EEL 2043

Principles of Machines and Power

Learning Outcome 3:

DC MACHINES

Topics of Learning Outcome 3 :

1: Explain the operational principles of DC motors and generators.

2: Derive and sketch the torque-speed and torque-current characteristics of DC motors.

3: Identify the industrial applications of DC motors in relation to excitation schemes and explain the influence of supply voltage, armature resistance, and field current on the rotational speed.

4: Measure the no - load characteristics of DC generators, loading characteristics of separately-excited and shunt DC generators, torque-speed characteristics of separately-excited, series and shunt DC motors, and torque-current characteristics of separately-excited, series and shunt DC motors.

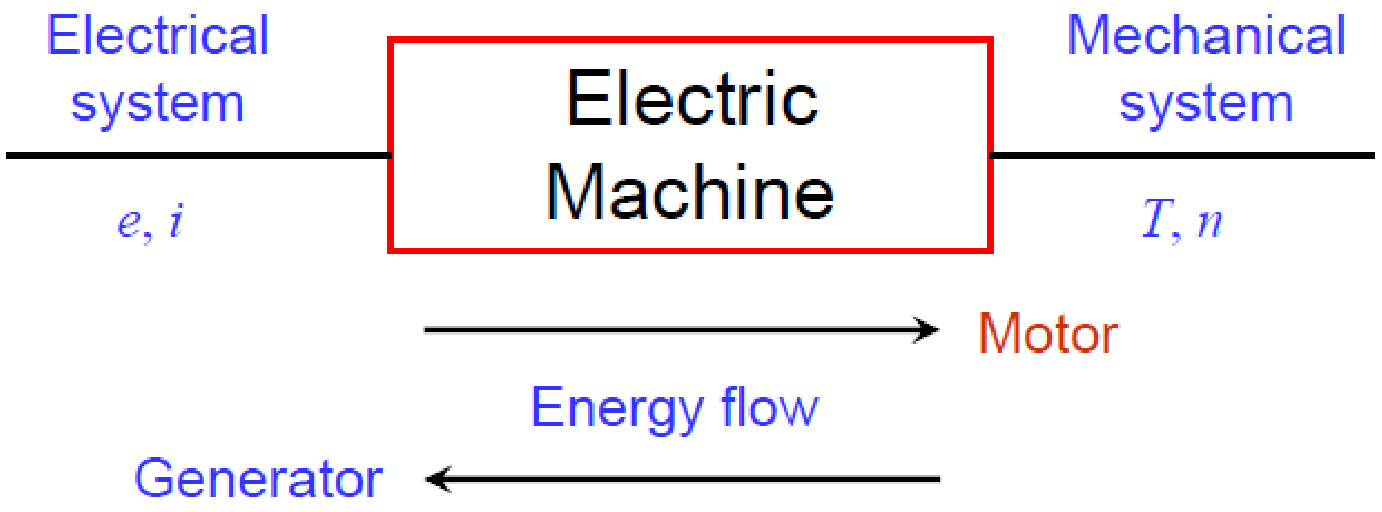
5: Describe the construction and operation of stepper motors.

6: Determine the expected step angle and direction of rotation, given the excitation scheme for the permanent magnet, variable reluctance, and hybrid stepper motor.

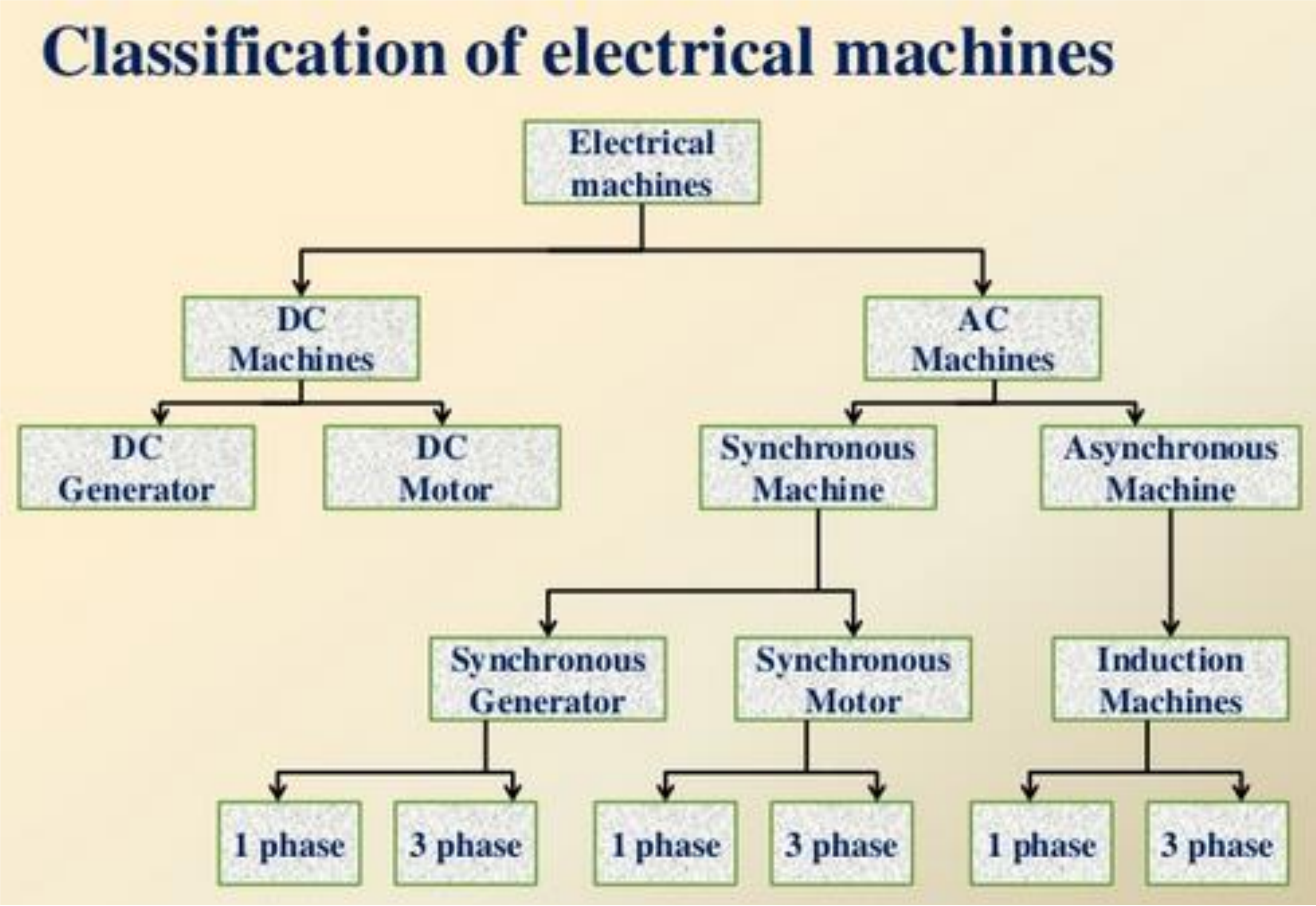
Introduction

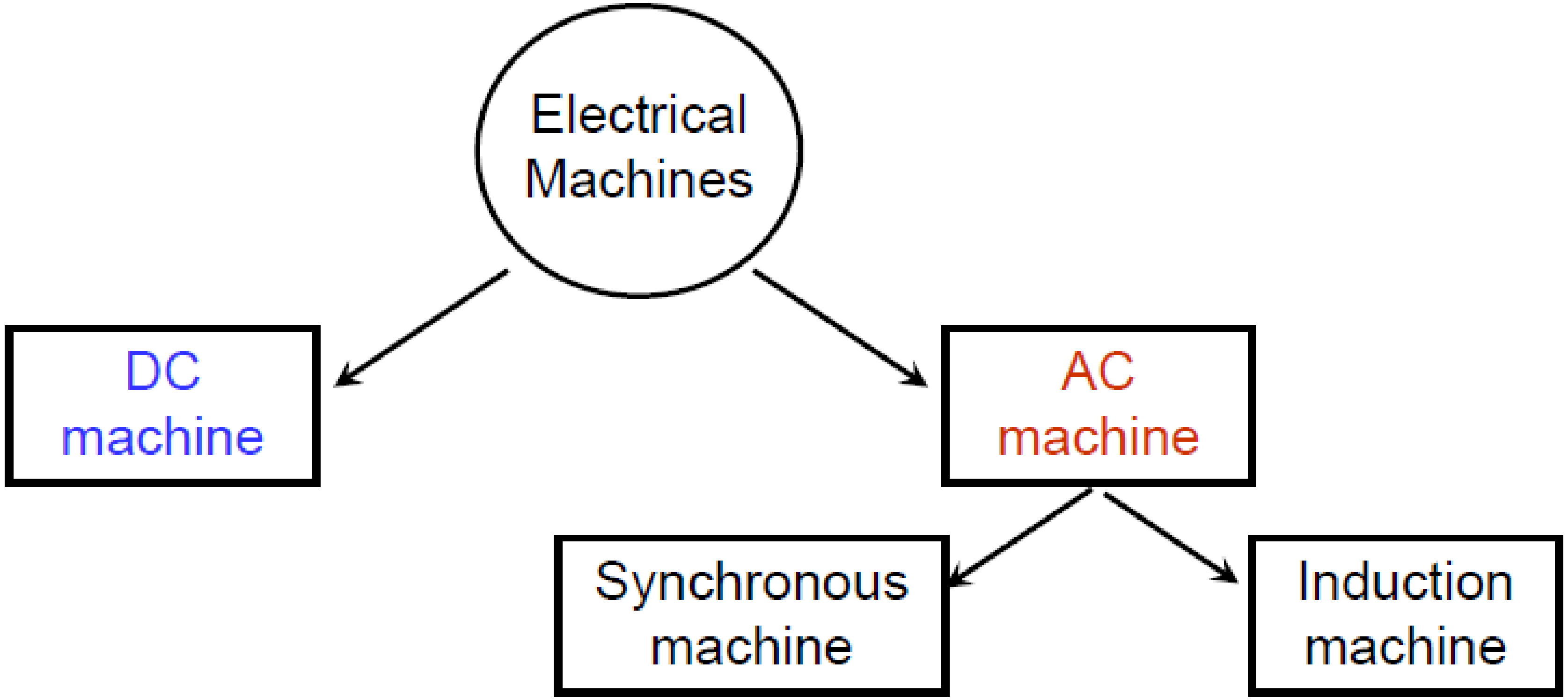
- One form of energy can be obtained from another form with the help of converters. Converters that are used to continuously translate electrical input to mechanical output or vice versa are called electric machines.

- The process of translation is known as electromechanical energy conversion.

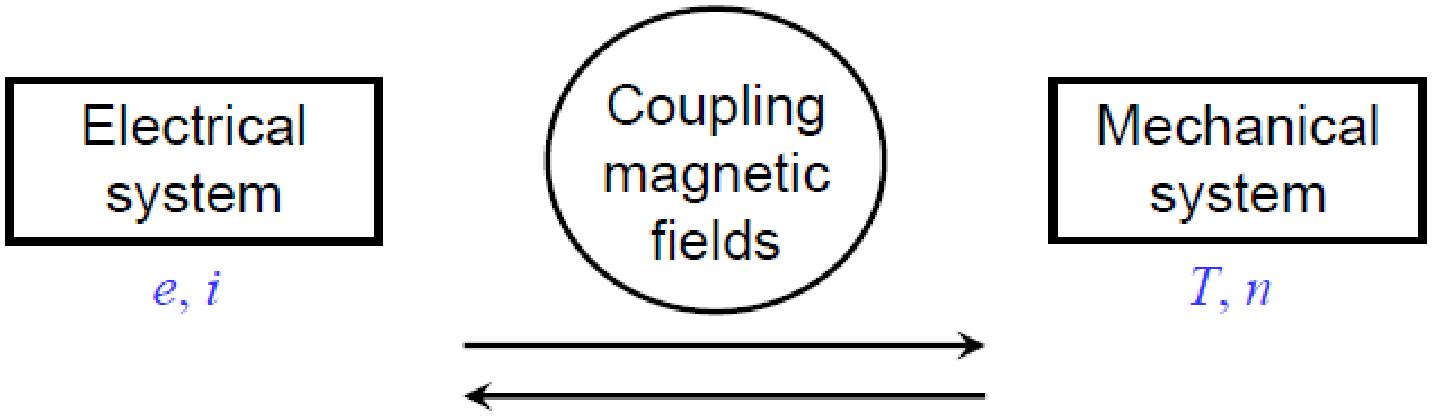


- An electrical machine is a link between an electrical system and a mechanical system.
- Conversion from mechanical to electrical: generator
- Conversion from electrical to mechanical: motor


Classification of electrical machines
Electrical machines
DC Machines
AC Machines
DC Generator
DC Motor
Synchronous Machine
Asynchronous Machine
Synchronous Generator
Synchronous Motor
Induction Machines
1 phase
3 phase
1 phase
3 phase
1 phase
3 phase



- Machines are called AC machines (generators or motors) if the electrical system is AC.
- DC machines if the electrical system is DC.



Two electromagnetic phenomena in the electric machines:

When a conductor moves in a magnetic field, voltage is induced in the conductor (generator).

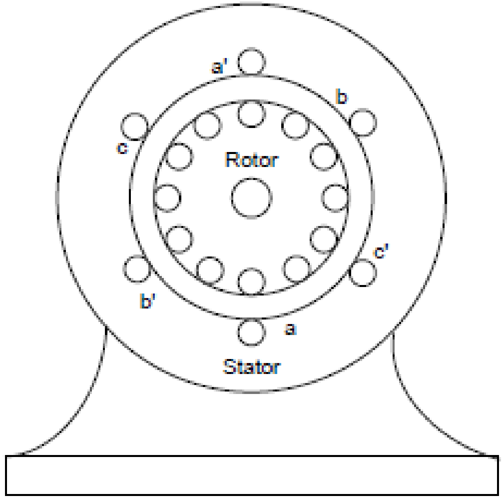
When a current-carrying conductor is placed in a magnetic field, the conductor experiences a mechanical force (motor).

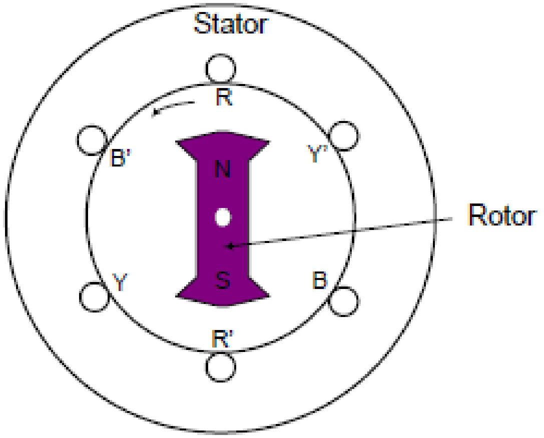
Electric Machines
Basic Structure

The structure of an electric machine has two major components, stator and rotor, separated by the air gap.

• Stator:
Does not move and normally is the outer frame of the machine.

• Rotor:
Is free to move and normally is the inner part of the machine.

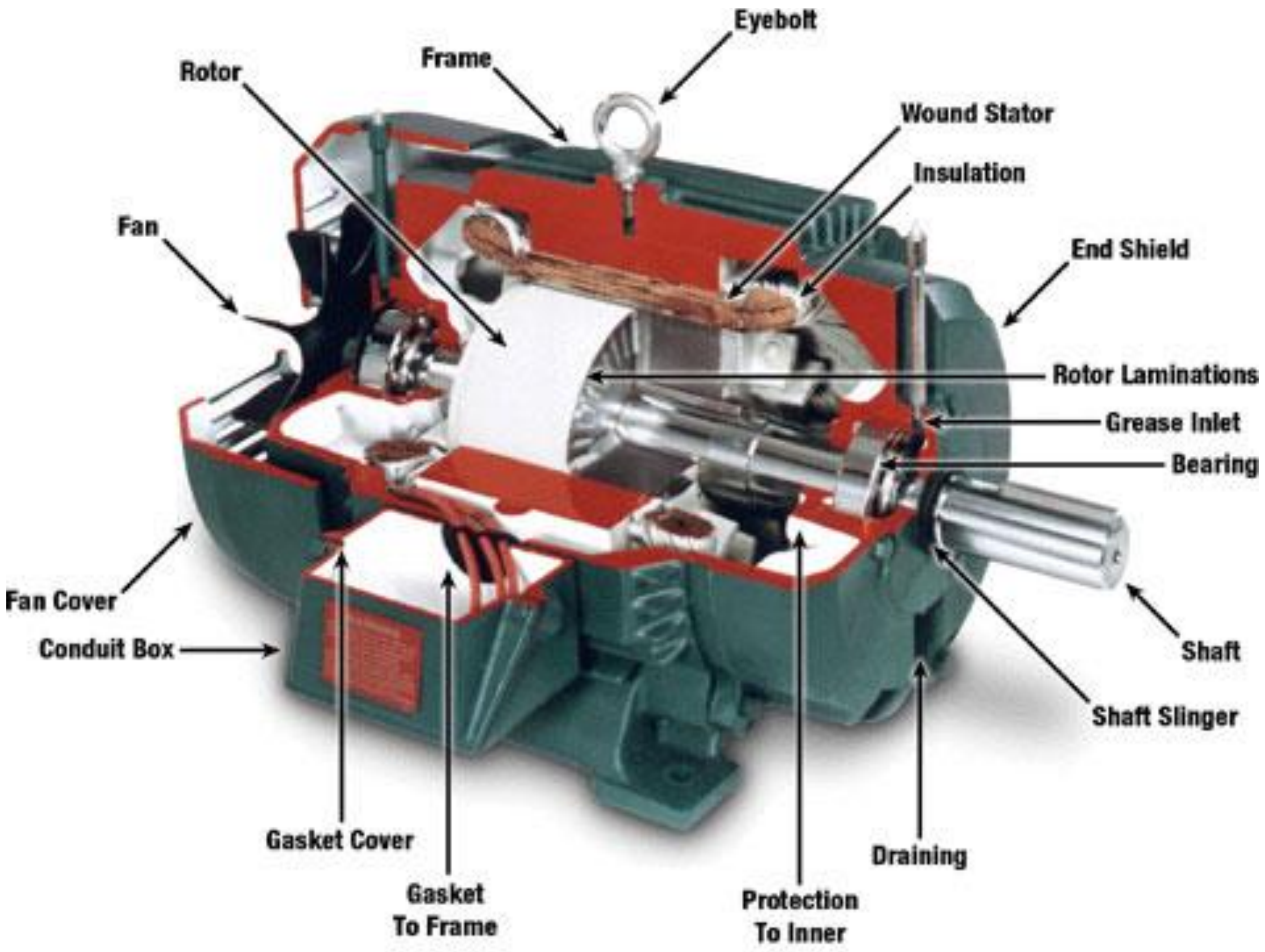




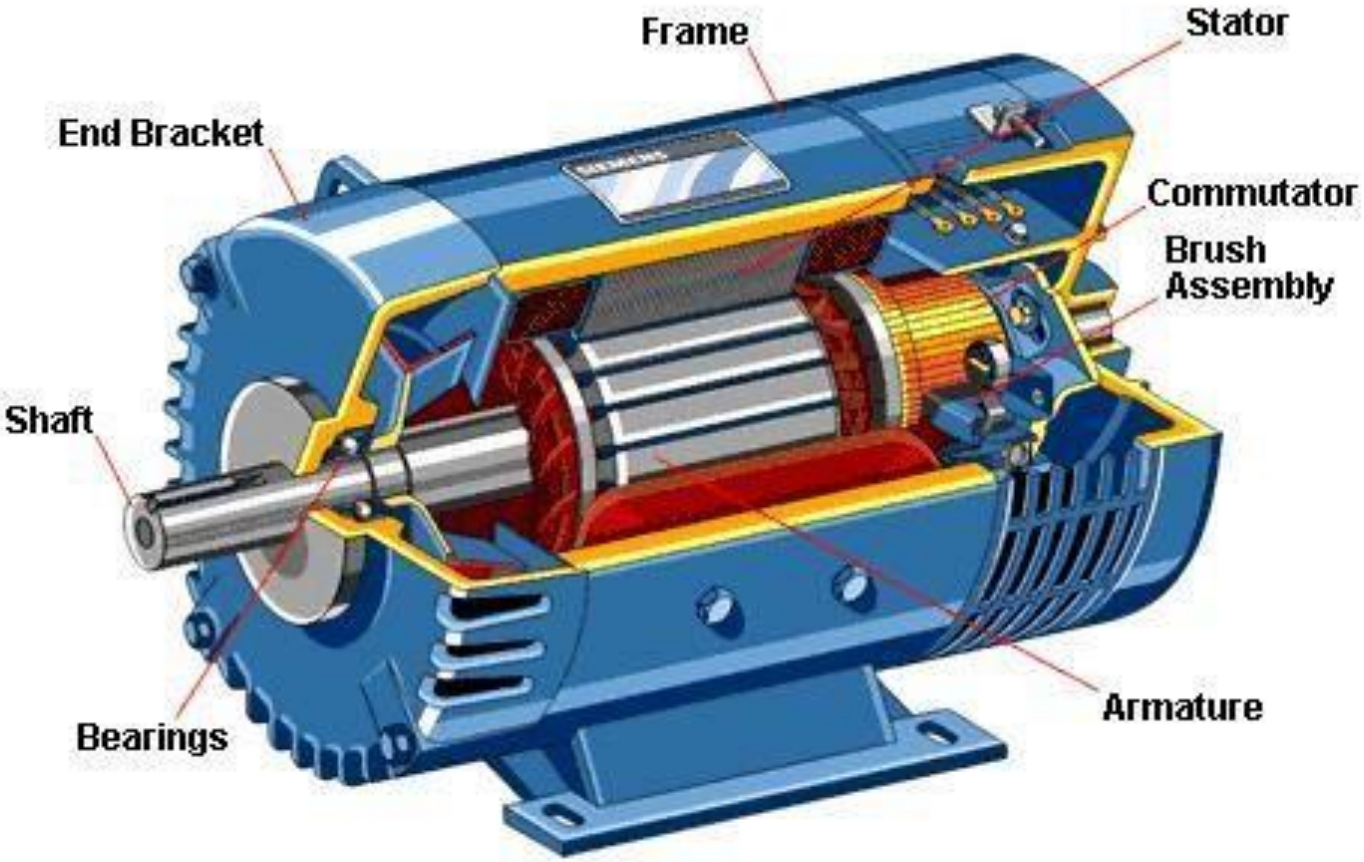
Both rotor and stator are made of ferromagnetic materials.

Electric Motor

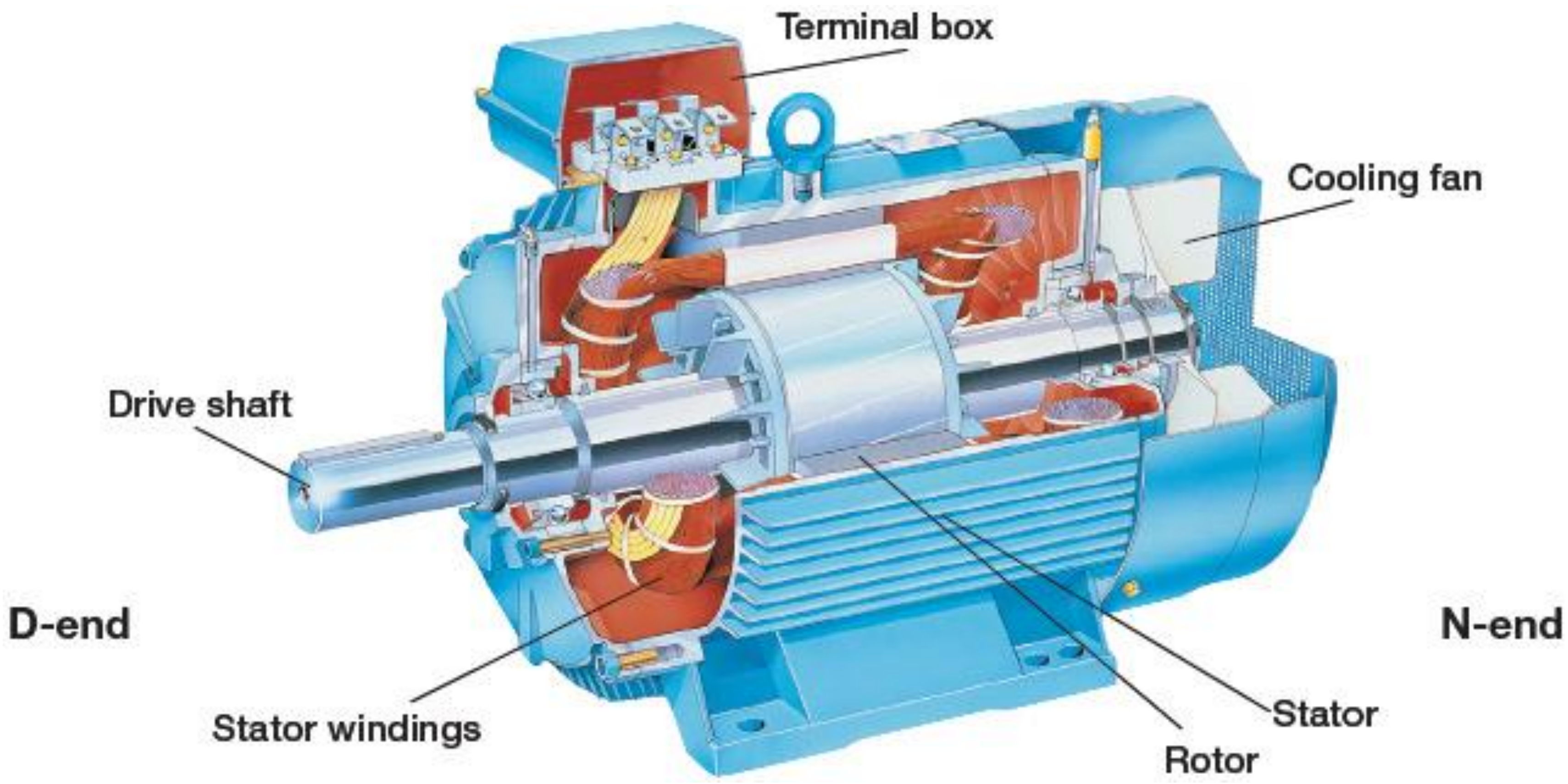
- A motor is a machine which converts electrical energy into mechanical energy.



DC Machines Construction



Induction Machines Construction



Synchronous Machines Construction

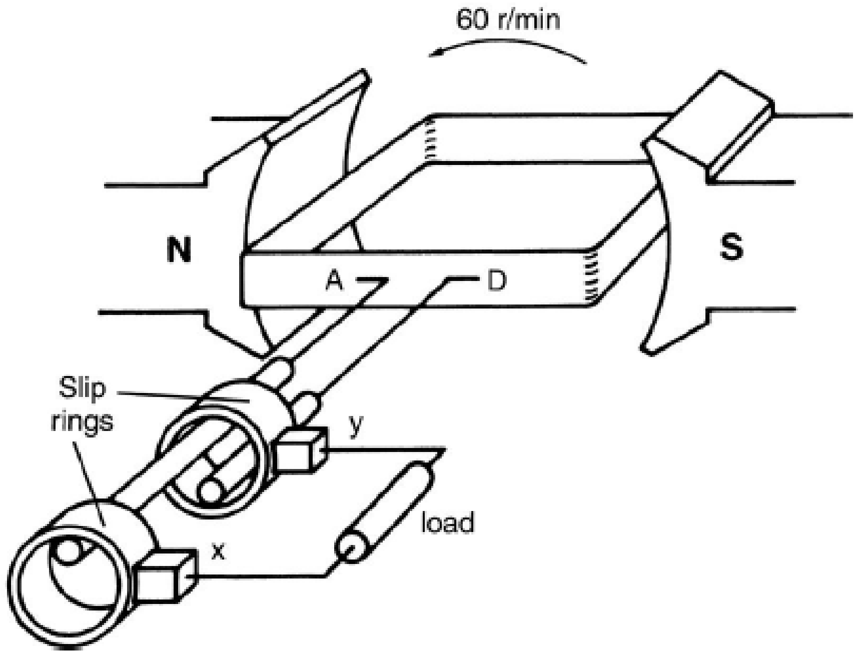
Direct-Current Generators

DC Generator

- The study of a direct- current (dc) generator has to begin with a knowledge of the alternating-current (ac) generator. The reason is that the voltage generated in any dc generator is inherently alternating and only becomes dc after it has been rectified by the commutator.

AC Generator

- The figure shows an elementary ac generator composed of a coil that revolves between the N and S poles of a magnet. The rotation is due to an external driving force.
- The coil is connected to two slip rings mounted on the shaft. The slip rings are connected to an external load by means of two stationary brushes x and y.

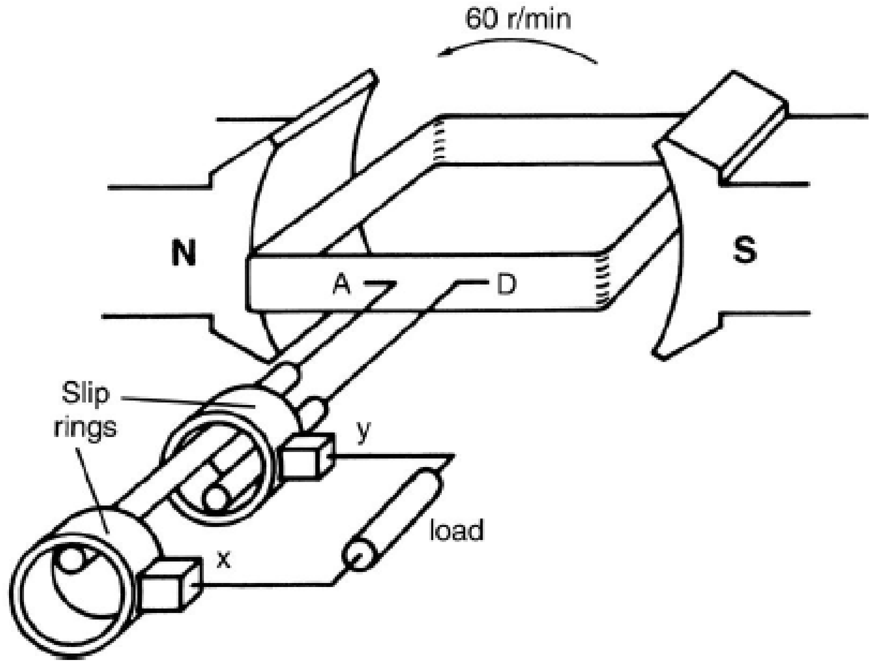


AC Generator

- As the coil rotates, a voltage is induced between its terminals A and D. This voltage appears between the brushes and, therefore, across the load.

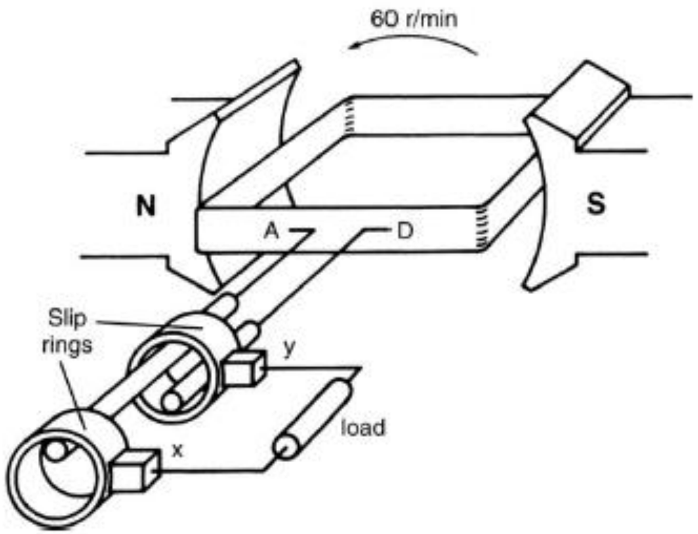
$$E = B\,l\,v$$

- The voltage is generated because the conductors of the coil cut across the flux produced by the N, S poles.
- The induced voltage is maximum when the coil is momentarily in the horizontal position, as shown.

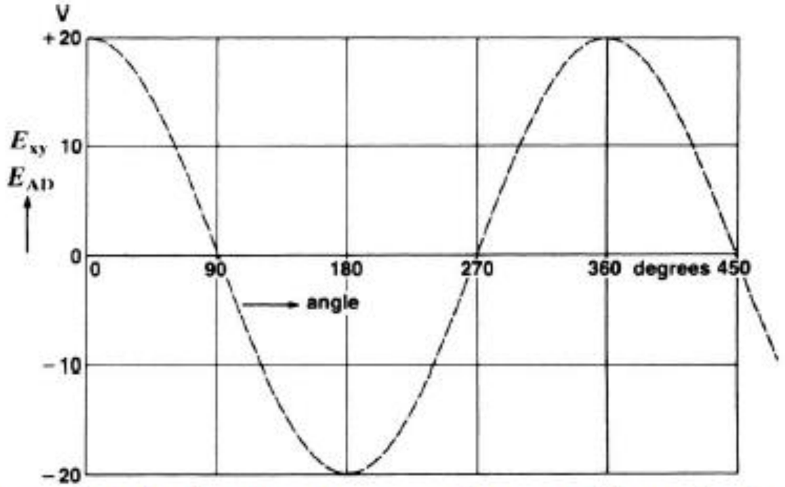


AC Generator

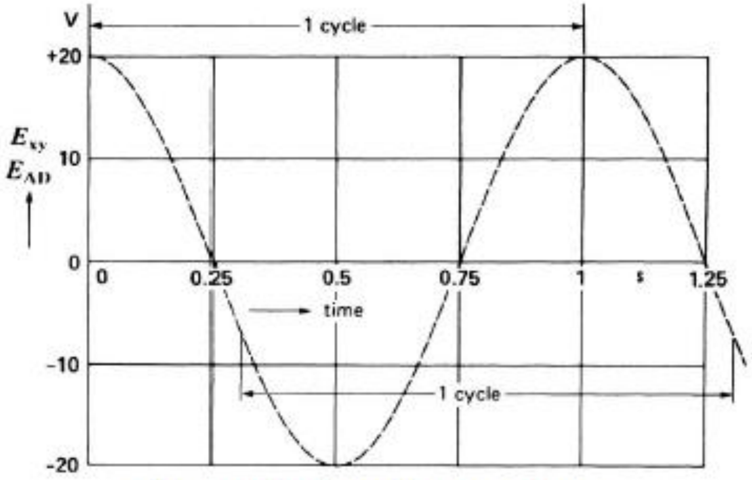
- No flux is cut when the coil is momentarily in the vertical position; consequently the voltage at these instants is zero.
- Another feature of the voltage is that its polarity changes every time the coil makes half a turn. The voltage can therefore be represented as a function of the angle of rotation.



$$E = B\,l\,v\,\sin\,\theta$$



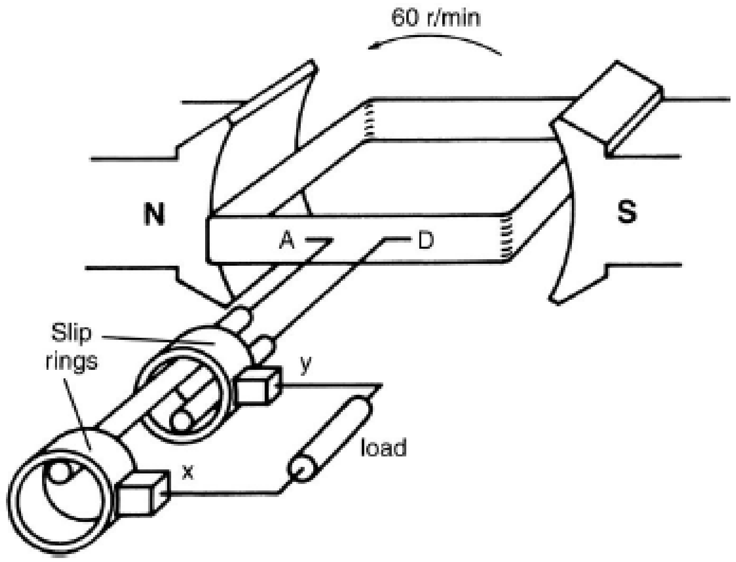
Voltage induced in the ac generator as a function of the angle of rotation.

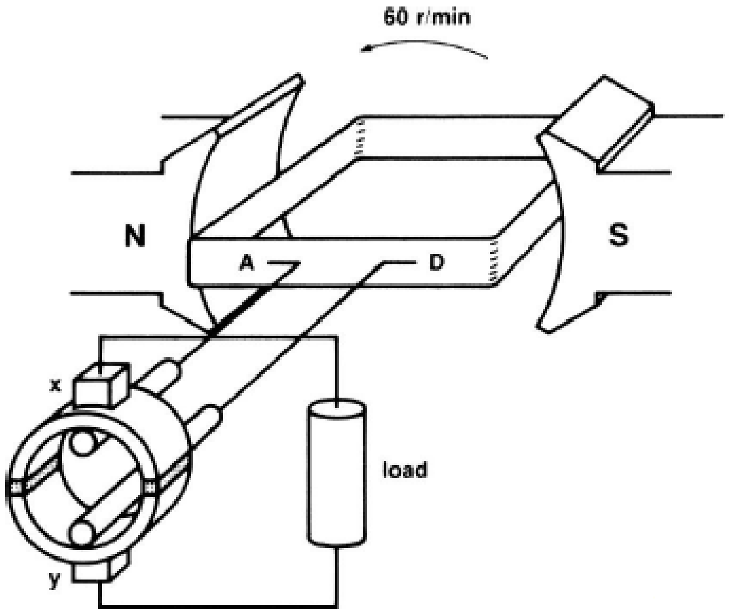


Voltage induced as a function of time.

DC Generator

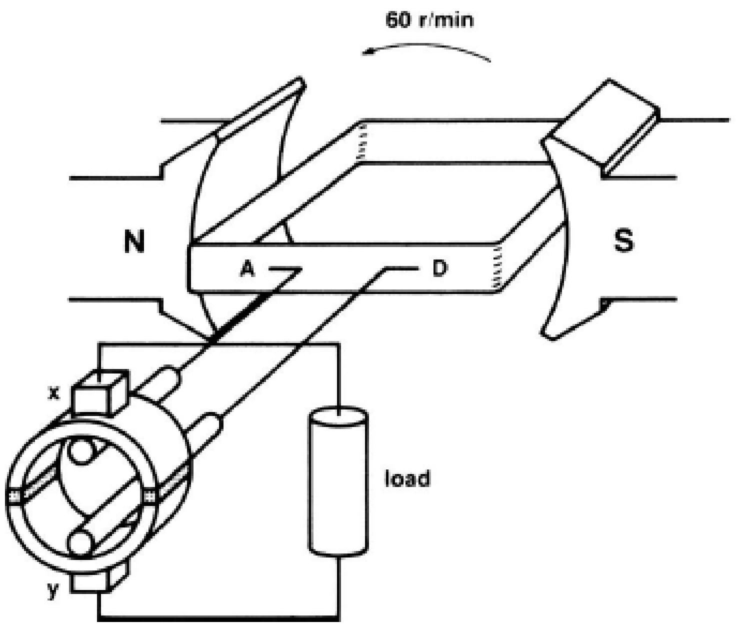
- If the brushes could be switched from one slip ring to the other every time the polarity was about to change, we would obtain a voltage of constant polarity across the load. Brush x would always be positive and brush y negative.
- We can obtain this result by using a commutator.

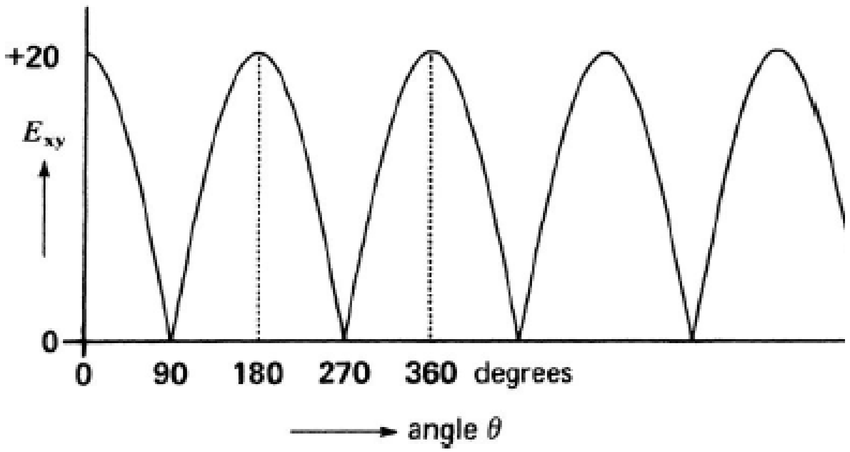




DC Generator

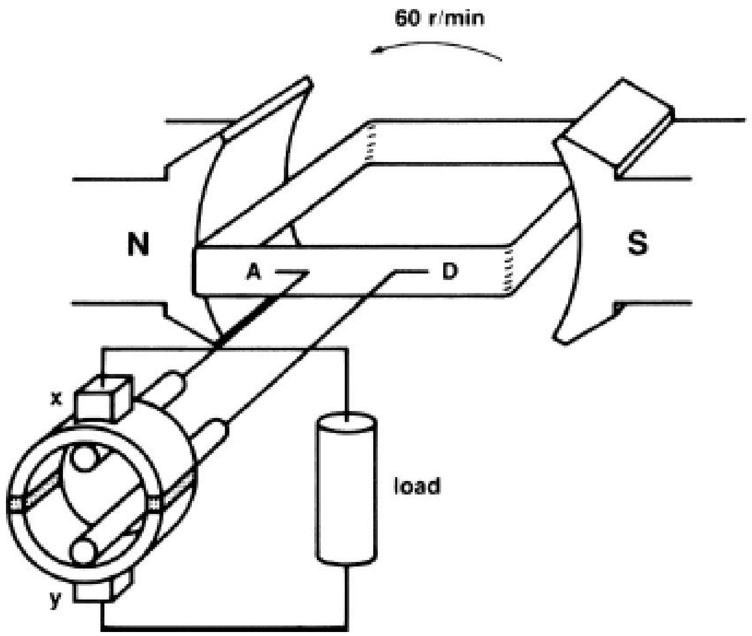
- Acommutator in its simplest form is composed of a slip ring that is cut in half, with each segment insulated from the other as well as from the shaft. One segment is connected to coil-end A and the other to coil-end D. The commutator revolves with the coil and the voltage between the segments is picked up by two stationary brushes x and y.
- The voltage between brushes x and y pulsates but never changes polarity. The alternating voltage in the coil is rectified by the commutator, which acts as a mechanical reversing switch.

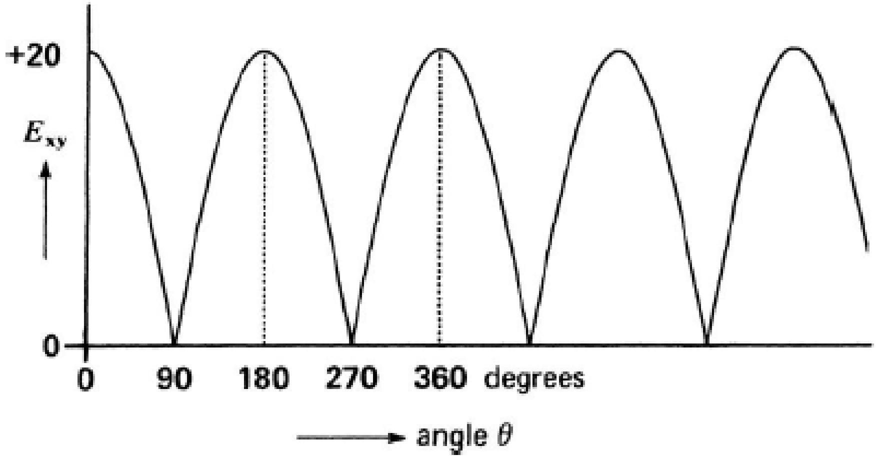




DC Generator

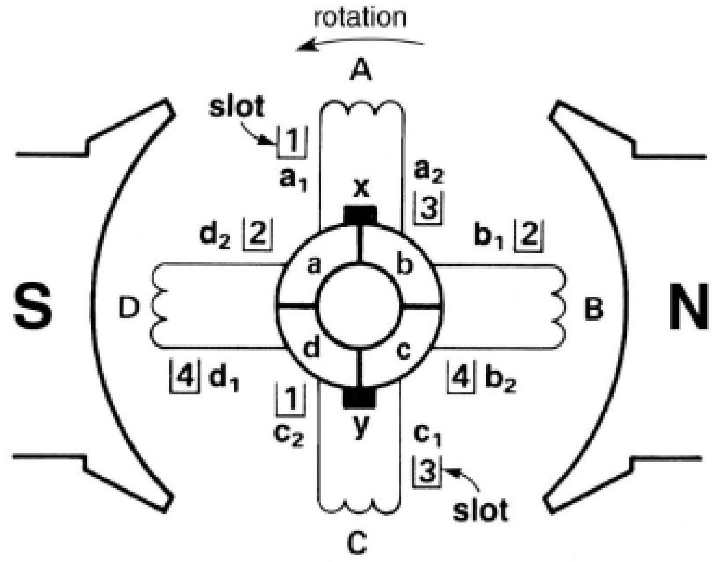
- Due to the constant polarity between the brushes, the current in the external load always flows in the same direction. This machine is called a direct-current generator, or dynamo.

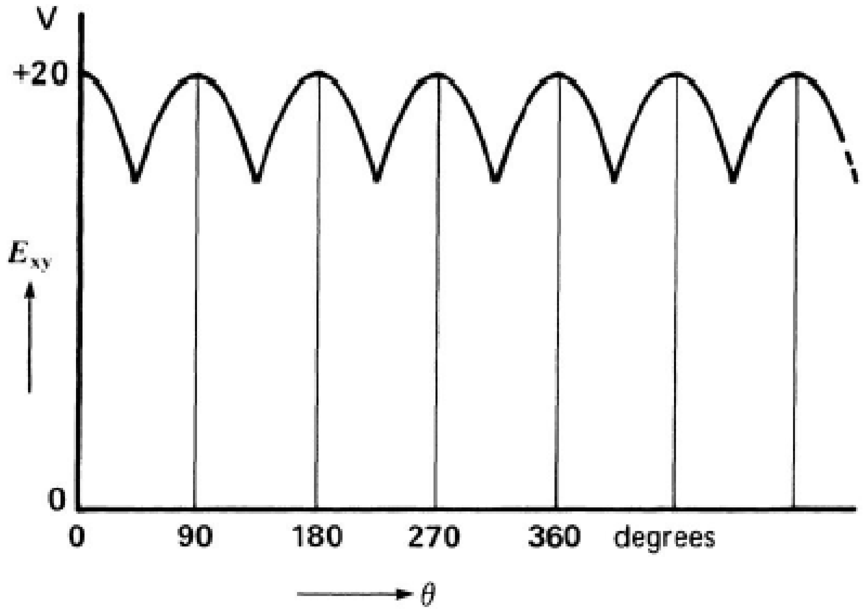




DC Generator

- we can improve the pulsating dc voltage by using four coils and four segments.
- The voltage still pulsates but it never falls to zero; it is much closer to a steady dc voltage.
- By increasing the number of coils and segments, we can obtain a dc voltage that is very smooth.





DC Generator

- The voltage induced in a dc generator having a lap winding is given by:

$$E_o = Z\, n\, \phi / 60$$

where:

  - E_o = voltage between the brushes [V]
  - Z = total number of conductors on the armature
  - n = speed of rotation [r/min]
  - ϕ = flux per pole [Wb]

- For a given generator the voltage is directly proportional to the flux per pole and to the speed of rotation.

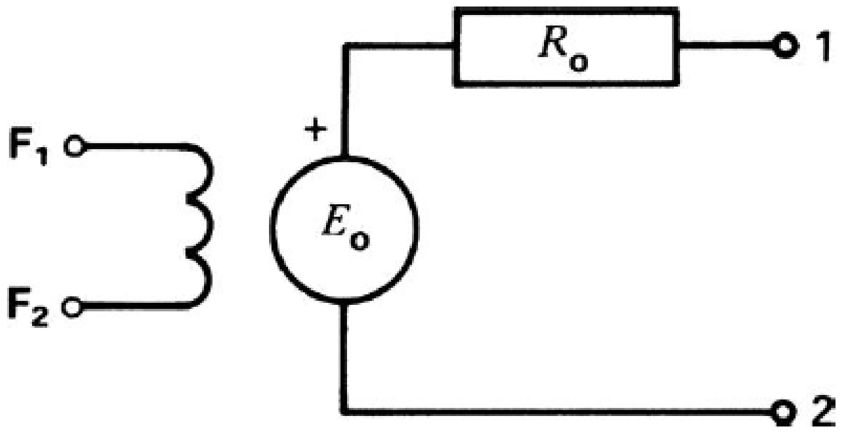
Example-1

- The armature of a 6-pole, 600r/min generator, has 90 slots. Each coil has 4 turns and the flux per pole is 0.04Wb. Calculate the value of the induced voltage.

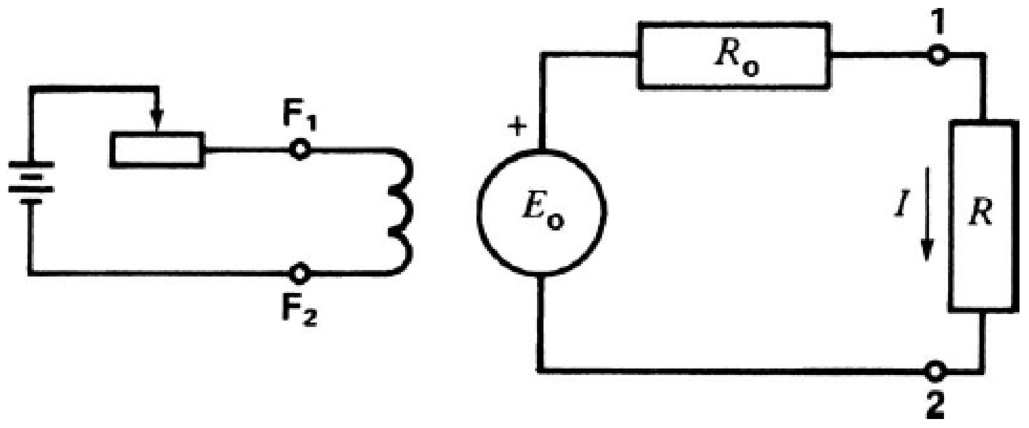
Equivalent Circuit of a DC Generator

The equivalent circuit of a generator is composed of a resistance R_o (the total armature resistance) in series with a voltage E_o (the voltage induced in the revolving conductors).

- Terminals 1, 2 are the external armature terminals of the machine.
- F_1, F_2 are the field winding terminals.



Equivalent circuit of a dc generator



Separately excited generator under load

Direct-Current Motors

DC Motor

DC Motor converts electrical energy into mechanical energy. They are used to drive such devices as;

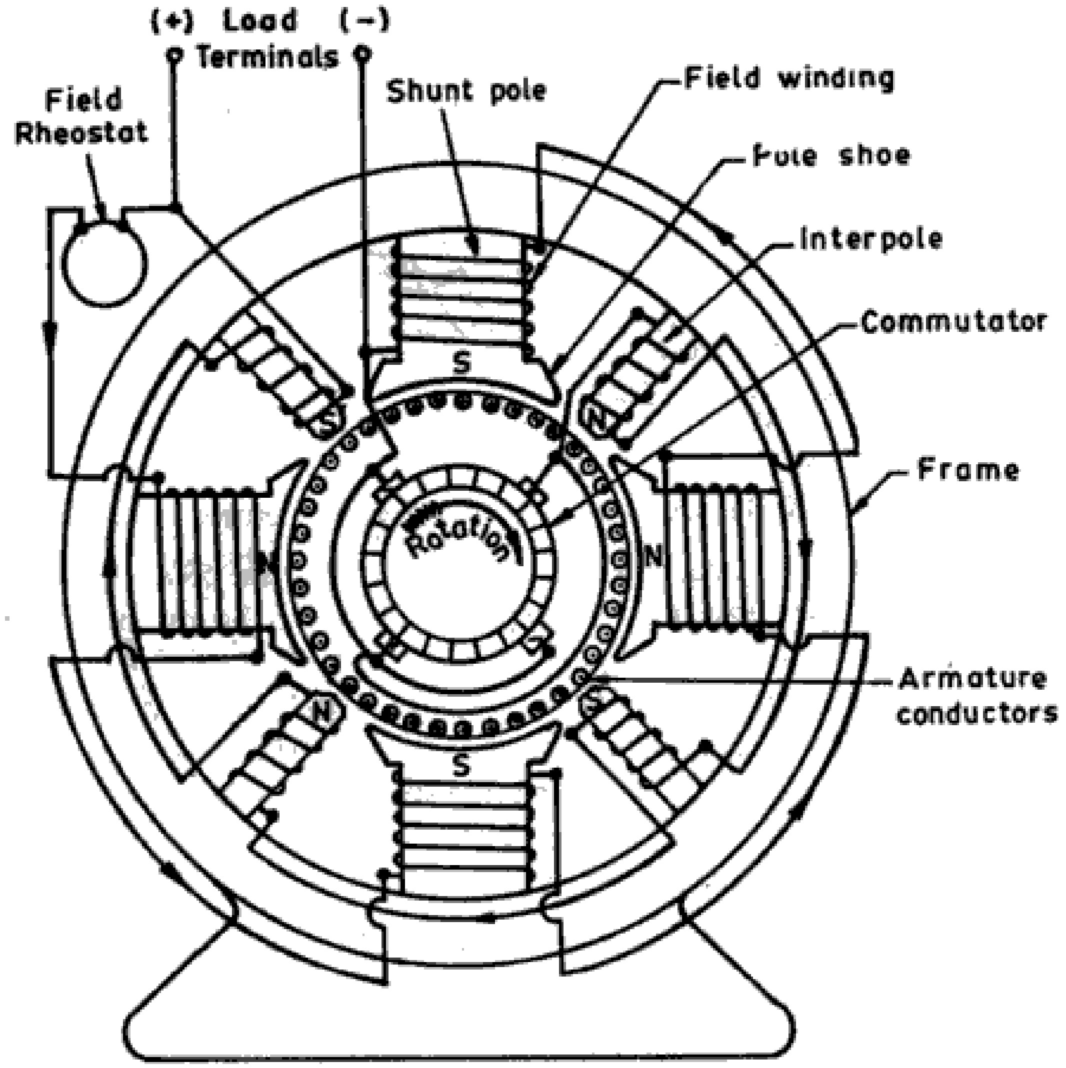
- Hoists
- Fans
- Pumps
- Punch press
- Cars

DC Motor

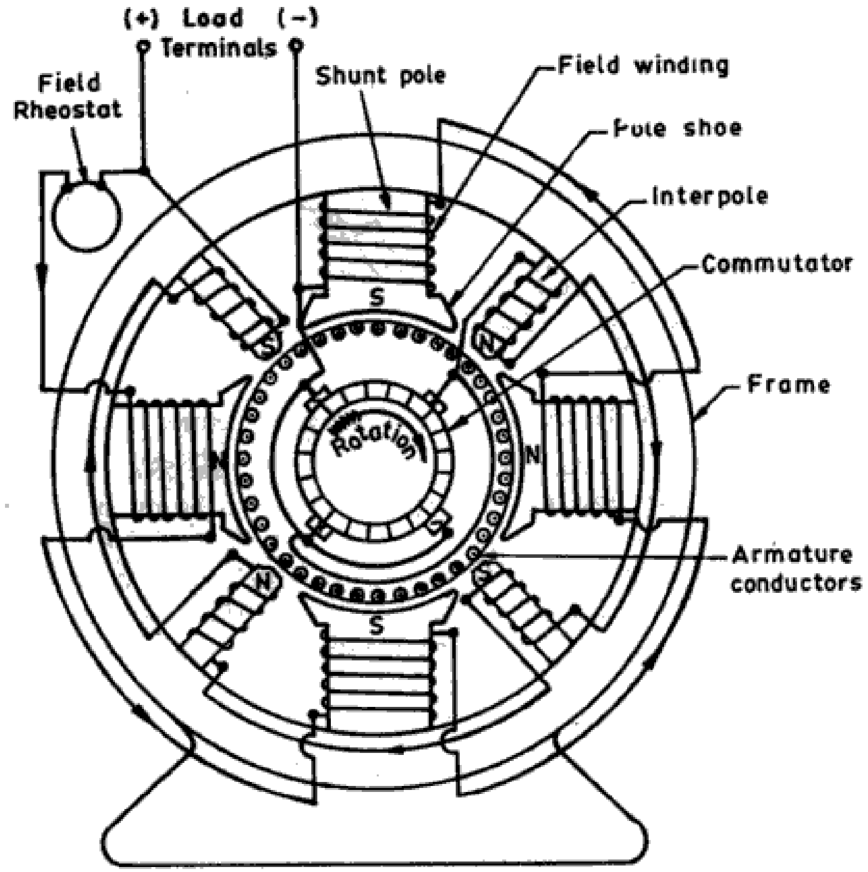
- DC Motors are rarely used in ordinary industrial application because all electrical utility systems are alternating current, AC.
- However, for special applications such as in steel mills, mines and electric trains, it is sometimes an advantage to use DC rather than AC motors.
- The reason is that the torque – speed characteristic of a DC motors can be varied over a wide range while retaining high efficiency.

Construction of DC Motor

1. Stator
2. Rotor
3. Air gap
4. Yoke or Frame
5. Pole Core
6. Pole Shoes
7. Commutator
8. Brushes
9. Bearings
10. Shaft



1. *Stator* :- In Which field winding is placed. Field winding is excited by DC supply and it is concentrated on the pole cores on the stator.
2. *Rotor*:- In which armature is placed. Electrical input is given to the armature in case of motor and electrical output is taken in case of generator.
3. *Air gap*:- Stator and rotor are separated by a small air gap in which flux is set up.
4. *Yoke or Frame*:- it covers the whole machine and provides the mechanical support to the poles.
5. *Pole Core*:- field winding is mounted on the pole core



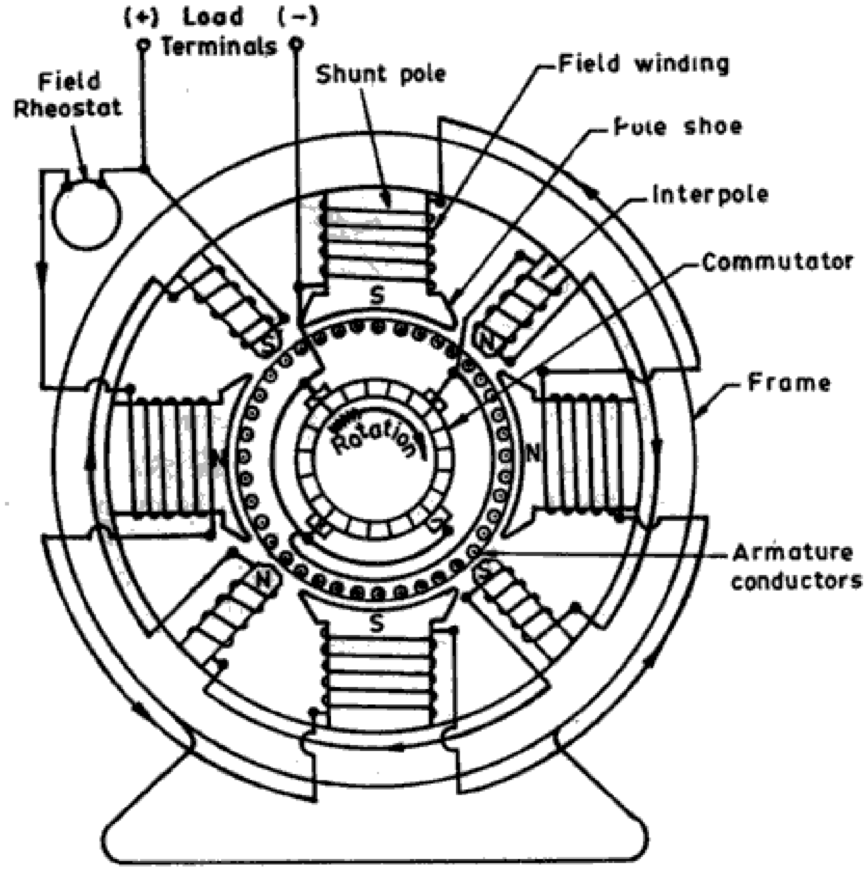
6. *Pole Shoes*:- the pole shoes acts as a support to the field coils and spreads out the flux over the armature periphery more uniformly and also being of larger cross section reduces the reluctance of the magnetic path.

7. *Commutator*:- This is used for rectification (ac to dc) in case of generator and for conversion (dc to ac) in case of motor.

8. *Brushes*:- The function is to collect current from commutator. They are made of carbon.

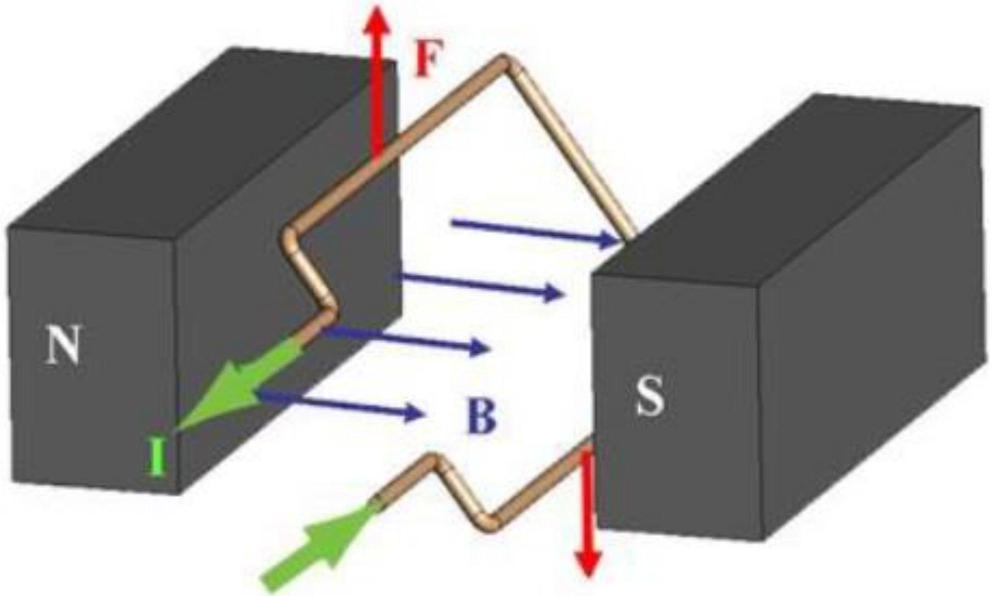
9. *Bearings*:- The main function of a bearing is to support the rotating parts and to allow its smooth motion with minimum friction.

10. *Shaft*:-The shaft is made of mild steel with a maximum breaking strength.



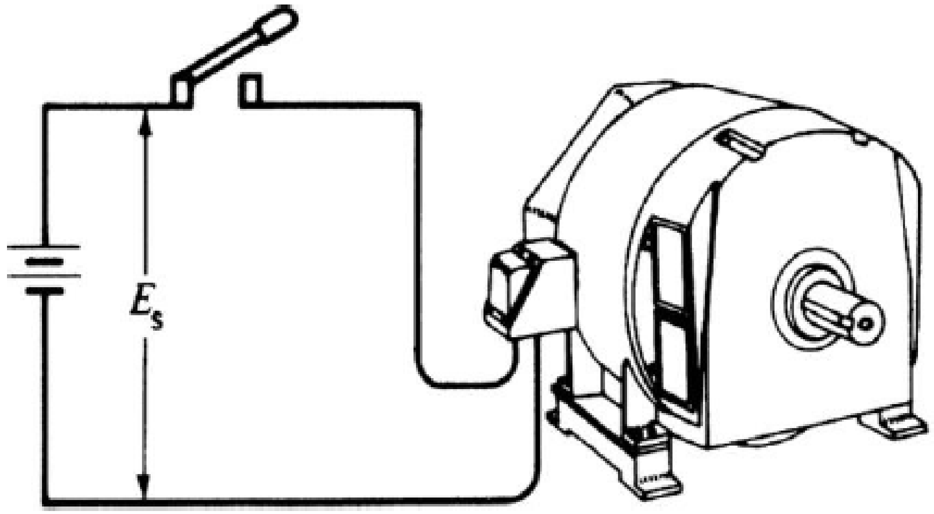
Working Principle of DC Motor

- When ever a current carrying conductor is placed in a magnetic field, it experienced a force whose direction is given by fleming's left hand rule(also called motor rule)
- It shows the field set up by the poles.
- It shows the conductor field due to flow of current in the conductor.



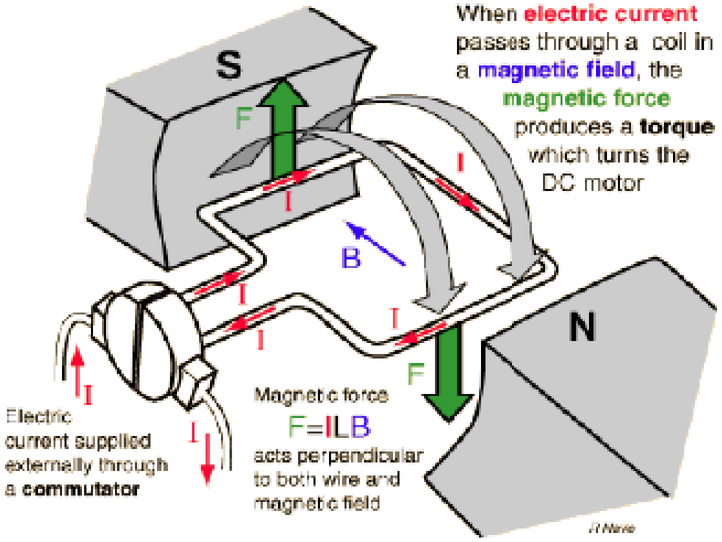
Working Principle of DC Motor

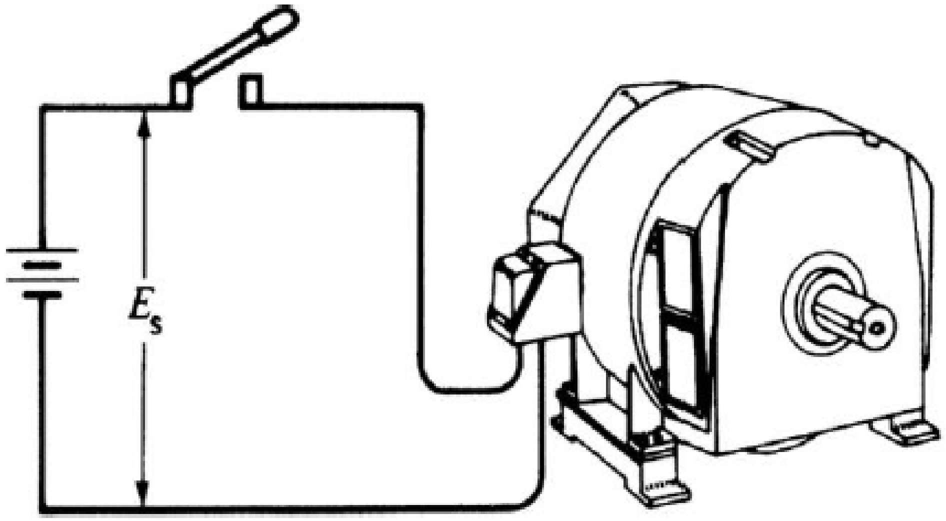
- A DC machine can operate either as a motor or as generator. To consider a DC generator in which the armature, initially at rest, is connected to a DC source E_s by means of a switch. The armature has a resistance R and the magnetic field is created by a set of permanent magnets.



Working Principle of DC Motor

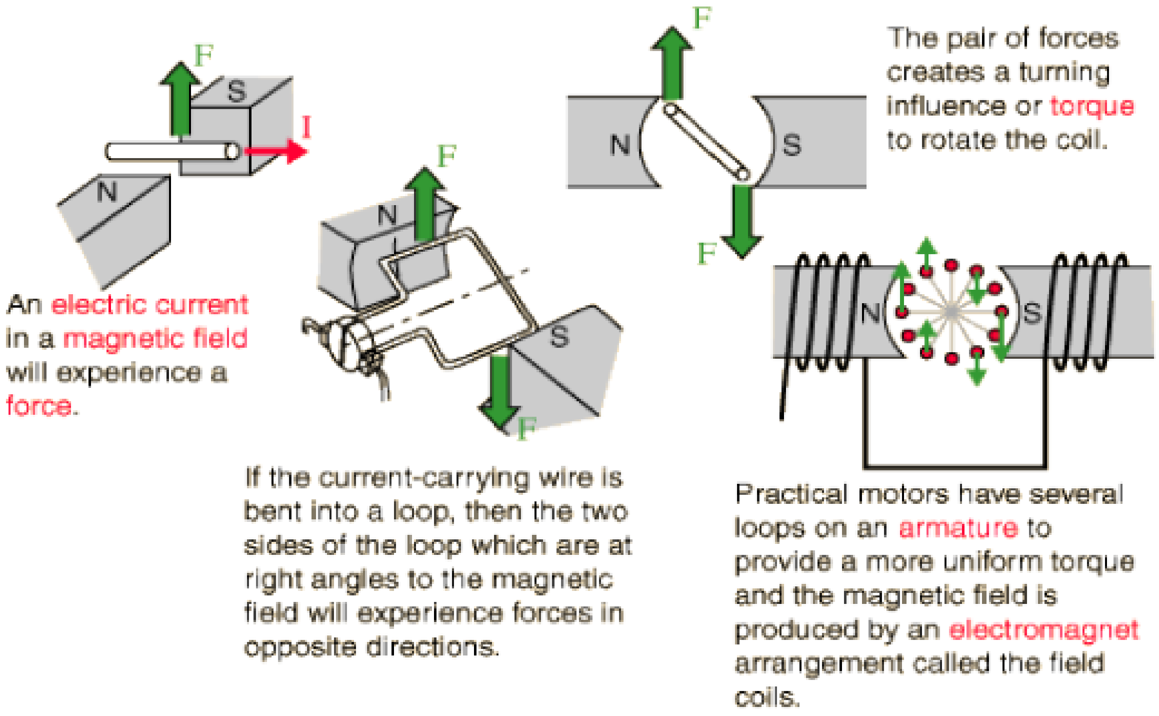
- As soon as the switch is closed, a large current flows in the armature because the resistance is very low. The individual armature conductors are immediately subjected to a force created by the permanent magnets. These forces add up to produce a powerful torque, causing the armature to rotate,.





Working Principle of DC Motor

- At the same time, as soon as the armature begins to turn, a second phenomenon happens: the generator effect. We will realise that a voltage E_o is induced in the armature conductors as soon as they cut magnetic field.



Working Principle of DC Motor

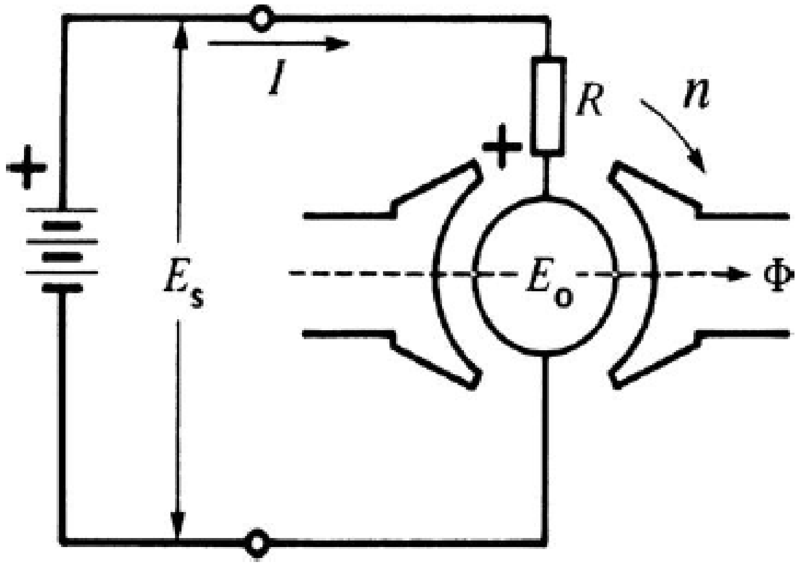
- The value and polarity of this induced voltage are the same as a generator.
- The induced E_o is proportional to the speed of rotation n of the motor and the flux, ϕ per pole:

$$E_o = Z\, n\, \phi / 60$$

- Z is a constant that depends upon the number of turns on the armature and the type of winding.
- In the case of a motor, the induced voltage E_o is called counter electromotive force (cemf) because the polarity is always the voltage that acts against the source voltage E_s .

Working Principle of DC Motor

- The induced voltage E_o is called counter electromotive force (cemf) because the polarity is always the voltage that acts against the source voltage E_s .
- It acts against the voltage in the sense that the net voltage acting on the armature circuit is equal $(E_s - E_o)$ volts.



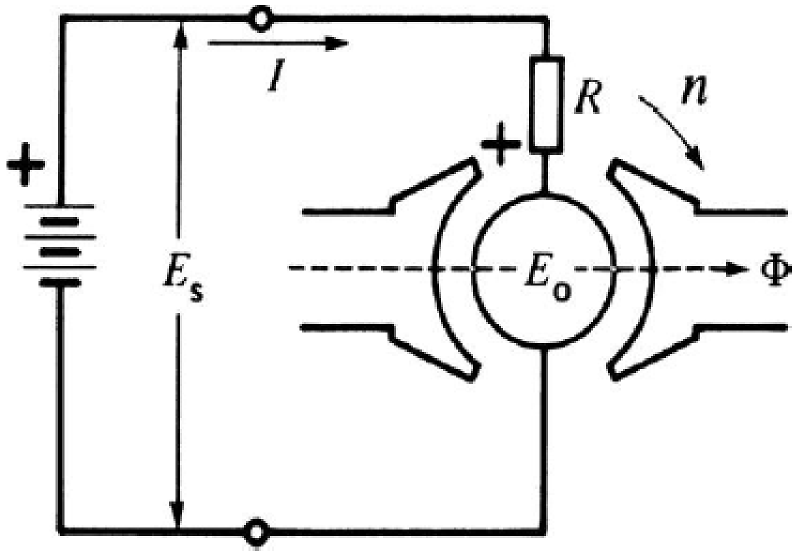
Working Principle of DC Motor

- The net voltage in the armature circuit is $(E_s - E_o)$ volts.
- The resulting armature current I is limited only by the armature resistance R:

$$I = (E_s - E_o) / R \qquad \text{Amperes}$$

- When the motor is at rest, the induced voltage E_o = 0 volts and so the starting current is:

$$I = E_s / R \qquad \text{Amperes}$$



Working Principle of DC Motor

- The starting current may be as much as 20 to 30 times greater than the nominal full-load current of the motor.
- In practise, this would cause the fuse to blow or circuit breaker to trip. However, if they are absent, the large forces acting on the armature conductors produce powerful starting torque and a consequent rapid acceleration of the armature.
- As the speed increases, the CEMF, E_o, increases. With the result that the value of $(E_s - E_o)$ diminishes, it follows that I will also drop progressively as the speed increases.

Working Principle of DC Motor

- Although the armature current decreases, the motor continues to accelerate until it reaches maximum speed.
- At no-load this speed produces a CEMF E_o slightly less than the source voltage, E_s. In effect, if E_o were equal to E_s, the net voltage, ($E_s - E_o$) would become zero and so, too would the current I.
- The driving forces would cease to act on the armature conductors and the mechanical drag imposed by the fan and bearings would immediately cause the motor to slowdown.
- As the speed decreases the net voltage ($E_s - E_o$) increases and so does the current I.
- The speed will cease to fall as soon as the torque developed by the armature current is equal to the load torque. Thus, when a motor runs at No – load, the CEMF must be slightly less than E_s so as to enable a small current to flow, sufficient to produce the required torque.

Example 2

The armature of a permanent magnet dc generator has a resistance of 1Ω and generates a voltage 50Vwhen the speed is 500rpm. If the armature is connected to a source of 150V, calculate the following:

(a) Starting Current

(b) CEMF when the motor runs at 1000 and 1460 rpm

(c) Armature current at 1000 and 1460 rpm

Power and Torque

- The power & torque of a DC motor are two of its most important properties.
- CEMF induced in a the armature is given by:

  $E_o = Z\, n\, \phi / 60$

- **Electrical power P_a** supplied to the armature is equal the supply voltage E_s multiplied by the armature current I

  $P_a = E_s\, I$

- Since, E_s is equal to the sum of E_o plus the IR drop in the armature

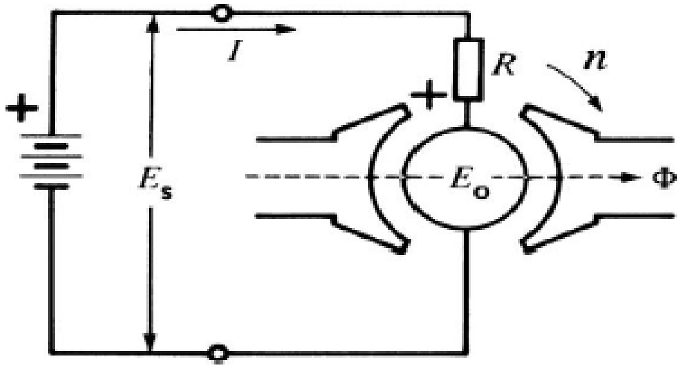
  $E_s = E_o + IR$

- Therefore,

  $P_a = E_s\, I$

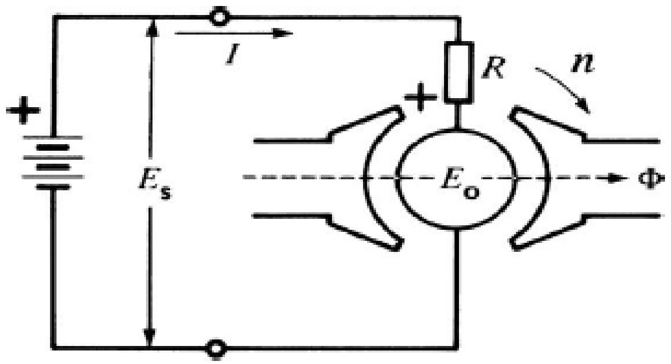
  $P_a = (E_o + IR)\, I$

  $P_a = E_o\, I + I^2 R$



Power and Torque

$$P_a = E_o I + I^2R$$



The two terms represent:

- I^2R : heat dissipated in the armature
- $E_o I$: electrical power that is converted into mechanical power

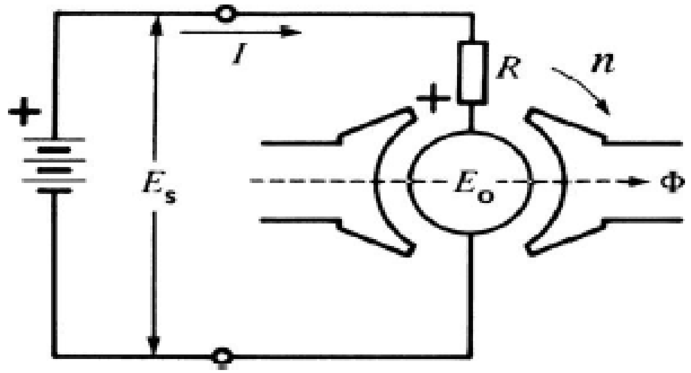
The mechanical power *P* of the motor is therefore

$$P = E_o I$$

where

- P = mechanical power developed by the motor [W]
- E_o = induced voltage in the armature (CEMF) [V]
- I = total current supplied to the Armature [A]

Power and Torque



- The electrical power of the motor:

$$P_a = E_o\, I + I^2 R$$

- The mechanical power P of the motor:

$$P = E_o\, I$$

- The mechanical power P, is given by the expression:

$$P = n\, T / 9.55$$

where *n* is the speed of rotation (rpm), and *T* is the torque *(N.m)*

- Combining the two equations of mechanical power:

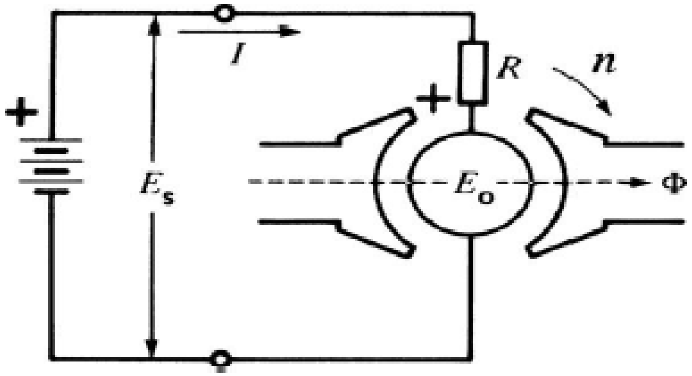
$$n\, T / 9.55 = E_o\, I$$

$$n\, T / 9.55 = Z\, n\, \phi\, I / 60$$

Power and Torque

$$n\,T / 9.55 = E_o\,I$$

$$n\,T / 9.55 = Z\,n\,\phi\,I / 60$$



- Torque *T* developed by the motor is:

$$T = Z\,\phi\,I / 6.28$$

where,

6.28 = 2π is a constant.

Example 3

The following details are given on a 225 kW, (300 hp), 250V DC 1200 rpm motor:

Armature coils	243
Turns per coil	1
Type of winding	Lap
Armature slots	81
Commutator segments	243
Field poles	6
Diameter of armature	559 mm
Axial length of armature	235 mm

Calculate

- The rated armature current
- The number of conductors
- The flux per pole

Speed of Rotation

- When a dc motor drives a load between no-load and full-load, the *IR* drop due to armature resistance is always small compared to the supply voltage E_s. This means that the cemf E_o is very nearly equal to E_s.

- On the other hand, we have already seen that E_o may be expressed by the equation:

$$E_o = Z\,n\,\phi / 60$$

- *Replacing E_o by E_s, we obtain:*

$$E_s = Z\,n\,\phi / 60$$

Speed of Rotation

Therefore

$$n \approx 60\ E_s / (Z\ \phi\ )$$

where

n is speed of rotation [r/min]

E_s is armature supply voltage [V]

Z is total number of armature conductors

ϕ is effective flux per pole [Wb]

- The speed of the motor is directly proportional to the armature supply voltage and inversely proportional to the flux per pole.

- If the flux per pole ϕ is kept constant (permanent magnet field or field with fixed excitation), the speed depends only upon the armature voltage E_s . By raising or lowering E_s , the motor speed will rise and fall in proportion.

Speed Control

Ward-Leonard

Armature Series Rheostat

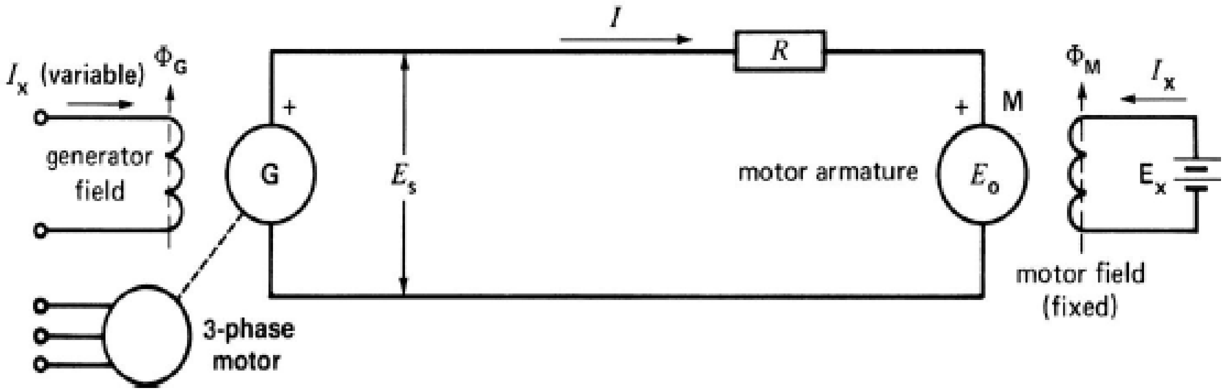
Field Flux Rheostat

Speed Control

$$n \approx 60\, E_s / (Z\, \phi)$$

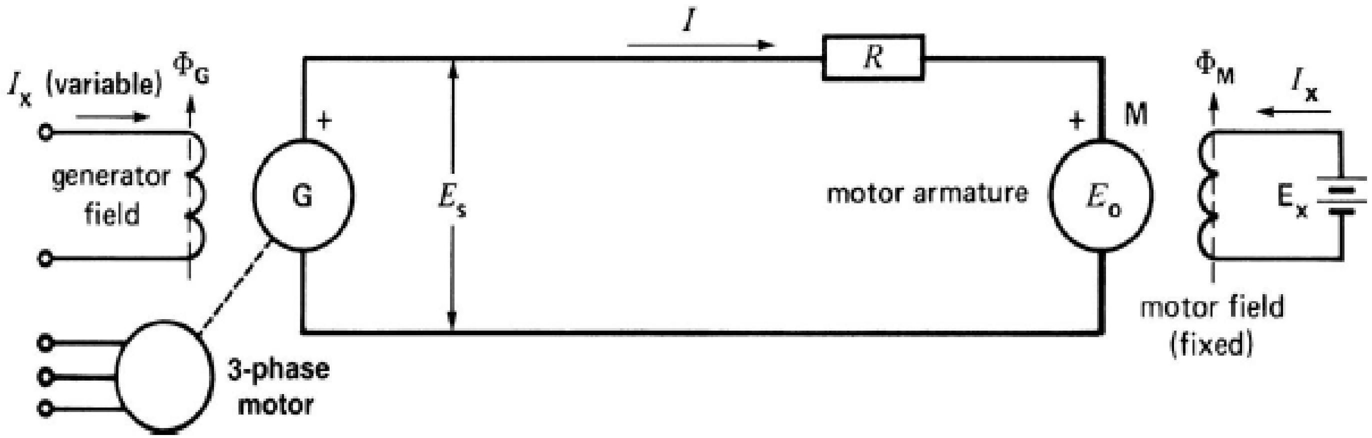
- If the flux per pole ϕ is kept constant (permanent magnet field or field with fixed excitation), the speed depends only upon the armature voltage E_s . By raising or lowering E_s , the motor speed will rise and fall in proportion.

- We can vary E_s by connecting the motor armature *M* to a separately excited variable-voltage DC generator. The field excitation of the motor is kept constant, but the generator excitation I_x can be varied from zero to maximum and even reversed. The generator output voltage E_s can therefore be varied from zero to maximum, with either positive or negative polarity.



Speed Control

- Consequently, the motor speed can be varied from zero to maximum in either direction. Note that the generator is driven by an ac motor connected to a 3-phase line. This method of speed control, known as the **Ward-Leonard system,** is found in steel mills, high-rise elevators, mines, and paper mills.



Example 4

A 2000 kW, 500 V, variable-speed motor is driven by a 2500 kW generator, using a Ward-Leonard control system. The total resistance of the motor and generator armature circuit is 10 mΩ. The motor turns at a nominal speed of 300 r/min, when E_o is 500 V.

Calculate:

a. The motor torque and speed when E_s = 400 V and E_o = 380 V

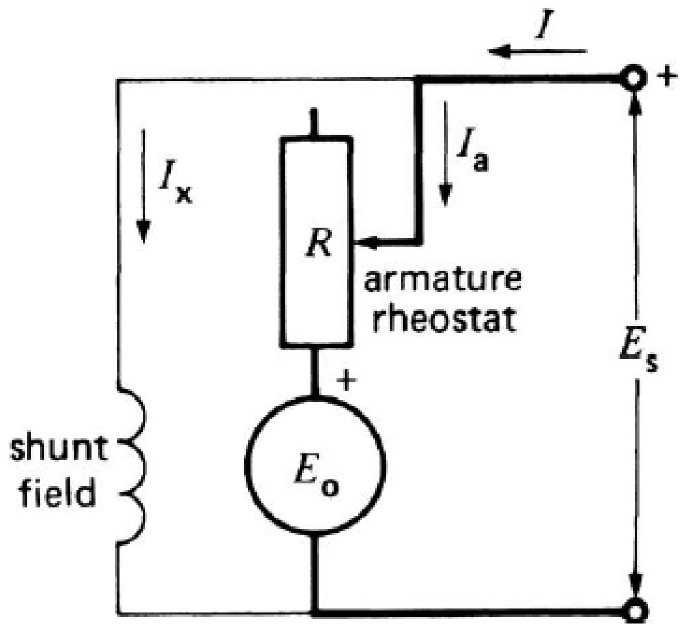
b. The motor torque and speed when E_s = 350 V and E_o = 380 V

Rheostat Speed Control

- The current in the rheostat produces a voltage drop which subtracts from the fixed source voltage E_s , yielding a smaller supply voltage across the armature.

- This method enables us to reduce the speed below its nominal speed.

- It is only recommended for small motors because a lot of power and heat is wasted in the rheostat, and the overall efficiency is low.



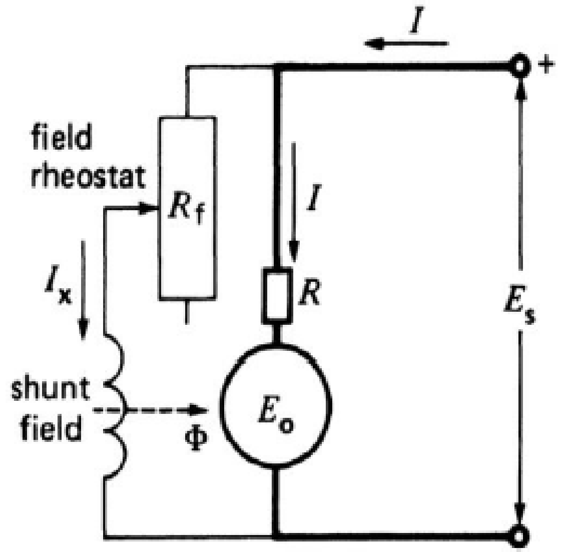
Field Speed Control

- In this method, a rheostat is placed in series with the field winding and alters the field flux.

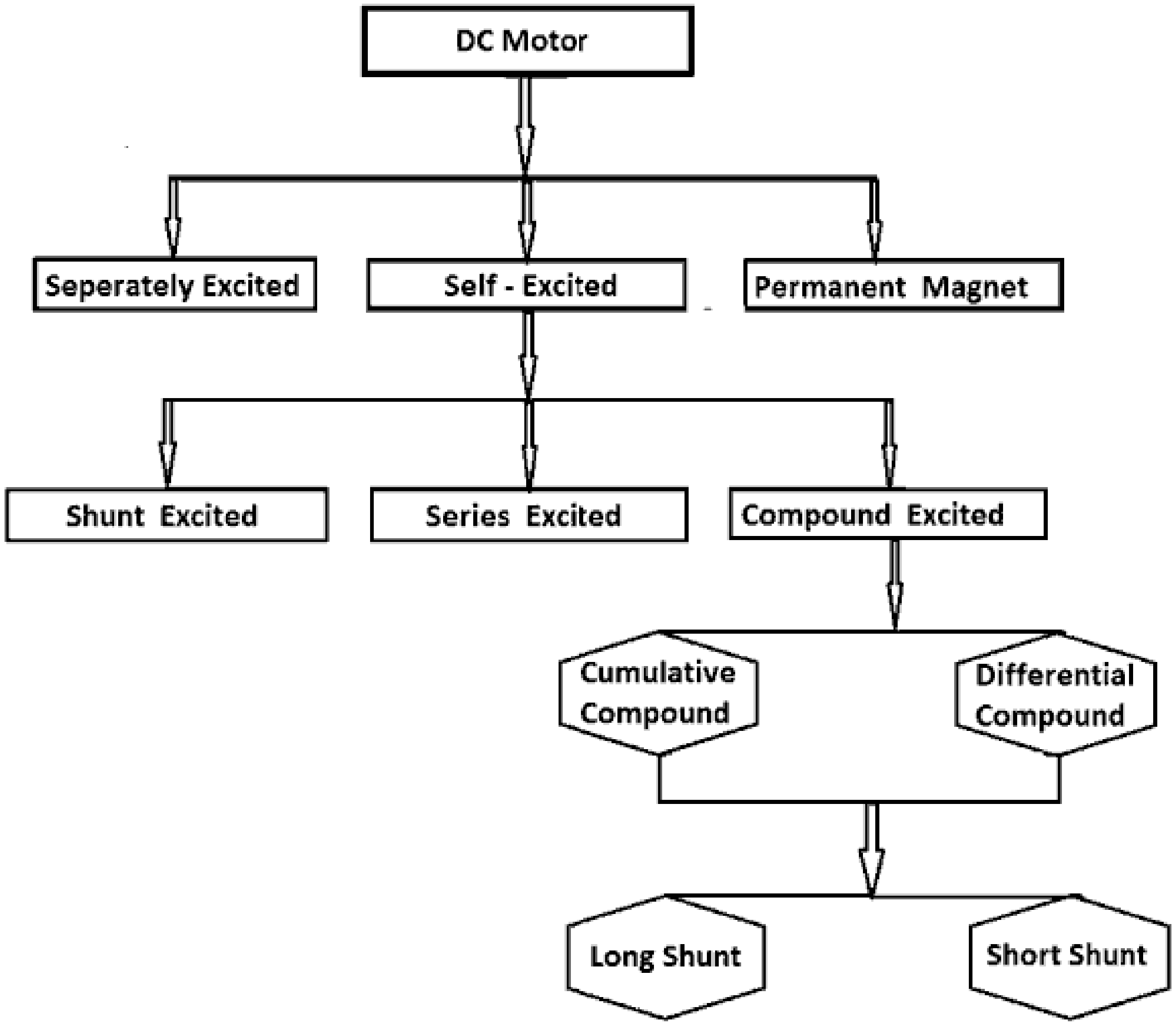
- By altering the resistance and subsequently affecting the field current and supply current. The speed, n of the motor is inversely proportional to the field flux Φ

$$n \approx 60\, E_s / (Z\, \Phi)$$

(a)



Types of DC Motors



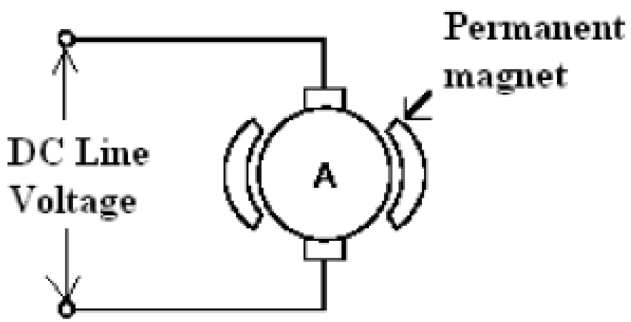
Types of DC Motors

- Permanent magnet DC motor
- Separately-excited DC motor
- Self-excited DC motor
  - Series DC motor
  - Shunt DC motor
  - Compound DC motor

Permanent Magnet DC Motors

Characteristics:

- Excellent starting torque capability.
- Good speed regulation.
- Low horsepower applications.

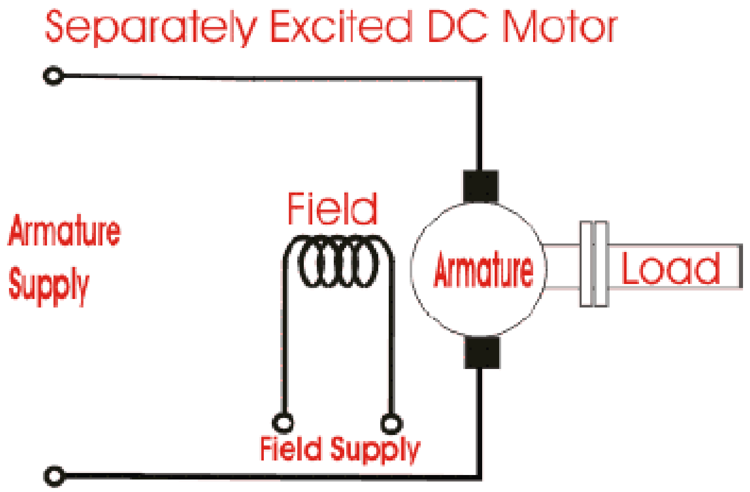


Disadvantages:

- Limited amount of load.
- Torque is usually limited to 150% of rated torque to prevent demagnetization of the permanent magnets.

Separately Excited DC Motors

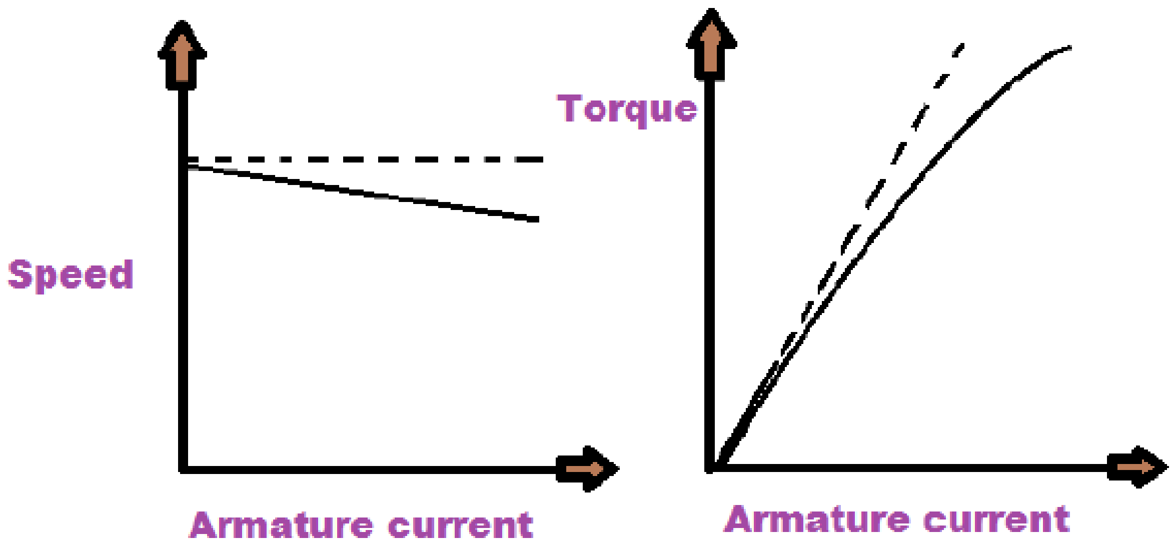
- The supply is given separately to the field and armature windings.
- The armature current does not flow through the field windings, as the field winding is energized from a separate external source of dc.



Separately Excited DC Motor

Characteristics:

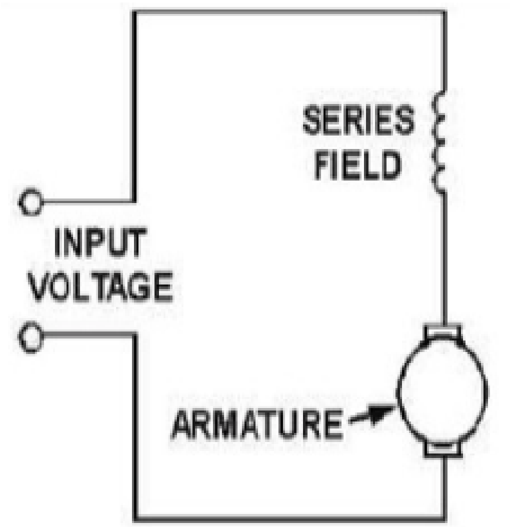
- Relatively low starting torque
- Constant speed regulation under varying load conditions

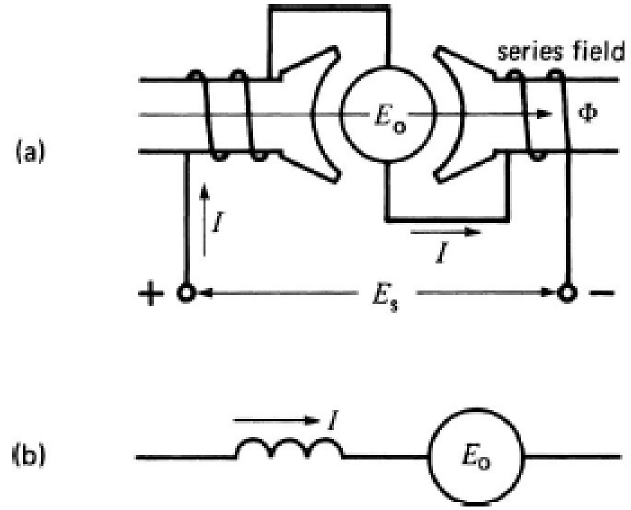


Series DC Motor

- **SERIES MOTOR**

  Series motor in which the armature and field winding are connected in series

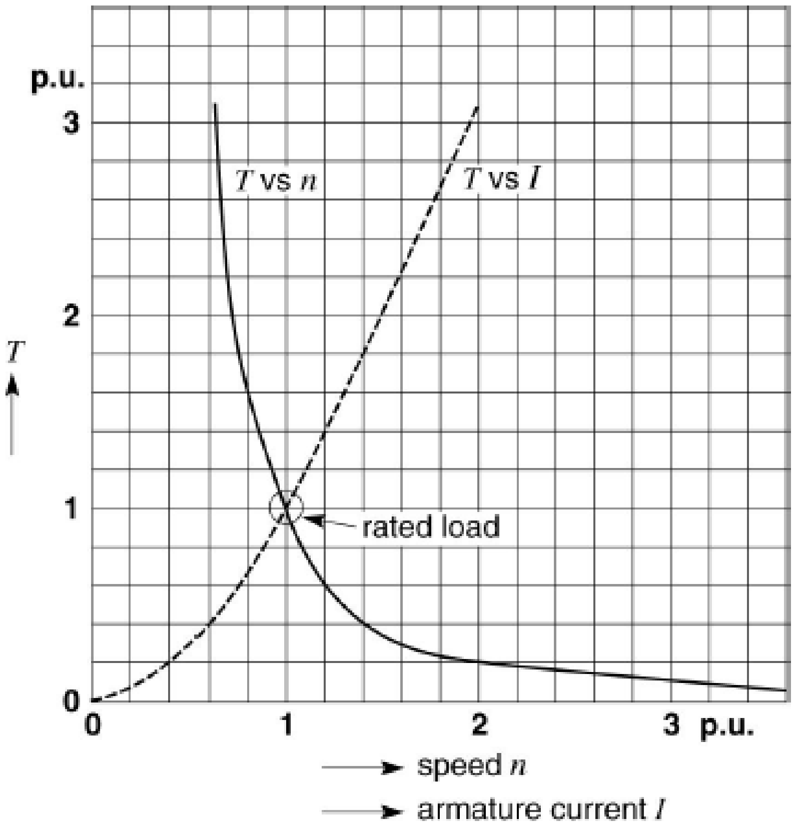




Series DC Motor

Characteristics:

- High starting torque
- Poor speed regulation under varying load conditions

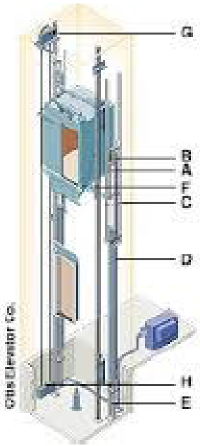


Typical speed-torque and current-torque characteristic of a series motor

Series DC Motor

It is used where large starting torque is required:

electric traction, elevators, air compressors, vacuum cleaners, hair drier, sewing machines, etc...



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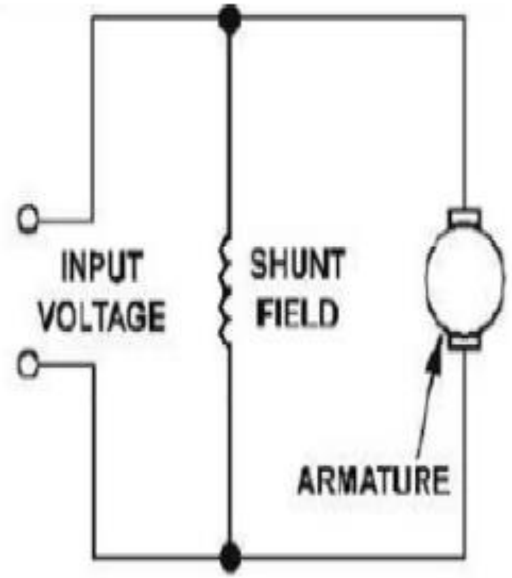
Speed Control of Series DC Motor

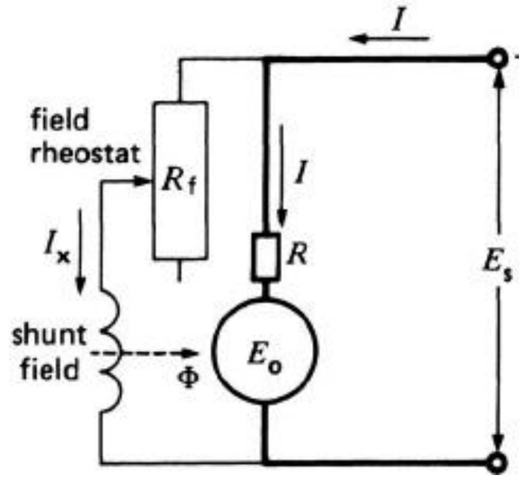
- The speed can be increased by placing a low resistance in parallel with the series field. The field current is then smaller than before, which produces a drop in flux and increase in speed.
- Alternatively, the speed may be lowered by connecting an external resistor in series with the armature and the field. The total *IR* drop across the resistor and field reduces the armature supply voltage and so the speed.

Shunt DC Motor

SHUNT MOTOR.

Shunt motor in which the field winding is connected in parallel with the armature





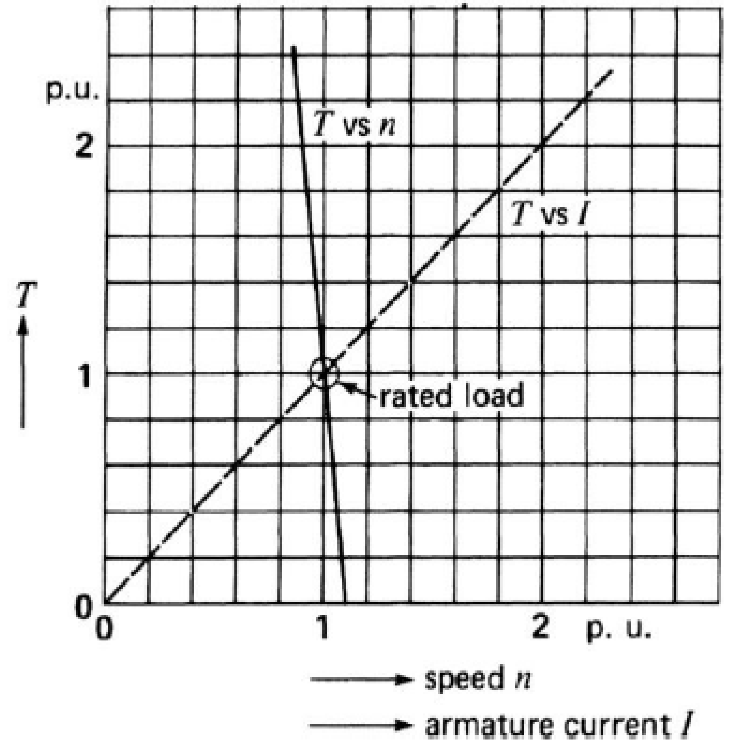
(a)

Shunt DC Motor

Characteristics:

- Relatively low starting torque
- Constant speed regulation under varying load conditions

(b)



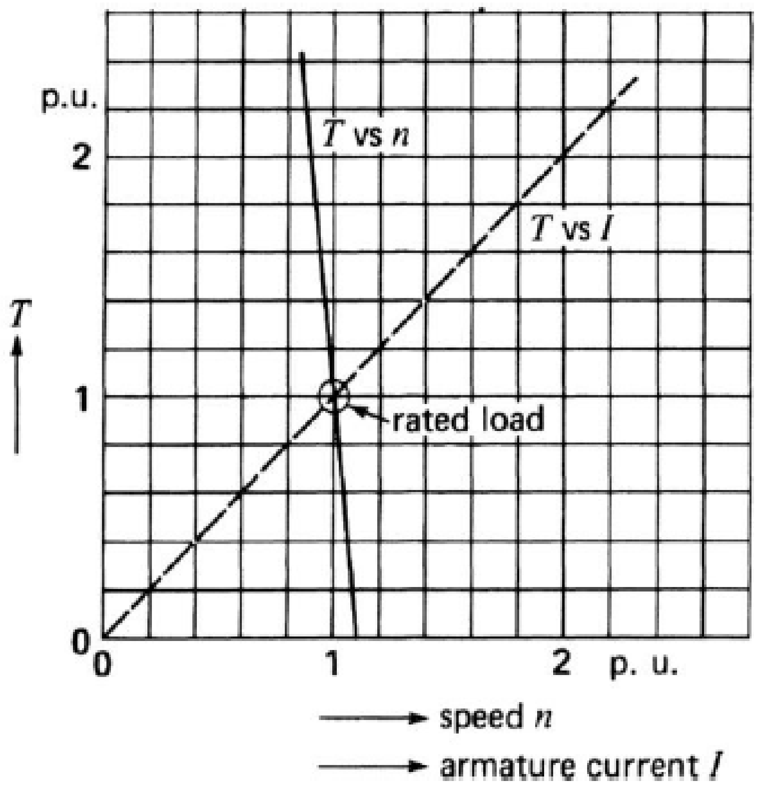
Torque-speed and torque-current characteristic of a shunt motor

Shunt DC Motor

Characteristics:

- Relatively low starting torque
- Constant speed regulation under varying load conditions

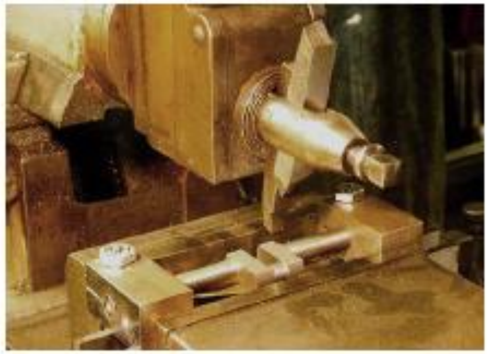
(b)

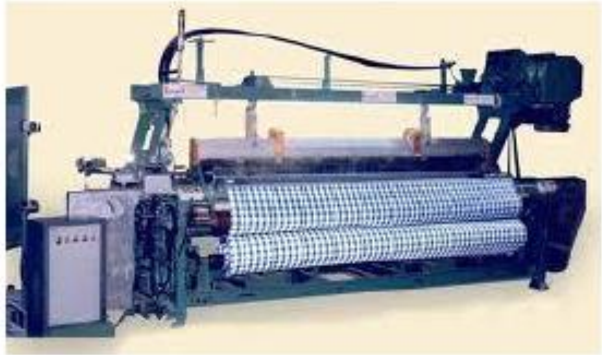


Shunt DC Motor

Industrial Uses:

Lathes, Drills, Boring Mills, Shapers, Spinning and Weaving Machines





Starting Arrangement for a DC Shunt Motor

If we apply a full voltage to a stationary shunt motor, the starting current in the armature will be very high and run the risk of:

- Burning out the motor
- Damaging the Commutator & brushes due heavy sparking
- Overload the feeder circuit
- Snapping off the shaft due mechanical shock
- Damaging the driven equipment because of the sudden mechanical hammer blow.

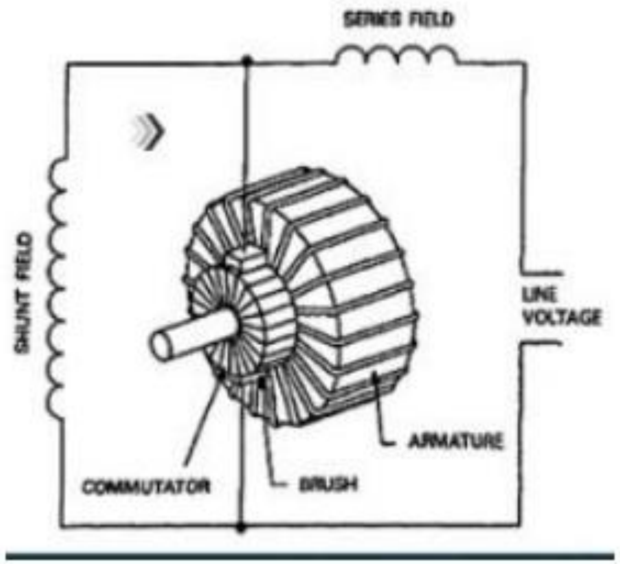
Starting Arrangement for a DC Shunt Motor

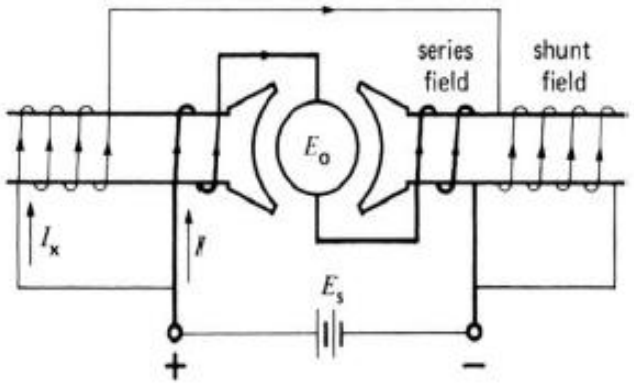
- To avoid these risks and limit large starting currents flowing through the armature, a control method is provided to reduce the start-up currents to 1.5 to twice the full-load current.
- Typically a rheostat is connected in series with armature and is gradually reduced and eventually eliminated when the motor accelerates to its nominated speed.
- Such a rheostat would be a FACE-Plate starter.

Compound DC Motor

- **COMPOUND MOTOR**

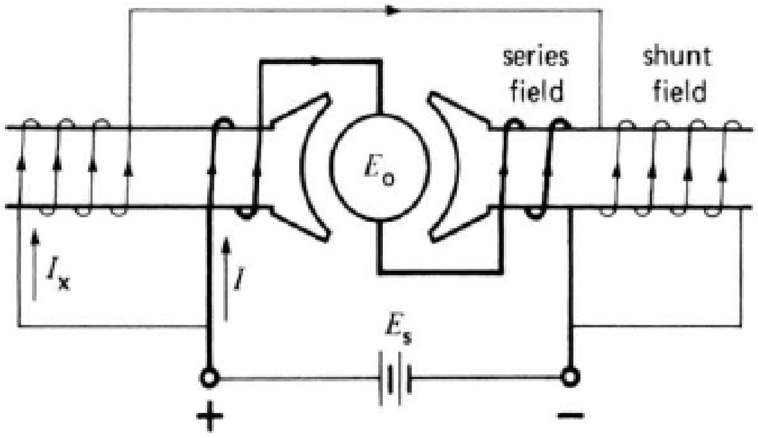
  Which has two field winding, one of which is connected in parallel with the armature and other in series with it.





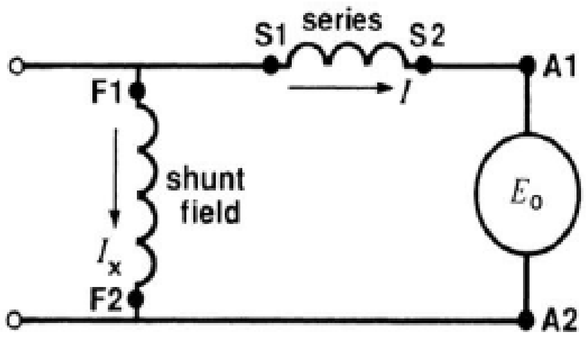
(a)

Compound DC Motor



(a)

Connection diagram



(b)

Schematic diagram

Compound DC Motor

Depending upon the direction of magnetizing effect of shunt and series field windings, these motors are classified in the following two types:

(i) Cumulative compound motor

The field windings are so connected that the field due to series field winding is in the same direction as the field due to the shunt field winding. thus the total flux, for any load, is the sum of both fluxes.

(ii) Differential compound motor

In this type of motor, the flux due to series field winding is in opposite direction to the flux due to shunt field winding. for any load, the total flux is the difference of the shunt and series field fluxes

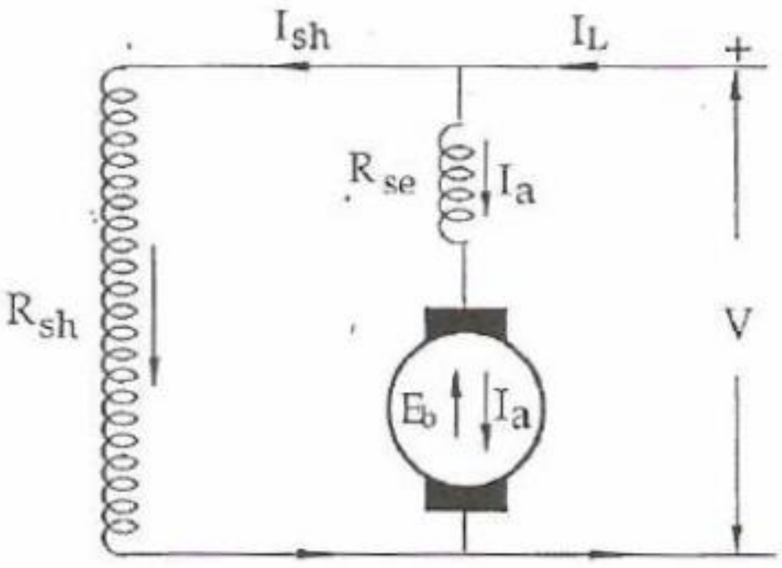


Figure. 9

Cumulative compound motor

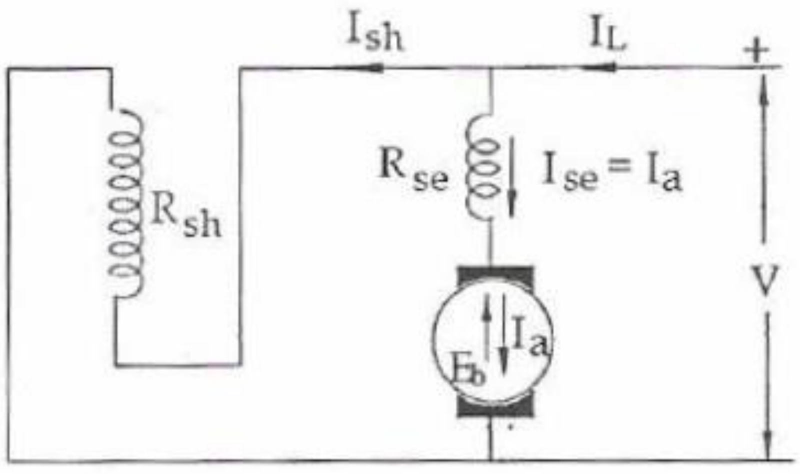


Figure 10

Differential compound motor

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

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

Compound DC Motor

Both the cumulative compound and differential compound dc motor can either be of short shunt or long shunt type depending on the nature of arrangement.

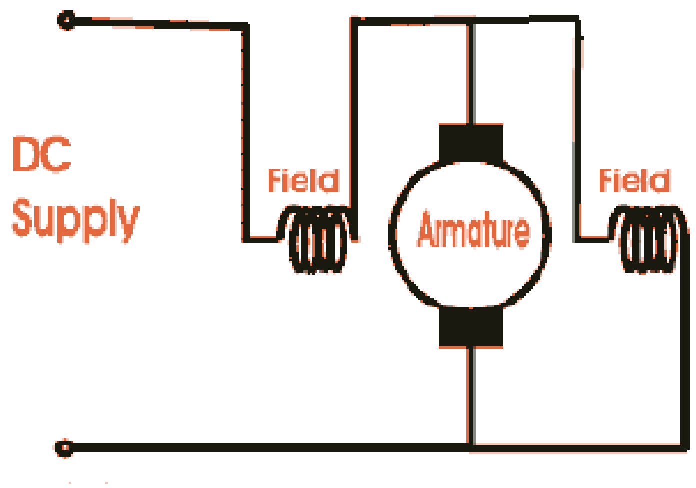
(i) Short Shunt DC Motor

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

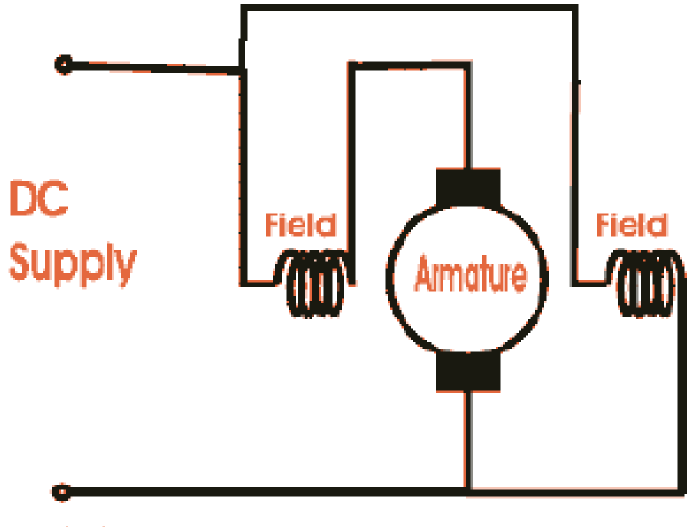
(ii) Long Shunt DC Motor

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.

Compound DC Motor



Short Shund DC Motor

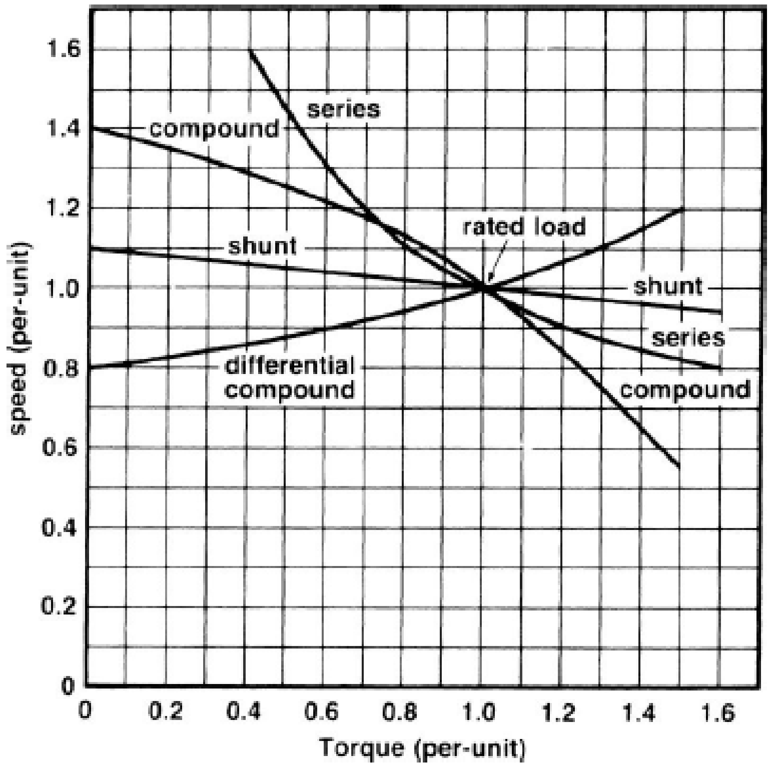


Long Shunt DC Motor

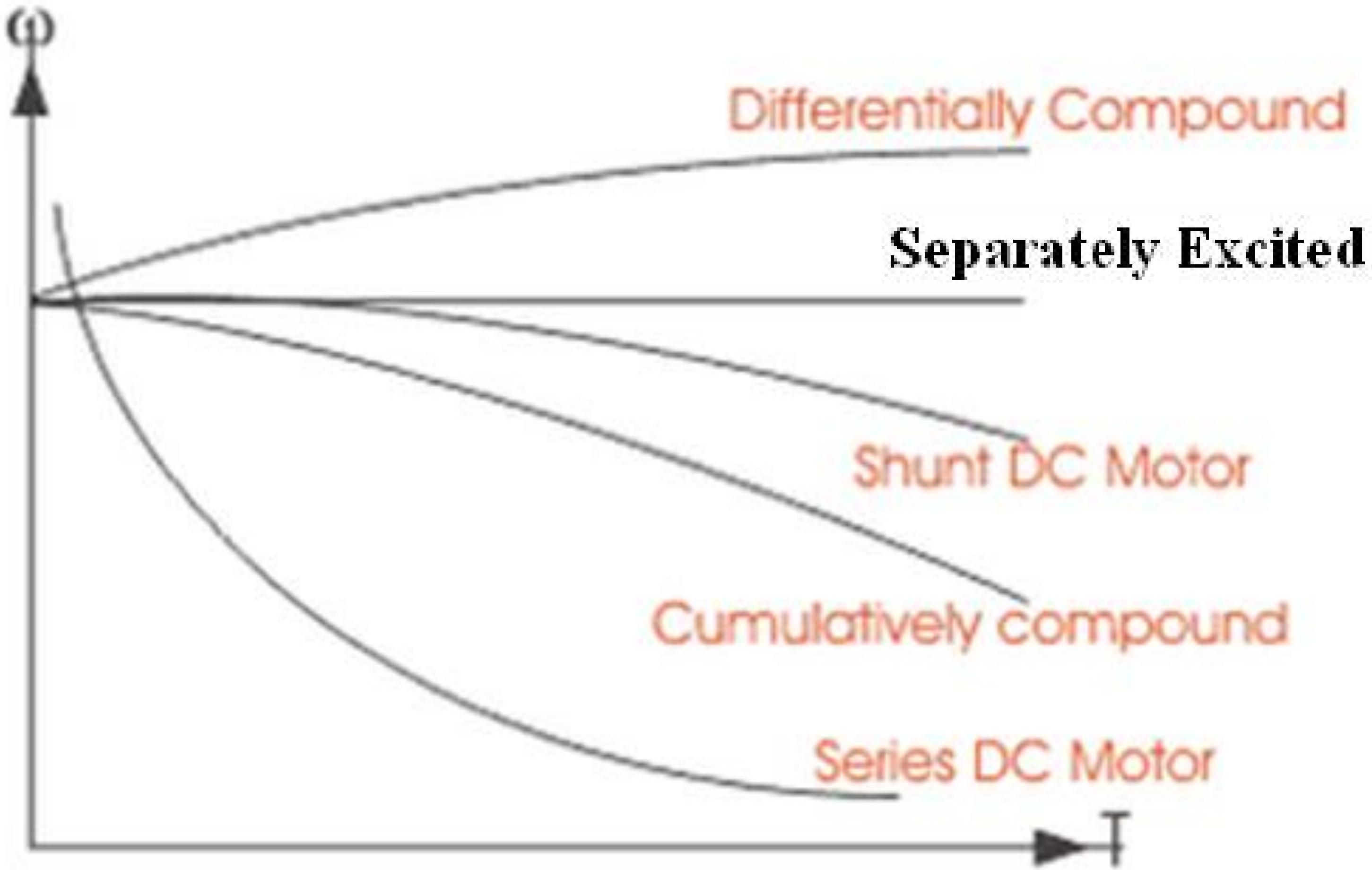
Compound DC Motor

Characteristics:

- High starting torque, but not as high as a series DC motor
- Constant speed regulation, but not as constant as a shunt DC motor



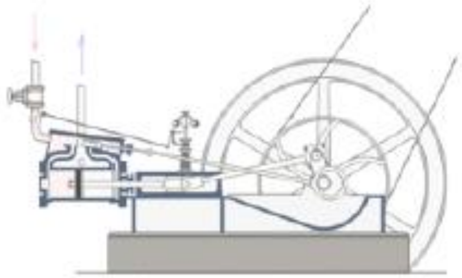
Typical speed versus torque characteristics of various dc motors


ω
Differentially Compound
Separately Excited
Shunt DC Motor
Cumulatively compound
Series DC Motor
T

Compound DC Motor

Industrial Use:

Presses, Shears, Reciprocating Machines etc ...



Characteristics of DC Motor

1. When power is applied. DC motor turn in one direction at a fixed speed.
2. They are optimized to run at a fixed, usually high RPM.
3. Torque is highest at the rated speed and lowest at low speeds.
4. Inexpensive and commonly available.
5. If the applied load is greater than the capacity of the motor, the motor will stall and possibly burn out.

DC Motors

- DC Motors:

http://www.wisc-online.com/Objects/ViewObject.aspx?ID=IAU11508

- DC Shunt Motors:

http://www.wisc-online.com/Objects/ViewObject.aspx?ID=IAU13708

- DC Compound Motors:

http://www.wisc-online.com/objects/ViewObject.aspx?ID=IAU13908

END OF LEARNING OUTCOME 3

EEL 2043

Principles of Machines and Power

Learning Outcome 3:

Part 2: Stepper Motors

Topics of Learning Outcome 3 :

1: Explain the operational principles of DC motors and generators.

2: Derive and sketch the torque-speed and torque-current characteristics of DC motors.

3: Identify the industrial applications of DC motors in relation to excitation schemes and explain the influence of supply voltage, armature resistance, and field current on the rotational speed.

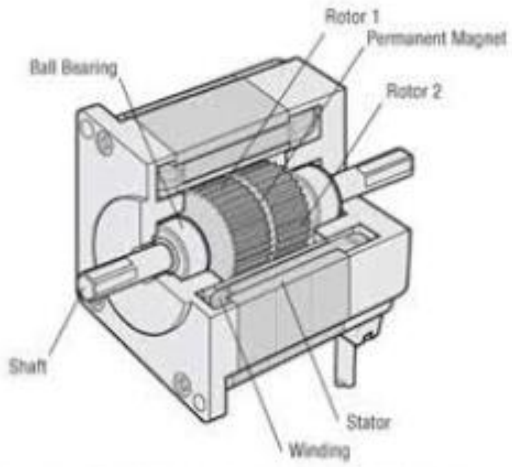
4: Measure the no - load characteristics of DC generators, loading characteristics of separately-excited and shunt DC generators, torque-speed characteristics of separately-excited, series and shunt DC motors, and torque-current characteristics of separately-excited, series and shunt DC motors.

5: Describe the construction and operation of stepper motors.

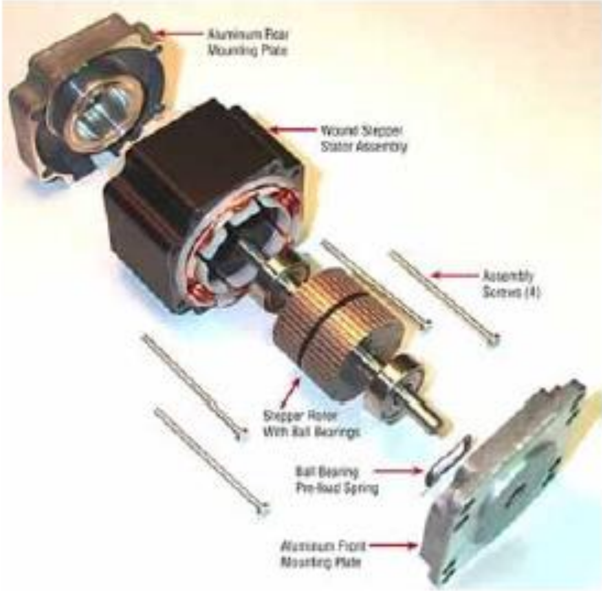
6: Determine the expected step angle and direction of rotation, given the excitation scheme for the permanent magnet, variable reluctance, and hybrid stepper motor.

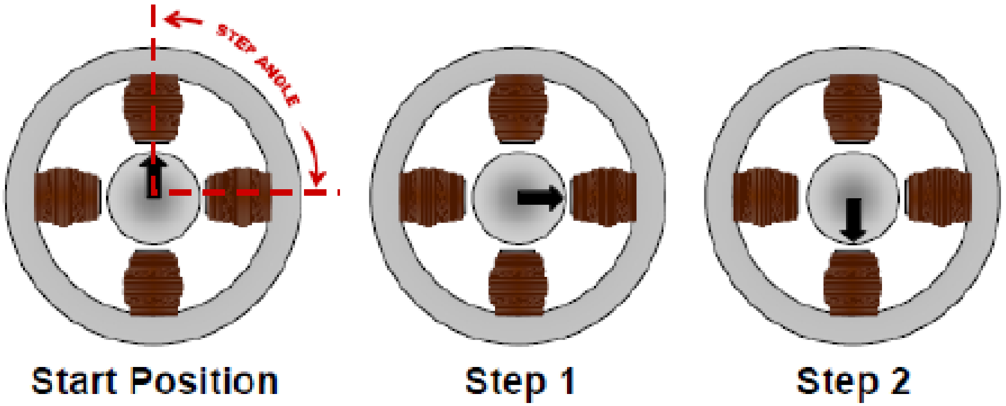
Introduction

- Stepper Motor is a motor that moves one step at a time
- Each step is defined by a Step Angle
- A digital version of an electric motor



Motor Structural Diagram: Cross-Section Parallel to Shaft





- As the name implies, the stepper motor moves in distinct steps during its rotation.

- Each of these steps is defined by a Step Angle. In the example above you may notice that there are 4 distinct steps for the rotor to make a complete 360 degree rotation. This defines the step angle at 90 degrees.

- Since this motor does move in a discreet fashion, we can say that a stepper motor is actually a digital motor. This characteristic makes it very suitable for digital interfaces such as with a microcontroller.

Why Use a Stepper Motor?

- Relatively inexpensive
- Ideal for open loop positioning control
  - Can be implemented without feedback
  - Minimizes sensing devices
  - Just count the steps.
- Torque
  - Holds its position firmly when not turning
  - Eliminates mechanical brakes
  - Produces better torque than DC motors at lower speeds
- Positioning applications

- There are a number of stepper motor designs that run from the most basic to very complex depending on the motor you choose, the resolution required and the application at hand will determine the cost of the motor required.

- More important is the fact that a stepper motor can actually be used without any type of feedback loop. Since the motor moves in distinct steps as defined by a step angle, we need only count the number of steps to position the motor accordingly.

- This doesn't mean you wouldn't use a feedback loop in some applications. However, if feedback isn't required, board real estate can be maximized by minimizing these sensing components.

- The unique torque characteristics of the stepper motor make it ideal for position applications. In fact, stepper motors have been used for years in such applications as printers and machining equipment. This type of motor will hold its position firmly at a given step providing a relatively high holding torque. Other torque related benefits include the higher torque at lower revolutions per minute than your typical DC motor as well as no need for mechanical braking.

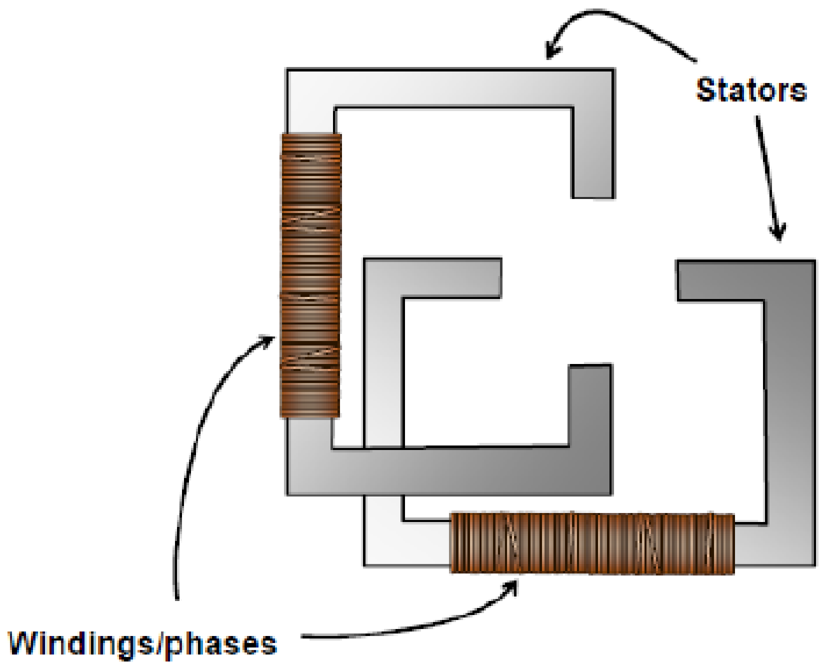
Main Components

Consists of:

1- **Stators**

– **Holds multiple windings/phases**

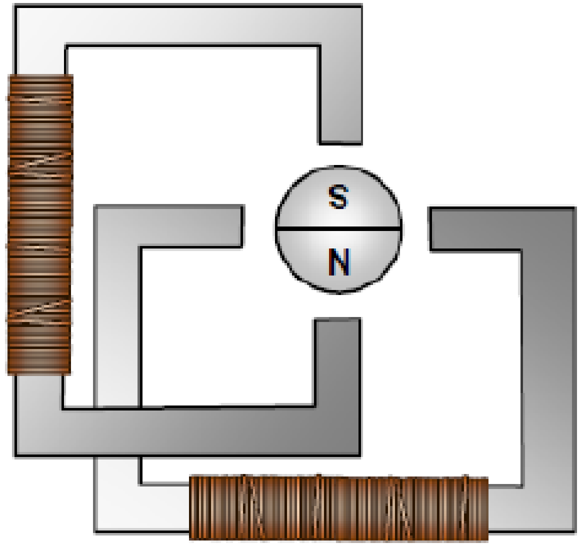
- A stepper motor has some basic components. First, we have a soft iron stator. As the name implies this is a stationary component. Each stator will be wrapped with multiple windings or phases that will be energized using a voltage source, initiating current flow through the winding to produce a polarity on each end or pole of the stator.



2- A Rotor

- Magnetized
- Non-magnetized

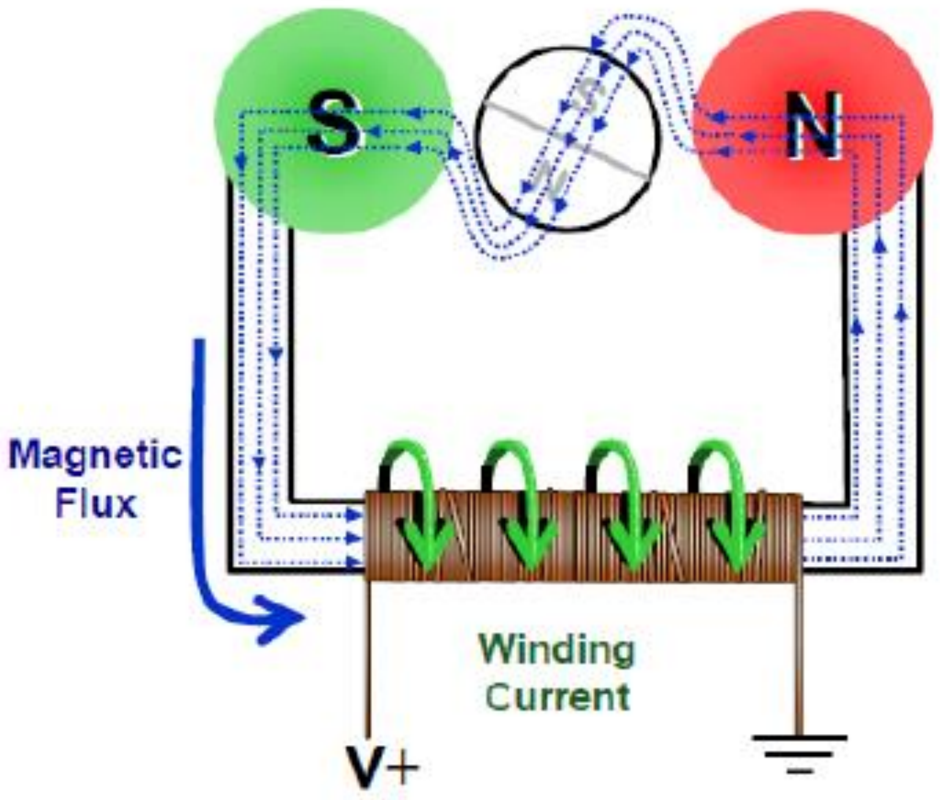
➢ The rotor is the actual rotating component on the motor. This can either be magnetized, as shown here, or non-magnetized depending on the type of motor you select.



How a Stepper Motor Works?

1- Voltage applied to winding initiates current flow.

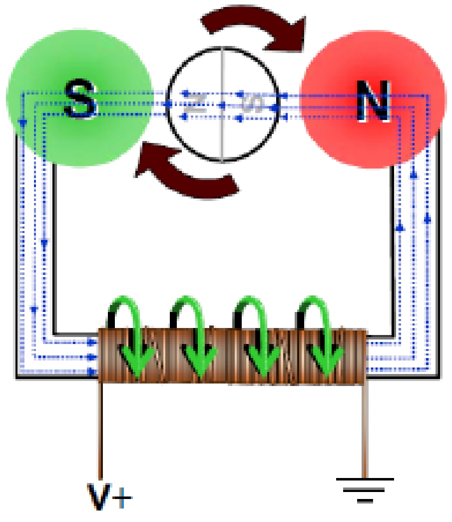
2- Magnetic flux begins to flow.



- If we apply a voltage across the windings around a stator, current will flow through the winding. If you remember back the *right hand rule*. If you take your right hand and position your fingers over a winding in the direction of current flow, you thumb will point in the direction of the magnetic flux. Here we can see that each end of the stator is magnetized to opposite poles. Magnetic flux will flow from North to South thereby continuing through the magnetic rotor to the opposite stator pole. The flux will want to travel the path of least resistance or decrease the reluctance of the path.

3- Rotor rotates to minimize flux path (or reluctance)

- Since the rotor does rotate it will position itself to minimize this reluctance. As you can see, by adding more stators and phases, we can charge a winding attracting the rotor poles accordingly then remove the applied voltage allowing other stators to attract the rotor poles.



Types of Stepping Motors

1-Permanent Magnet

- Magnetic rotor

2- Variable Reluctance

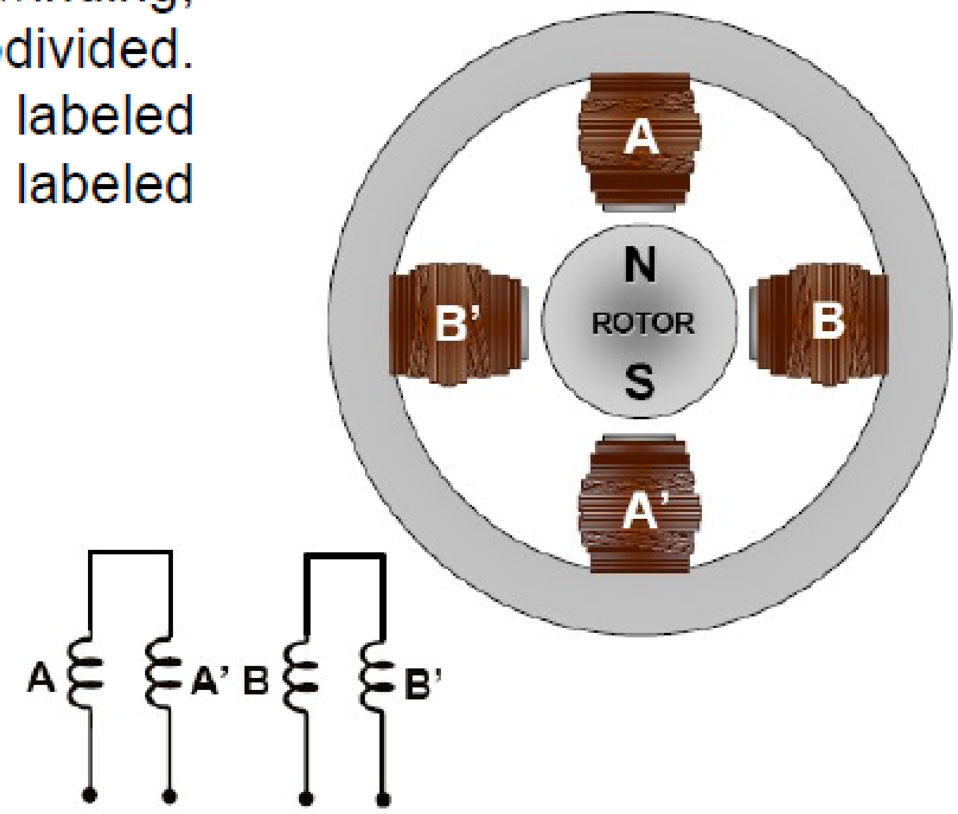
- Non-magnetic, geared rotor

3- Hybrid

- Combines characteristics from PM and VR
- Magnetic, geared rotor

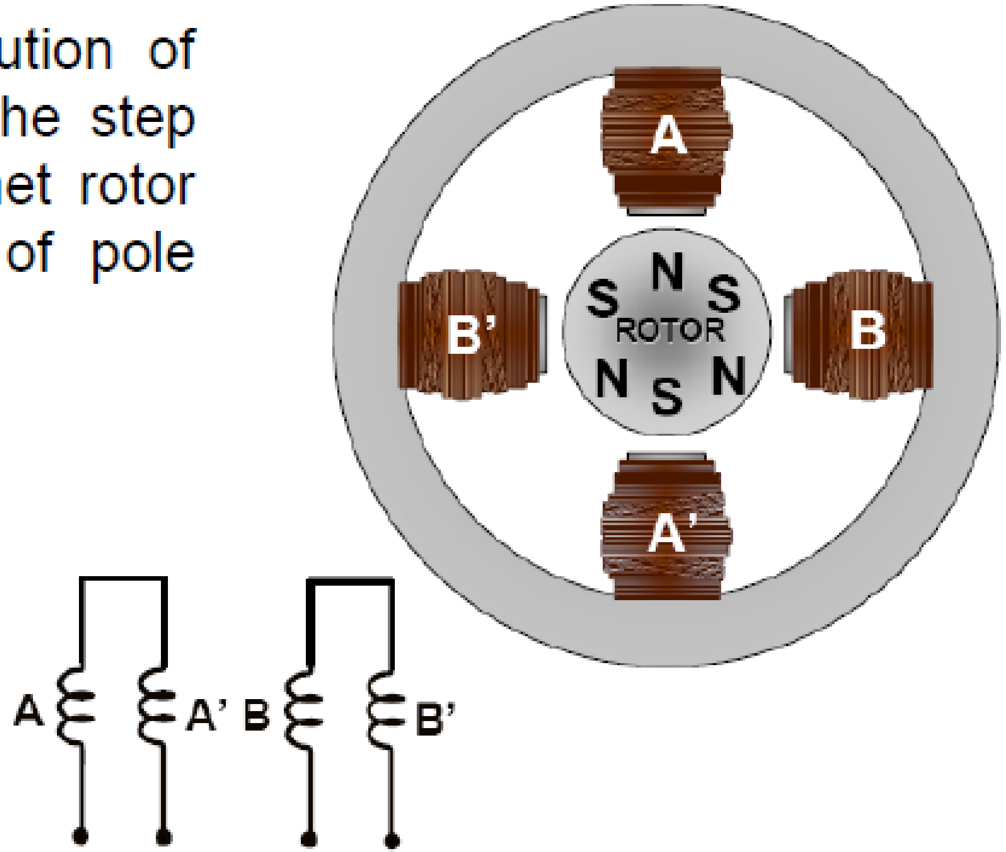
1- Permanent Magnet Stepper Motor

- The permanent magnet type of stepper motor has the characteristic magnetized rotor. Each winding, although one entity, will be subdivided. In the given figure Winding A is labeled as A and A' and Winding B is labeled as B and B'.



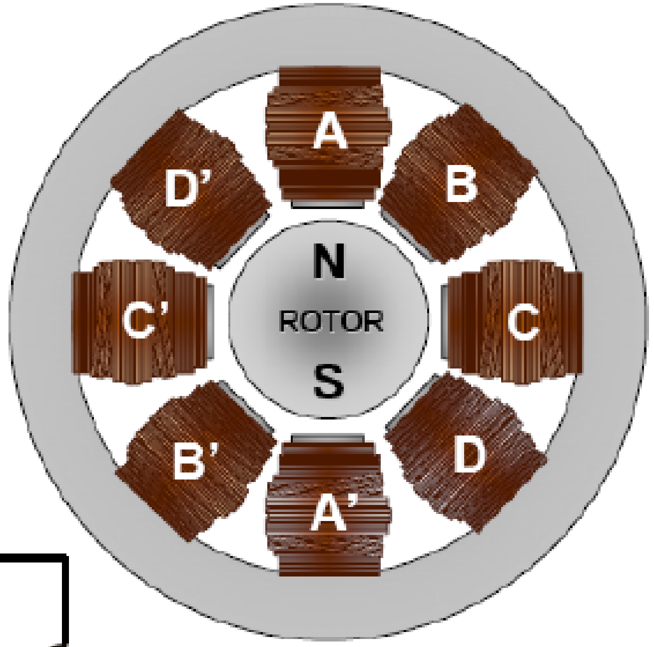
- **Greater resolution as pole pairs increase.**

- We can improve the resolution of rotor rotation, or decrease the step angle in a permanent magnet rotor by increasing the number of pole pairs on the rotor itself.

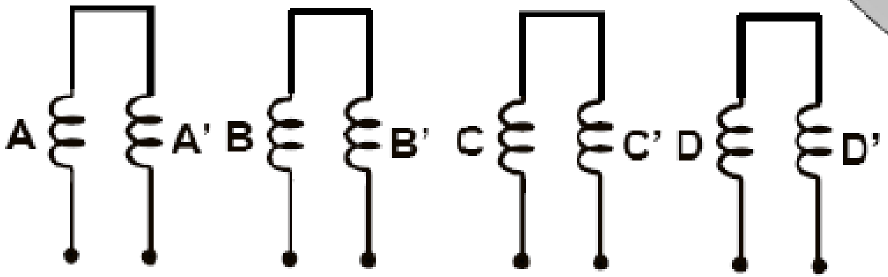


- **Greater resolution by additional phases**

  - We could also increase the resolution by adding more stators and phases.



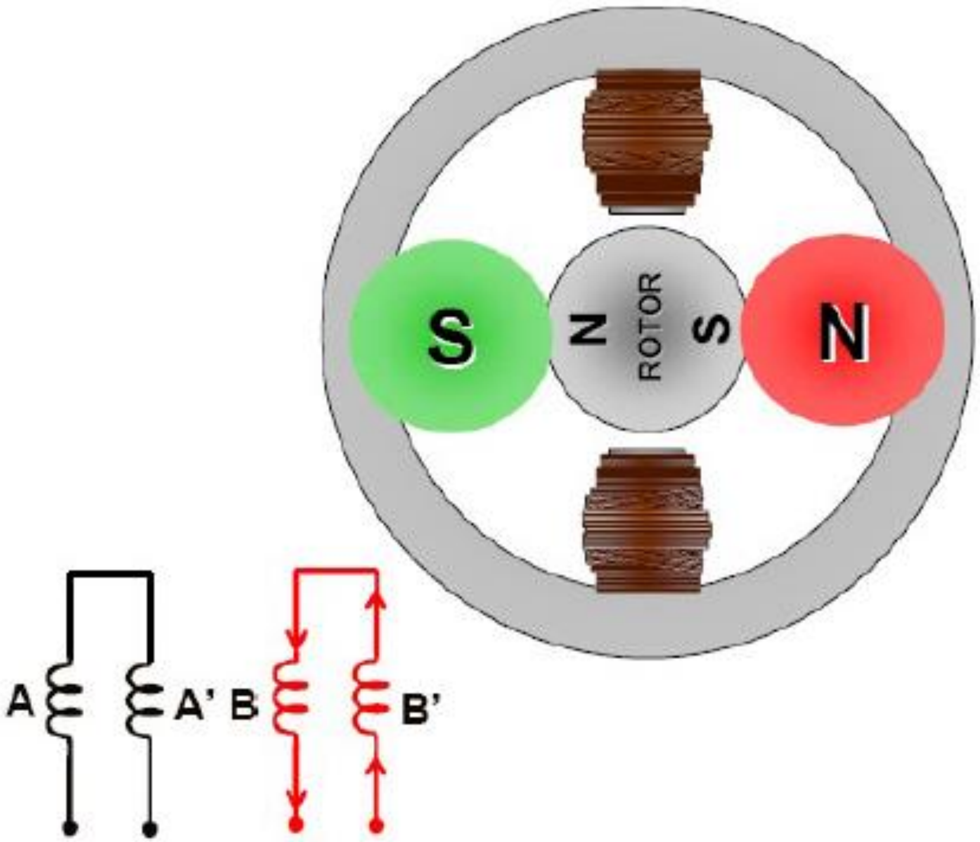
Additional Phases



How Permanent Magnet Motor Work?

Rotor rotates by energizing each winding

- **Current flow generates magnetic polarity on each stator**



How Permanent Magnet Motor Work?

Rotor rotates by energizing each winding

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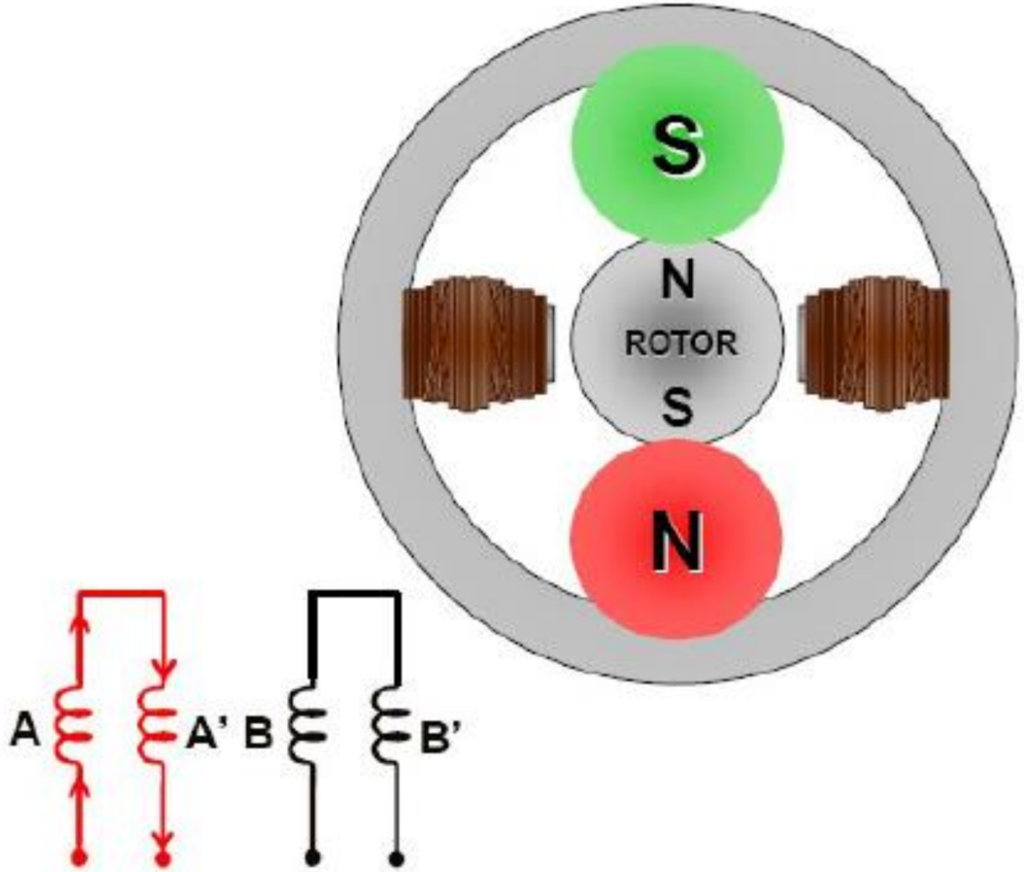


- Rotation in a particular direction is accomplished by applying voltage to the individual phases in a particular sequence.

- This means that to rotate the rotor in the opposite direction, simply reverse this voltage sequence.

- To hold the rotor at a particular position, step it to that angle and then stop the sequence maintaining voltage on the appropriate phase.

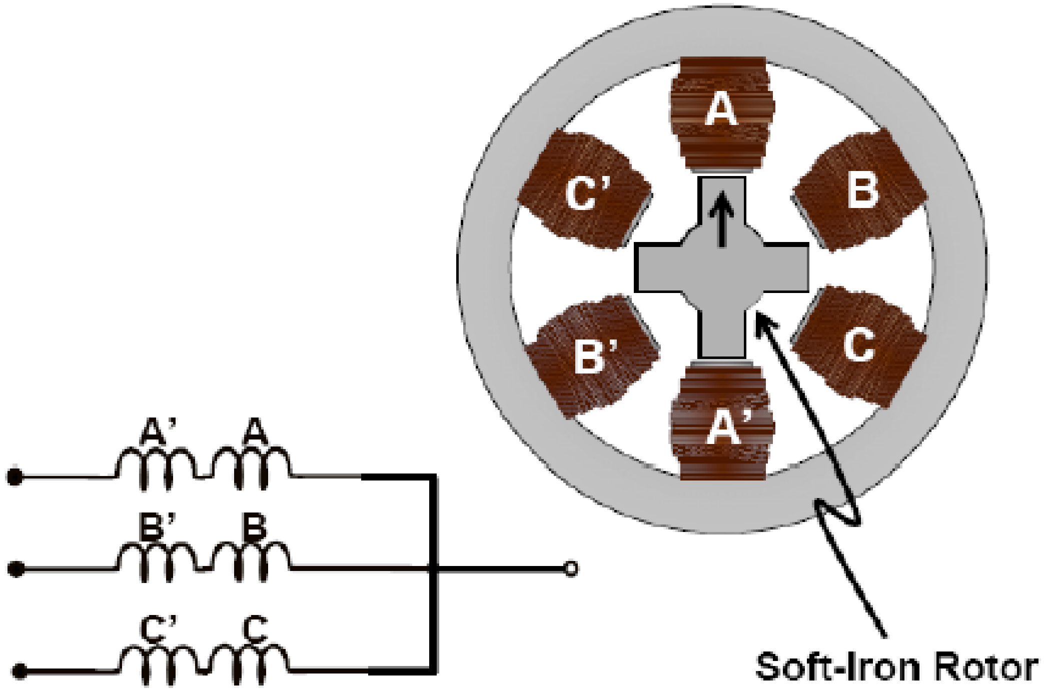
2- Variable Reluctance Stepper Motor

Characterized by:

1- Non-magnetic rotor

- Made of soft-iron

2- Greater resolution as more teeth are added



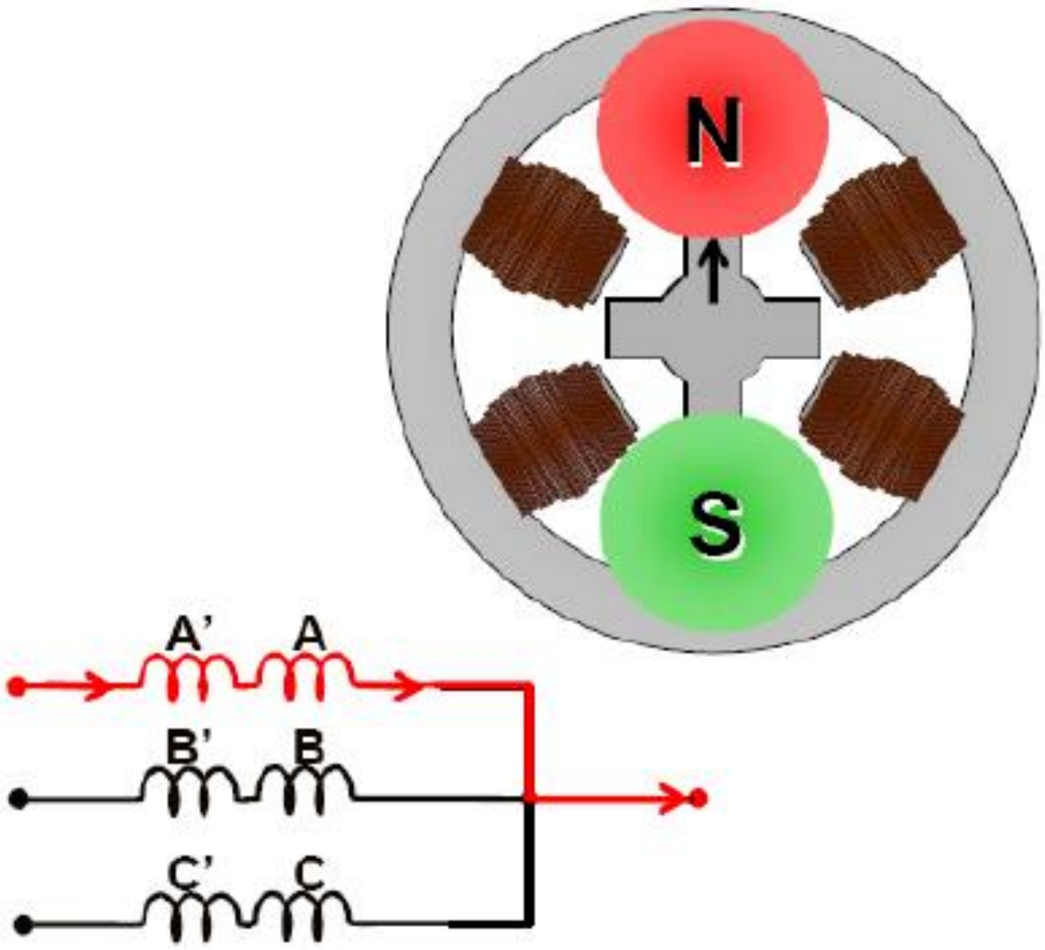
- This motor uses a non-magnetized, soft-iron rotor.

- The rotor here actually has teeth that are carefully offset from the stator poles to accomplish rotation. Notice also that the individual stator windings are configured differently than previous type.

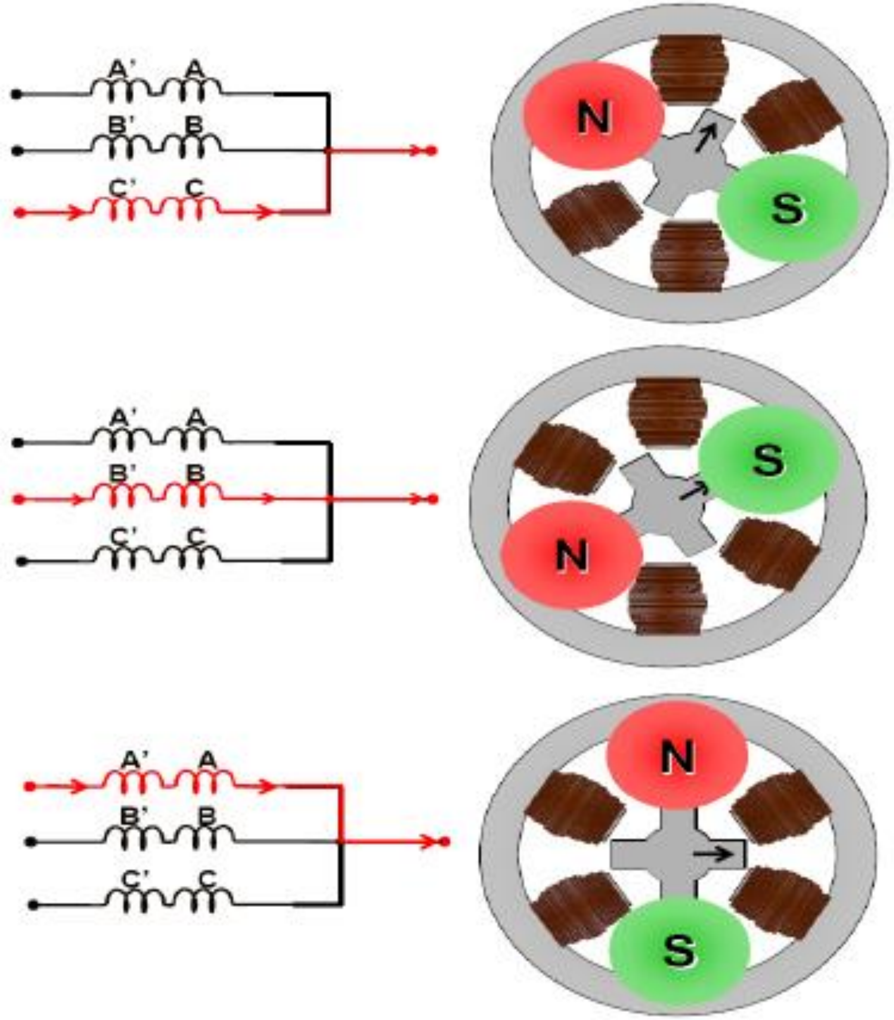
- All windings have a common terminal that will be connected to a voltage source. The opposite end of each winding is kept separate from the other windings.

- To increase the resolution on this type of motor, typically more teeth are added to the geared rotor.

- Normally have three or five stator windings
  - Energized one at a time to rotate the rotor

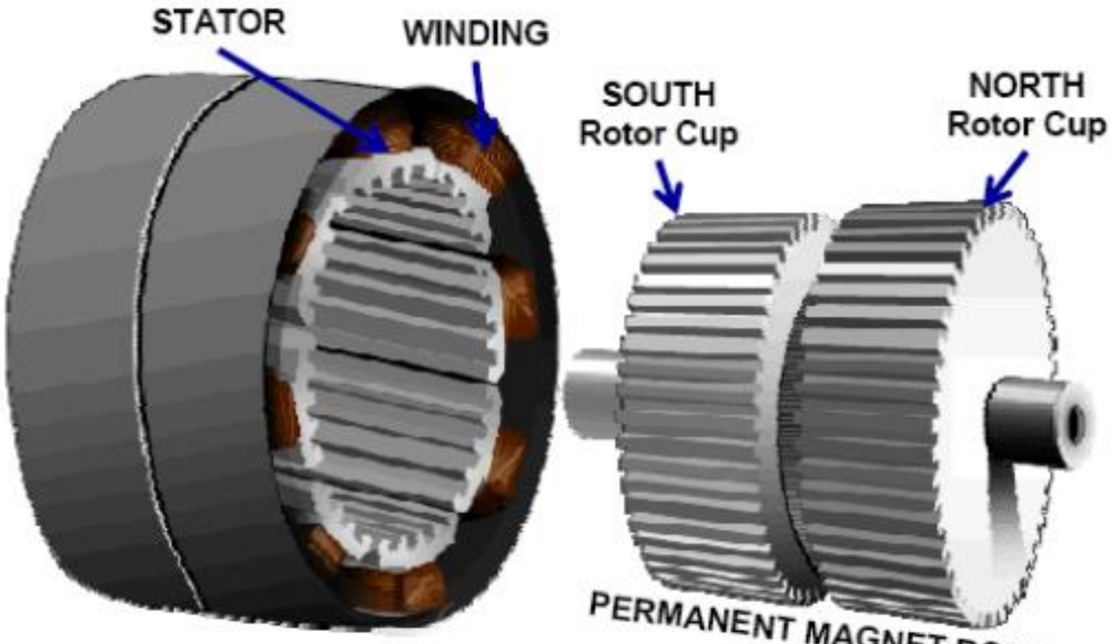


➢ Each winding is again energized one at a time to create a polarity on the appropriate stator poles. The rotor rotates to minimize the reluctance of the magnetic flux path.



3- Hybrid Stepper Motor

- **Hybrid of Permanent Magnet and Variable Reluctance type motors.**



Side View

- This type of Stepping motor borrows characteristics from both permanent magnet and variable reluctance motors. This slide shows a side view of Hybrid Stepper Motor with the rotor removed. The rotor is magnetized and also has teeth. Each stator now has a number of teeth or poles.

PM vs. VR vs. Hybrid

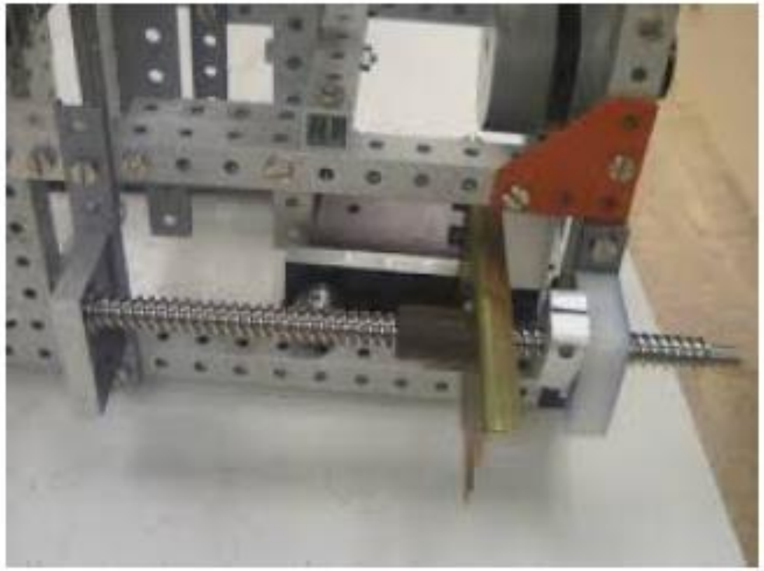
Characteristic	Permanent Magnet	Variable Reluctance	Hybrid
COST	Cheapest	Moderate	Most Expensive
		More expensive due to manufacturing processes	
Design	Moderately Complex	Simple	Complex
Resolution	30° - 3 °/step	1.8 °/step and smaller	
Torque vs. Speed		Less pronounced torque drop at higher speeds	
Noise	QUIET	Noisy no matter what type of excitation	QUIET

Stepper motors and linear drives

Most stepper motors are coupled to a lead screw of some kind which permits the rotary motion to be converted to a linear displacement.
Suppose, for example, that a stepper motor having 200 steps per revolution is coupled to a lead screw having a pitch of 5 threads per inch. The motor has to make 200 × 5 = 1000 steps to produce a linear motion of 1 inch.
Consequently, each step produces a displacement of 0.001 inch.

Stepper Motors and Linear Drives

By counting the pulses precisely, we can position a machine tool, X-Y arm, and so on, to a precision of one-thousandth of an inch over the full length of the desired movement.
This great precision without feedback is the reason why stepper motors are so useful in control systems.

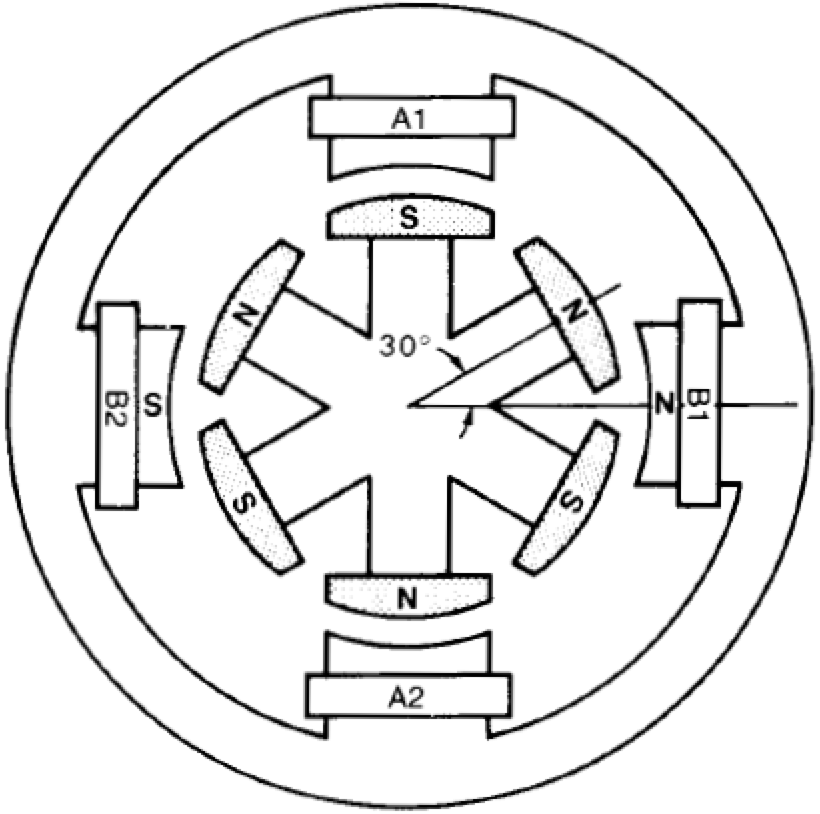


Example 1:

A stepper motor advances 2.5° per step. How many pulses are needed to complete 8 revolutions?

Example 2:

The stepper motor shown is driven by a series of pulses having a duration of 20 ms. How long will it take for the rotor to make one complete revolution?



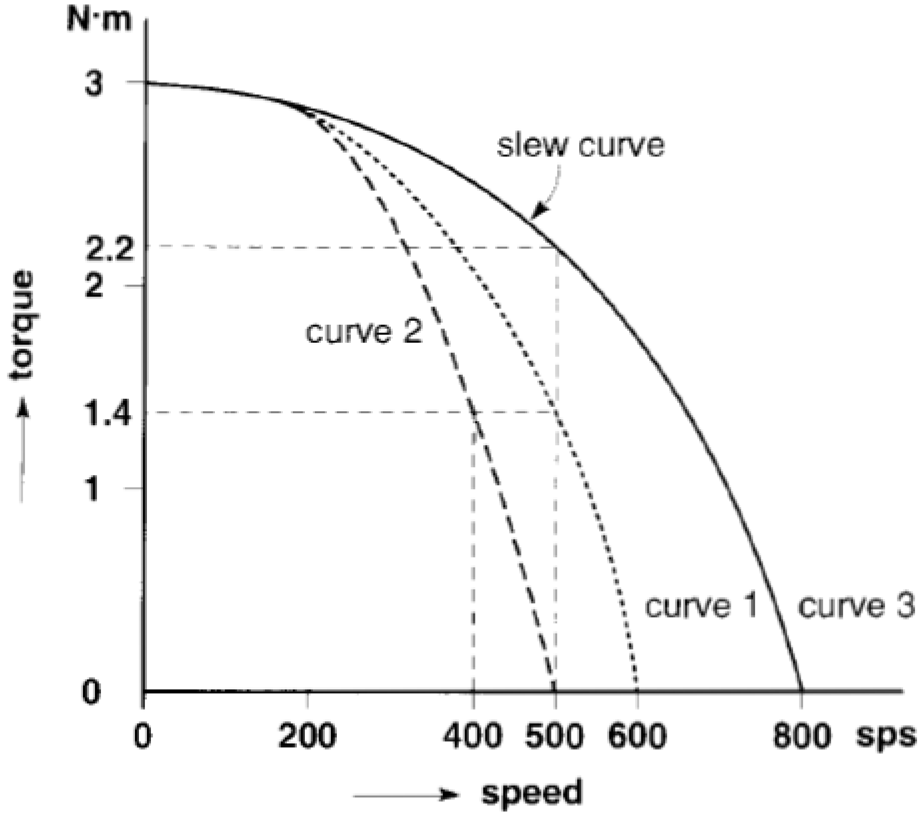
Example 3:

A stepper motor rotates 1.8° per step. It drives a lead screw having a pitch of 20 threads per inch. The lead screw, in turn, produces a linear motion of a cutting tool. If the motor is pulsed 7 times, by how much does the cutting tool move?

Example 4:

A stepper motor advances 7.5° per pulse. If its torque-speed characteristic is given by Fig. 19.8, calculate the power [watts] it develops when it is slewing

a. At 500 steps per second
b. At 200 steps per second



END OF LEARNING OUTCOME 3- Part 2