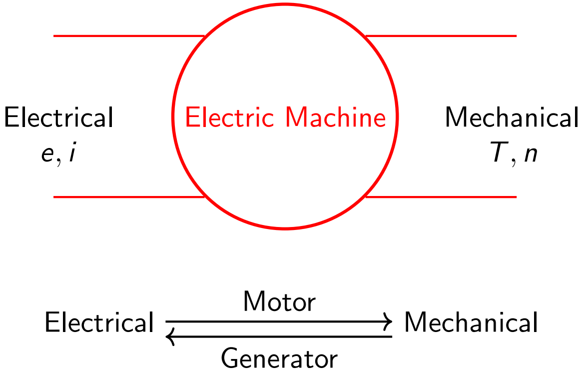
What you will study hereafter....

- Introduction
- Magnetic Circuits
- Transformers
- Electromechanical energy conversion
- DC Machine
- AC Machines
  1. Induction Machine
  2. Synchronous Machine

Electrical Machines

- An electric machine is a link between an electrical system and a mechanical system.
- Electric Machines convert mechanical energy to electrical energy and vice versa continuously.
- The conversion takes place in the presence of magnetic field.
- The process is called *electro mechanical energy conversion*.
- If the conversion is from mechanical to electrical, it is called a **Generator**. If the conversion is from electrical to mechanical, it is called as a **Motor**.


Electrical
e, i
Electric Machine
Mechanical
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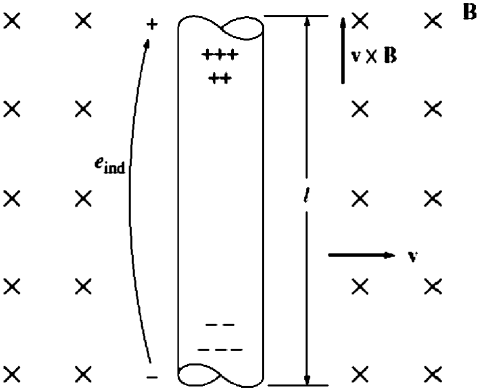
Electrical
Motor
Generator
Mechanical

Electromagnetic Phenomena

1. When a conductor moves in a magnetic field, voltage is induced in the conductor (**Generating action**).
2. When a current carrying conductor is placed in a magnetic field, the conductor experiences a mechanical force (**Motoring action**).

- These two actions occur simultaneously irrespective of energy conversion.
- In both modes, the magnetic field is involved in producing torque and voltage.

Induced Voltage



$$e_{\text{ind}} = l(\text{v} \times \text{B})$$

$$e_{\text{ind}} = vlB \sin\theta$$

If $\theta = 90^\circ$,

$$e_{ind} = vlB \text{ volts}$$

where

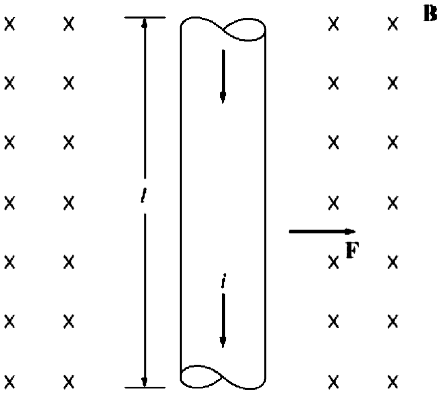
$v =$ velocity of the conductor

$B =$ magnetic flux density vector

$l =$ length of the conductor

$\theta =$ angle between the conductor and the magnetic flux density vector

Developed Force



$$F = l(\text{i} \times \text{B})$$

$$F = Bil \sin \theta$$

If $\theta = 90^\circ$,

$$F = Bil \text{ Newton}$$

where

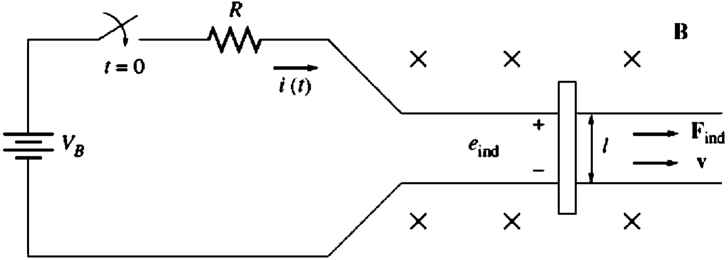
$i =$ current in the conductor

$B =$ magnetic flux density vector

$l =$ length of the conductor

$\theta =$ angle between the conductor and the magnetic flux density vector

Linear DC Machine



1. When the switch is closed,

$$i = \frac{V_B - e_{ind}}{R}$$

At starting, $e_{ind} = 0$. $i = \frac{V_B}{R}$.

Linear DC Machine (contd.)

2. The conductor moves in the right direction.

$$F = Bil$$

3. When it moves in a field, it gets induced emf.

$$e_{\text{ind}} = Blv$$

4. The current then decreases.

$$i \downarrow = \frac{V_B - e_{\text{ind}} \uparrow}{R}$$

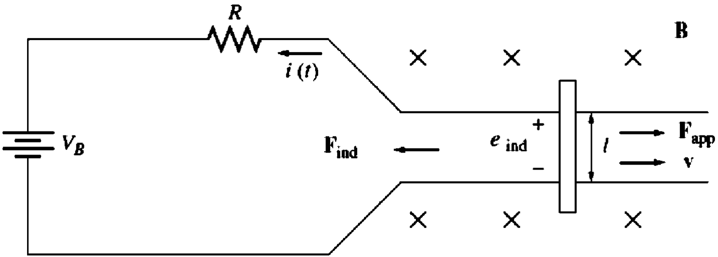
5. It settles at a speed.

$$V_B = e_{\text{ind}} = Blv$$

$$v = \frac{V_B}{Bl} \text{ m/s}$$

$$F = 0$$

Linear DC Machine - Generator



Let us apply a force in the direction of motion.

1. v increases. As v increases,

$$e_{\text{ind}} \uparrow = Blv \uparrow$$

2. The current reverses its direction. $e_{\text{ind}} > V_B$.

$$i = \frac{e_{\text{ind}} - V_B}{R}$$

Linear DC Machine - Generator (contd.)

3. Since the current direction is upwards, the conductor produces a force opposite to the applied force.

$$F_{\text{ind}} = Bil$$

4. The machine runs at a higher speed than the no load speed.

$$F_{\text{ind}} = F_{\text{app}}$$

5. The battery gets charged.
6.

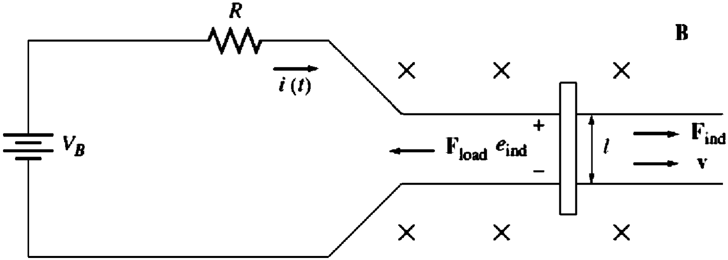
$$e_{\text{ind}} i = F_{\text{ind}} v$$

In rotating machines,

$$e_{\text{ind}} i = T_{\text{ind}} \omega$$

7. It acts as a generator.

Linear DC Machine - Motor



Let us apply a force opposite to the direction of motion.

1. v decreases. As v decreases,

$$e_{\text{ind}} \downarrow = Blv \downarrow$$

2. The current increases.

$$i = \frac{V_B - e_{\text{ind}}}{R}$$

Linear DC Machine - Motor (contd.)

3. The induced force increases.

$$F_{\text{ind}} \uparrow = Bi \uparrow l$$

4. The machine runs at a lower speed than the no load speed.

$$F_{\text{ind}} = F_{\text{load}}$$

5.

$$e_{\text{ind}} i = F_{\text{ind}} v$$

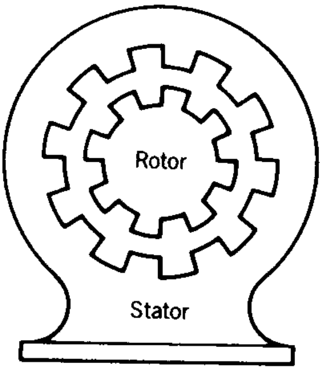
In rotating machines,

$$e_{\text{ind}} i = T_{\text{ind}} \omega$$

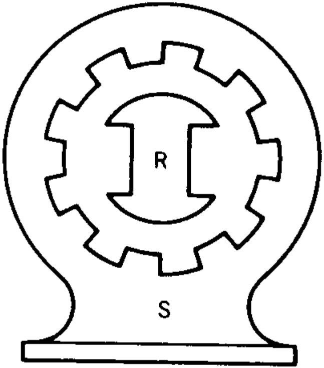
6. It acts as a motor.

- The same machine acts as both motor and generator.
- It moves in the same direction whether it acts as a generator or a motor. But the speed of a generator is higher than a motor.
- In generators, the applied force (mechanical torque) creates motion and the induced force (developed torque) opposes the motion.
- In motors, the induced force (developed torque) sustains motion and the applied force (load torque) opposes the motion.
- Whether motor or generator, both generator and motor actions (induced voltage and developed torque) are present.
- In steady state, $F_{\text{app}} = F_{\text{ind}}$ for linear machines. $T_m = T_e$ for rotating machines.
- In generators, $e_{\text{ind}} > V_B$. In motors, $V_B > e_{\text{ind}}$.

Structure of Electric Machines



(a) Cylindrical Machine

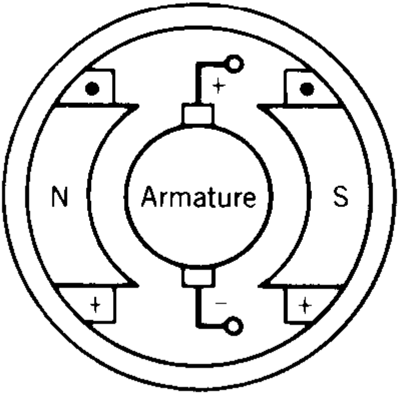


(b) Salient Pole Machine

1. Stator: This part of the machine does not move and normally is the outer part of the machine.
2. Rotor: This part is free to move and normally is the inner part of the machine.

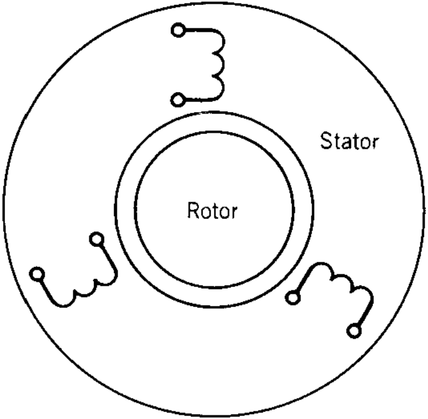
- If the stator or rotor (or both) is subjected to time varying magnetic flux, the iron core is laminated to reduce eddy current losses.
- The conductors placed in the slots of the stator or rotor are interconnected to form windings.
- The winding in which voltage is induced is called the **armature winding**.
- The winding through which a current is passed to produce flux is called the **field winding**.
- The basic machines are DC machines, Induction Machines and Synchronous Machines.
- The other machines are Permanent magnet machines, hysteresis machines and stepper machines.

DC Machine



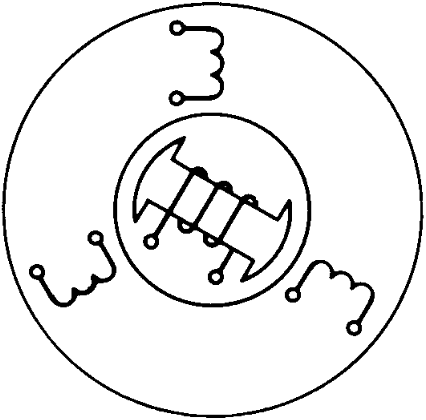
1. Armature winding is placed in the rotor.
2. Field winding is placed in the stator.

Induction Machine



- Stator windings serve as both armature windings and field windings.

Synchronous Machine



1. Field winding is placed in the rotor. It is excited by DC.
2. Armature winding is in the stator.

- Though they differ in physical construction, they are governed by the same principles.
- In DC machines, the stator and rotor flux distributions are fixed in space and a torque is produced because of the tendency of these two fluxes to align.
- In Induction and synchronous machines, the stator flux and the rotor flux rotate in synchronism in the air gap. Torque is developed because of the tendency of these two fluxes to align with each other.