Lecture 1

Definition, Construction and Types of Three-phase Induction Motor

1. Introduction:

Induction motor (Also called **asynchronous motor**) is an A.C. motor. The motor line current flows into the stator windings to set up a flux called the main flux or the stator flux, which passes through the air gap to be cut by the conductors of the rotor windings. Consequently, an electromotive force to be **induced** in the rotor windings and produces currents flow in the rotor windings and producing flux called the rotor flux. The interact between the two fluxes (stator and rotor fluxes) producing rotation of the rotating part of the motor (rotor). The rotor receives electrical power in the same way as the secondary winding of the electrical transformer receiving its power from the primary winding by means of the electrical induction. That is why an induction motor can be called as a **rotating transformer** i.e., in which primary winding is stationary but the secondary is free to rotate.

2. Induction Motor Types:

Depending on the construction of the rotor circuit there are two types of induction motors:

I. Squirrel cage induction motor:

Rotors is very simple and consist of **bars** of aluminum (or copper) with shorting rings at the ends.

II. Wound rotor induction motor:

Rotor consists of three phase **windings** (star connected) with terminals brought out to slip rings for external connections.

Squirrel cage type is more **common** compared to the wound rotor type due to:

a. **Robust**, as no brushes, no contacts on the rotor shaft.
b. **Simple** in construction and **easy** to manufacture.
c. Almost **maintenance-free**, except for bearing and other mechanical parts.
d. **High efficiency** as rotor has very low resistance and thus low copper loss.

3. Construction:

There are two main types of components which are used in induction motor manufacturing as follows:

a) Active components: which are classified into two categories:

   i. Magnetic materials (0.5 mm electrical steel).

   ii. Electrical materials (copper wires, insulations, bars, end rings, slip rings, brushes, and lead wires).

b) Constructional components: like frame, end shields, shaft, bearings, and fan. These components are shown in figure 1.

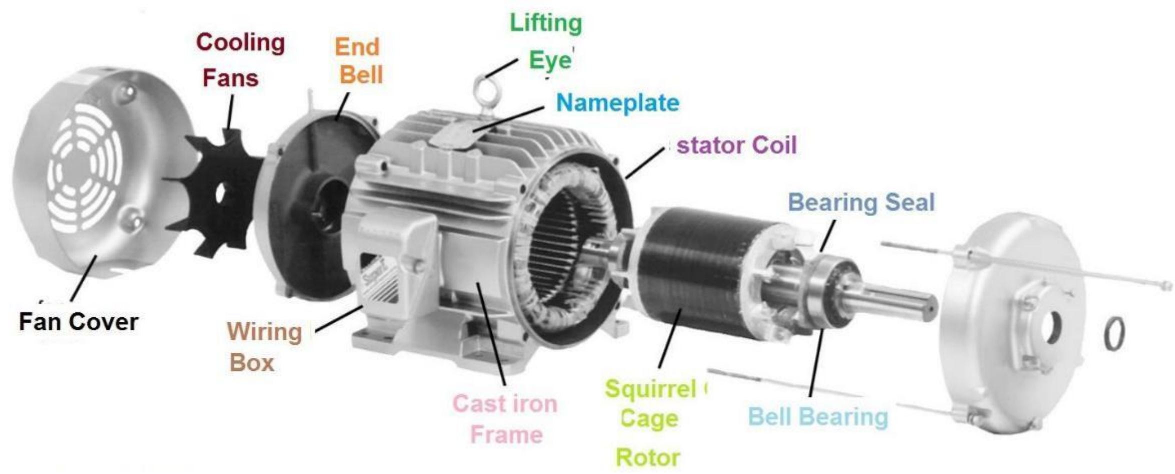


Figure 1 Parts of Squirrel Cage Induction Motor

3.1 Stator construction:

The stator is made up of several thin laminations (0.5 mm) of electrical steel (silicon steel), they are punched and clamped together to form a hollow cylinder (stator core) with slots, as shown in Figure 2.

Coils of insulated wires are inserted into these slots. Each group of coils, together with the core that it surrounds, forms an electromagnet, forms an electromagnet (a pair of poles). The number of poles of an induction motor depends on the internal connection of the stator windings.

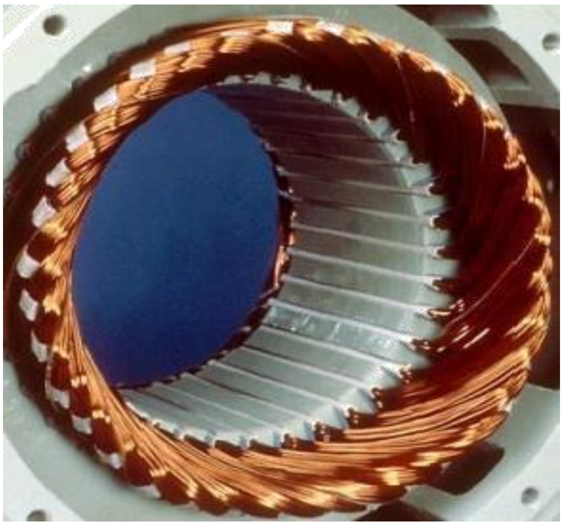


Figure 2 Typical Stator of Three-phase Induction Motor

3.2 Rotor construction:

The squirrel cage rotor is made up of several thin electrical steel lamination (0.5mm) with evenly spaced bars , which are made up of aluminum or copper , along the periphery .In the most popular type of rotor (squirrel cage rotor), +these bars are connected at ends mechanically and electrically by the use of end rings as in Figure 3 (A). Almost 90 % of induction motors have squirrel cage rotors. The rotor slots are not exactly parallel to the shaft. Instead, they are given a skew for two main reasons, firstly to make the motor run quietly by reducing magnetic hum and to decrease slot harmonics, secondly to help reducing the locking tendency of the rotor (the rotor teeth tend to remain locked under the stator teeth due to direct magnetic attraction between the two). The rotor is mounted on the shaft using bearings on both ends.

The wound rotor has a set of windings on the rotor slots which are not short circuited, but they are terminated to a set of slip rings. These are helpful in adding external resistors and contactors, as in Figure 3 (B). The typical squirrel cage rotor circuit is shown in figure 4 (A), while the typical wound rotor circuit with an external rotor resistor circuit is shown in figure 4 (B).

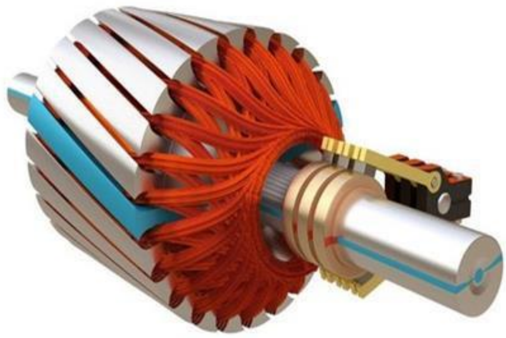
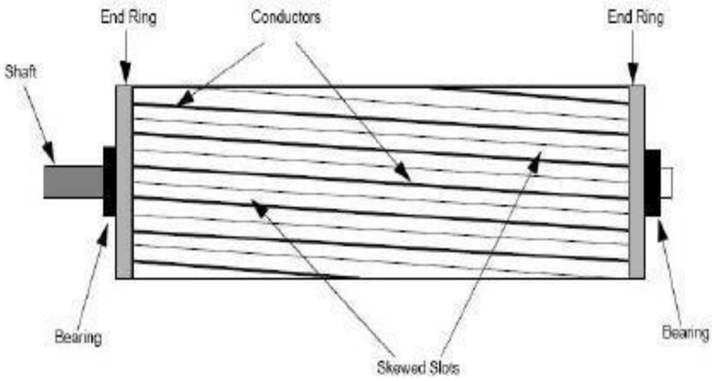


Figure 3 (A) Squirrel Cage Rotor Type (B) Wound Rotor Type



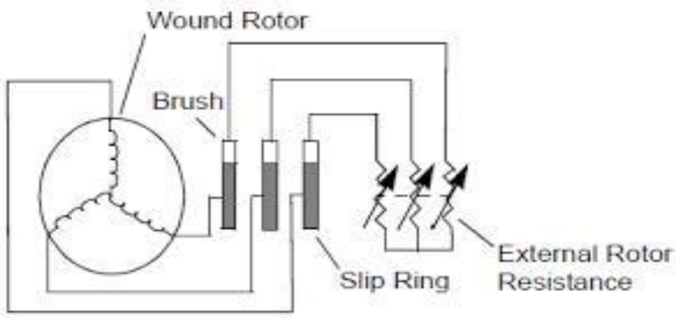
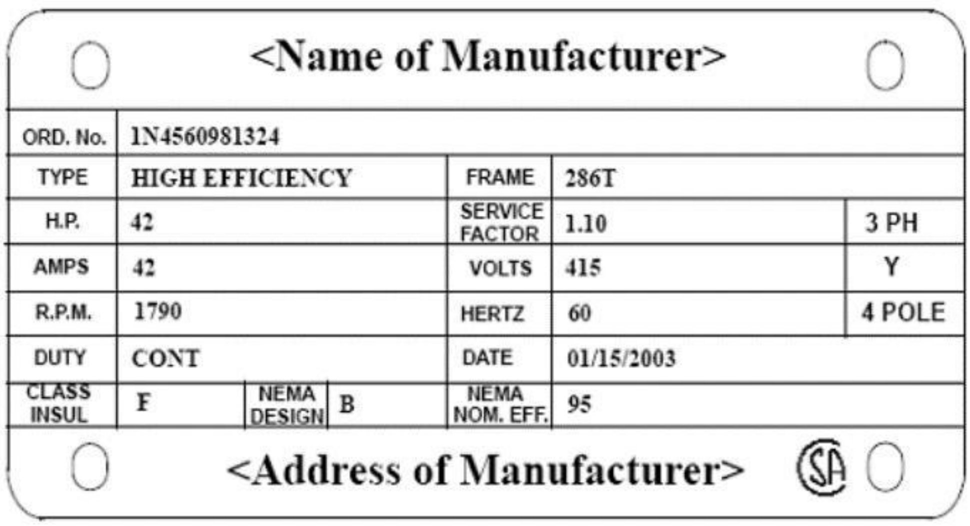


Figure 4 (A) Typical Squirrel Cage (B) Typical Wound rotor

4. Typical name plate of induction motor:

A typical name plate of induction motor is shown in Figure 5, and table 1.



<Name of Manufacturer>

ORD. No.	1N4560981324						
TYPE	HIGH EFFICIENCY			FRAME	286T		
H.P.	42			SERVICE FACTOR	1.10		3 PH
AMPS	42			VOLTS	415		Y
R.P.M.	1790			HERTZ	60		4 POLE
DUTY	CONT			DATE	01/15/2003		
CLASS INSUL	F	NEMA DESIGN	B	NEMA NOM. EFF.	95		

<Address of Manufacturer>

Figure 5 Typical Name Plate of Induction Motor

Table 1 Name Plate Terms and Their Meaning

Term	Description
Volts	Rated terminal supply voltage.
Amps	Rated full-load supply current.
H.P.	Rated motor output.
R.P.M	Rated full-load speed of the motor.
Hertz	Rated supply frequency.
Frame	External physical dimension of the motor based on the NEMA standards.
Duty	Motor load condition, whether it is continuos load, short time, periodic, etc.
Date	Date of manufacturing.
Class Insulation	Insulation class used for the motor construction. This specifies max. limit of the motor winding temperature.
NEMA Design	This specifies to which NEMA design class the motor belongs to.
Service Factor	Factor by which the motor can be overloaded beyond the full load.
NEMA Nom. Efficiency	Motor operating efficiency at full load.
PH	Specifies number of stator phases of the motor.
Pole	Specifies number of poles of the motor.
CSA	Specifies the motor safety standard.
Y	Specifies whether the motor windings are start (Y) connected or delta (Δ) connected.

All the information of the above table is according to the motor standards:

NEMA: **N**ational **E**lectrical **M**anufactures **A**ssociation

IEC: **I**nternational **E**lectrotechnical **C**ommission

5. Motor insulation class:

Insulations have been standardized and graded by their resistance to thermal aging and failure. Four insulation classes are in common use, they have been designated by the letters **A, B, F**, and **H**. The temperature capabilities of these classes are separated from each other by **25 °C** increments. The temperature capabilities of each insulation class are defined as being **the maximum temperature at which the insulation can be operated to yield an average life of 20,000 hours,** as in Table 2 below.

Table 2 Motor Insulation Classes

Insulation Class	Temperature Rating
A	105° C
B	130° C
F	155° C
H	180° C

6. Motor Degree of Protection:

I P: International Protection, I P * #

*	Protection against ingress of Bodies	#	Protection against ingress of Water
0	Non protected	0	Non protected
1	Protected against ingress of foreign solid bodies of 50 mm or greater.	1	Protected against ingress of dripping water.
2	Protected against ingress of foreign solid bodies of 12 mm or greater.	2	Protection against ingress of dripping water at maximum angle of 150 degrees from the vertical.
3	Protected against ingress of foreign solid bodies of 2.5 mm or greater.	3	Protection against water falling like rain.
4	Protected against ingress of foreign solid bodies of 1 mm or greater.	4	Protection against splashing water.
5	Partially protected against ingress of dust.	5	Protection against water jets.
6	Totally protected against ingress of dust.	6	Protection against special conditions on ship's board.
		7	Protection against immersion in water.
		8	Protection against prolonged immersion in water.

7. Solved Examples:

i. **The name plate data of three-phase Induction Motor are illustrated below:**

Type	High Efficiency	**Frame**	106 T
H.P.	4	**NEMA Design**	B
AMPS	6.4	**VOLTS**	380
R.P.M.	1440	**Hertz**	50
Duty	S1	**P.F.**	0.8
Ins. Class	F	**Service Factor**	1.1
IP	55	**Phase**	3 Y

Determine:

- **The efficiency**
- **Maximum allowable power**
- **Total losses**
- **Motor Torque**
- **Maximum temperature for stator winding**
- **Shaft center to base height**
- **Immersion in water possibility**

Solution:

- Output power = 4 * 746 = 2984 W
- Input power = √3 * 6.4 * 380 * 0.8 = 3370 W
- Efficiency = P_{out} / P_{in} * 100 % = 88.5 %

- Maximum allowable power = Service factor * P_{out} = 1.1 * 2984 = 3282 W

- Total Losses = P_{in} - P_{out} = 3370 – 2984 = 386 W

- Motor torque = P_{out} / Angular velocity = 2984 / 150.8 = 19.78 NM
- Angular velocity = (2 π N) / 60 = (2* π * 1440) / 60 = 150.8 red /sec

- Maximum temperature for stator winding for class F is 155°

- The shaft center to base is height is 106 mm

- Immersion in water for IP 55 protection is not applicable.

ii. The name plate data of three-phase Induction Motor are illustrated below:

Type	High Efficiency	**Frame**	98 T
H.P.	7	**NEMA Design**	B
AMPS	11	**VOLTS**	380
R.P.M.	1480	**Hertz**	50
Duty	S1	**P.F.**	0.85
Ins. Class	B	**Service Factor**	1.15
IP	67	**Phase**	3 Δ

Determine:

- **The efficiency**
- **Maximum allowable power**
- **Total losses**
- **Motor Torque**
- **Maximum temperature for stator winding**
- **Shaft center to base height**
- **Immersion in water possibility**

Solution

- Output power = 7 * 746 = 5222 W
- Input power = √3 * 11 * 380 * 0.85 = 6154 W
- Efficiency = P_{out} / P_{in} * 100 % = 84.8 %

- Maximum allowable power = Service factor * P_{out} = 1.15 * 5222 = 6005 W

- Total Losses = P_{in} - P_{out} = 6154 – 5222 = 932 W

- Motor torque = P_{out} / Angular velocity = 5222 / 155 = 33.7 NM
- Angular velocity = (2 π N) / 60 = (2* π * 1480) / 60 = 155 red /sec

- Maximum temperature for stator winding for class B is 130˚

- The shaft center to base is height is 98 mm

- Immersion in water for IP 67 protection is applicable.

8. Questions:

i. **How does the name of an induction motors is derived?**
Ans. The name of an induction motor is derived from the fact that it works on the basic principle of mutual induction. The current in the rotor conductions is induced by the motion of rotor conductor relative to the magnetic field produced by the stator currents.

ii. **Classify 3-phase induction motors based on their construction. Which one is generally preferred and why?**
Ans. Three-phase induction motors may be classified as (*i*) squirrel cage induction motors and (*ii*) wound rotor or slip-ring induction motor.
Squirrel cage induction motor is generally preferred due to its low construction cost, low maintenance, high pf, high efficiency, robust construction.

iii. **Why the rotor slots of an induction motor are skewed?**
Ans. The rotor slots of an induction motor are skewed to reduce humming noise and ensuring quiet running, reduce magnetic locking and for smooth and uniform torque.

iv. **Why the rotor conductors of the squirrel cage rotor are short-circuited in the case of slip-ring induction motors, the rotor circuit is closed through resistors?**
Ans. In induction motors, torque develops by the interaction of stator and rotor fields. The rotor field is developed only if current flows through the rotor conductors which is only possible if rotor circuit is closed or short-circuited.

v. **How the iron losses are reduced in induction motor?**
Ans. Iron loss consists of Eddy current loss and Hysteresis loss. Eddy current loss is minimized by laminating the iron core and hysteresis loss is minimized by selecting the material with minimum hysteresis coefficient.

vi. **Why length of air gap is kept small in induction motors?**
Ans. Length of the air gap in the induction motor is kept as small as possible so that the impedance of the magnetic circuit of the motor is high and the corresponding magnetizing current becomes small, which lead to better power factor.

vii. **Why Induction motor is called rotating transformer?**

Ans. The principle of operation of induction motor is similar to that a transformer. The stator winding is equivalent to primary of the transformer and the rotor winding is equivalent to short circuited secondary of a transformer. In transformer the secondary is fixed but in induction motor it is allowed to rotate. Hence the induction motor also called rotating transformer

viii. **State the difference between squirrel cage Induction motor and slip ring Induction motor?**

Ans.

Parameters	Squirrel cage IM	Slip ring IM
Rotor winding	Copper bars are short circuited at both ends	Three phase winding
End ring	present	Absent
Efficiency	high	low
External resistance in rotor	Not possible	Possible
Starting torque	Moderate	High
Construction	Simple & robust	Complicated
Maintenance	less	High
Industrial use	95%	5%
Speed control from rotor side	Not possible	Possible
cost	Economical	Expensive
Applications	Lathes, drilling machine, water pumps, blowers, fans, printing machine	Lifts, compressors, hoists, cranes, elevators, belt, conveyor