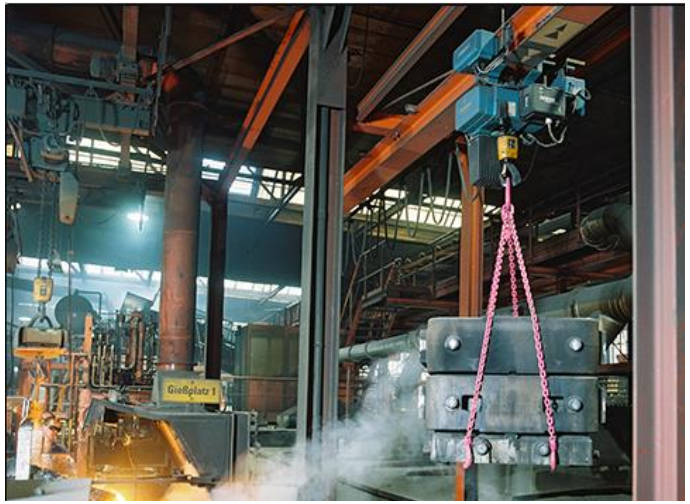
- High starting torque.



Applications of DC Motors

Series Motor:

- Cranes
- Hoists , Elevators
- Trolleys
- Conveyors
- Electric locomotives

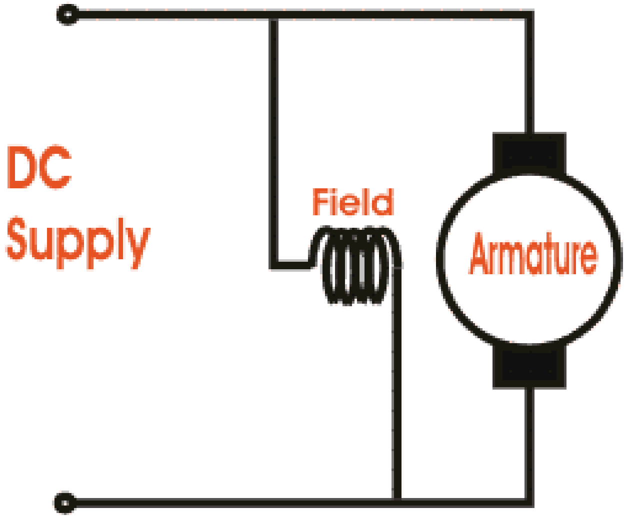


Shunt DC Motor (Self-Excited)

- in which the field winding is connected in parallel with the armature.
- Field resistance should be high, otherwise maximum current would flow across the field winding. That results in lower value of torque.
- This is achieved by using field windings of thin wire and more number of turns.

Important Properties:

- Constant Speed of Operation.



Applications of DC Motors

Shunt Motor:

- Blowers and fans
- Lathe machines
- Machine tools
- Milling machines
- Drilling machines

QUICK QUIZ (POLL)

Which of the following motors is used in blowers?

A. Shunt dc motor

B. series dc motor

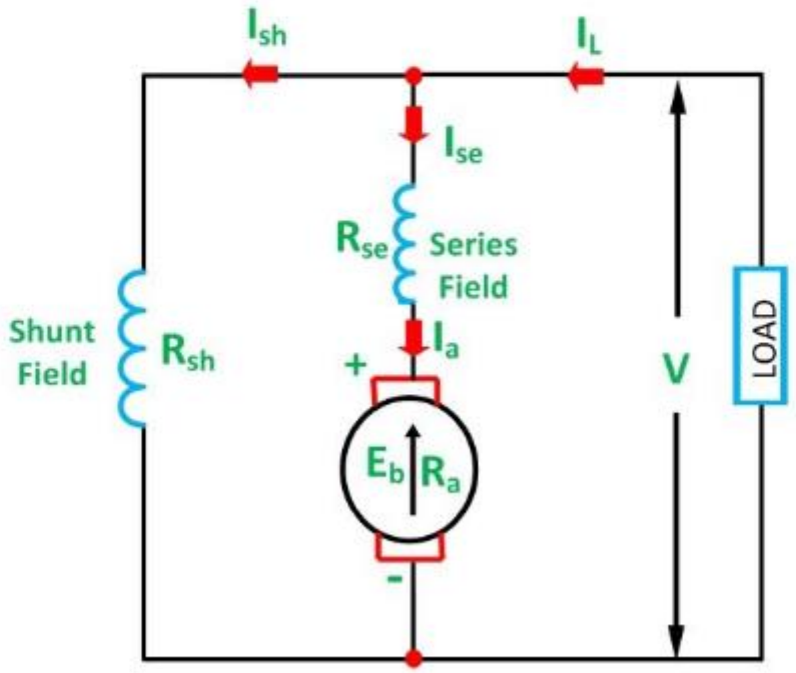
C. PMDC Motor

D. Compound dc motor

Cumulatively Compound DC Motor (Self-Excited)

- A DC Motor having both shunt and series field windings is called a Compound Motor.
- In a cumulative compound motor the flux produced by both the windings is in the same direction, i.e.

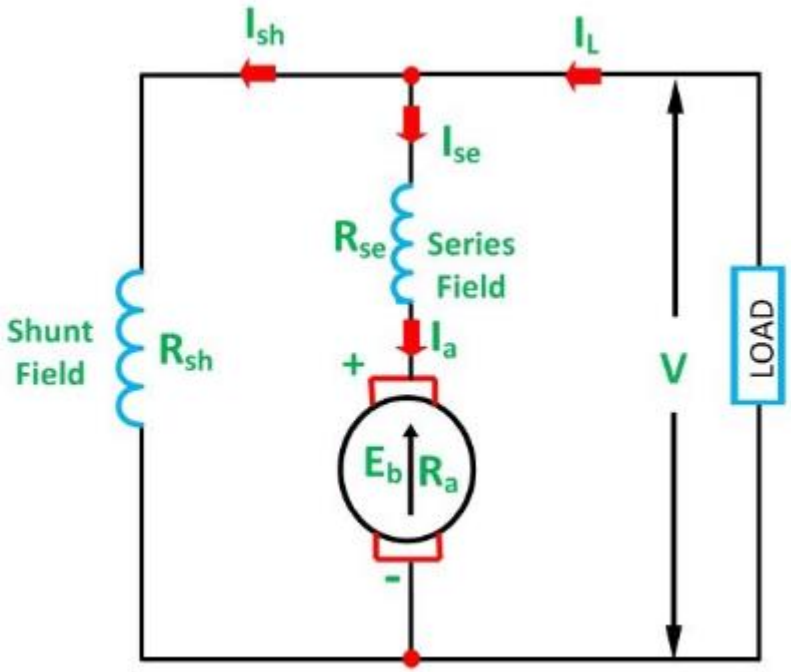
$$\phi_{total} = \phi_{series} + \phi_{shunt}$$



Differentially Compound DC Motor (Self-Excited)

- A DC Motor having both shunt and series field windings is called a Compound Motor.
- In differential compound motor, the flux produced by the series field windings is opposite to the flux produced by the shunt field winding, i.e.

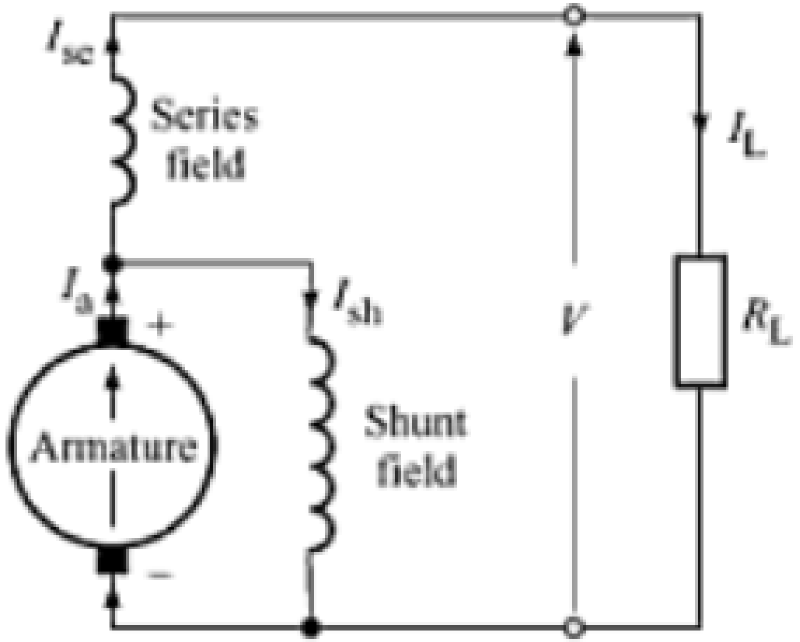
$$\phi_{total} = \phi_{series} - \phi_{shunt}$$

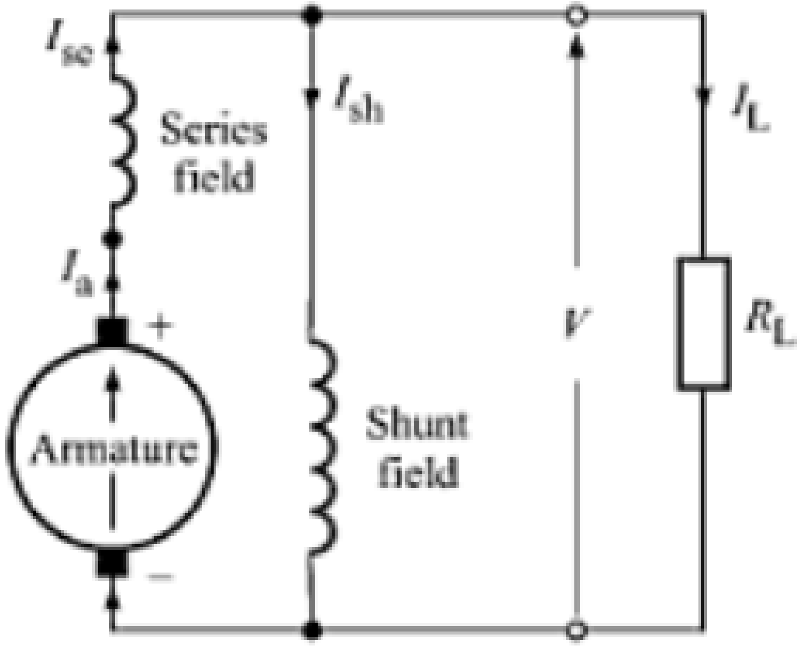


Long Shunt and Short Shunt Compound DC Motors (Self Excited)

If the shunt field winding is only parallel to the armature winding and not the series field winding then its known as short shunt DC motor or more specifically short shunt type compound wound DC motor.

If the shunt field winding is parallel to both the armature winding and the series field winding then it's known as long shunt type compounded wound DC motor or simply long shunt DC motor.

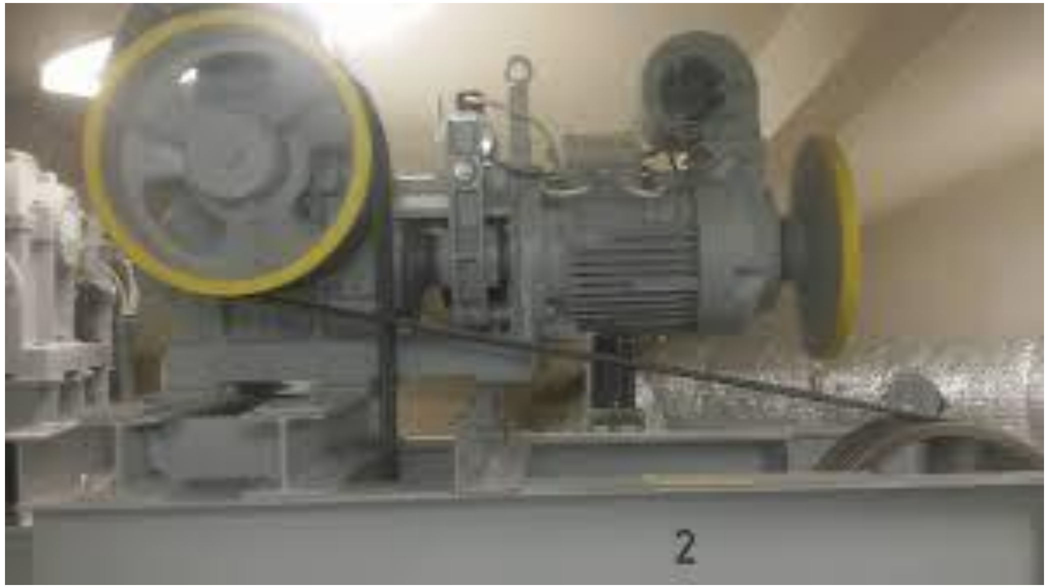




Applications of DC Motors

<u>Cumulative compound Motor:</u>

- Rolling mills
- Punches and Shears
- Elevators



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.
- Also called as **Asynchronous Motors**.
- Depending on the number of phases, it can be classified as:

1. Single Phase Induction Motor
2. Three Phase Induction Motor

Three Phase Induction Motor

- Three-phase AC induction motors are widely used in industrial and commercial applications.
- Induction motors are used in industry and domestic appliances because these are rugged in construction requiring hardly any maintenance, that they are comparatively cheap, and require supply only to the stator.
- These are of two types, squirrel cage and slip ring motors.
- Squirrel cage motors are widely used due to their **rugged construction and simple design**.
- Slip ring motors require external resistors to have high starting torque.

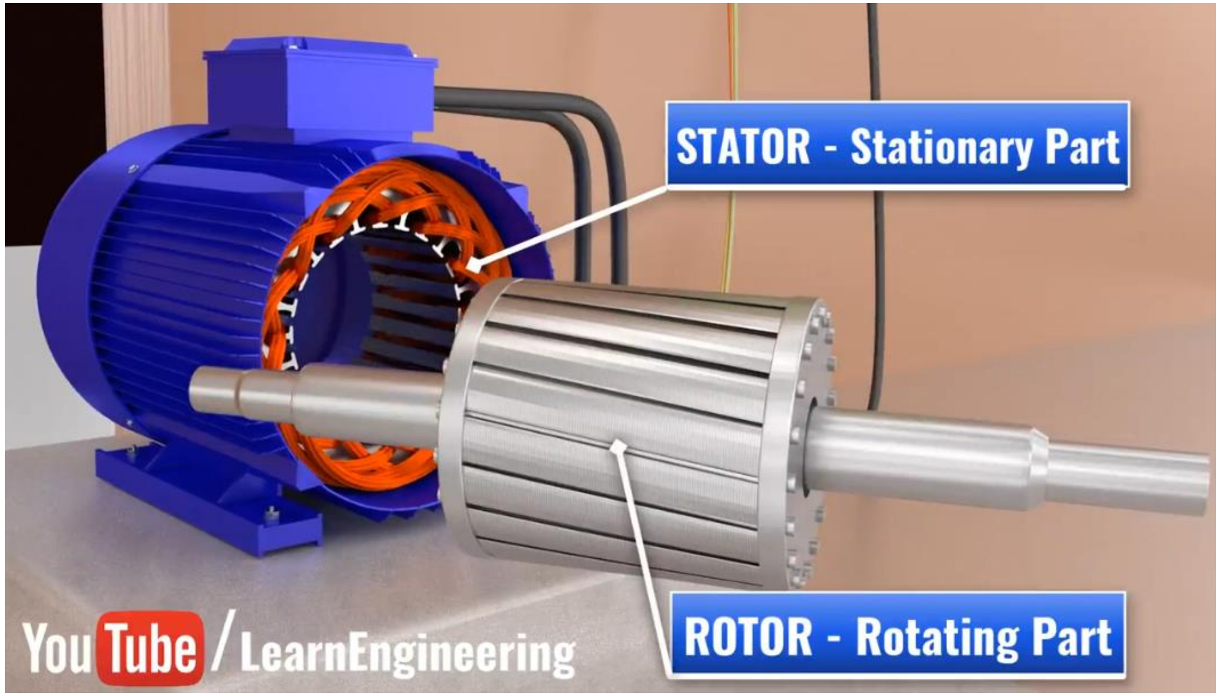
Construction of 3 Phase Induction Motor

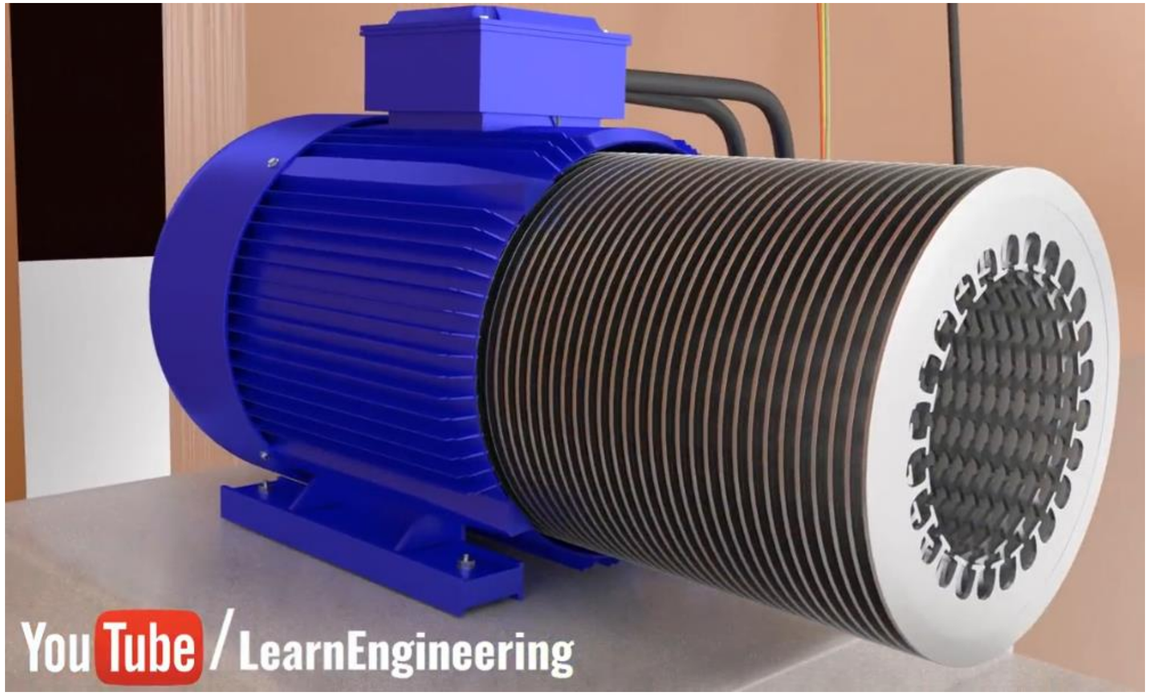
STATOR

- Consists of outer frame, core and the stator windings
- Carries a 3-phase winding (3-Phase Induction Motor) OR
- The revolving magnetic flux induces an e.m.f. in the rotor by mutual induction.

ROTOR

- The squirrel cage rotor consists of **aluminum, brass or copper** bars. These bars are called rotor conductors and placed in the slots on the periphery of the rotor. The copper or aluminum rings permanently short the rotor conductors called the end rings.
- As end rings **permanently short** the bars, the rotor electrical resistance is very small and it is not possible to add external resistance as the bars get permanently shorted.


STATOR - Stationary Part
ROTOR - Rotating Part
YouTube / LearnEngineering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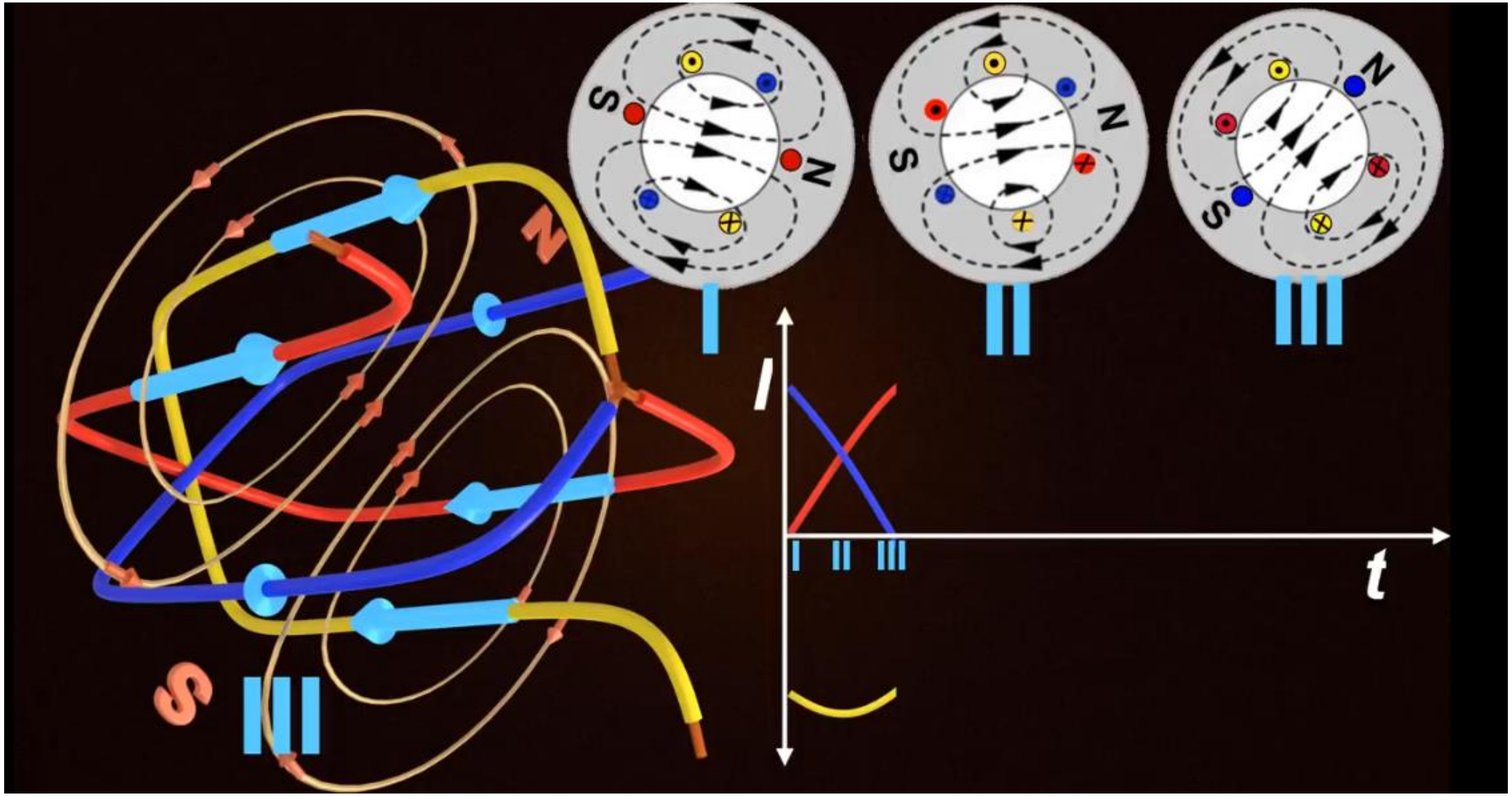
Working Principle of 3 Phase Induction Motor

- https://www.youtube.com/watch?v=AQqyGNOP_3o
- The stator of the motor consists of overlapping winding offset by an electrical angle of 120°. When we connect the primary winding, or the stator to a 3 phase AC source, it establishes rotating magnetic field which rotates at the synchronous speed.
- According to Faraday's law, an e.m.f. would be induced in any circuit whenever there is a rate of change of magnetic flux linkage through the circuit.
- As the rotor winding in an induction motor are either closed through an external resistance or directly shorted by end ring, and cut the stator rotating magnetic field, **an emf is induced in the rotor copper bar** and due to this emf a **current flows through the rotor conductor**.
- Here the relative speed between the rotating flux and static rotor conductor is the cause of current generation.



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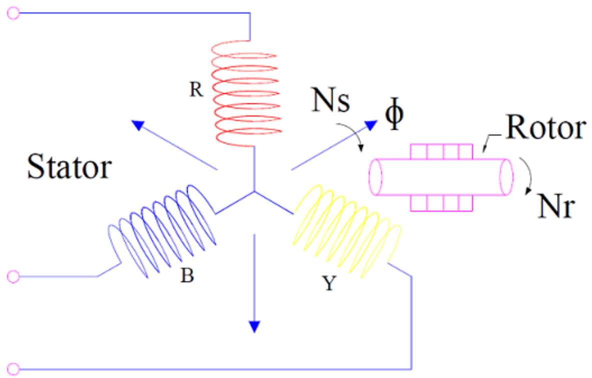

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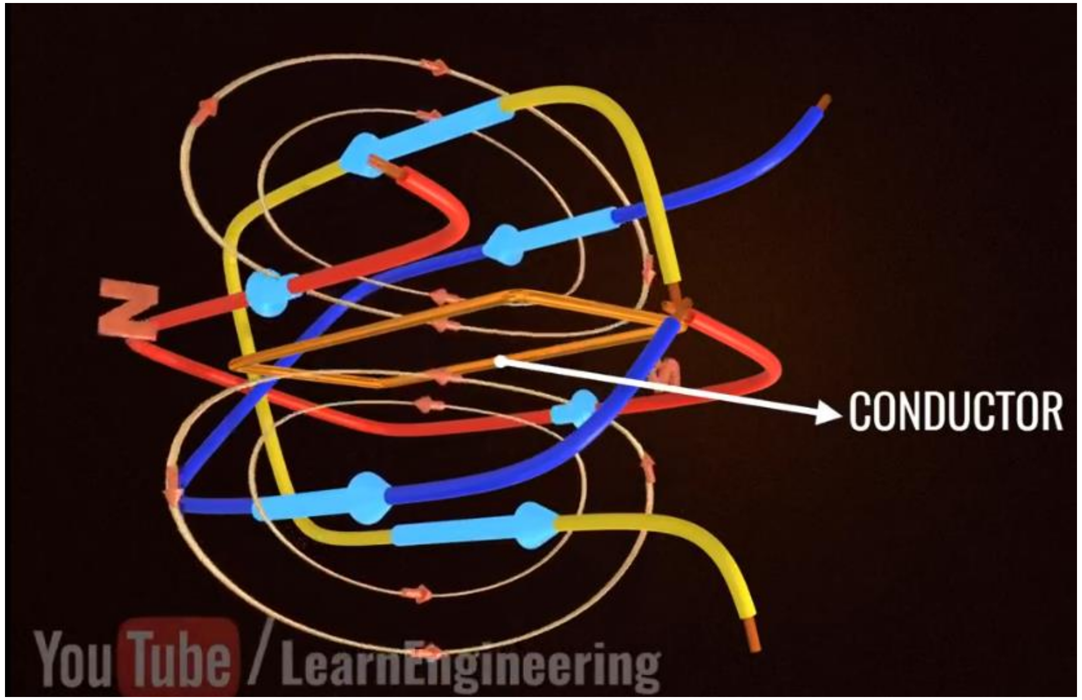
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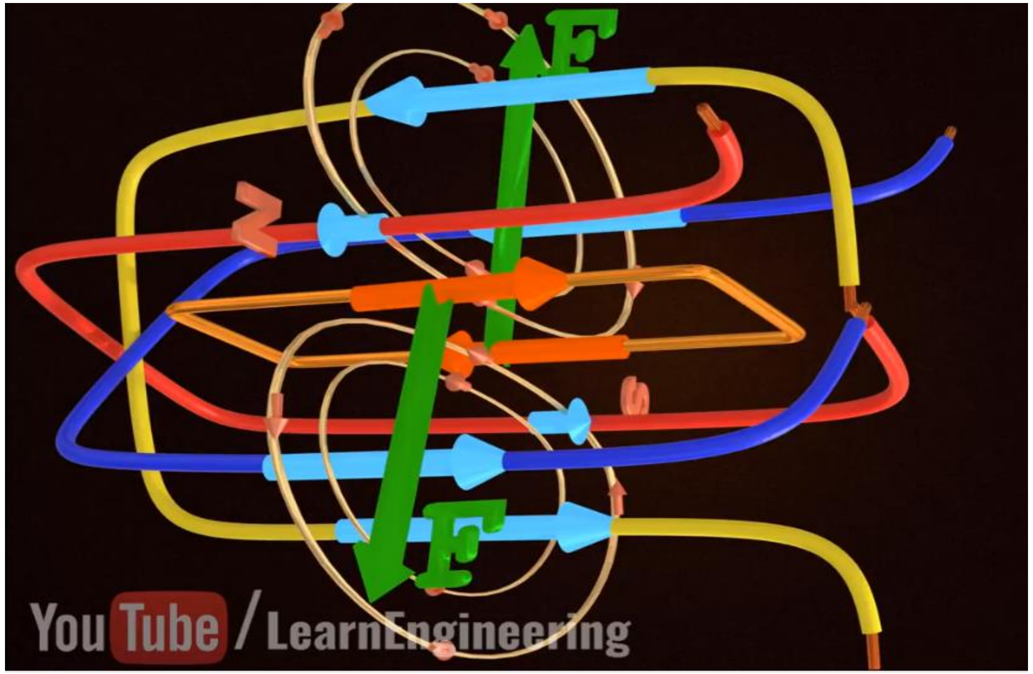
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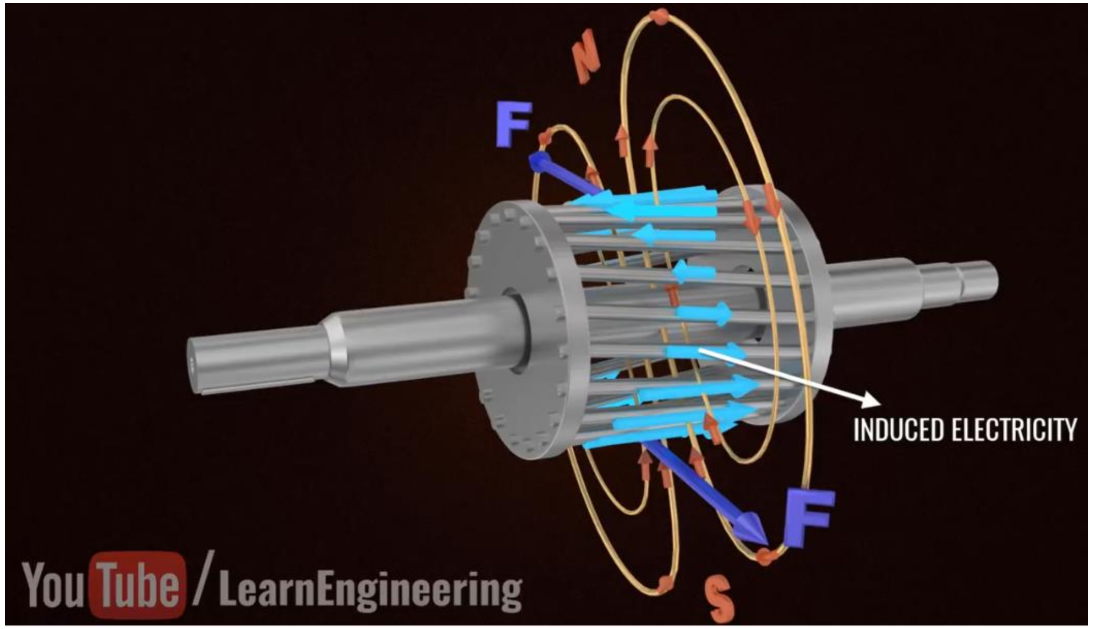
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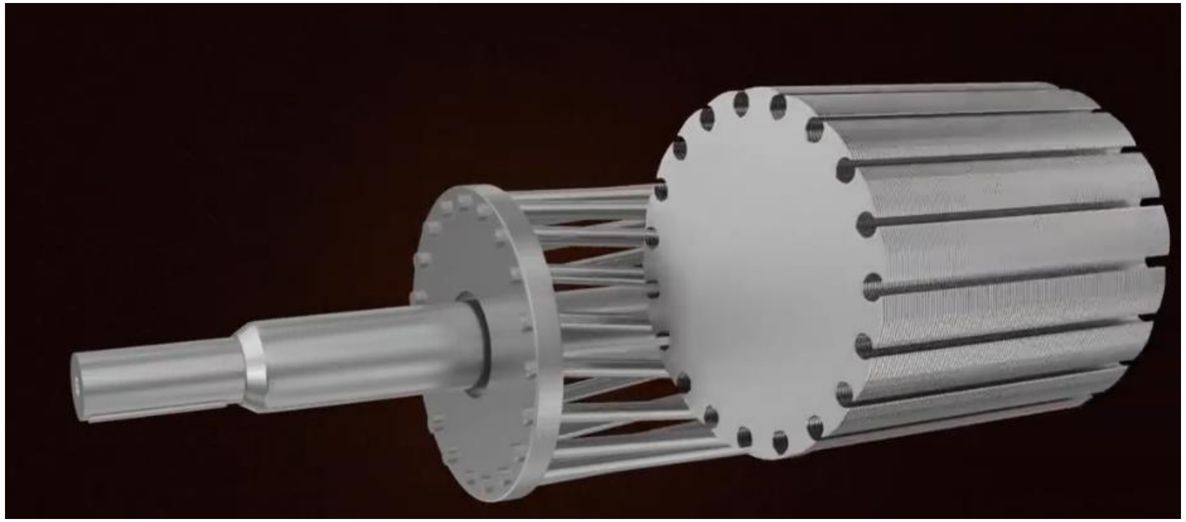


QUICK QUIZ (POLL)

The basic operation of an induction motor is based on

(a) self induction.

(b) mutual induction.

(c) magnetic locking.

(d) Coulomb's law.

Working Principle of 3 Phase Induction Motor

Q: What must be the speed of the rotor?

- From the working principle of three phase induction motor, it may be observed that the **rotor speed should not reach the synchronous speed produced by the stator**.
- If the speeds become equal, there would be no such relative speed, so no emf induced in the rotor, and no current would be flowing, and therefore no torque would be generated.
- Consequently, the rotor cannot reach the synchronous speed. The difference between the stator (synchronous speed) and rotor speeds is called the slip. The rotation of the magnetic field in an induction motor has the **advantage** that no electrical connections need to be made to the rotor.

Slip

Definition: The slip in an induction motor is the difference between the main flux speed and their rotor speed. The symbol S represents the slip. It is expressed by the percentage of synchronous speed. Mathematically, it is written as

$$\%S = \frac{N_s - N}{N_s} \times 100$$

The value of slip at full load varies from 6% in case of small motor and 2% in the large motor.

QUICK QUIZ (POLL)

When the rotor of three phase induction motor run at synchronous speed, the value of slip will be

(a) 0

(b) 0.1

(c) 0.5

(d) 1

Quick Quiz Poll

- The induction motor the unit of slip is
- A)
- B) Farad
- C)
- D) Unitless

Advantages of 3 Phase Induction Motor

1. Self-starting.
2. No Brushes
3. No commutator
4. Rugged in construction.
5. Cheaper.
6. Ease of operation
7. High Starting torque

Applications of 3 Phase Induction Motor

1. Lifts
2. Cranes
3. Hoists
4. Large capacity exhaust fans
5. Driving lathe machines
6. Crushers
7. Oil extracting mills
8. Electric Vehicle
9. Textile and etc.

Single Phase Induction Motor

- We use the single-phase power system more widely than three phase system for domestic purposes, commercial purposes and some extent in industrial uses.
- single-phase system is more economical than a three-phase system and the power requirement in most of the houses, shops, offices are small, which can be easily met by a single phase system.
- single phase motors are simple in construction, cheap in cost, reliable and easy to repair and maintain.
- Due to all these advantages, the single phase motor finds its application in **vacuum cleaners, fans, washing machines, pumps, blowers, etc.**
- 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

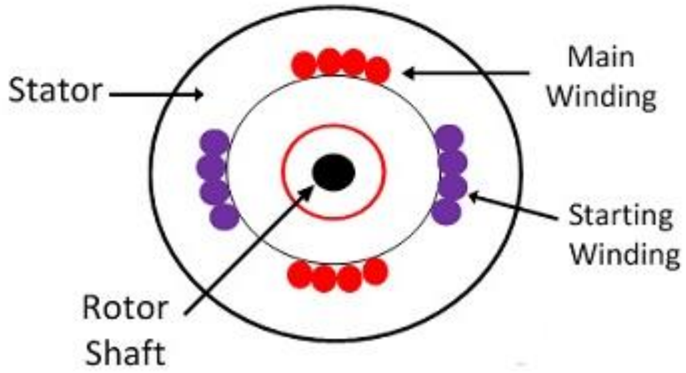
Construction of Single Phase Induction Motor

STATOR

- The construction of the stator of the single-phase induction motor is similar to that of three phase induction motor.
- However, 1-Phase motor has two stator windings namely the main winding and the auxiliary winding.
- These two windings are placed perpendicular to each other.

ROTOR

- The construction of the rotor of the single-phase induction motor is similar to the squirrel cage three-phase induction motor.



Working Principle of Single Phase Induction Motor

- Link: https://www.youtube.com/watch?v=awrUxv7B-a8
- The working principle of single phase induction motor is explained with **Double Revolving Field Theory.**
- This theory states that:

"A pulsating magnetic field is resolved into two rotating magnetic fields. They are equal in magnitude but opposite in directions. The induction motor responds to each of the magnetic fields separately. The net torque in the motor is equal to the sum of the torque due to each of the two magnetic fields".