Three-phase Induction Motor: Types and Structure

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Three-phase Induction Motor: Types and Structure

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Abstract

The popularity of 3 phase induction motors on board ships is because of their simple, robust construction, and high reliability factor in the sea environment. A 3-phase induction motor can be used for different applications with various speed and load requirements. Electric motors can be found in almost every production process today. Getting the most out of your application is becoming more and more important in order to ensure cost-effective operations.

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.

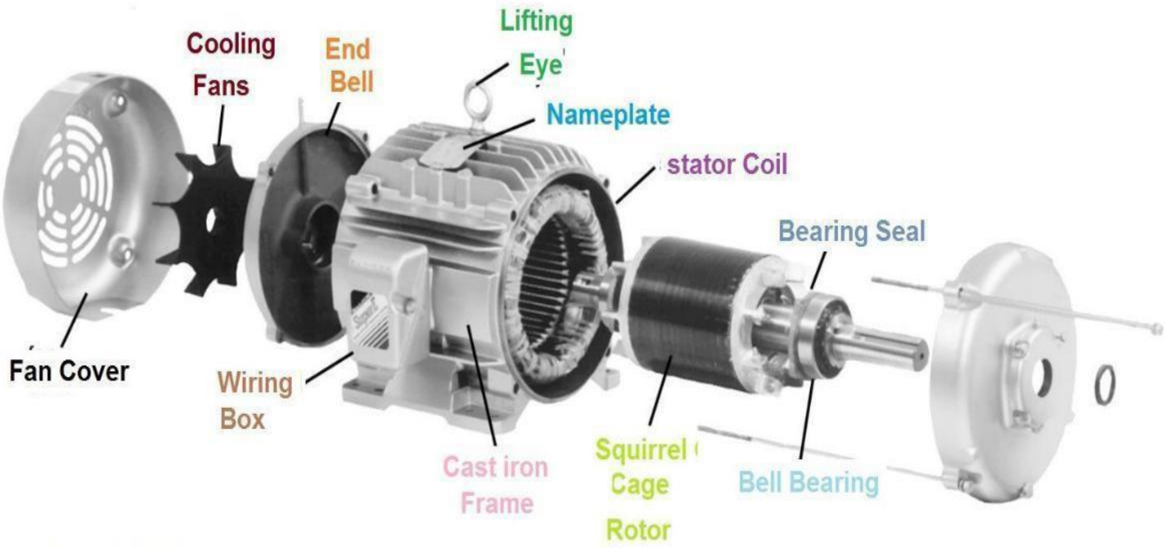


Figure 1 Parts of Squirrel Cage Induction Motor

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.

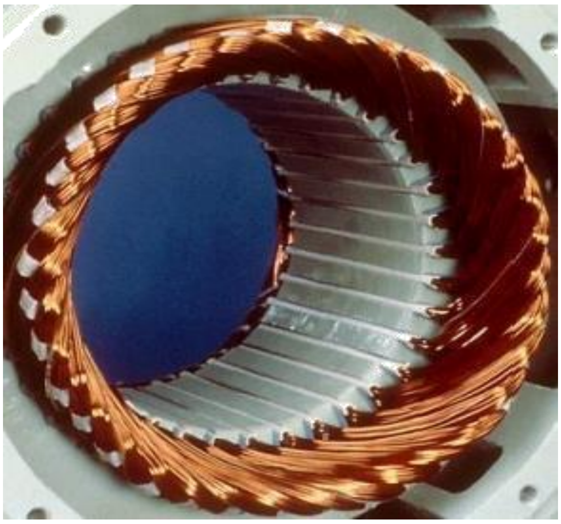


Figure 2 Typical Stator of Three-phase Induction Motor

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).

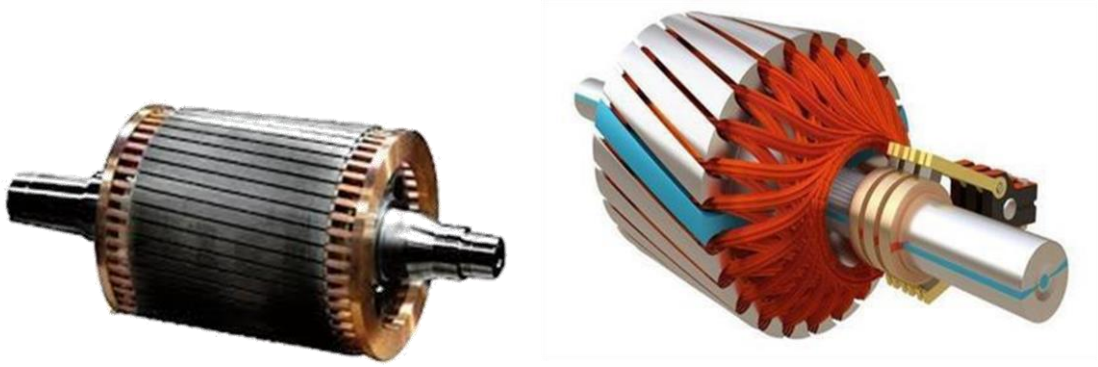


Figure 3 (A)

Squirrel Cage Rotor Type (B) Wound Rotor Type

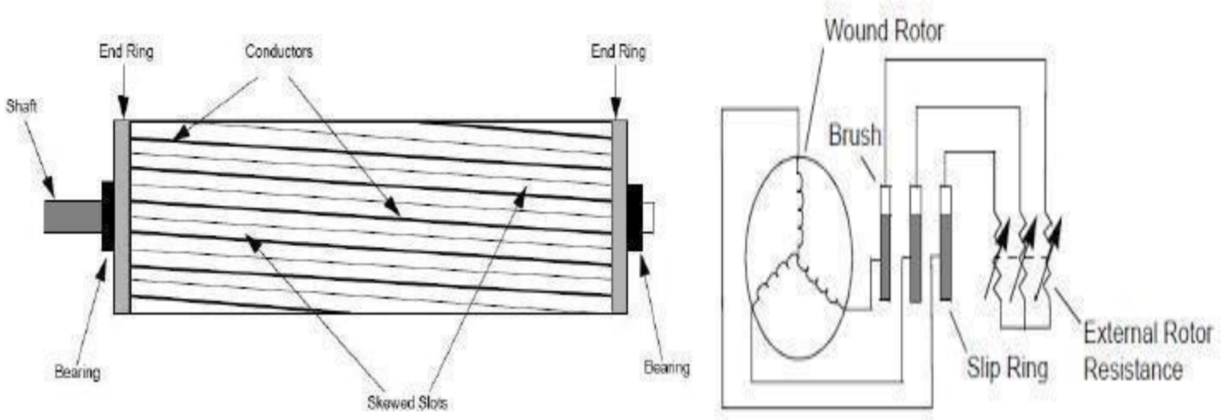
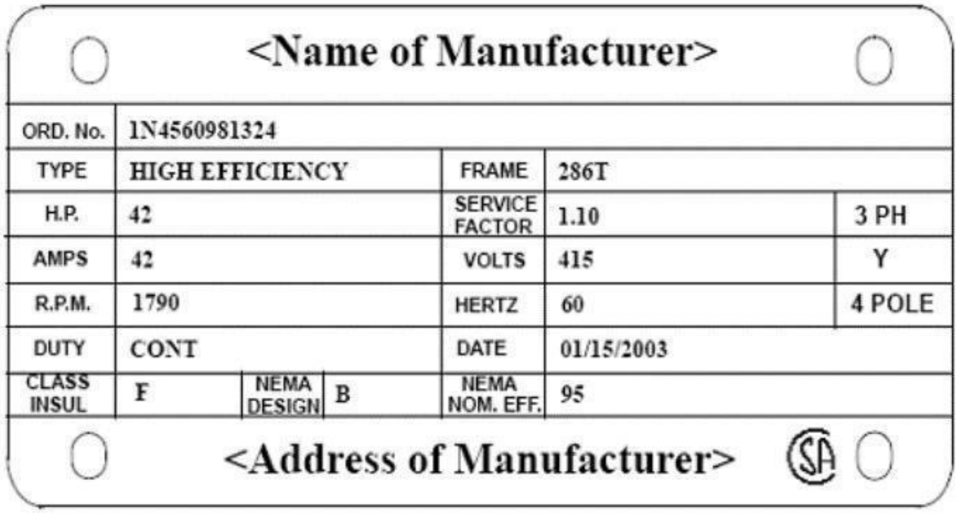


Figure 4 (A) Typical Squirrel Cage (B) Typical Wound rotor

4. Typical name plate of induction motor:

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



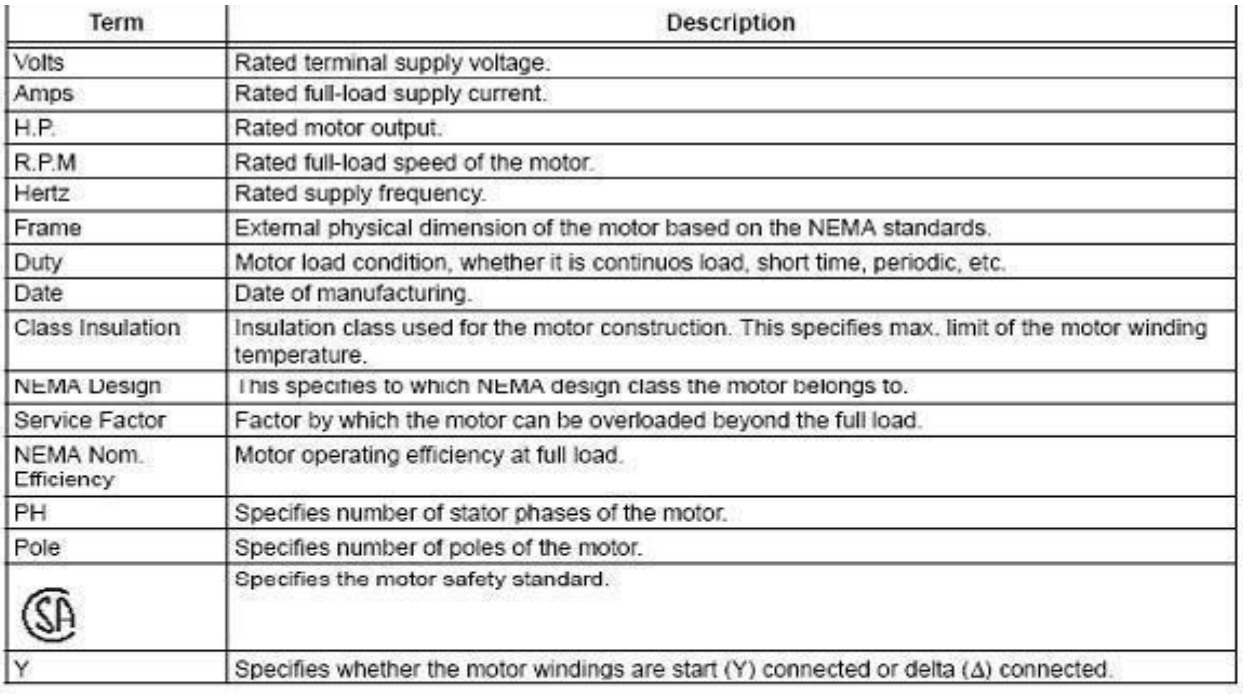
<Name of Manufacturer>

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

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: National Electrical Manufactures Association.
IEC: International Electrotechnical Commission.

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. Principle of Operation:

In order to clarify the principles of operations, consider a portion of 3-phase induction motor as shown in Figure 6. The operation of the motor can be explained as below:

I. When 3-phase stator winding is energized from a 3-phase supply, a rotating magnetic field is set up which rotates round the stator at synchronous speed Ns (= 120 f/P).

II. The rotating field passes through the air gap and cuts the rotor conductors, which still in stationary condition. Due to the relative speed between the rotating flux and the stationary rotor, an electromotive force (e.m.f.) is induced in the rotor conductors. Since the rotor circuit is short-circuited, currents start flowing in the rotor conductors.

III. The current-carrying rotor conductors are placed in the magnetic field produced by the stator. Consequently, mechanical force acts on the rotor conductors. The sum of the mechanical forces on all the rotor conductors produces a torque which tends to move the rotor in the same direction as the rotating magnetic field.

IV. The fact that rotor is urged to follow the stator field (i.e., rotor moves in the direction of stator field) can be explained by Lenz's law. According to this law, the direction of rotor currents will be such that they tend to oppose the cause producing them.

V. Now, the cause producing the rotor currents is the relative speed between the rotating magnetic field and the stationary rotor conductors. Hence to reduce this relative speed, the rotor starts running in the same direction as that of stator field and tries to catch its speed.

VI. We have seen above that rotor rapidly accelerates in the direction of rotating field. In practice, the rotor can never reach the speed of stator flux. If it did, there would be no relative speed between the stator field and rotor conductors, no induced rotor currents and, therefore, no torque to drive the rotor. The friction and windage would immediately cause the rotor to slow down. Hence, the rotor speed (Nr) is always less than the suitor field speed (Ns). This difference in speed depends upon load on the motor.

VII. The difference between the synchronous speed (Ns) of the rotating stator field and the actual rotor speed (Nr) is called slip. It is usually expressed as a percentage of synchronous speed i.e.,

$$\mathbf{Slip} = S = \frac{Ns - Nr}{Ns} \times 100\ \%$$

Where, the quantity (**Ns – Nr**) is called **slip speed**, and the slip at the stationary situation is **unity** or 100%.

VIII. The frequency of a voltage or current induced due to the relative speed between a vending and a magnetic field is given by the general formula:

Frequency of the rotor circuit = **Fr = N P/ 120**

Where, **N** is the slip speed **(Ns - Nr) ,** and by the substitution of the slip speed and the slip in the above equation we will get:

$$\mathbf{Fr = S\,F}$$

Where, **S** is the slip, **F** is the supply frequency

IX. When the rotor is at standstill or stationery (i.e., s = 1), the frequency of rotor current is the same as that of supply frequency. As the rotor picks up speed, the relative speed between the rotating flux and the rotor decreases. Consequently, the slip s and hence rotor current frequency decreases.

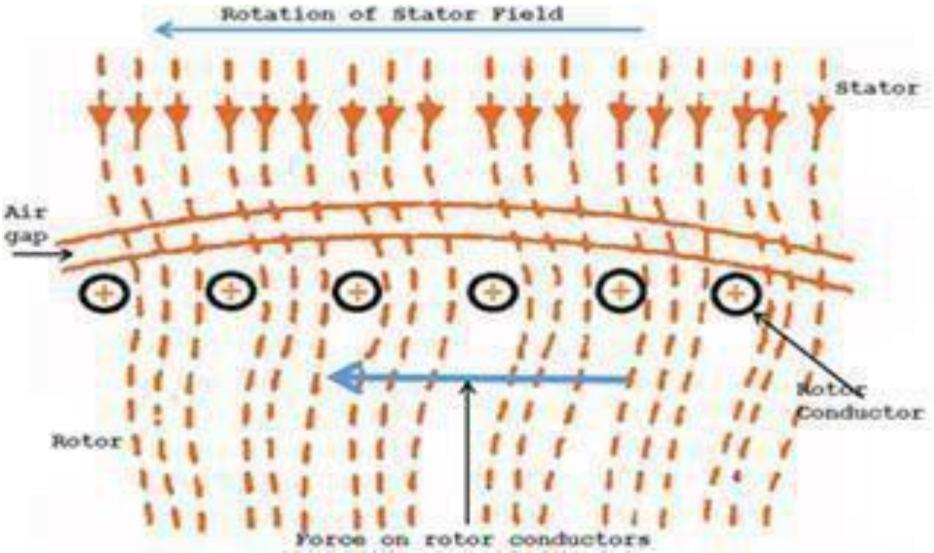


Figure 6 Principle of Operation of Three-phase Induction Motor

8. Rotating Magnetic Field (RMF):

Three phase induction motor have a symmetric three phase stator windings displayed 120 degree in space, so each winding sets up a field that varies sinusoidally around the circumference of the air gap and varies sinusoidally with time. These fields are displayed from one another by 120 degree in

both time and space. The flux density from phase A (for example) is maximum in certain point and drops sinusoidally to zero, ninety degree away from this point. So, the stator field can be visualized as a set of north and south poles rotating around the circumference of the stator as shown in the figure 7 below.

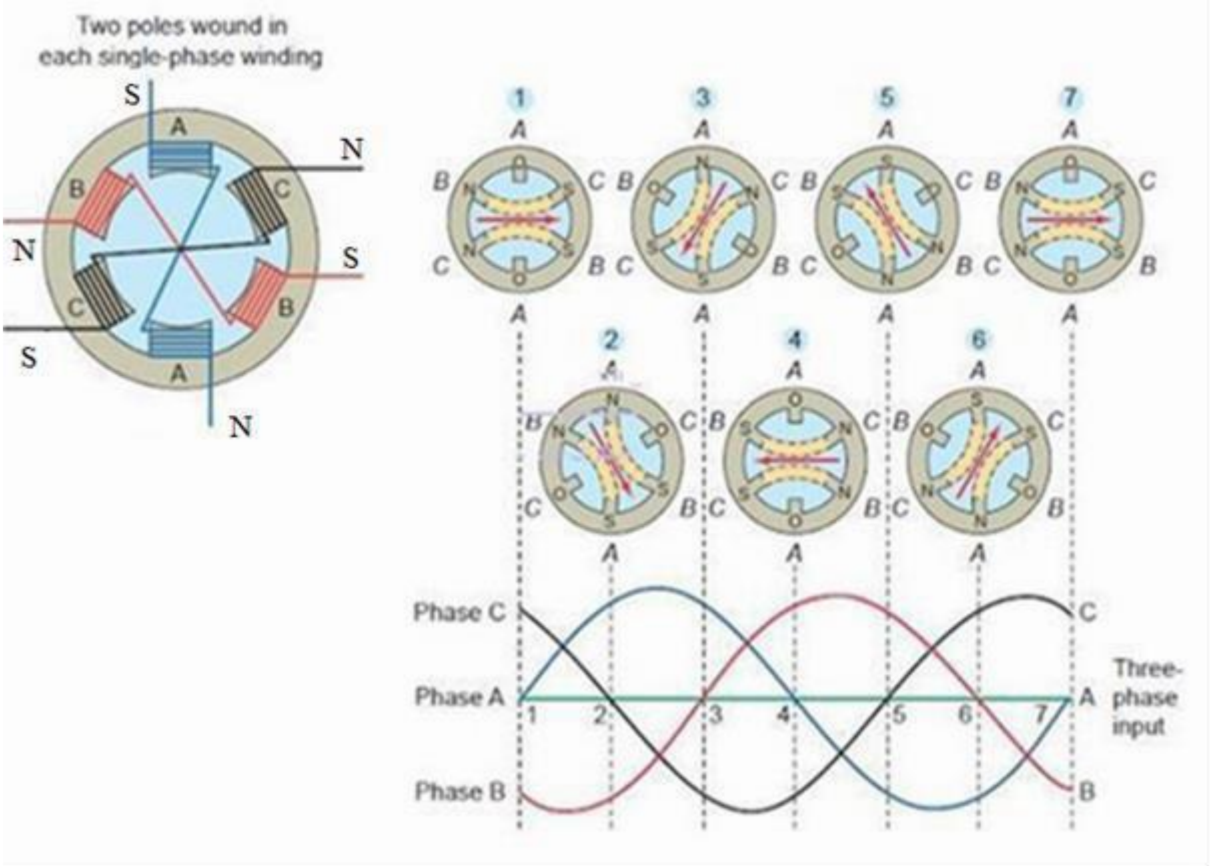


Figure 7 Production of Rotating Magnetic Field (RMF)

For a phase sequence ABC , the phase the magnetic motive force (m.m.f.) as functions of time are as follows:

$$\mathbf{F_a = F_{max} \cos wt} \qquad (1)$$

$$\mathbf{F_b = F_{max} \cos (wt - 120^\circ)} \qquad (2)$$

$$\mathbf{F_c = F_{max} \cos (wt +120^\circ)} \qquad (3)$$

Where (F_{max}) is the maximum (m.m.f.) of any one phase. The resultant stator (m.m.f.) is (F_s) along an axis at an angle of (β) to the horizontal is found by summing up the projections of the three-phase (m.m.f's)along this line:

$$\mathbf{F_s = F_a + F_b + F_c = 1.5\, F_{max} \cos (wt - \beta)} \qquad (4)$$

That means the magnitude of the resultant rotating magnetic field (RMF) is (**1.5 times**) the field produced by any one phase.

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