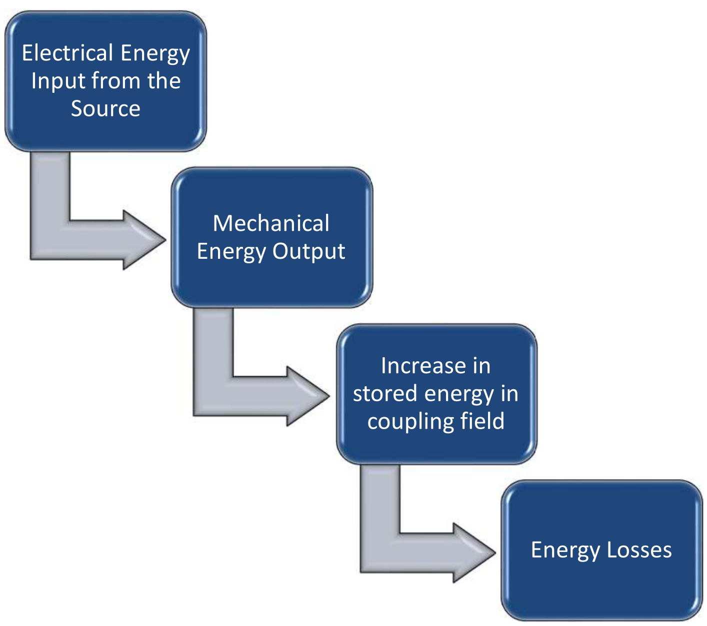
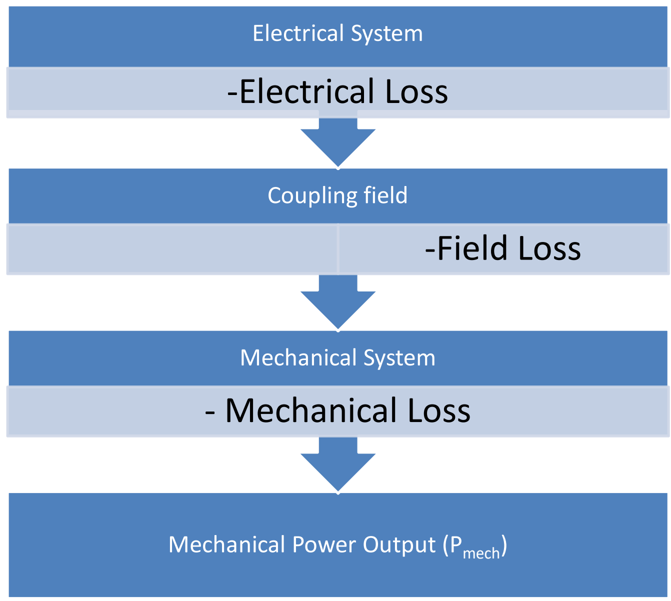
Module – 4
ELECTRICAL MACHINES

Energy Conversion Process



Energy Flow



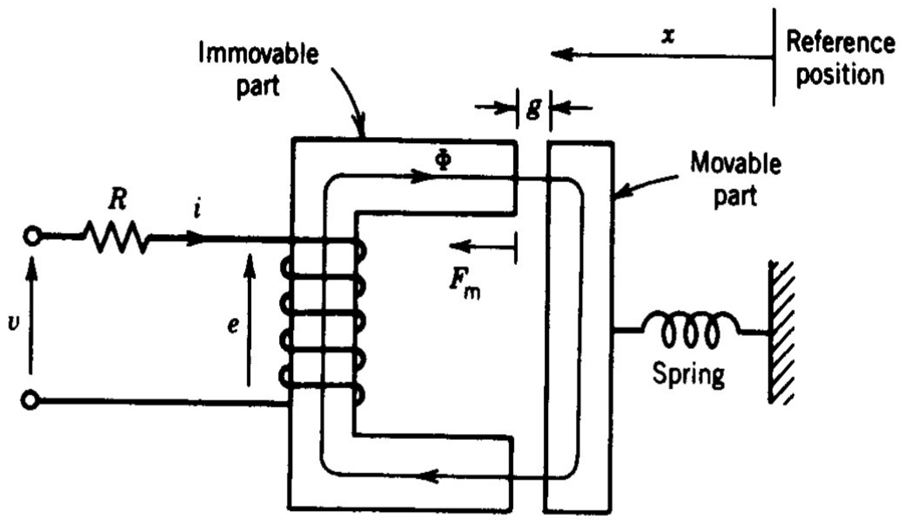
Energy Balance Equation:

$$Electrical\ energy\ input\ from\ source\ -resistance\ loss$$
$$= Mechanical\ Energy\ output$$
$$+ friction\ and\ windage\ losses$$ + increase in stored energy +core loss

In a differential time interval *dt*

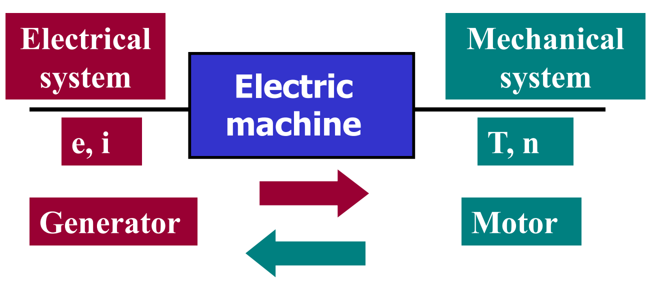
$$dW_e = dW_m + dW_f$$

Singly Excited Electromagnetic-mechanical System
or
Singly excited system



Electrical Machines

- An electromechanical converter which is used to continuously translate electrical input to mechanical output, or vice versa.
- The process of translation is known as Electromechanical Energy Conversion.



Definitions

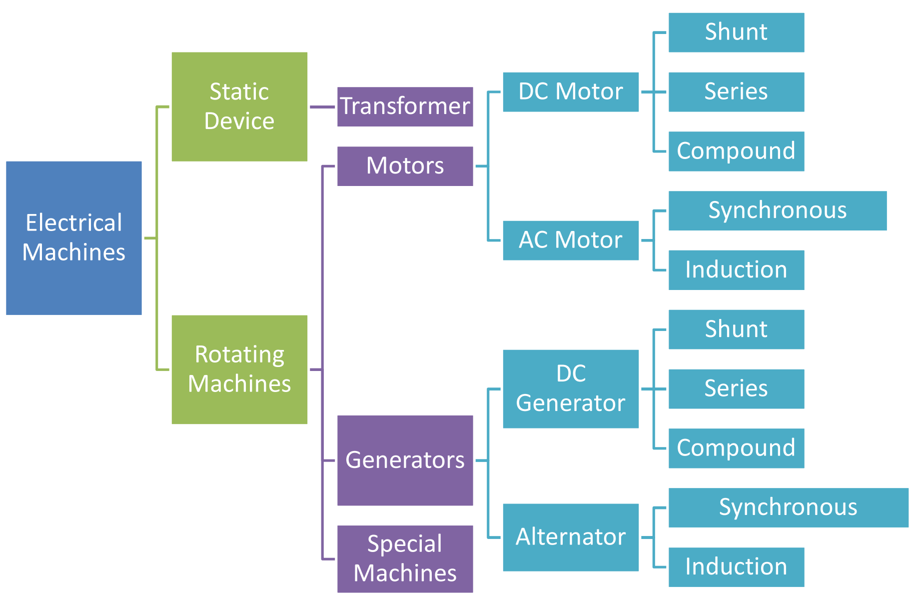
Generator:

Electro – mechanical, electro – dynamic equipment which converts input mechanical energy into electrical energy output

Motor:

Electro – mechanical, electro – dynamic equipment which converts input electrical energy into mechanical energy output

Classification of Electrical Machines



Faraday's Laws – The Basics

Electro Magnetic Induction: (Generator)

When a conductor moves in a magnetic field, voltage is induced in the conductor

$$\boxed{e = B\, l\, v}$$

Electro Magnetic Interaction: (Motor)

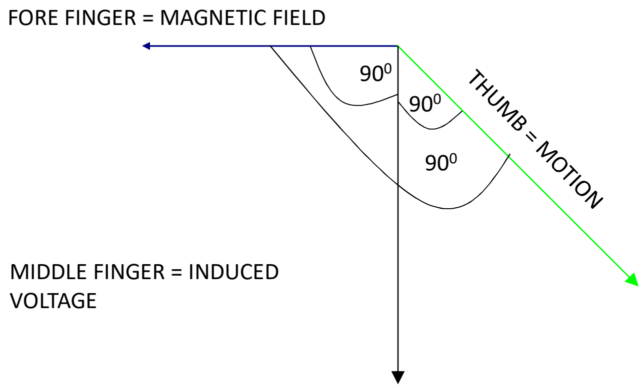
When a current-carrying conductor is placed in a magnetic field, the conductor experiences a mechanical force.

$$\boxed{F = B\, l\, I}$$

Working Principle of a DC Machine

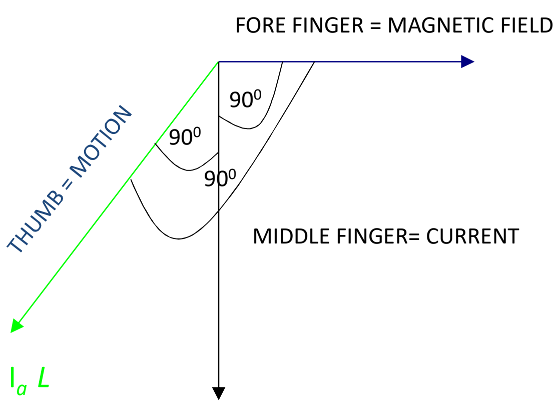
- **Generator** – When armature conductors are rotated externally in the magnetic field produced by field windings, an emf is induced in it according to Faraday's law of electromagnetic induction. This emf causes a current to flow which is alternating in nature. It is converted into unidirectional current by the commutator.
- **Motor** – When field winding is excited and armature conductors are connected across the supply, it experiences a mechanical force whose direction is given by Fleming's left hand rule. Because of this force, the armature starts rotating. It cuts the magnetic field and an emf is induced in the armature winding. As per Lenz's law, the induced emf acts in the opposite direction to the armature supply voltage. This emf is called Back EMF.

Fleming’s Right Hand Rule Or Generator Rule



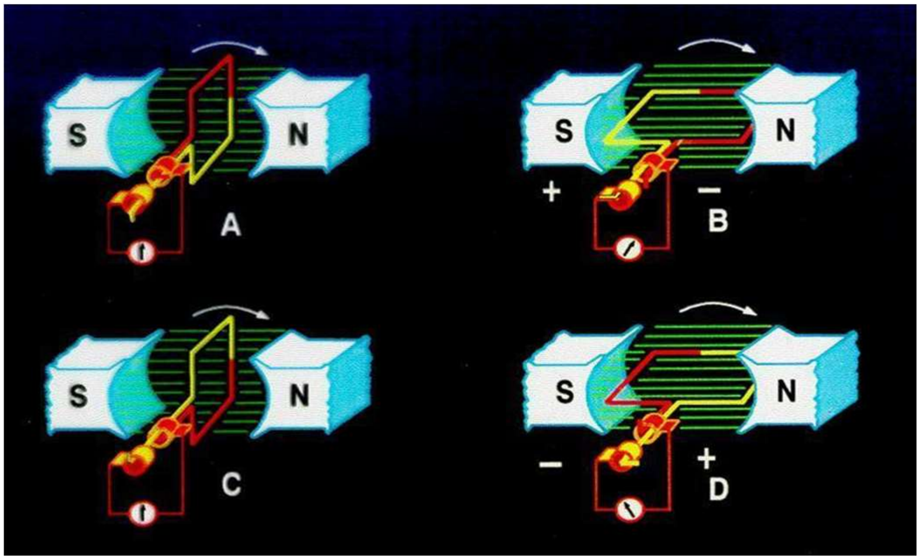
VOLTAGE = B l v

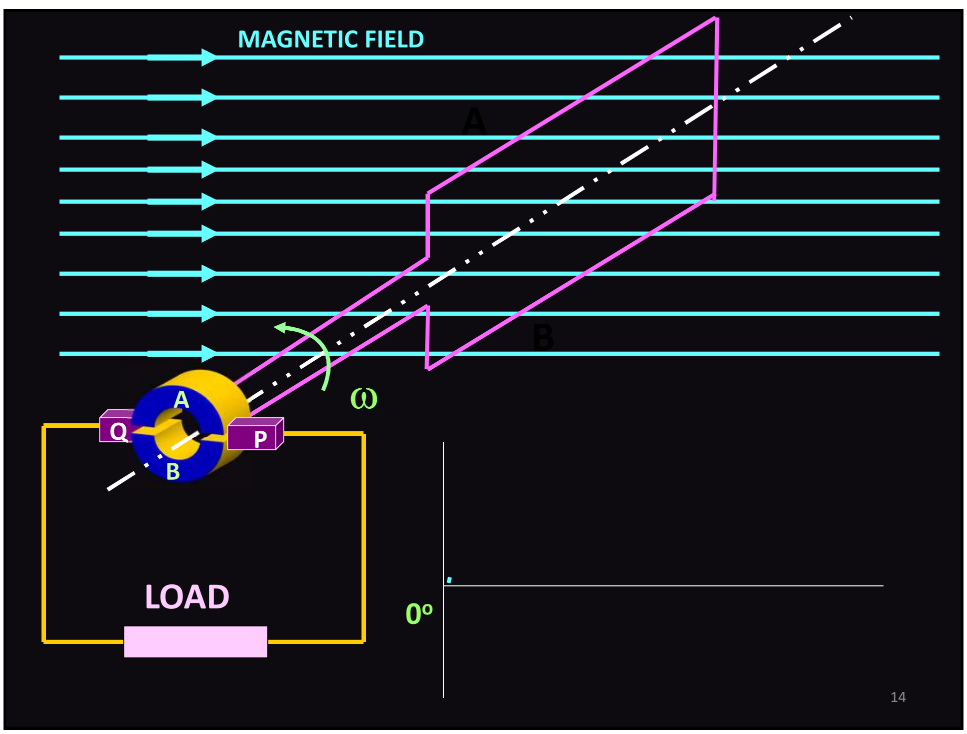
Fleming’s Left Hand Rule Or Motor Rule

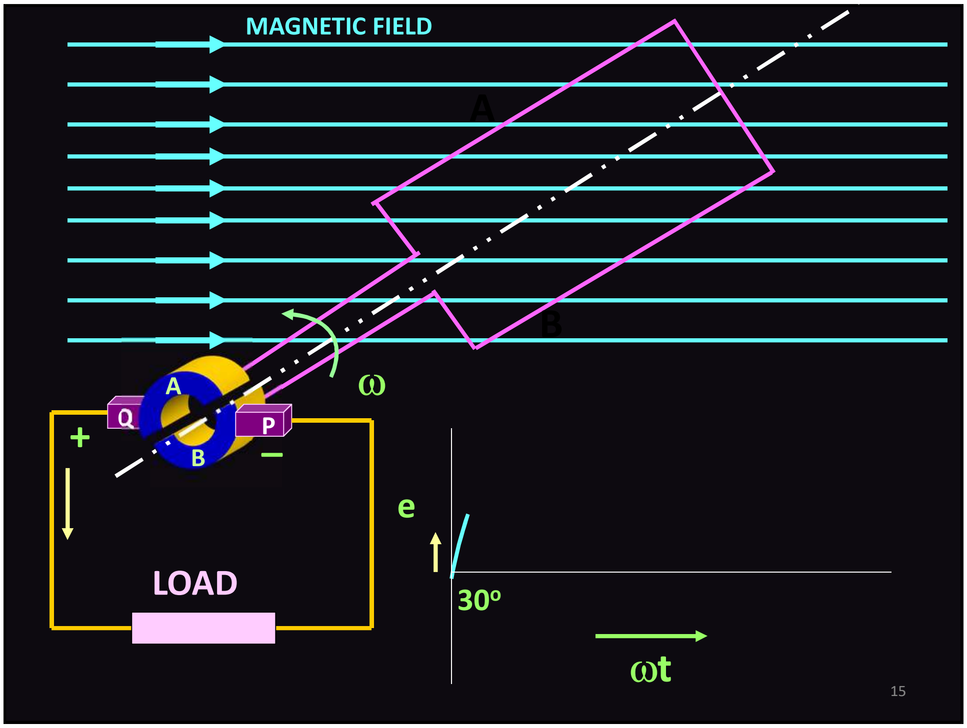


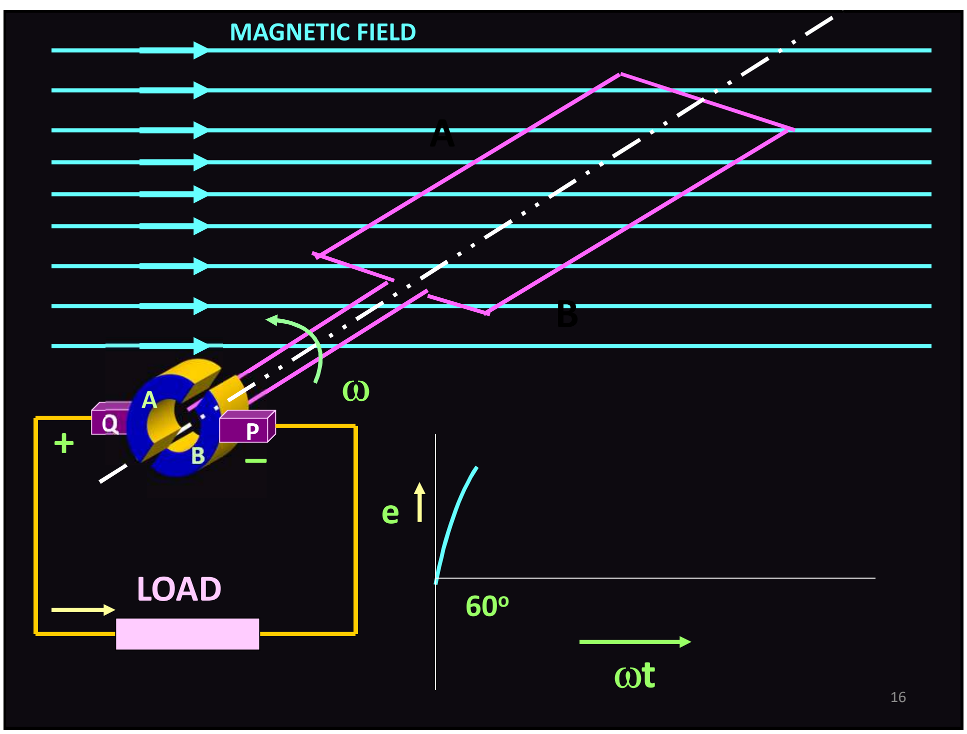
FORCE = B I_a L

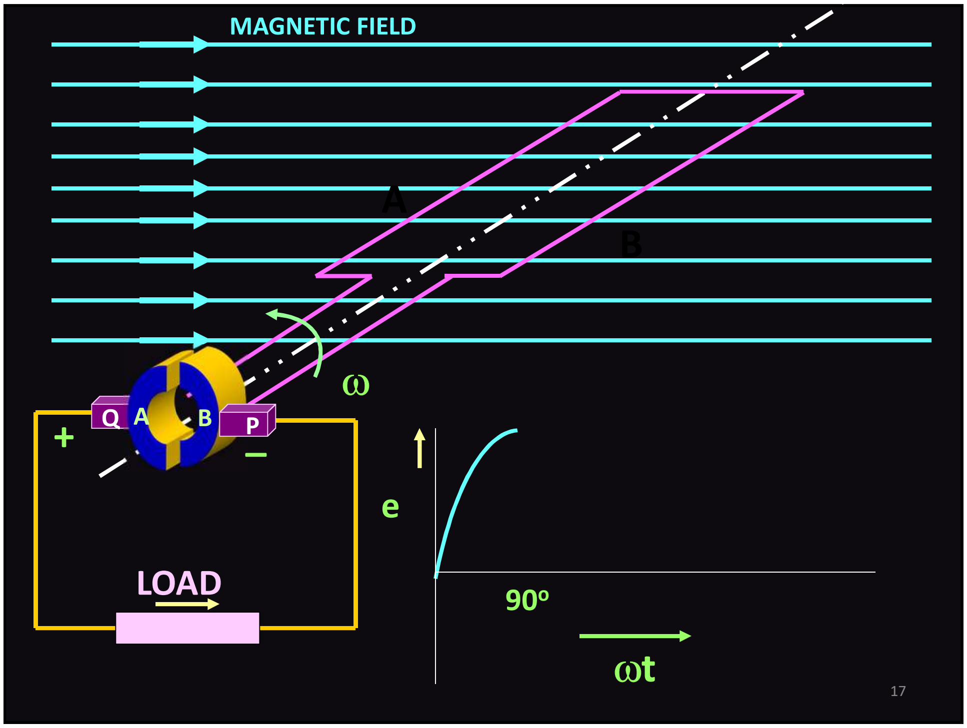
Principle of Operation






MAGNETIC FIELD
A
B
A
Q
P
B
+
–
ω
LOAD
e
30°
ωt
15


MAGNETIC FIELD
A
B
A
Q
P
B
+
–
ω
LOAD
e
60°
ωt
16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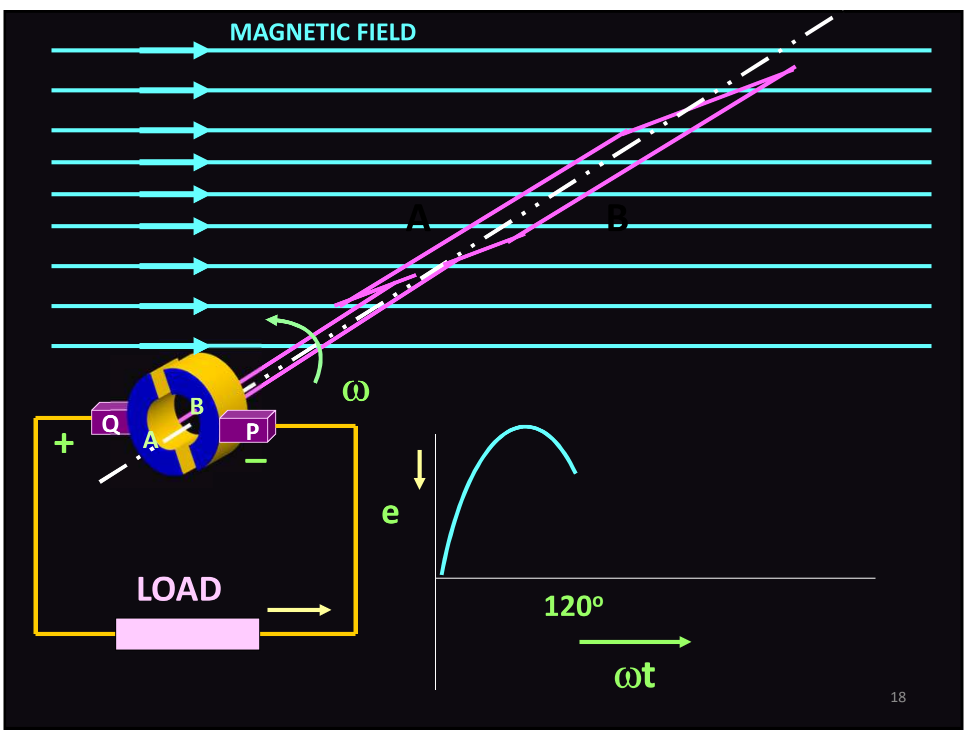
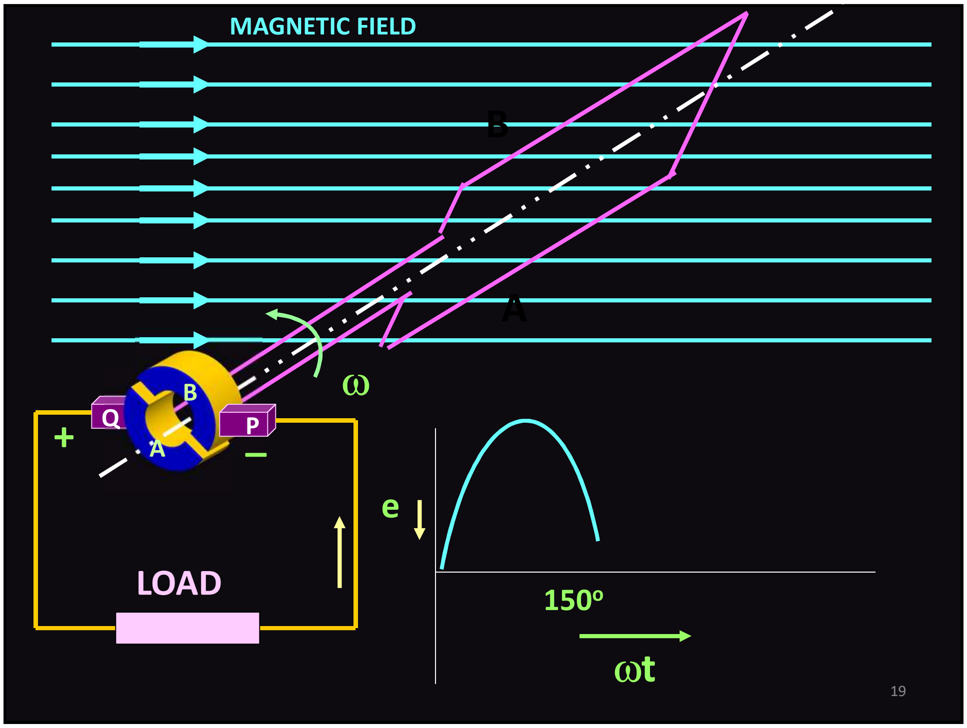
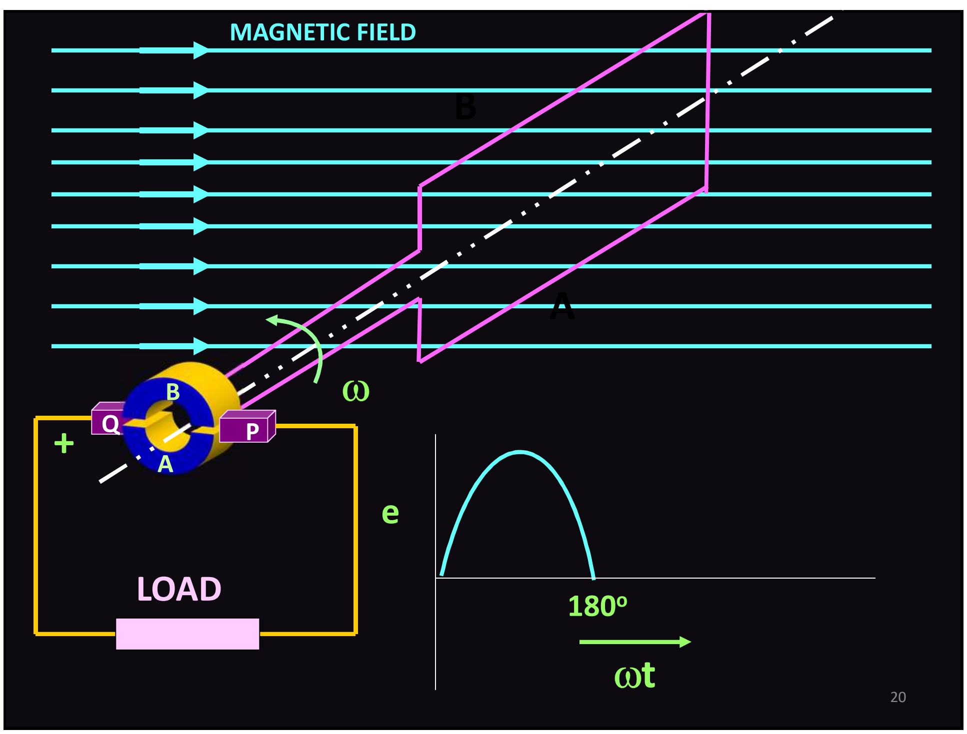
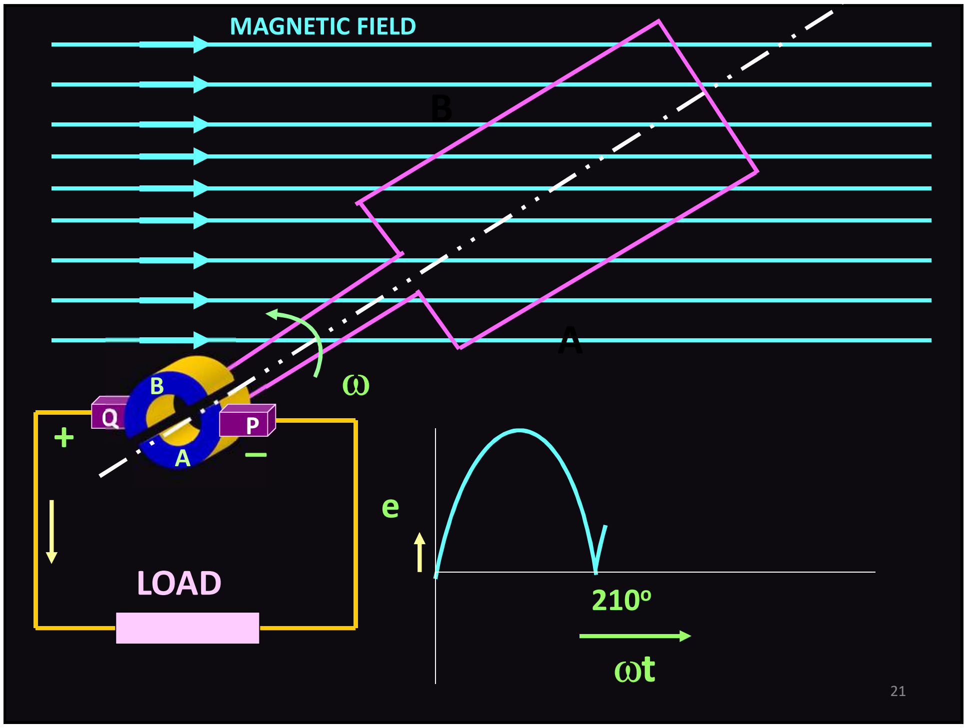
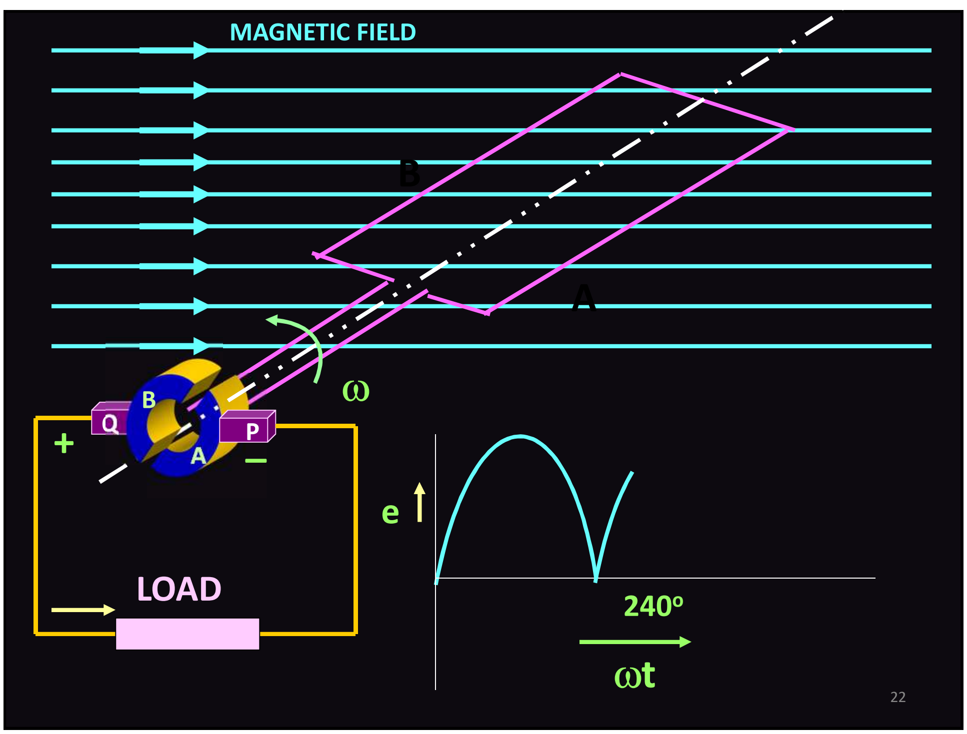
A
B
ω
Q
A
B
P
+
–
e
LOAD
90°
ωt
17

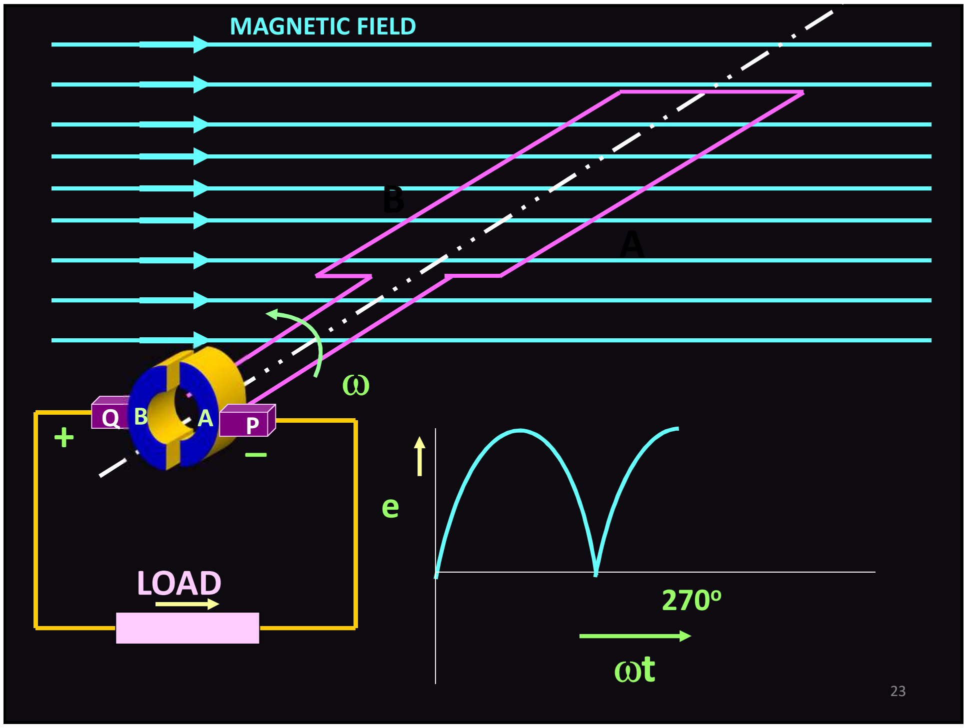

MAGNETIC FIELD
A
B
ω
Q
B
A
P
+
–
e
LOAD
120°
ωt
18

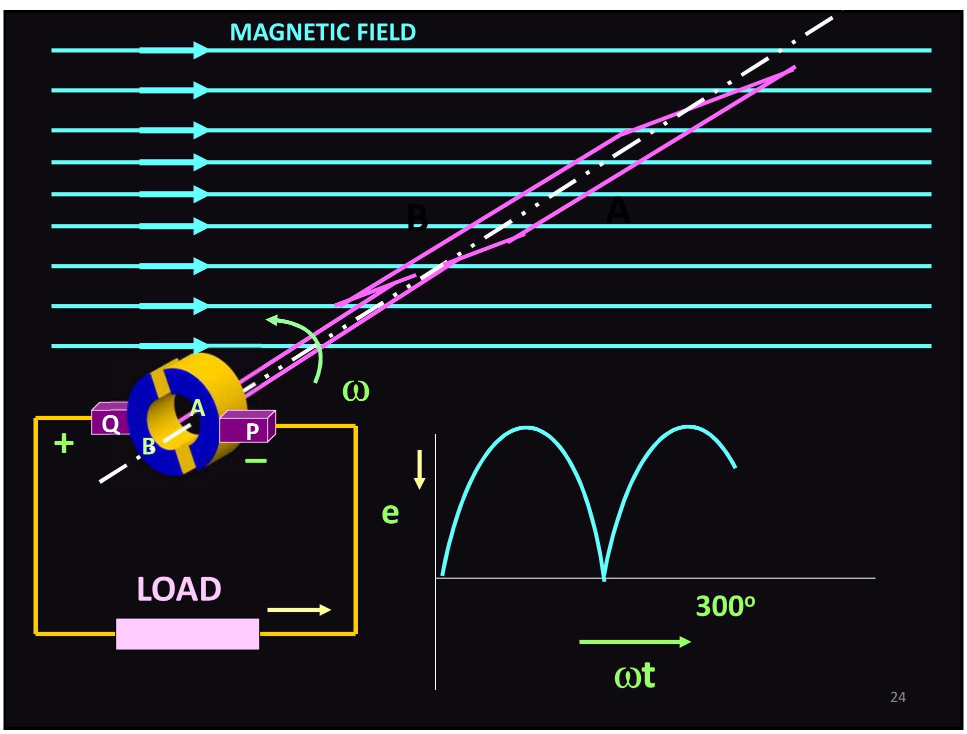

MAGNETIC FIELD
B
A
ω
B
Q
P
A
+
–
e
LOAD
150º
ωt
19

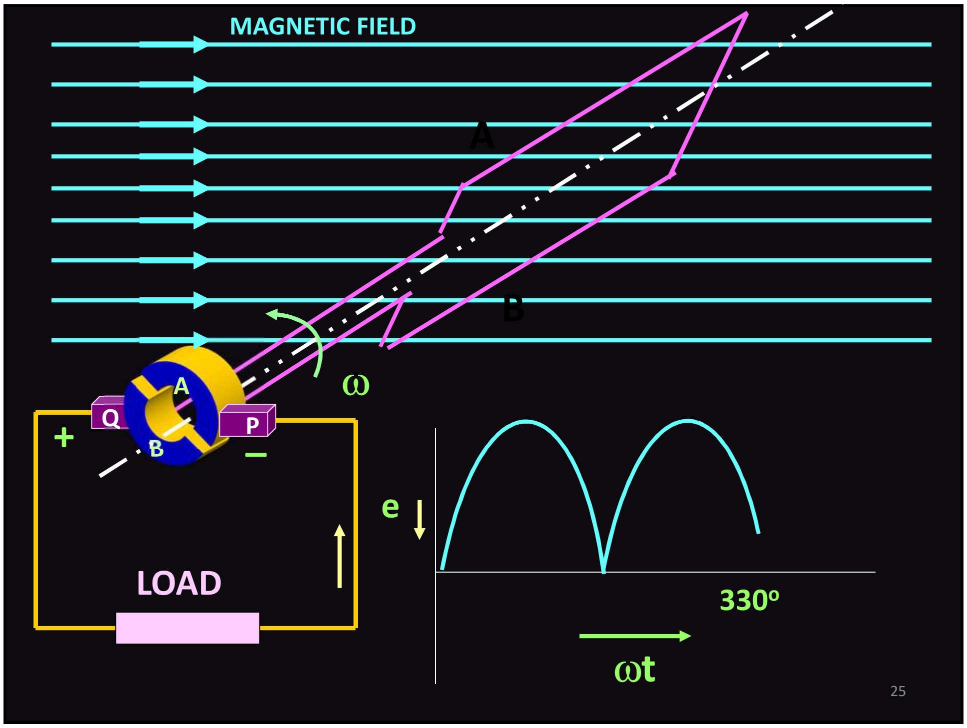

MAGNETIC FIELD
B
A
ω
B
Q
P
A
+
e
LOAD
180º
ωt
20

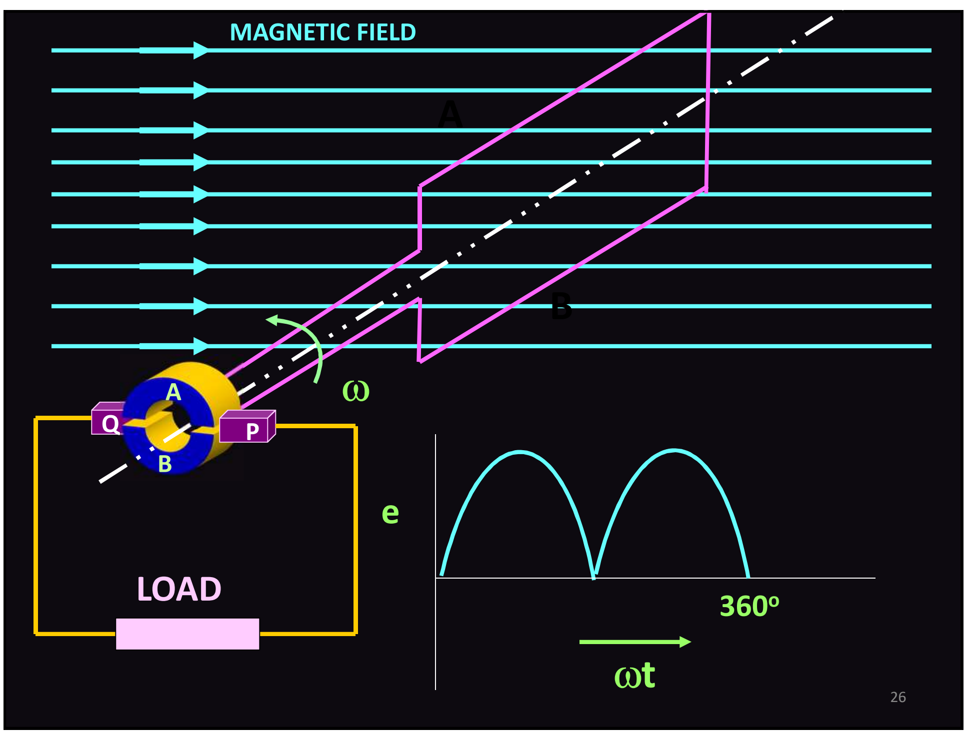

MAGNETIC FIELD
B
A
ω
B
Q
P
A
+
–
e
LOAD
210º
ωt
21


MAGNETIC FIELD
B
A
ω
B
Q
P
A
+
–
e
LOAD
240º
ωt
22


MAGNETIC FIELD
B
A
ω
Q
B
A
P
+
−
e
LOAD
270º
ωt
23


MAGNETIC FIELD
B
A
ω
Q
A
B
P
+
−
e
LOAD
300º
ωt
24


MAGNETIC FIELD
A
B
ω
A
Q
P
B
+
—
e
LOAD
330º
ωt
25


MAGNETIC FIELD
A
B
ω
A
Q
P
B
e
LOAD
360º
ωt
26

Constructional Details

Stator:

Static part, produces magnetic field, even number of poles.

Rotor:

Rotating part, called as armature, consists of laminated core, armature windings are placed in slots, emf will be induced (voltage will be applied)

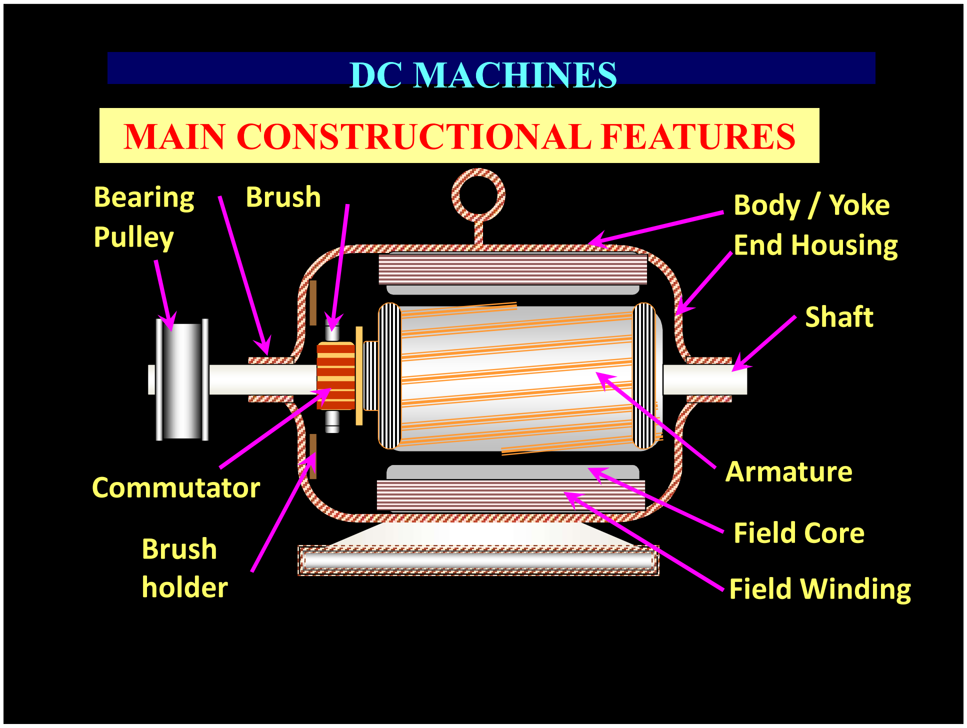
Constructional Details …

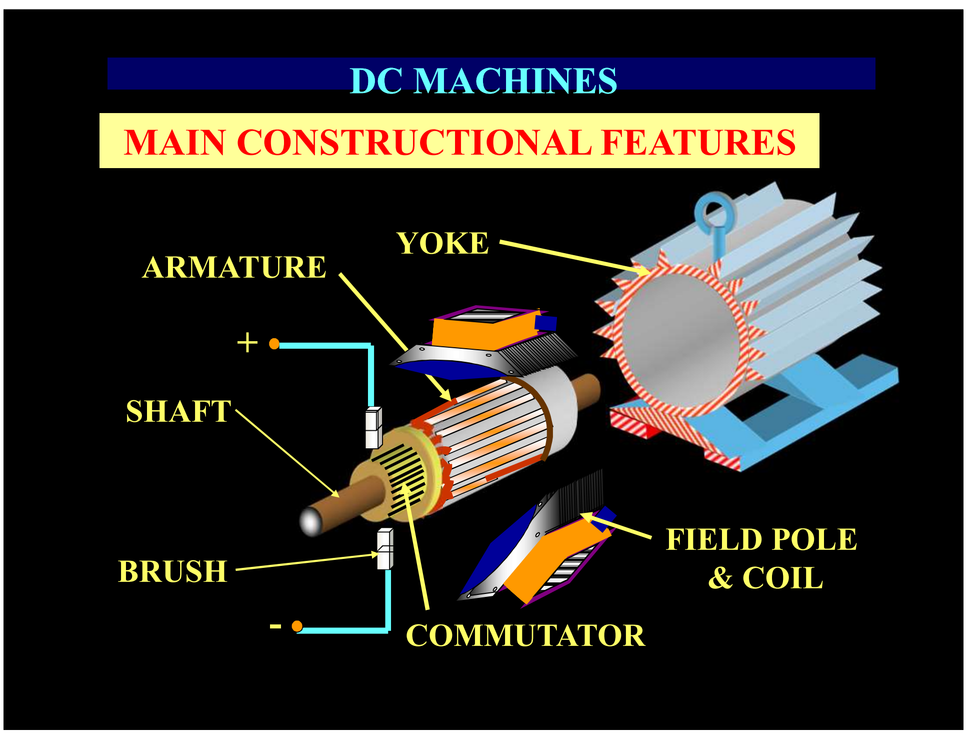
Commutator:

Mechanical rectifier, made of copper segments, armature conductors are soldered

Brushes:

Ensures electrical connections, made of carbon, brush pressure is adjusted using adjustable springs

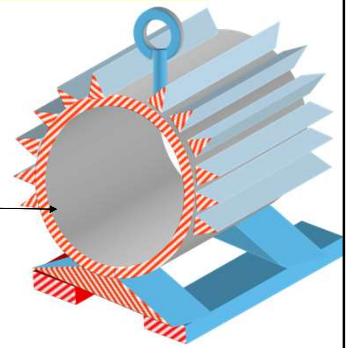

DC MACHINES
MAIN CONSTRUCTIONAL FEATURES
Bearing
Pulley
Brush
Body / Yoke
End Housing
Shaft
Commutator
Armature
Field Core
Brush
holder
Field Winding


DC MACHINES
MAIN CONSTRUCTIONAL FEATURES
YOKE
ARMATURE
+
SHAFT
BRUSH
-
COMMUTATOR
FIELD POLE
& COIL

MAIN CONSTRUCTIONAL FEATURES

1. MAGNETIC FRAME or YOKE :

The outer cylindrical frame to which main poles and inter poles are fixed and by means of the machine is fixed to the foundation is called YOKE.



It serves two purposes:
a) It provides mechanical protection to the inner parts of the machines.
b) It provides a low reluctance path for the magnetic flux.

The yoke is made of cast iron for smaller machines and cast steel or fabricated rolled steel for larger machines.

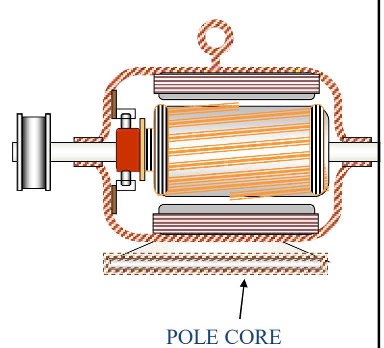
2. POLE CORE AND POLE SHOES :

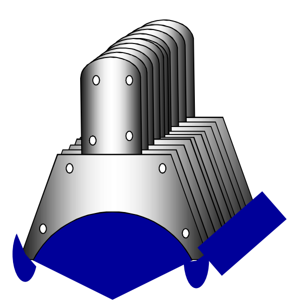
The pole core and pole shoes are fixed to the yoke by bolts. They serves the following purpose :

a) They support the field or exciting coils.

b) They distribute the magnetic flux on the armature periphery more uniformly.

c) The pole shoes have larger X section, so, the reluctance of the magnetic path is reduced. The pole core and pole shoes are made of laminated steel assembled by riveting together under hydraulic pressure.

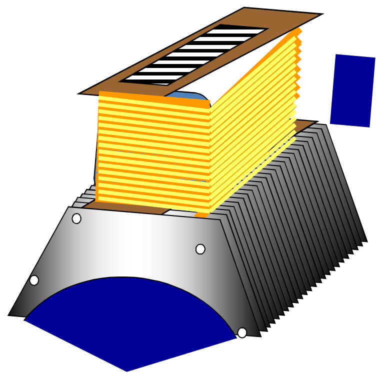




3. FIELD or EXCITING COILS :

- Field coils or exciting coils are used to magnetize the pole core. Enameled copper wire is used for the construction of these coils.

- When direct current is passed through these coils/ winding, it sets up the magnetic field which magnetize the pole core to the reqd. flux.



4. ARMATURE CORE:

- Armature is a rotating part of the DC machine, reversal of flux takes place, so hysteresis losses are produced. To minimize this loss, silicon steel is used for the construction.

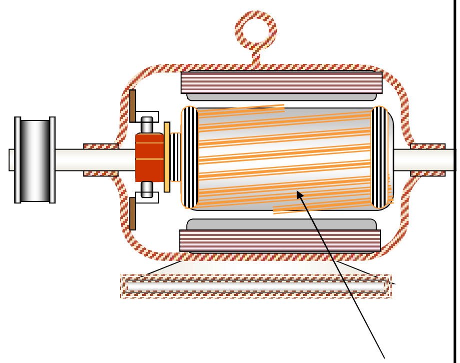
- The rotating armature cuts the main magnetic field , therefore an e.m.f is induced in the armature core. This e.m.f circulates eddy currents in the core which results in eddy current loss in it.

- The armature core is laminated to reduce the eddy current loss.

- Armature core serves the following purposes:
  a) It houses the conductors in the slots.
  b) It provides an easy path for magnetic flux

5. ARMATURE WINDING

- The no. of conductors in form of coils placed in the slots of the armature and suitably inter connected are called winding .
- In the armature winding where conversion of power takes place i.e. in case of generator mechanical power is converted into electrical power and in case of a motor, electrical power is converted into mechanical power.

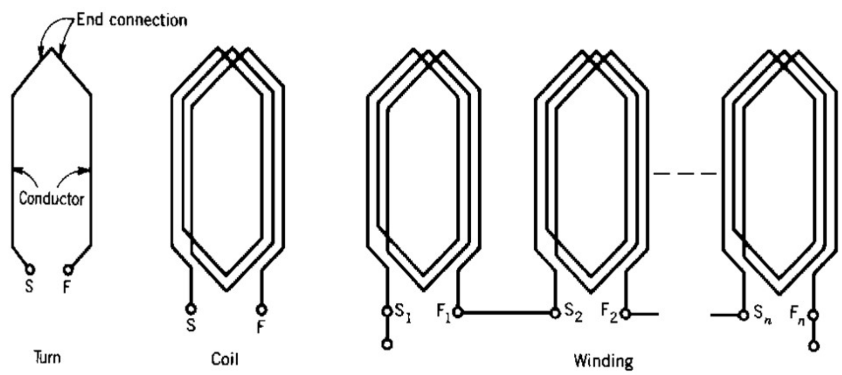


Armature Windings

Terms:

- **A turn consists of 2 conductors connected to one end by an end connector.**
- **A coil is formed by connecting several turns in series**
- **A winding is formed by connecting several coils in series**

Turn, Coil and Winding



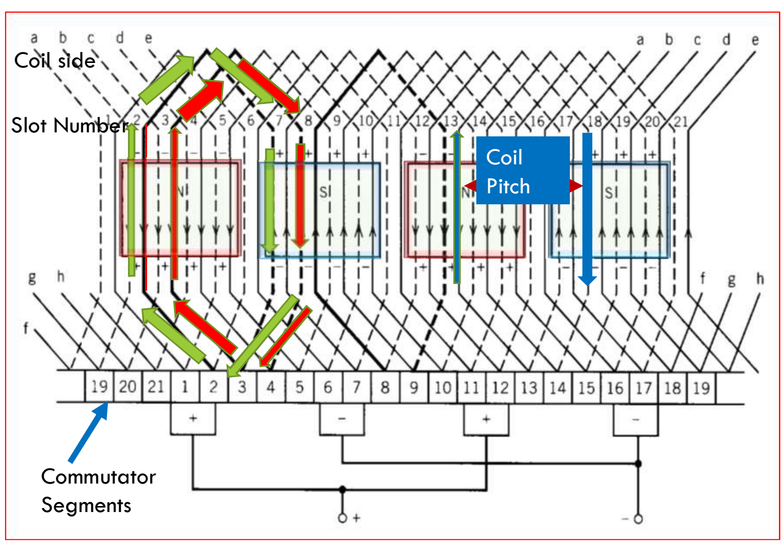
Lap Winding

- **The 2 ends of a coil are connected to adjacent commutator segments.**
- **The number of brushes is equals to the number of poles.**
- **The number of parallel paths is equals to the number of poles.**
- **Each path takes 1/p times the load current (p = no. of poles)**

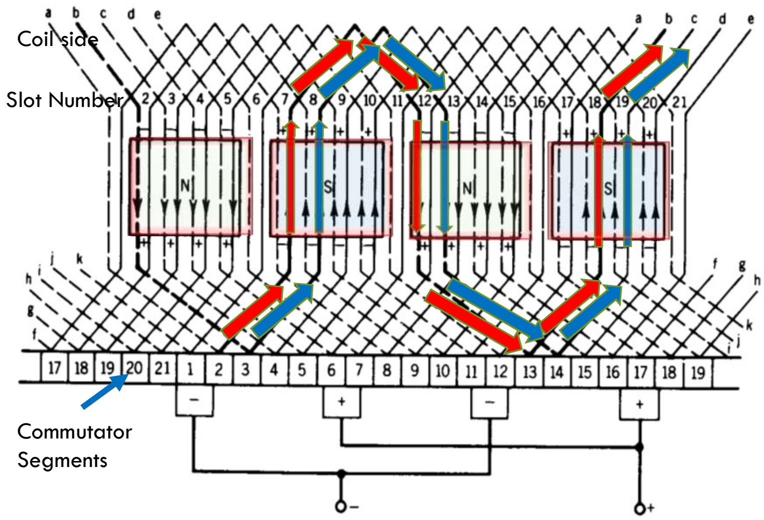
Wave Winding

- The 2 ends of a coil are connected to commutator segments which separated by twice the pole-pitch.
- Only 2 brushes are necessary, irrespective of the number of poles, but 4 or more may be used.
- The number of parallel paths is always 2.
- Each path takes 1/2 of the load current.

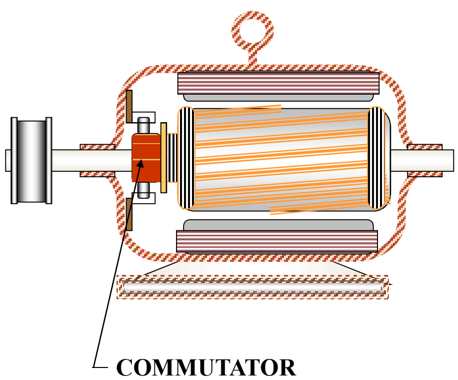
LAP WINDING



WAVE WINDING

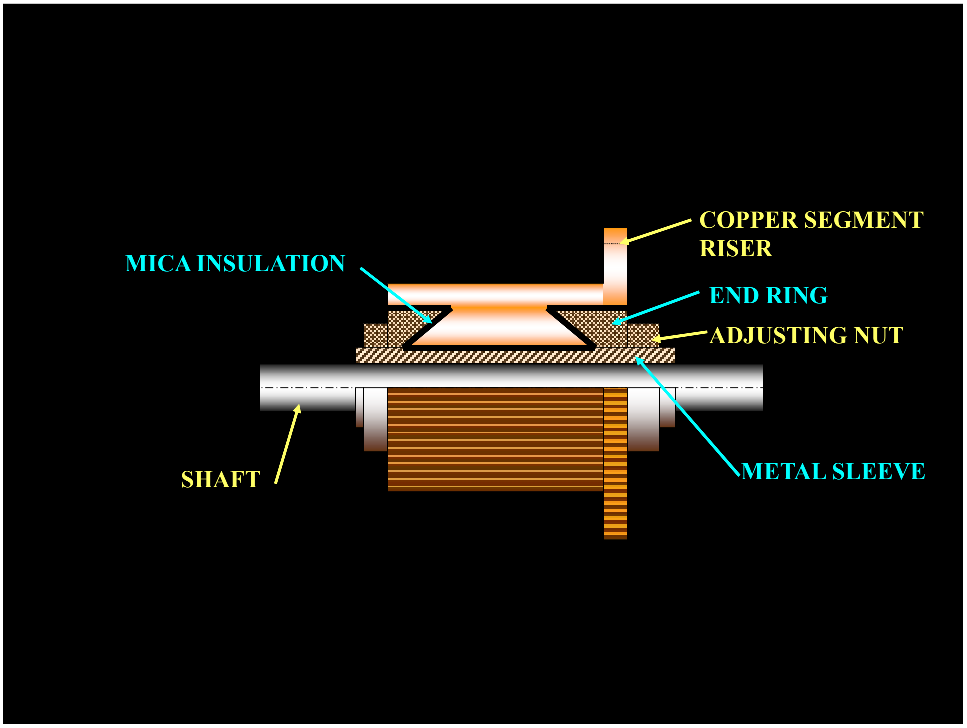


7. COMMUTATOR



It is the most important part of a DC machine and serves the following purpose :-

i) It connects the rotating armature conductors to the stationary external circuit through the brushes.



ii) It converts altering current induced in the armature conductors into unidirectional current in the external load circuit in generating action and it converts alternating torque into unidirectional torque produced in the armature in motoring action.

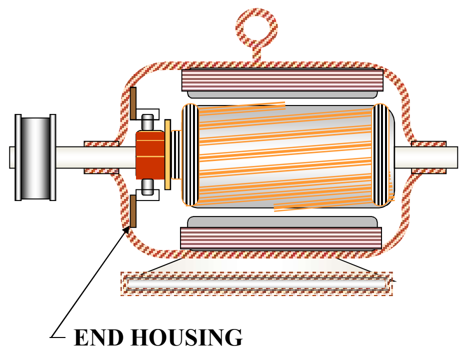
iii) The commutator is of cylindrical shape and is made of wedge shaped hard drawn copper segments. The segments are insulated from each other by a thin sheet of mica.
iv) The segments are held together by means of two V-shaped rings that fit into the V-grooves cut into the segments. Each armature coil is connected to the commutator segment through riser.

8. BRUSHES

Brushes are made of high grade carbon. They form the connecting link between armature winding and the external circuit. The brushes are held in particular position around the commutator by brush holders.

9. END HOUSINGS

They are attached to the ends of main frame and support bearing . The front housing supports the bearing and the brush assembly whereas rear housing supports the bearing only.

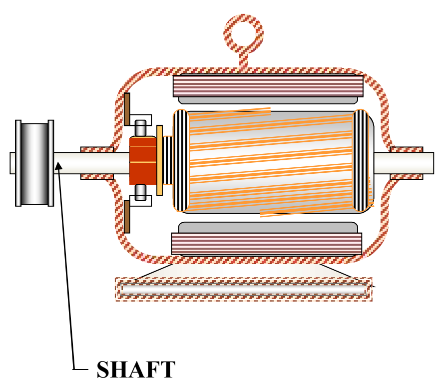


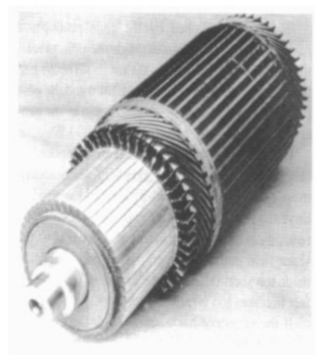
9. BEARINGS

The function of the bearing is to reduce friction between the rotating and stationary parts of the machines. These are fitted in the end housings. Generally, high carbon steel is used for the construction of the bearings.

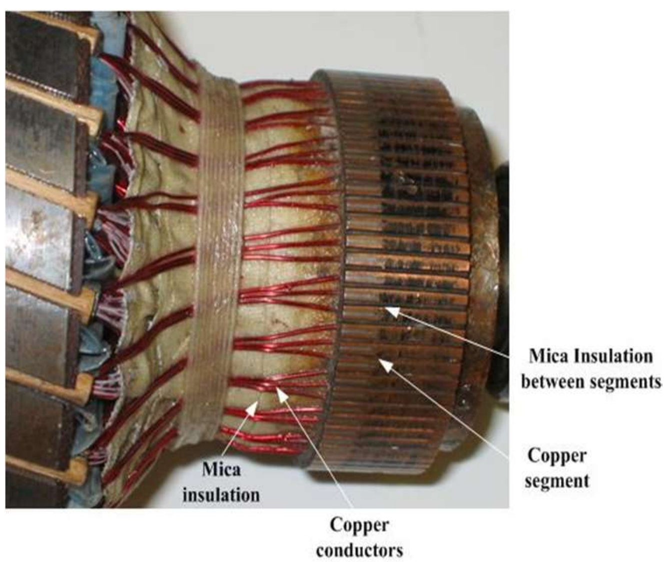
10. SHAFT

The function of shaft is to transfer mechanical power to the machine or from the machine. Shaft is made of mild steel with maximum breaking strength. All the rotating parts like armature core, commutator, cooling fan etc. are keyed to the shaft.





Commutator


Mica Insulation
between segments
Copper
segment
Mica
insulation
Copper
conductors

Voltage Rectification

- Armature winding is placed on the rotor
- Voltage induced in armature winding is alternating
- Commutator-brush combination is used as a mechanical rectifier to make the armature terminal voltage unidirectional and also to make the mmf wave due to armature current fixed in space

Emf Equation

Emf Equation

Let Φ = Total flux per pole in Webers

N = Speed of the armature in rev/min

P = number of poles

Z = Total number of conductors on armature

a = Number of parallel paths through armature

(wave winding, a = 2, lap winding, a = P)

Emf Equation

Total number of poles = P

Flux per pole = Φ webers

Flux cut by one conductor passes $P\Phi$ webers

Speed of the armature = N rev/min

Time taken to pass one pole = 60/N sec

Emf induced per conductor = $d\Phi/dt = P\Phi/60/N$

$= P\Phi N/60$ volts

On the armature, there are Z/a conductors in series

$\therefore$ Total induced emf, $E_a = (P\Phi N/60)Z/a$ volts

Armature Voltage

- As the armature rotates in the magnetic field produced by the stator poles, voltage is induced in the armature winding. Also we find from the previous equation,

$$E_g \propto \Phi\omega_m$$

$$E_g = K_a\Phi\omega_m$$

E_g= Generated Voltage in case of Generator

E_g= Back Emf in case of Motor

Generally denoted as E_b

Types of DC Generator

Broadly classified as

- **Self Excited and Separately Excited**

Separate DC Supply for field – separately excited DC Machine

Self Excited – Field supply from the output of generator itself. Classified as

(i) Shunt (ii) Series and (iii) Compound DC Machine

What is an Electric Motor

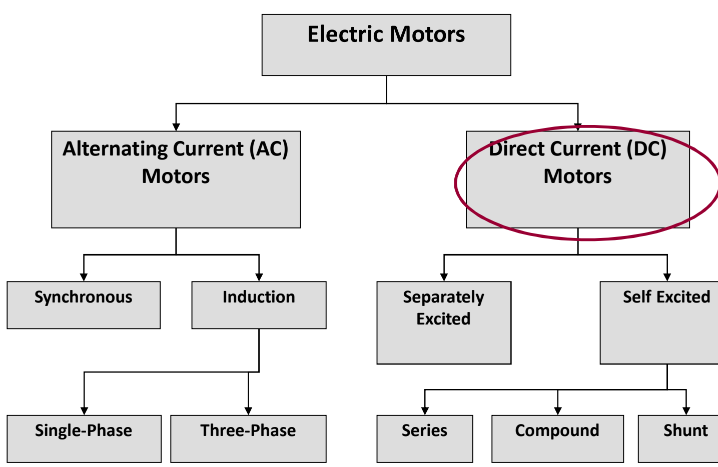
- Electromechanical device that converts electrical energy to mechanical energy
- Mechanical energy used to e.g.
  - Rotate pump impeller, fan, blower
  - Drive compressors
  - Lift materials
- Motors in industry: 70% of electrical load

Three types of Motor Load

Motor loads	Description	Examples
Constant torque loads	Output power varies but torque is constant	Conveyors, rotary kilns, constant-displacement pumps
Variable torque loads	Torque varies with square of operation speed	Centrifugal pumps, fans
Constant power loads	Torque changes inversely with speed	Machine tools

Type of Electric Motors

Classification of Motors



DC Motors

•The major advantages of dc machines are the easy speed and torque regulation.

•However, their application is limited to mills, mines and trains. As examples, trolleys and underground subway cars may use dc motors.

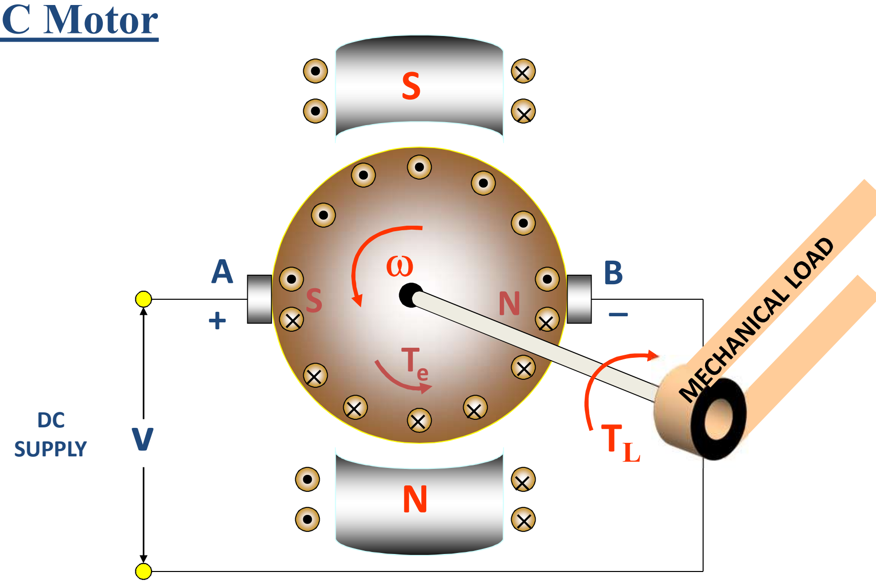
•In the past, automobiles were equipped with dc dynamos to charge their batteries.

• Even today the starter is a series dc motor.

• However, the recent development of power electronics has reduced the use of dc motors and generators.

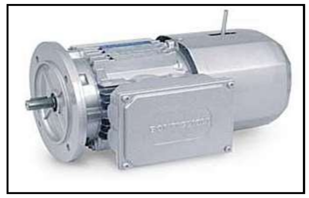
• Nevertheless, a large number of dc motors are still used by industry and several thousand are sold annually.

DC Motor

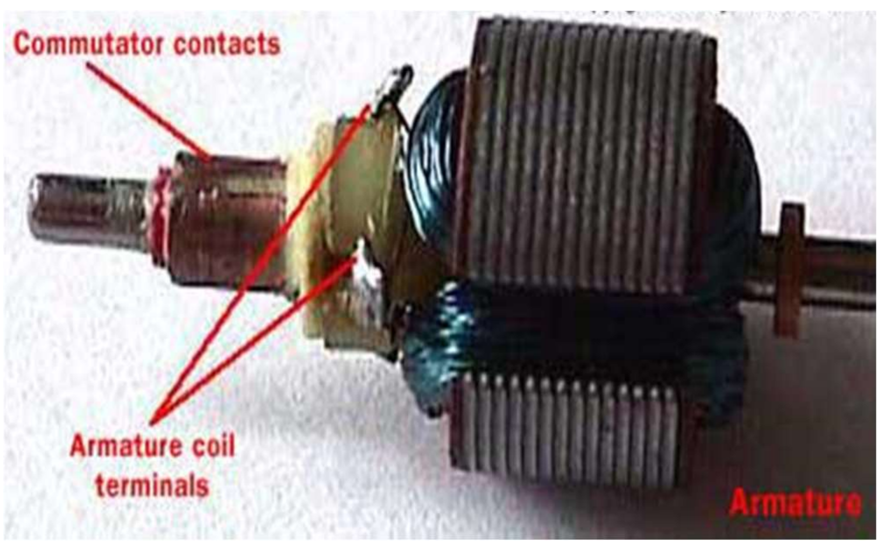


DC Motors – Components

- **Field pole**
  - North pole and south pole receive electricity to form magnetic field
- **Armature**
  - Cylinder between the poles Electromagnet when current goes through linked to drive shaft to drive the load
- **Commutator**
  - Overturns current direction in armature



DC Motor



Principles of Operation

- Conversion of electrical energy to mechanical energy is called **motor action**
- Two requirements for motor action:
  - Current flow through a conductor
  - A force on the conductor develops
    - This force is produced when the conducting wire is placed inside the magnetic field formed between two magnetic poles

Rotary Motion

- Current-carrying conductor in a magnetic field will tend to move at right angles to the field
- The reaction of the wire to the field produces **torque**

Continuous Rotation

- Achieved by reversing the direction of current flow in a wire
- Current change is provided by a switching device called a commutator
- The commutator and loop form the armature

FACTORS DETERMINING THE SPEED OF DC MOTOR

The expression for back e.m.f. developed in the armature of a dc motor is given as follows :

$$E = \frac{P \phi Z N}{60 A} \qquad .....(i)$$

$$E = V - I_a R_a \qquad .....(ii)$$

FACTORS DETERMINING THE SPEED OF DC MOTOR

Comparing expressions (i) and (ii)

$$\frac{P \phi Z N}{60 A} = V - I_a R_a$$

OR $$K \phi N = V - I_a R_a$$

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

CHARACTERISTICS OF DC MOTORS

It is very much important to know the characteristics mentioned above for different types of dc motors because it enables the selection of a specific type of dc motor for specific purpose.

The important characteristics of dc motors are :

1) Speed - armature current (Load) characteristics
2) Torque - armature current (Load) characteristics
3) Speed - Torque characteristics

Motor Classification

- Motors are generally classified by how their windings are connected to their DC power supply
- There are three types of wound-field DC motors
  - Shunt
  - Series
  - Compound

What is a **Transformer**?

- A static device which can transfer electrical energy from one circuit to another circuit without change of frequency.
- Can increase or decrease the voltage but with a corresponding increase or decrease in current.
- Works on the principle of Mutual Induction.

Applications

- Major application is to increase voltage before transmitting electrical energy over long distances through wires and to reduce voltage at places where it is to be used.
- Used in electronic circuits to step down the supply voltage to a level suitable for low voltage circuits they contain.

Working Principle

- When an alternating voltage V_1 is applied to the primary winding, an alternating current I_1 flows in it producing an alternating flux in the core.
- By Faraday's law, an emf e_1 is induced in the primary winding.

  $$e_1 = -N_1 (d\Phi/dt)$$

  where N_1 is the number of turns in the primary winding.
- The induced emf in the primary winding is nearly equal and opposite to the applied voltage V_1.

Contd…

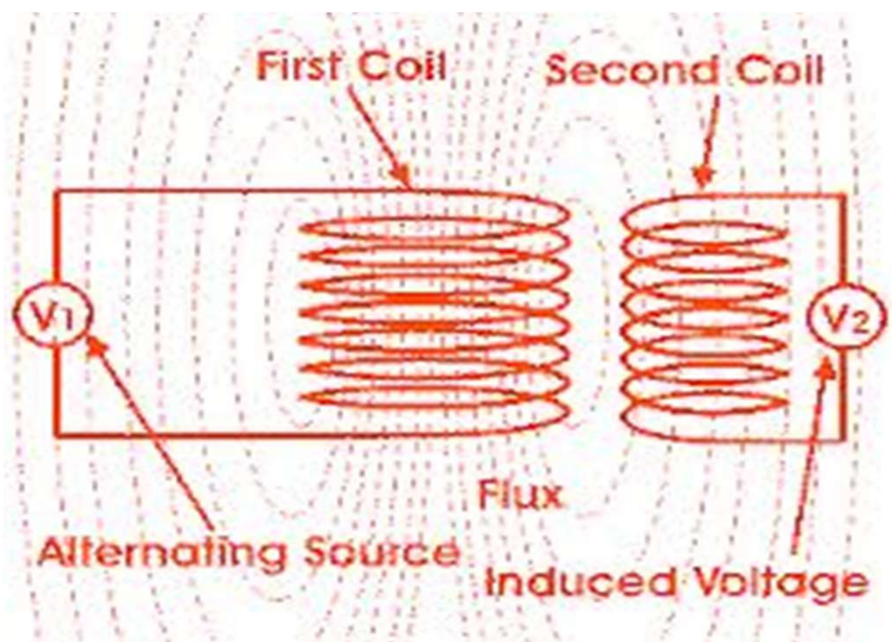
- Assuming leakage flux to be negligible, almost the whole flux produced in primary winding links with the secondary winding.

  $$e_2 = -N_2\,(d\Phi/dt)$$

  where N_2 is the number of turns in the secondary winding.

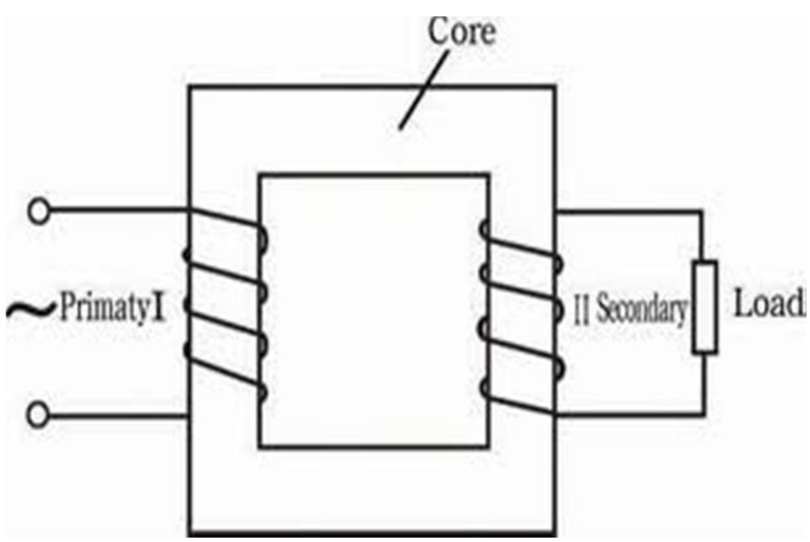
- If the secondary circuit is closed through the load, a current I_2 flows in the secondary winding.

- Thus energy is transferred from the primary winding to the secondary winding.



Construction

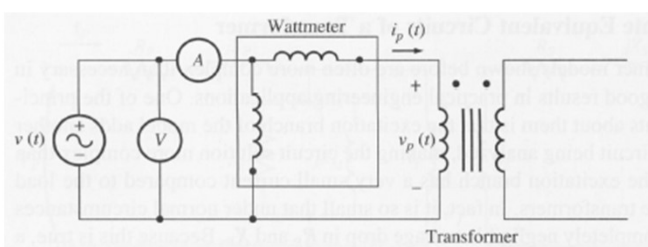
- A transformer mainly consists of two coils or windings placed on a common core.
- Core – Soft iron or steel
- Windings – Primary and Secondary
  - Primary winding – Electrical energy is fed
  - Secondary winding – Connected to Load



EMF Equation of a Transformer

- $E_1 = 4.44\ f\ \Phi_m\ N_1$
- $E_2 = 4.44\ f\ \Phi_m\ N_2$
  where E_1 is rms valued of induced emf in primary winding and E_2 is rms value of induced emf in the secondary winding.
- Using the emf equation transformation ratio can be written as $K = N_2/ N_1 = E_2/ E_1$
- For step up transformer K > 1 and for step down transformer, K < 1.

Circuit Parameters: Open-Circuit Test



- Transformer's secondary winding is open-circuited
- Primary winding is connected to a full-rated line voltage. All the input current must be flowing through the excitation branch of the transformer.
- The series elements R_p and X_p are too small in comparison to R_C and X_M to cause a significant voltage drop, so essentially all the input voltage is dropped across the excitation branch.
- Input voltage, input current, and input power to the transformer are measured.

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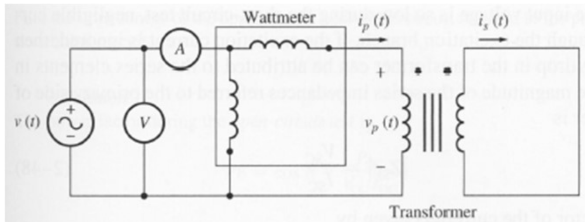
Circuit Parameters: Short-Circuit Test



- Transformer's secondary winding is short-circuited
- Primary winding is connected to a fairly low-voltage source.
- The input voltage is adjusted until the current in the short-circuited windings is equal to its rated value.
- Input voltage, input current, and input power to the transformer are measured.
- Excitation current is negligible, since the input voltage is very low. Thus, the voltage drop in the excitation branch can be ignored. All the voltage drop can be attributed to the series elements in the circuit.

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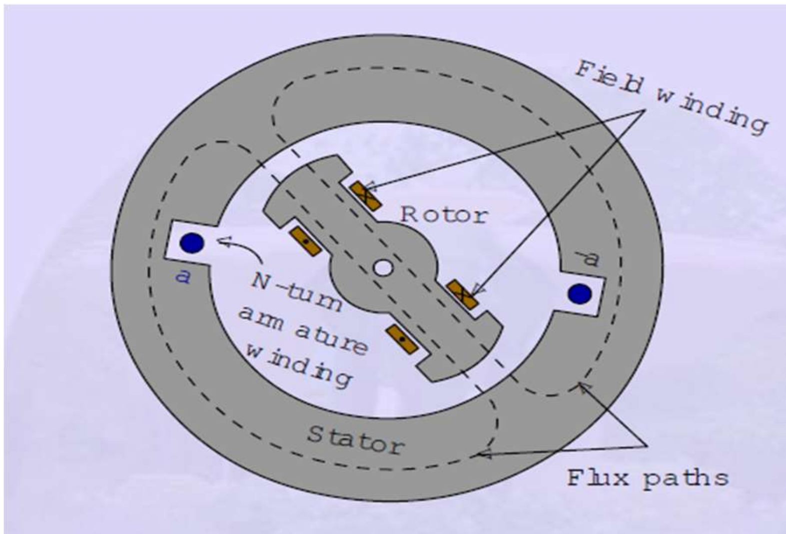
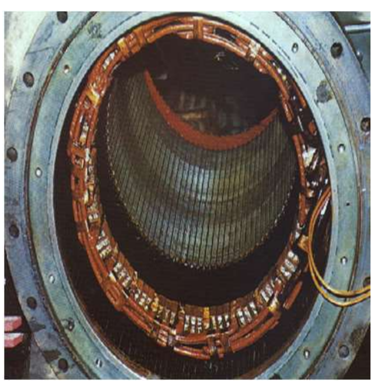
AC Generators or Alternators

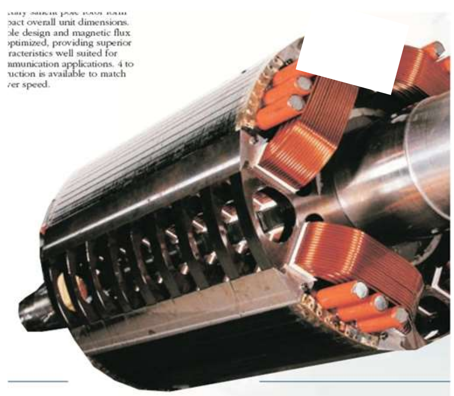
- Alternators do not require commutation
  - This allows a simpler construction
  - The *field coils* are made to rotate while the *armature* windings are stationary
    - *Note*: the armature windings are those that produce the output
  - Thus the large heavy **armature windings** are in the **stator**
  - The lighter **field coils** are mounted on the **rotor** and direct current is fed to these by a set of slip rings

Synchronous Generator



Salient-Pole Synchronous Generator

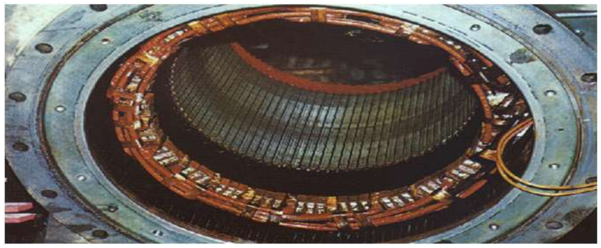




- Stator

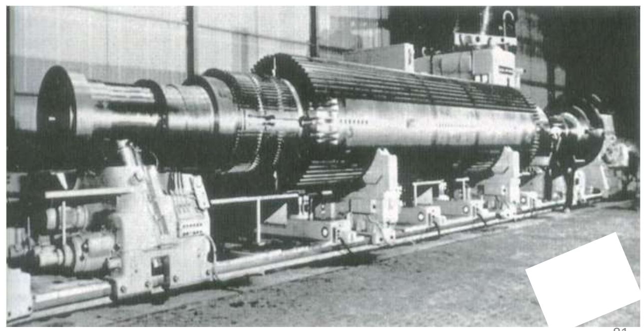
- Salient-pole rotor

Cylindrical-Rotor Synchronous Generator



- Stator

- Cylindrical rotor



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Operation Principle

The rotor of the generator is driven by a prime-mover

↓

A dc current is flowing in the rotor winding which produces a rotating magnetic field within the machine

↓

The rotating magnetic field induces a three-phase voltage in the stator winding of the generator

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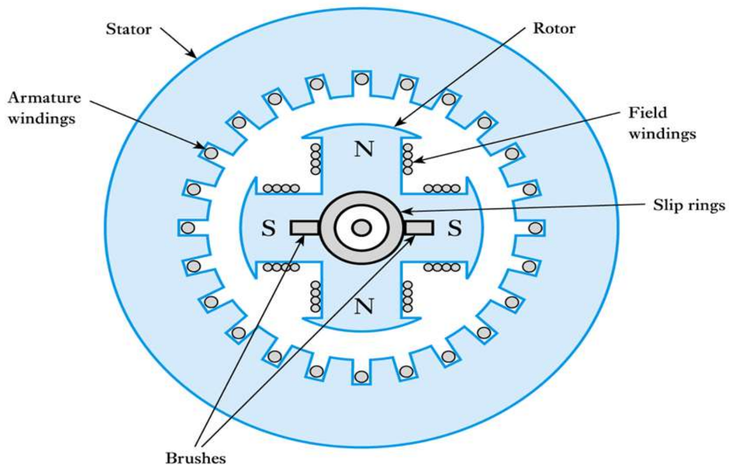
A Four-pole Alternator



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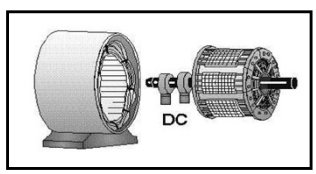
AC Motors

- Electrical current reverses direction
- Two parts: Stator and Rotor
  - Stator: stationary electrical component
  - Rotor: rotates the motor shaft
- Speed difficult to control
- Two types
  - Synchronous motor
  - Induction motor
  - Synchronous motors supply power to both the rotor and the stator, where induction motors only supply power to the stator coils, and rely on induction to generate torque.



SYNCHRONOUS MOTORS

- Just as a DC generator can be used as a DC motor, so AC generators (or alternators) can be used as **synchronous AC motors**
- **Three phase motors** use three sets of stator coils
  - the rotating magnetic field drags the rotor around with it
- **Single phase motors** require some starting mechanism
- Torque is only produced when the rotor is in sync with the rotating magnetic field
  - **not self-starting** – may be configured as an induction motor until its gets up to speed, then becomes a synchronous motor

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INDUCTION MOTORS

- These are perhaps the most important form of AC motor
- Rather than use slip rings to pass current to the field coils in the rotor, current is *induced* in the rotor by transformer action
- The stator is similar to that in a synchronous motor
- The rotor is simply a set of parallel conductors shorted together at either end by two conducting rings

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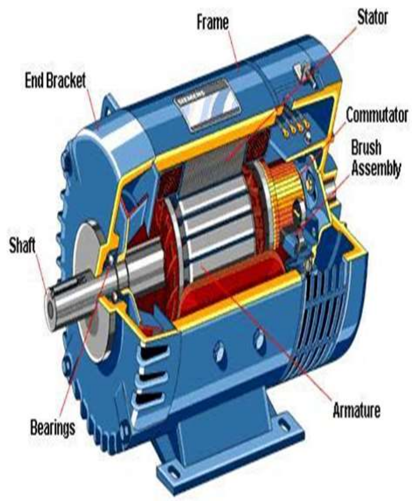
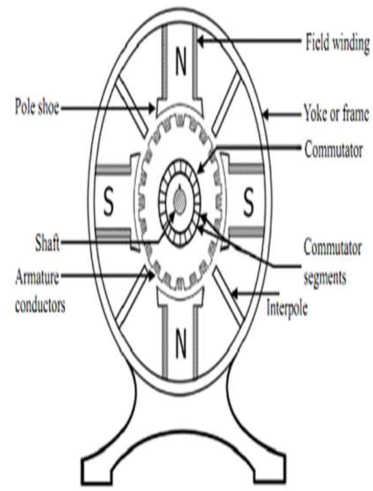


Cut – Away View

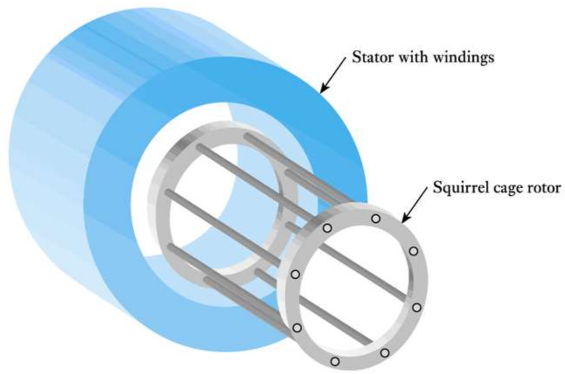


Cross-sectional View

AC Motors – Induction motor

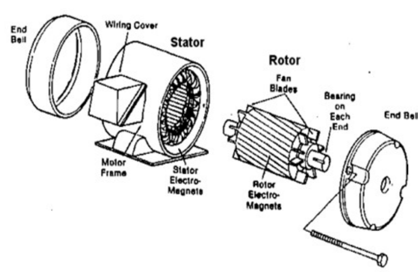
- Most common motors in industry
- Advantages:
  - Simple design
  - Inexpensive
  - High power to weight ratio
  - Easy to maintain
  - Direct connection to AC power source

Squirrel-cage induction motor



AC Motors – Induction motor

Components

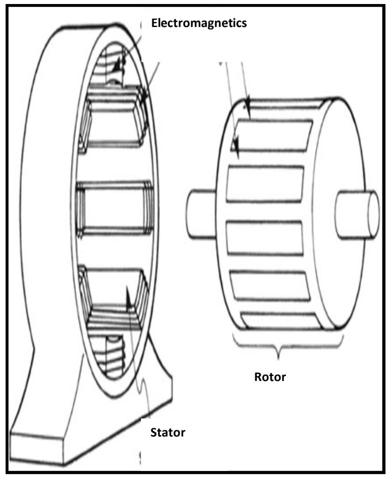


- Rotor
  - Squirrel cage: conducting bars in parallel slots
  - Wound rotor: 3-phase, double-layer, distributed winding
- Stator
  - Stampings with slots to carry 3-phase windings
  - Wound for definite number of poles

AC Motors – Induction motor

How Induction motors work

- Electricity supplied to stator
- Magnetic field generated that moves around rotor
- Current induced in rotor
- Rotor produces second magnetic field that opposes stator magnetic field
- Rotor begins to rotate



– In a **three-phase induction motor** the three phases produce a rotating magnetic field (as in a three-phase synchronous motor)

– A stationary conductor will see a varying magnetic field and this will induce a current

– Current is induced in the field coils in the same way that current is induced in the secondary of a transformer

– This current turns the rotor into an electromagnet which is dragged around by the rotating magnetic field

– The rotor always goes slightly slower than the magnetic field – this is the **slip** of the motor

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Stator and Rotor Laminations

Yoke / Frame

- Made of Galvanized Iron (G.I.)
- It serves as frame to support stator core / field windings
- It is a part of magnetic circuit of the machine
- It provides mechanical support and protective covering for the motor
- The terminal connections are provided on the frame/yoke

Poles

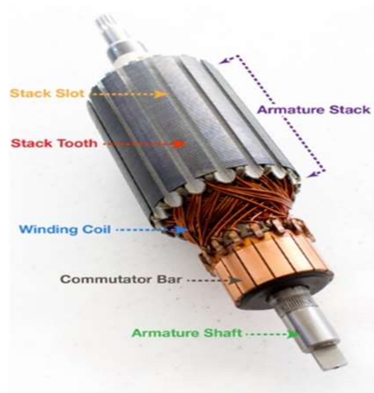
- Salient in nature
- It carries field winding and produces the necessary flux of the machine
- The pole shoes spread the flux and maintains uniform flux density in the airgap
- The poles are made up of sheet steel / silica steel laminations to minimize core loss
- The laminations are stamped together and slots are provided

Interpole

- It supports the main field poles
- To compensate the main flux in interpolar region
- It reduces sparking and aids in commutation

Armature

- It is the rotating part of the machine
- The armature is mounted on a shaft
- It has copper coils wound and placed on armature slots
- The windings carries the entire load current
- The windings are connected to the machines terminals through commutator and brushes



Windings

- Made of insulated copper wires
- Field winding – High Inductance and high resistance*
- Armature winding – Low inductance and less resistance
  - Two type of windings – Lap, wave
  - Lap winding – No. of parallel paths = No. of poles
  - Wave winding – No. of parallel paths = 2

Stepper Motor

A stepper motor is an electromechanical device which converts electrical pulses into discrete mechanical movements. The shaft or spindle of a stepper motor rotates in discrete step increments when electrical command pulses are applied to it in the proper sequence.

Main features

- The sequence of the applied pulses is directly related to the direction of motor shafts rotation.
- The speed of the motor shafts rotation is directly related to the frequency of the input pulses.
- The length of rotation is directly related to the number of input pulses applied.

Stepper Motor Features

Open loop
The motors response to digital input pulses provides open-loop control, making the motor simpler and less costly to control.

Brushless
Very reliable since there are no contact brushes in the motor. Therefore the life of the motor is simply dependant on the life of the bearing.

Incremental steps/changes
The rotation angle of the motor is proportional to the input pulse.

Speed increases -> torque decreases

Working principle

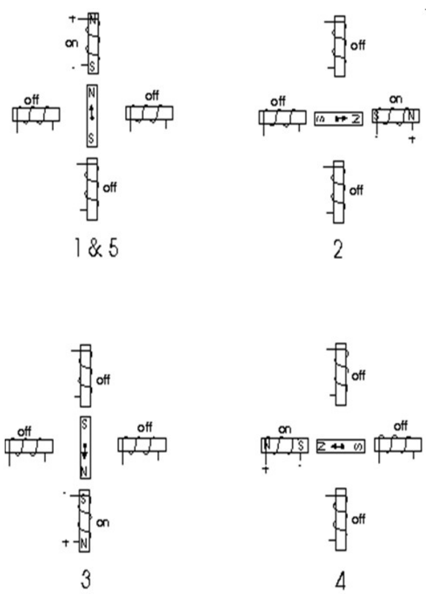
- Stepper motors consist of a permanent magnet rotating shaft, called the rotor, and electromagnets on the stationary portion that surrounds the motor, called the stator.

- When a phase winding of a stepper motor is energized with current, a magnetic flux is developed in the stator.

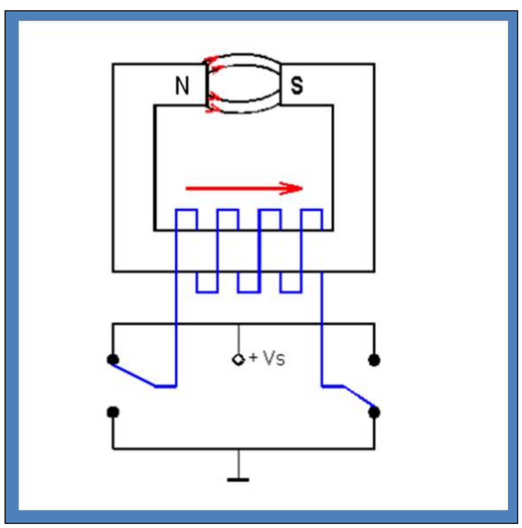
At position 1, the rotor is beginning at the upper electromagnet, which is currently active (has voltage applied to it).

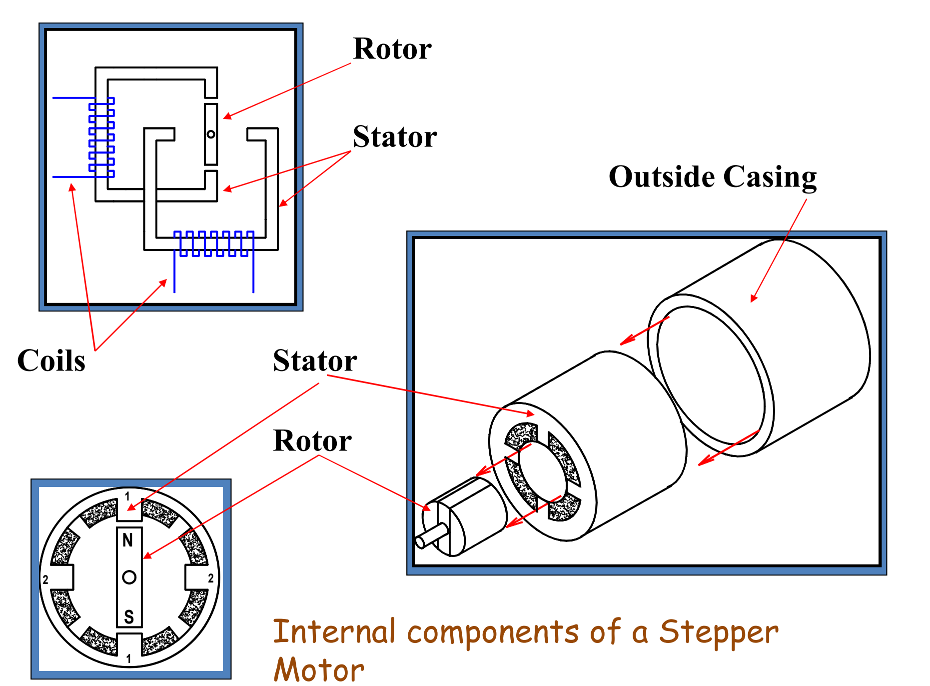
To move the rotor clockwise (CW), the upper electromagnet is deactivated and the right electromagnet is activated, causing the rotor to move 90 degrees CW, aligning itself with the active magnet.

This process is repeated in the same manner at the south and west electromagnets until we once again reach the starting position.



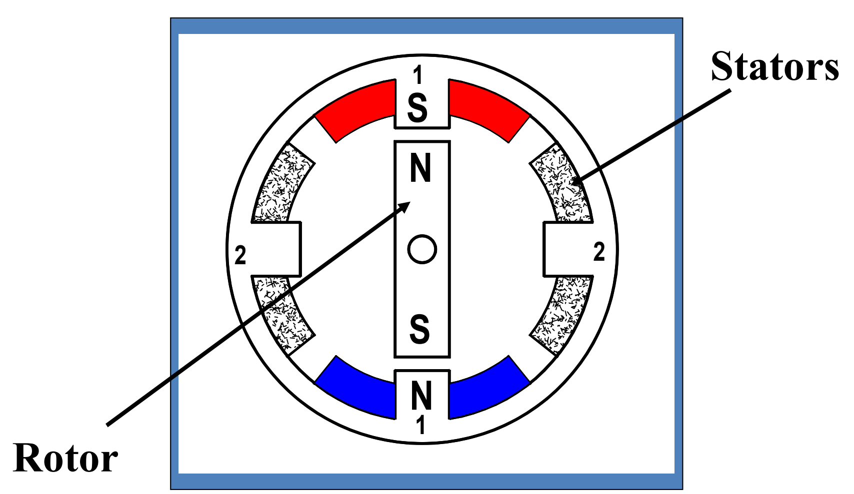
Stepper Motor / Electro magnet



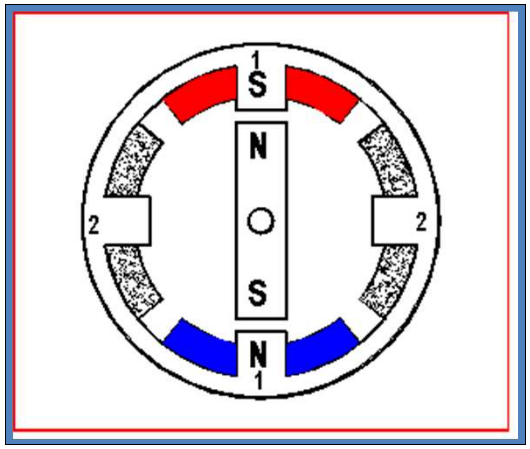


Internal components of a Stepper Motor

Cross Section of a Stepper Motor

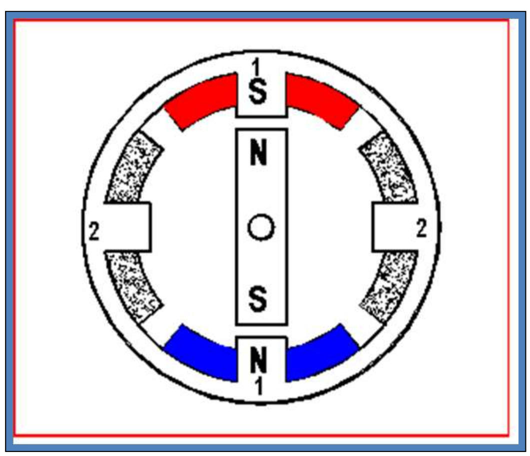


Full Step Operation

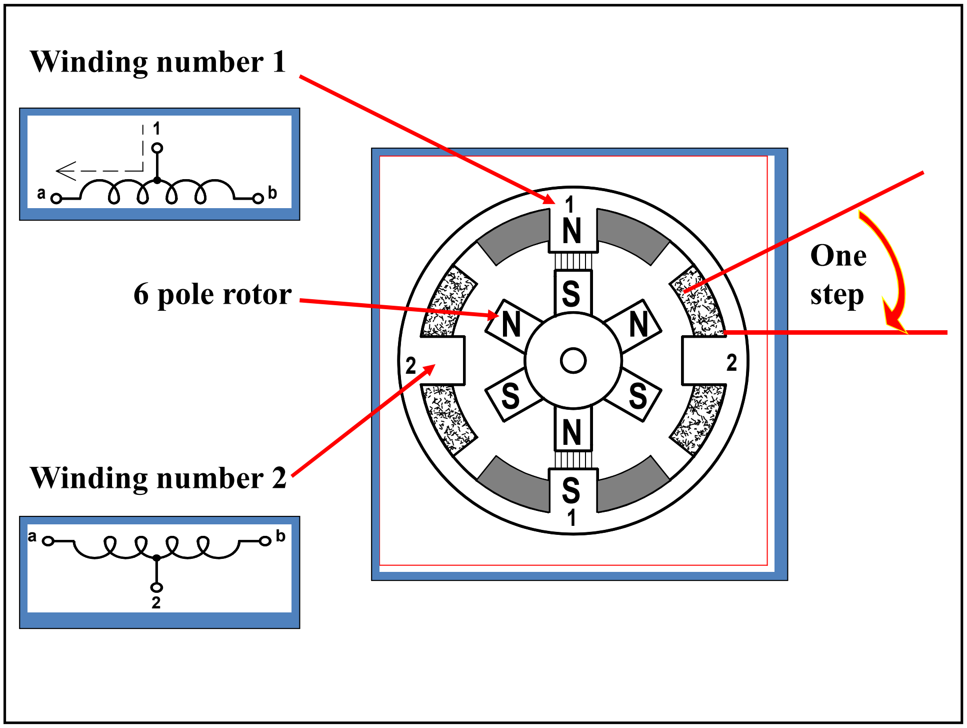


Four Steps per revolution i.e. 90 deg. steps.

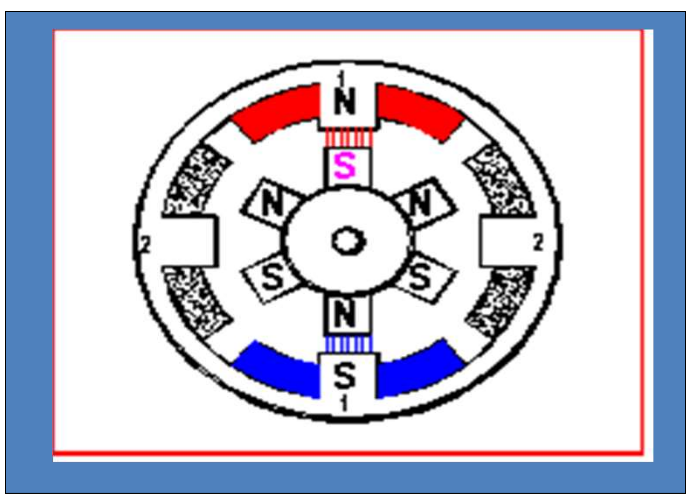
Half Step Operation



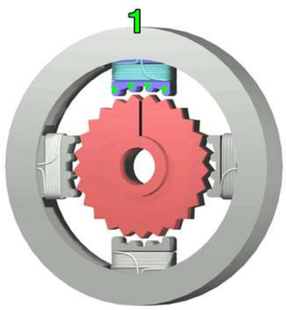
Eight steps per. revolution i.e. 45 deg. steps.



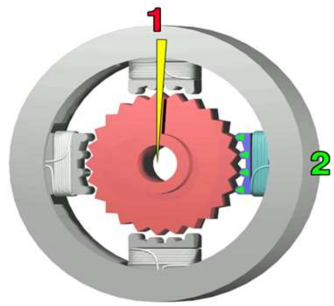
Six pole rotor, two electro magnets.



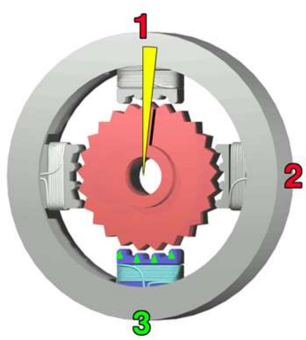
Practical Stepper motor operation



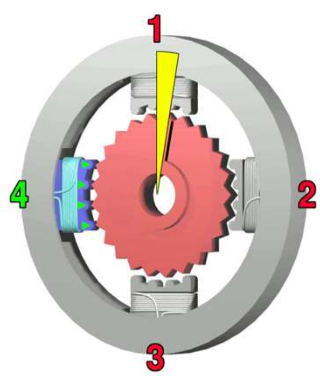
The top electromagnet (1) is turned on, attracting the nearest teeth of a gear-shaped iron rotor. With the teeth aligned to electromagnet 1, they will be slightly offset from electromagnet 2



The top electromagnet (1) is turned off, and the right electromagnet (2) is energized, pulling the nearest teeth slightly to the right. This results in a rotation of 3.6° in this example.

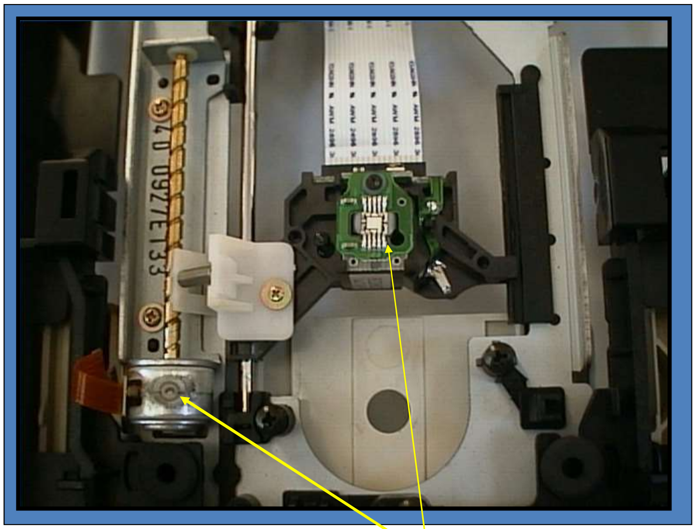


The bottom electromagnet (3) is energized; another 3.6° rotation occurs.



The left electromagnet (4) is enabled, rotating again by 3.6°. When the top electromagnet (1) is again enabled, the teeth in the sprocket will have rotated by one tooth position; since there are 25 teeth, it will take 100 steps to make a full rotation in this example.

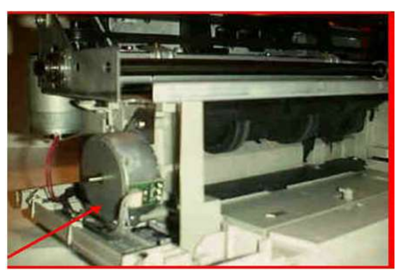
Stepper motor applications



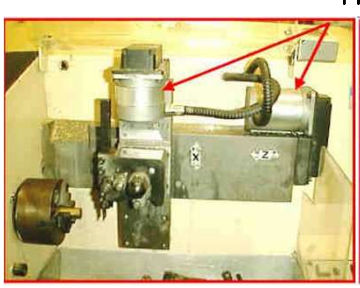
Stepping Motor to move read-write head

Stepper motor applications

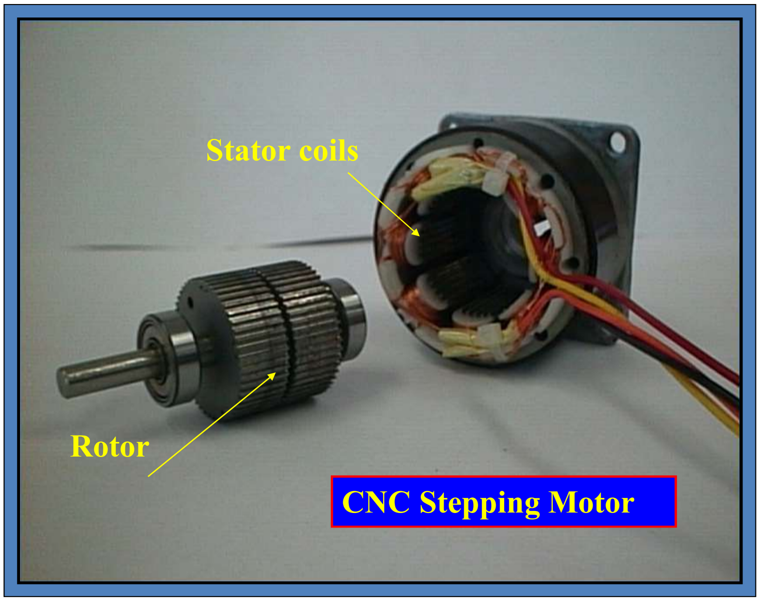
Paper feeder on printers



Stepper motors



CNC lathes



Advantages / Disadvantages

Advantages:-

- **Low cost for control achieved**
- **Ruggedness**
- **Simplicity of construction**
- **Can operate in an open loop control system**
- **Low maintenance**
- **Less likely to stall or slip**
- **Will work in any environment**

Disadvantages:-

- **Require a dedicated control circuit**
- **Use more current than D.C. motors**
- **High torque output achieved at low speeds**

Applications

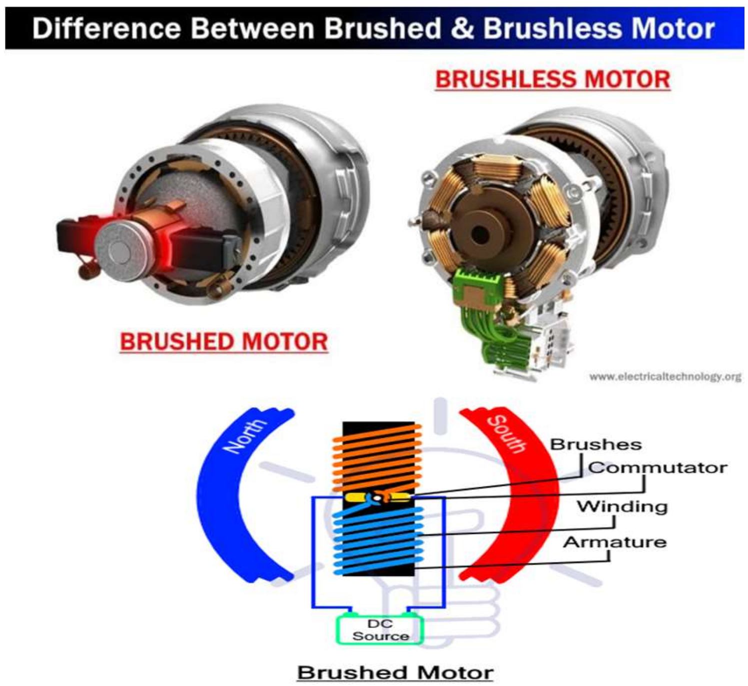
Stepper motors can be a good choice whenever controlled movement is required

They can be used to advantage in applications where you need to control rotation angle, speed, position and synchronism

These include

- printers
- plotters
- medical equipment
- fax machines
- automotive and scientific equipment etc.

Brushed/Brushless DC Motor

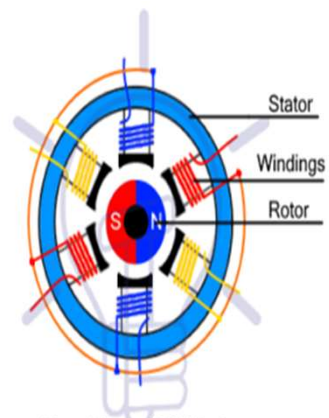


Brushed Motor

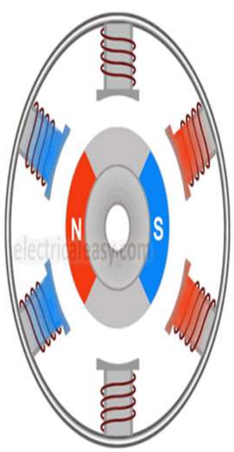
- The brushed motors are the earliest motor in the history.
- It uses carbon brushes mechanism to supply power to the rotating part of the machine called rotor.
- While the stator which is made of permanent magnet surrounds the rotor.
- The carbon brushes when slides across the commutator, it breaks and makes the contact with the armature windings (inductive load) that results in generating electromagnetic noise in the system.
- The brushed motors are very noisy. That is why the industries having very extreme environment where noise is not an issue often uses brushed motors due to its cheaper cost.

Brushless Motor

- The brushless motor (also known as BLDC Motor) as its name suggests, does not have brushes and it does not require it to operate.
- Since there are no brushes, the input power is supplied to the stator of the motor which in this case is made of multiple windings that surrounds the rotor. While the rotor is made of permanent magnet.
- The input is switched between the stators winding to generate magnetic field that push and pull on the rotor's magnetic field causing it rotate in its direction.
- A hall effect sensor is used to detect the position of the rotor and switch the input to the correct stators winding respectively.



Brushless DC Motor



Working Principle

- Brushless dc motors are essentially permanent-magnet stepping motors equipped with position sensors (either Hall effect or optical) and enhanced control units. As in the stepper motor, power is applied to one stator winding at a time.

- When the position sensor indicates that the rotor has approached alignment with the stator field, the controller electronically switches power to the next stator winding so that smooth motion continues.

- By varying the amplitude and duration of the pulses applied to the stator windings, speed can be readily controlled. The result is a motor that can operate from a dc source with characteristics similar to those of a conventional shunt dc motor.