Three Phase Induction Motors

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Three Phase Induction Motors

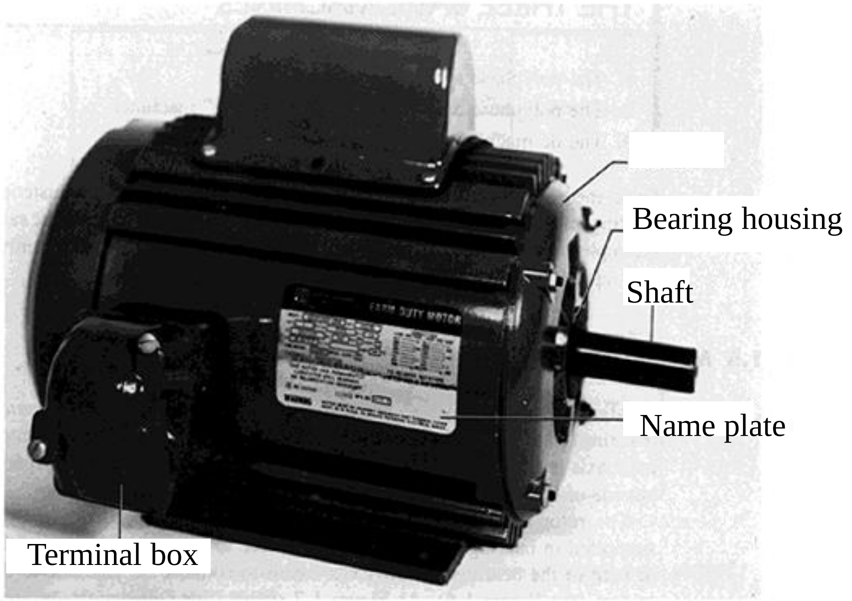
Part no. 1

Basic principles and physical construction

INDUCTION MOTORS

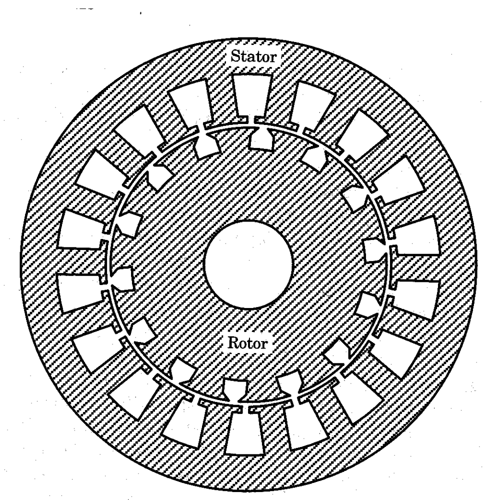
General

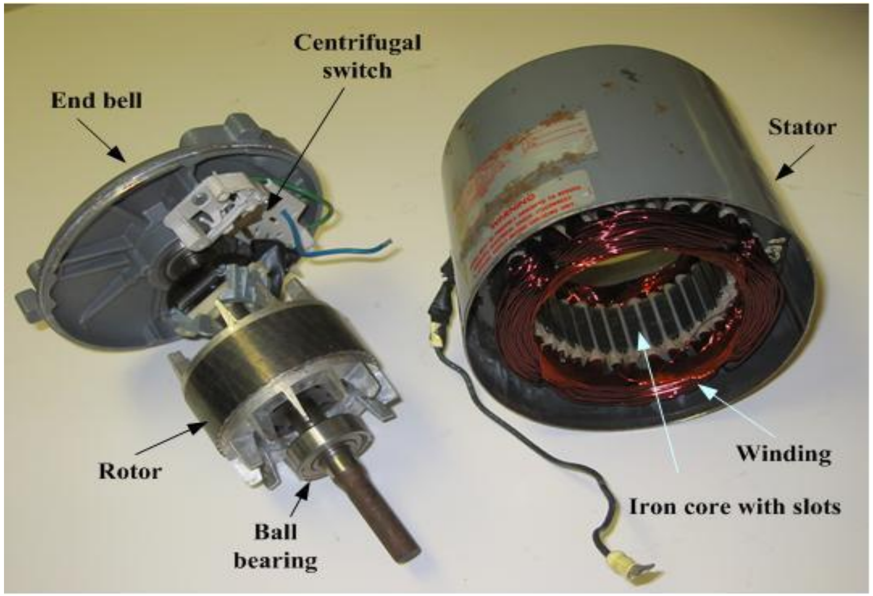
- The induction machine is used as a motor and as a generator. However, it is most frequently used as a motor. It is the Workhorse of industry.
- Two types of induction motors exist: **wound rotor** and **squirrel cage rotor**.
- Majority of the motors used by industry are squirrel cage induction motors.
- Both three-phase and single-phase motors are widely used.
- The induction generators are seldom used. Their typical application is the wind power plant.

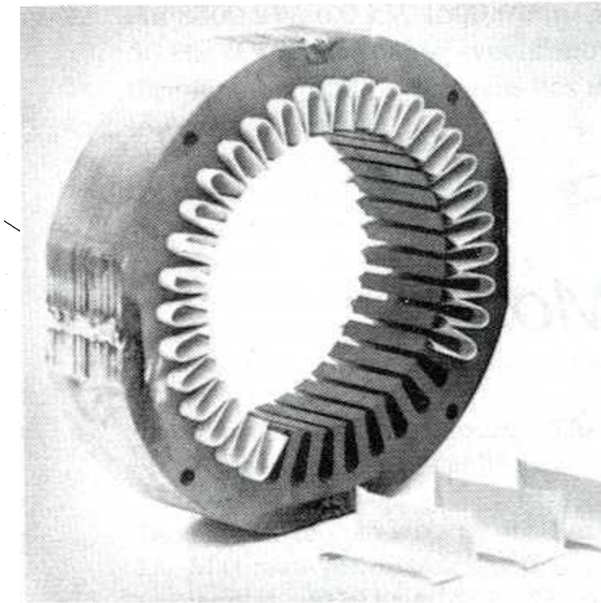


INDUCTION MOTORS

- **Stator construction**
  - Has same construction for both rotor types
  - Laminated iron core with slots
  - Coils are placed in the slots to form a three or single phase winding



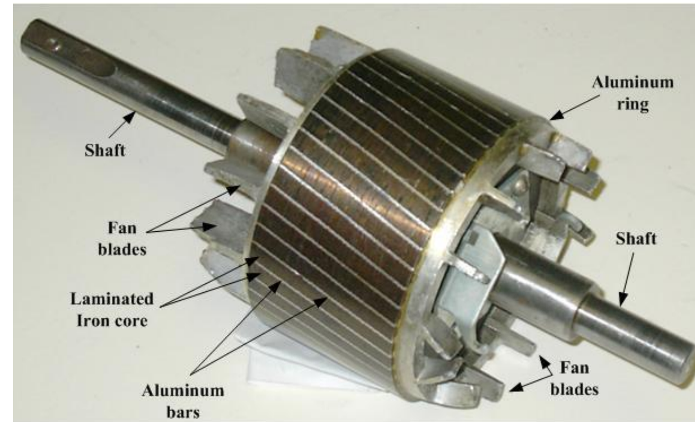


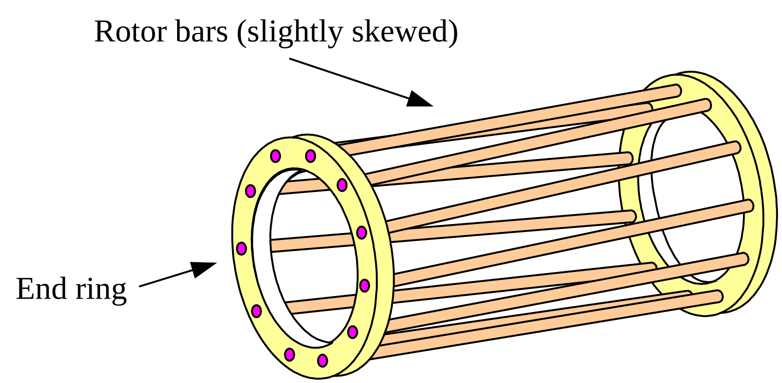


INDUCTION MOTORS, *Squirrel Cage*

Squirrel-cage rotor construction

- Laminated Iron core with slots
- Aluminum bars are molded in the slots
- Two rings are used to short circuit the bars
- The bars are slanted (skewed) to reduce noise



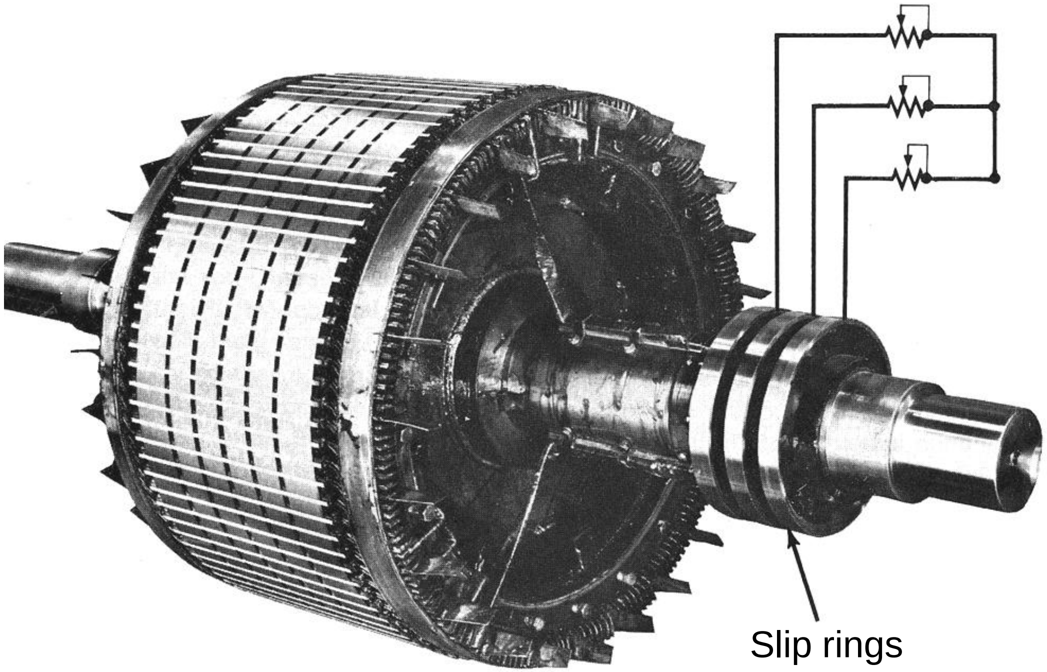


INDUCTION MOTORS, *wound rotor*

Wound-rotor

- The picture shows the rotor of a large **wound-rotor motor**
- The ends of each phase are connected to a slip ring.
- Three brushes contact the three slip-rings to three wye connected resistances.

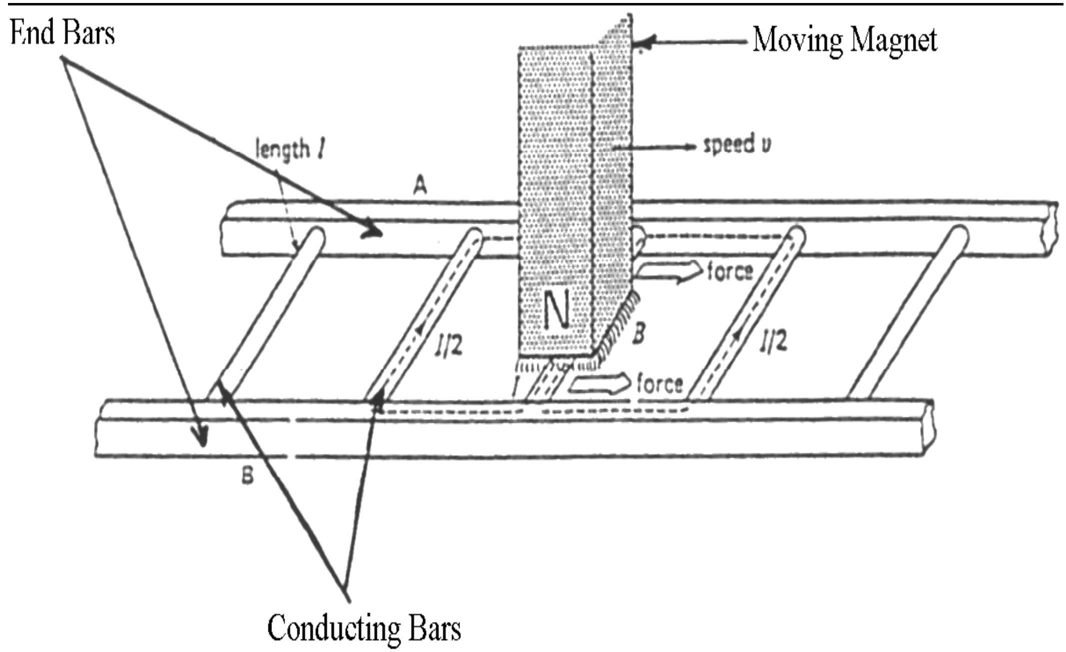
Rotor construction



INDUCTION MOTORS

Basic principles:

- An emf is induced in the conducting bars as they are “cut” by the flux while the magnet is being moved.
- $E = BvL$ (Faraday’s Law)
- The emf induces or produces a current *I*, which in term produces a force, *F*.
- $F = BiL$ (Lorentz Force)
- Force direction is the same as the magnet’s motion direction.



INDUCTION MOTORS

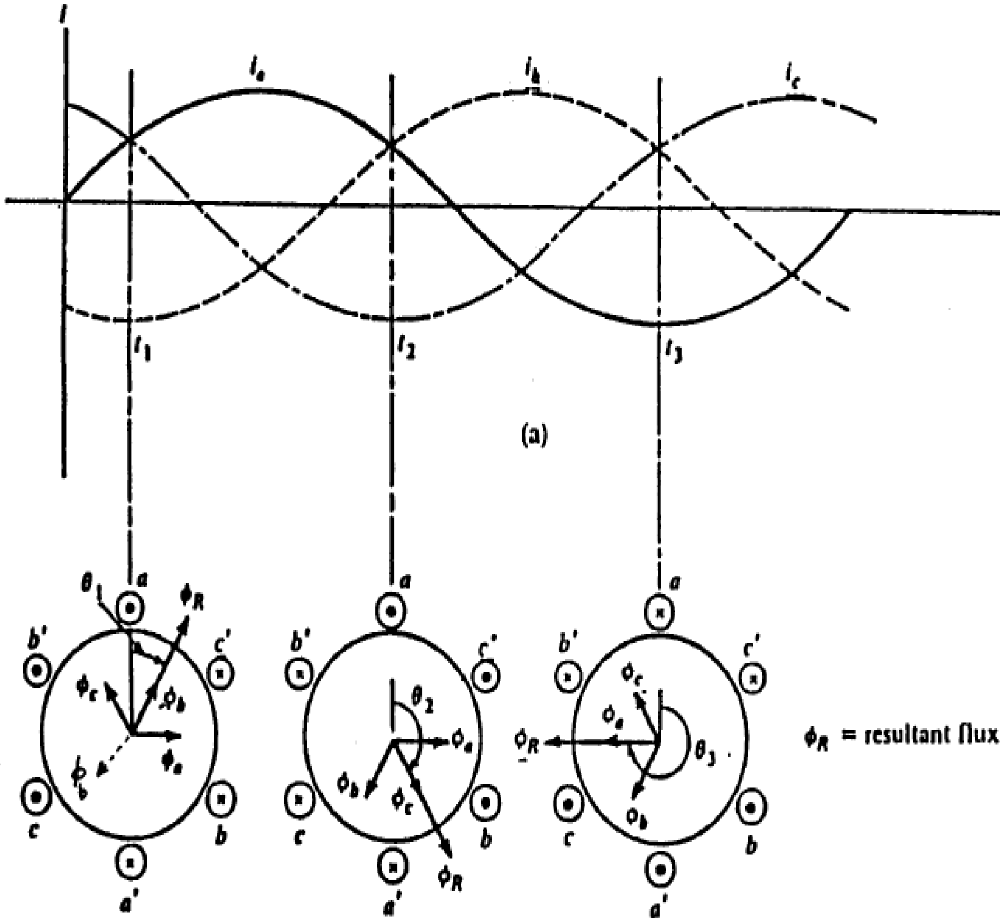
Rotating Magnetic Field

- In ac machines, the three-phase currents i_a, i_b and i_c, each of equal magnitude, but different in phase by 120°, produce a magnetic field of constant magnitude that rotates in the space. Such a magnetic field produced by balanced three phase currents flowing in thee-phase windings is called a rotating magnetic field (RMF). Existence of a RFM is an essential condition for the operation of a ac rotating machine.

INDUCTION MOTORS

Production of RMF:

- The concept of RMF can be illustrated using the following graphical representation. Consider a set of balanced three-phase currents i_a, i_b and i_c, flowing through the three-phase windings *aa'*, *bb'* and *cc'* (for simplicity, only one coil per phase is considered).
- The coils *aa'*, *bb'* and *cc'* are displaced in space, by 120°. The currents in each coil are responsible for producing their own magnetic flux, ϕ_a, ϕ_b and ϕ_c respectively.
- The following figure shows the resultant flux ϕ_r that results from these three fluxes at any given instant in time. ϕ_r is however, (i) constant in magnitude but (ii) rotates in space with time.



INDUCTION MOTORS

Three-phase motors. Operation principles.

1) Energize the stator with three-phase voltage.
2) Currents in the stator winding produce a rotating magnetic field. This field revolves in the air gap with a constant speed called *synchronous speed,* n_s.
3) The stator magnetic field links the rotor conductors through the air gap and voltage will be induced in the rotor conductors and currents will produce in the rotor conductors as they are short circuited.
4) Currents in the rotor conductors will produce their own magnetic field which interacts with the stator magnetic field.
5) The torque developed due to interaction of the stator and rotor magnetic fields pushes the rotor into rotation in the same direction of the rotation of the revolving magnetic field in the air gap trying to align the magnetic axes of the rotor and the rotating magnetic field.

INDUCTION MOTORS

Synchronous Speed and Slip

- The stator magnetic field (rotating magnetic field) rotates at a constant speed, n_s, the synchronous speed.
- Synchronous speed depends on the source or stator current frequency (f_s) and number of poles (p). $n_s = 120\ f_s / p$
- If, n_m = speed of the rotor, the "slip" (***s***) for an induction motor is defined;

$$s = \frac{n_s - n_m}{n_s} \times 100\%$$

- Slip is expressed as a percentage or fraction value, i.e. 3 % or 0.03.

INDUCTION MOTORS

Synchronous Speed and Slip

- At stand still, s = 1, that is $n_m = 0$. At synchronous speed, $n_m = n_s$, s = 0.
- The mechanical speed of the rotor, in terms of slip and synchronous speed:

$$n_m = (1 - s) n_s$$

$$\omega_m = (1 - s)\omega_s$$

INDUCTION MOTORS

Frequency of Rotor Currents and Voltages:

With the rotor at stand-still, the frequency of the induced voltages and currents is the same as that of the stator (supply) frequency, f_s.

$$E_r = E_{r0} = \text{rotor EMF at standstill}$$

If the rotor rotates at speed of n_m, then the relative speed is the slip speed

$$n_{slip} = n_s - n_m$$

n_{slip} is the speed responsible for the induction.

But $\mathbf{n_m = n_s(1 - s)}$ by definition of slip.

Hence, $n_{slip} = n_s - n_s(1 - s) = sn_s$,

thus the frequency of the induced voltages

and currents is, $\mathbf{f_r = sf_s}$ **and** $\mathbf{E_r = sE_{r0}}$**.** where f_s is the supply or stator current frequency.

The rotor's EMF is **maximum** at the **starting** of the Induction Motor and then starts to *decrease* with the *increase* of the rotor speed as the relative speed (n_{slip}) between the rotating field and the rotor *decreases*.

INDUCTION MOTORS

If the rotor attains the synchronous speed, $n_m = n_s$, so that the slip s = 0:

No induction takes place because there is no relative speed between the flux and the rotor conductors.

The frequency of the rotor's EMF and current is zero, $f_r = sf_s = 0 * f_s = 0$

No induced EMF in the rotor and hence there is no current induced in the rotor's conductors.

Therefore, there is no torque produced on the rotor and rotor starts to slow down to a speed a little bit lower than the synchronous speed.

The induction motor cannot run at synchronous speed.

The no load speed of the IM is in order of 99% of the synchronous speed.

The full load slip is in order of 0.05 or 5%.

INDUCTION MOTORS

Example no. 1:

A three-phase, 20 hp, 208 V, 60 Hz, six pole, wye connected induction motor delivers 15 kW at a slip of 5%.

Calculate:

a) Synchronous speed

b) Rotor speed

c) Frequency of rotor current

Solution

- Synchronous speed: $n_s = 120\ f_s / p = (120)(60) / 6 = 1200$ rpm
- Rotor speed: $n_r = (1\text{-}s)\ n_s = (1 - 0.05)\ (1200) = 1140$ rpm
- Frequency of rotor current: $f_r = s\ f_s = (0.05)\ (60) = 3$ Hz