ITMO UNIVERSITY

Saint Petersburg, Russia

Electrical Machines

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Basic of Asynchronous (Induction) Machine

- principle of operation
- Construction

Alternating current motors: synchronous motor and induction motor

AC motors

- synchronous motors
- asynchronous motors (induction motors)

Synchronous motors: efficiency, power density, dynamic response, and power factor.

Asynchronous motors (induction motors): simple construction,
reliability, ruggedness, low maintenance,
low cost, high-speed operation capability,
and the ability to be operated by a direct
connection to an AC power source

Principle of operation of induction motor: Ampere's Law

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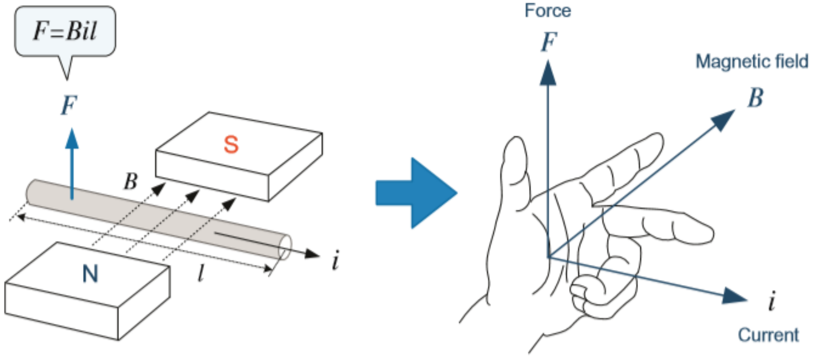
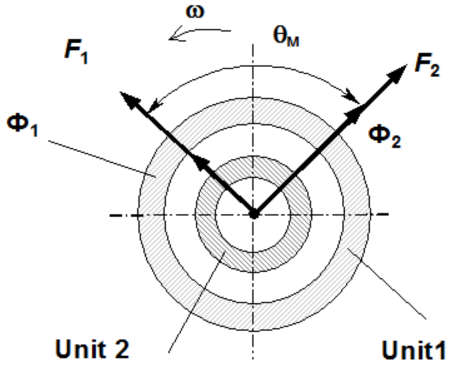


$$F = Bli\sin\theta$$

Figure 1 . Mechanical force for a current carrying conductor (classic form of Ampere's Law)



$$T = \frac{1}{\mathfrak{R}} F_1 \cdot F_2 \sin\theta_M$$

Figure 2. Mechanical force or a torque are generated due to the interaction of two magnetic fields or fluxes(generalized form of Ampere's Law)

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Principle of operation of induction motor: Faraday’s Law

From this experiment (1824), it was found that, when a magnet rotates along the rim of a copper disk (a nonmagnetic substance), the disk rotates in the direction of the magnet at a smaller speed

When a magnet passes along the rim of a copper disk, an electromotive force (EMF) is induced at the part in the disk that experiences a changing magnetic field.

The induced voltage causes an eddy current to flow in the disk. As a result, since the current-carrying part is built under the magnetic field of the magnet, a force (known as Lorentz force) is created on the current-carrying part.

The direction of the force is the same as that of the magnet’s movement, and this force makes the copper disk to rotate along with the magnet.

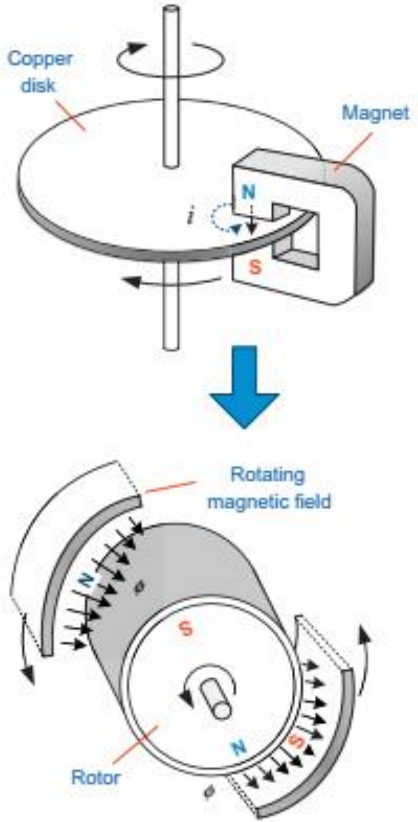

Figure 3. Arago’s disk and the fundamental concept of an induction motor

Structure of a typical induction motor: Cut-away diagram of a low-voltage motor

1 –
- Motor protection
- Motor connection and connection box
- Voltages, currents and frequencies

2 –
- Windings and insulation
- Coolant temperature and site altitude

3 –
- Heating and ventilation
- Mechanical design and degrees
- of protection
- Modular technology
- Special technology

4 –
Bearings and lubrication

5 –
Shaft and rotor
Balance and vibration quantity

6 -
Colors and paint finish

7 -
Types of construction

8 –
Rating plates and extra rating plates

Structure of a typical induction motor: Rating plates

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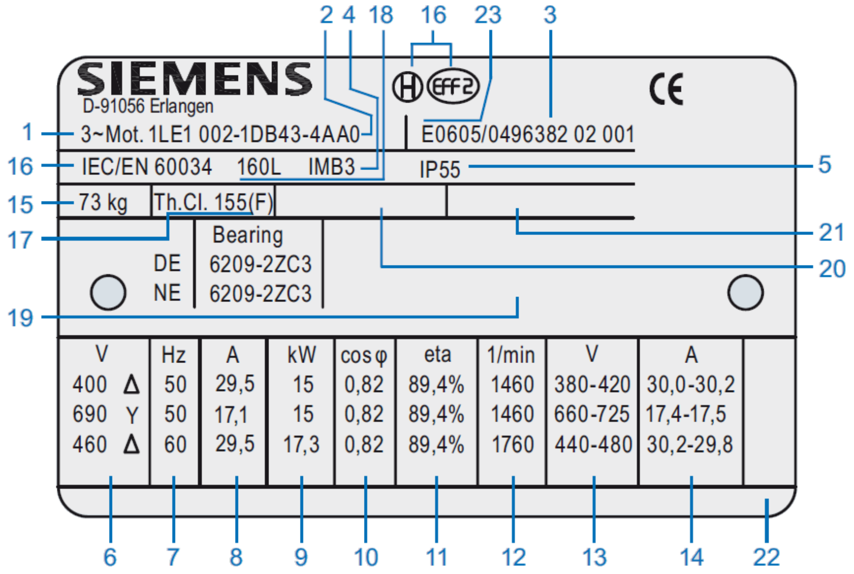
1LE1001-1DB20-1AA5-Z H00



1. Machine type: Three-phase Low-voltage motor
2. Order No.
3. Factory number (Ident No., serial number)
4. Type of construction
5. Degree of protection
6. Rated voltage [V] and winding connections
7. Frequency [Hz]
8. Rated current [A]
9. Rated output [kW]
10. Power factor [cos]
11. Efficiency
12. Rated speed [rpm]
13. Voltage range [V]
14. Current range [A]
15. Machine weight [kg]
16. Standards and regulations
17. Temperature class
18. Frame size
19. Additional details (optional)
20. Operating temberature range (only if it deviates from normal)
21. Site altitude (only when higher than 1000 m)
22. Customer data (optional)
23. Date of manufacture YYMM

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Assignment of the standard output power P_{rates} kW-HP and vice versa in accordance with IEC

kW · 1.341 = HP

HP · 0.746 = kW

Structure of a typical induction motor

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Structure of the Order No.:	Position:	1	2	3	4	5	6	7	-	8	9	10	11	12	-	13	14	15	16		
IEC squirrel-cage motors, surface-cooled																					
Positions 1 to 4: Digit, letter, letter, digit	**New generation** Design or version (motor type) • Standard: Self-ventilated by fan mounted on and driven by rotor • Expansion option (F90): Forced-air cooled by air flow from the fan to be driven	1	L	E	1																
	• Special: Self-cooled without external fan and fan cover	1	P	C	1																
Positions 5 to 7: 3 digits	• Motors with high efficiency (High Efficiency, EFF1), aluminum housing					0	0	1													
	• Motors with improved efficiency (Improved Efficiency, EFF2), aluminum housing					0	0	2													
Positions 8, 9 and 11: Digit, letter, digit	**Motor frame size** (frame size as a combination of shaft height and overall length, encoded)									1	A ... D		0 ... 6								
Position 10: Letter	**Number of poles** A ... D = 2-, 4-, 6-, 8-pole											A ... D									
Positions 12 and 13: 2 digits	**Voltage, circuit and frequency**													0 ... 9		0 ... 8					
Position 14: Letter	**Type of construction** (A – V)																A ... V				
Position 15: Letter	**Motor protection** (A – Z; special versions encoded)																	A ... Z			
Position 16: Digit	**Mechanical design (motor version and connection box position)** • **General Line motors with shorter delivery times, limited options** (connection box on top, cast feet, only basic versions possible, non-drive-end (NDE) cannot be modified) • **All options are possible or can be modified** - Connection box on top - Connection box on RHS (viewed from DE) - Connection box on LHS (viewed from DE) - Connection box below																		0 4 5 6 7		
	Special order versions: encoded – additional order code required not encoded – additional plain text required																			-	Z

The order number consists of a combination of figures and letters
and is divided into three blocks linked with hyphens for a better overview, e.g.
1LE1001-1DB20-1AA5-Z H00

<u>Externally or internally mounted components such as</u>

- Motor protection
- Brake
- Encoder
- Heating element
- Separately driven fan
- Plug connector

Structure of a typical induction motor : stator

stack of insulated laminations of silicon steel, usually with a thickness of about 0.3-0.5 mm to reduce eddy current losses

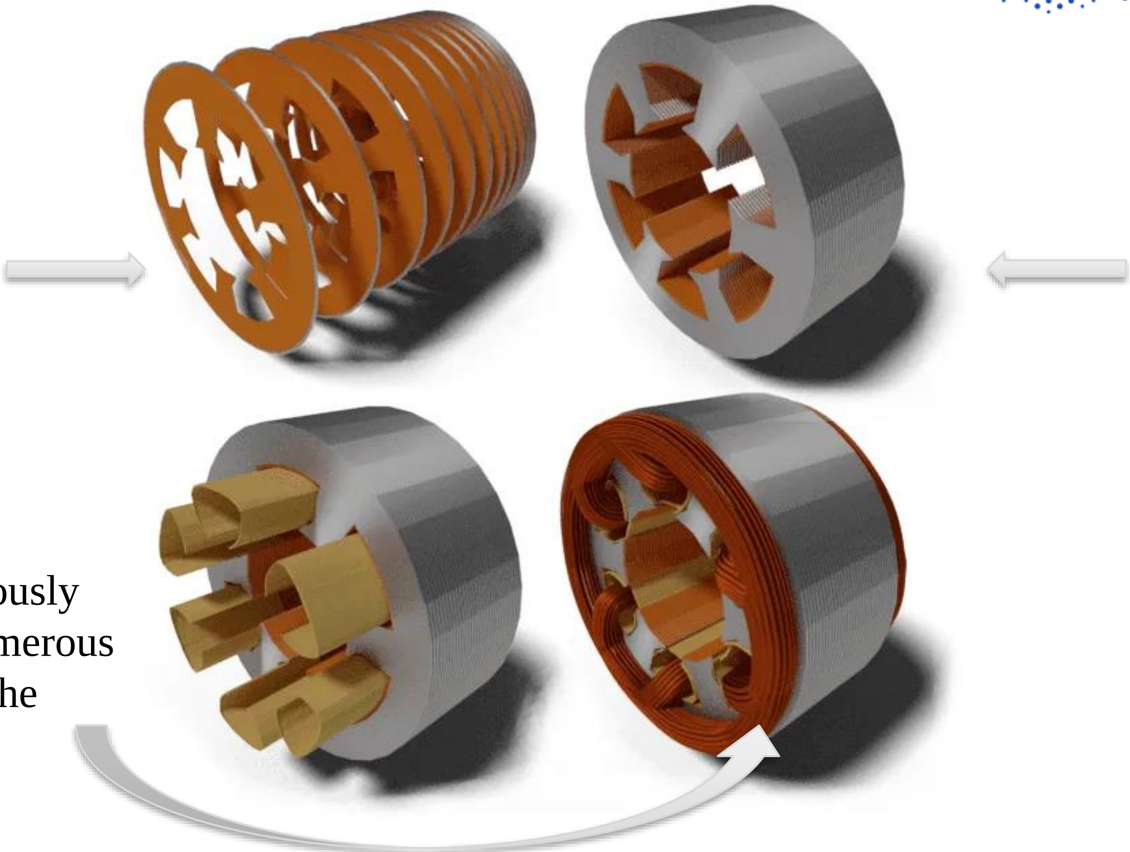

Figure 4 Structure of a stator of typical induction motor

The iron core is made from a ferromagnetic material such as steel, soft iron, or various nickel alloys to produce magnetic flux efficiently and reduce hysteresis losses

winding are continuously distributed in the numerous slots spread around the periphery of stator

Structure of a typical induction motor : stator's 3-phase windings

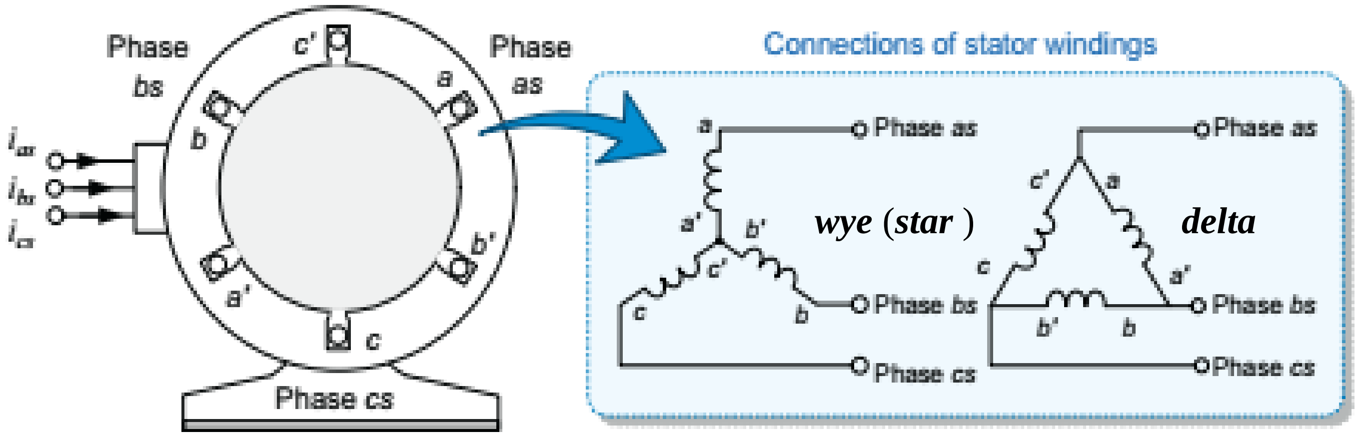

Figure. Stator windings.

$$U_{line} = \sqrt{3}U_{phase}$$

$$U_{line} = U_{phase}$$

These three-phase windings are placed in the slots that are axially cut along the inner periphery of the iron core. They are displaced from each other by 120 electrical degrees along the periphery and are typically connected in ***delta*** for low-supply voltage or in ***wye*** (***star***) for high-supply voltage

Structure of a typical induction motor: stator's 3-phase windings

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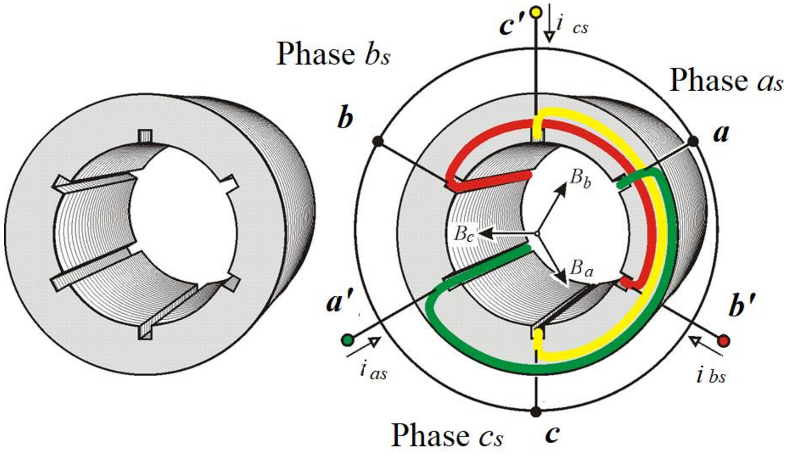

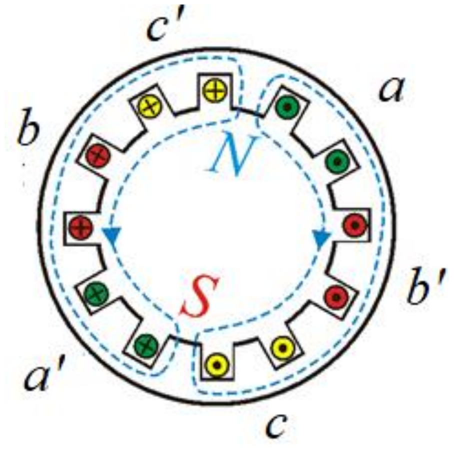

$$H = \frac{mmf}{l} = \frac{NI}{l} \quad \text{(A/m)}$$

$$B = \mu_0 \mu_r H \quad (\text{Wb/m}^2)$$

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Structure of a typical induction motor: stator phase winding

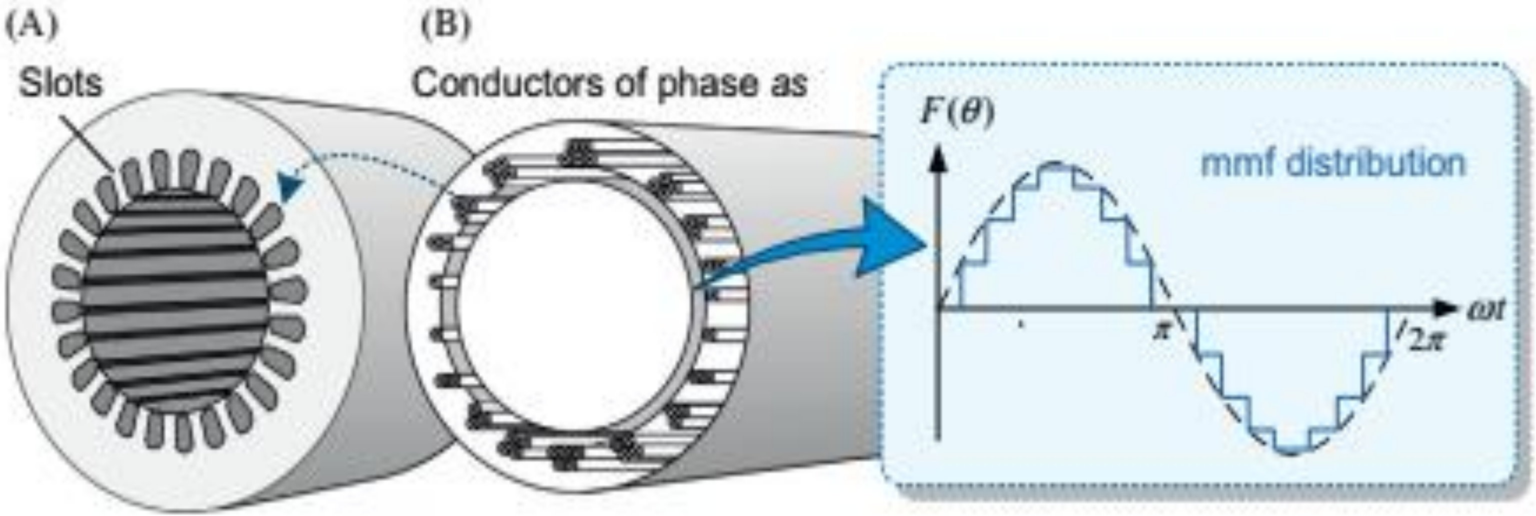


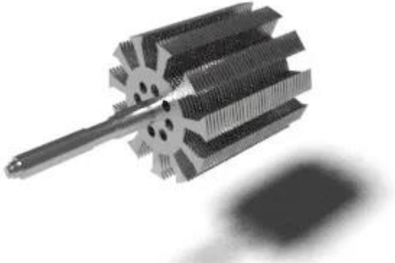
Figure 6. Stator *phase* winding.
(A) Stator core and (B) sinusoidally distributed winding and mmf

Structure of a typical induction motor: a squirrel-cage rotor

Figure 7 Squirrel-cage rotor

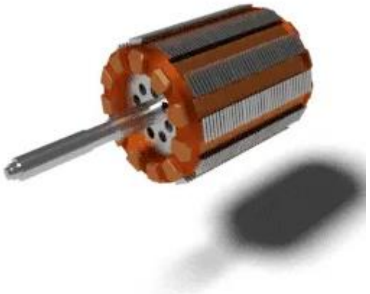
A squirrel-cage rotor has a laminated iron core with slots for placing skewed conductors, which may be a copper, aluminum, or alloy bar. These rotor bars are short-circuited at both ends through end rings

Because of its simple and rugged construction, about 95% of the induction motors use the squirrel-cage rotor.



a core

short-circuited copper/aluminum bars



Application of Squirrel Cage Induction Motor

•Centrifugal pumps
•Industrial drives (e.g. to run conveyor belts)
•Large blowers and fans
•Machine tools
•Lathes and other turning equipment

Structure of a typical induction motor: a squirrel-cage rotor

Advantages of Squirrel Cage Induction Motor

•They are low cost
•Require less maintenance (as there are no slip rings or brushes)
•Good speed regulation (they are able to maintain a constant speed)
•High efficiency in converting electrical energy to mechanical energy (while running, not during startup)
•Have better heat regulation (i.e. don't get as hot)
•Small and lightweight
•Explosion proof (as there are no brush which eliminate the risks of sparking)

Disadvantages of Squirrel Cage Induction Motor

•Very poor speed control
•Although they are energy efficient while running at full load current, they consume a lot of energy on startup
•They are more sensitive to fluctuations in the supply voltage. When the supply voltage is reduced, induction motor draws more current. During voltage surges, increase in voltage saturates the magnetic components of the squirrel cage induction motor
•They have high starting current and poor starting torque (the starting current can be 5-9 times the full load current; the starting torque can be 1.5-2 times the full load torque)

Figure 7 Squirrel-cage Induction Motor

Structure of a typical induction motor : a wound-rotor

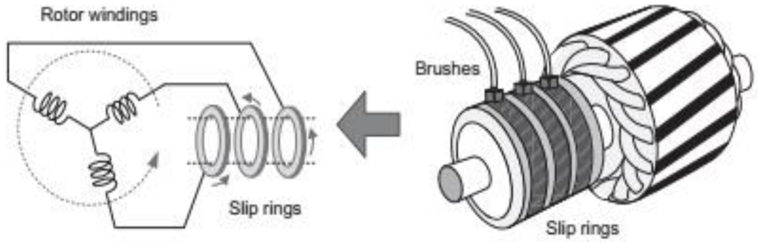


Figure 8 Wound-rotor

A slip ring or *wound-rotor* has a set of three-phase windings, which are usually Y-connected. The rotor windings are attached to the slip rings on the rotor's shaft. Due to this configuration, in a wound-rotor type induction motor, the rotor resistance can be varied by connecting external resistors to the rotor windings via the brushes. This allows the torque-speed characteristics of the induction motor to be varied as needed.

	Squirrel Cage Motor	**Slip Ring Motor**
Cost	Low	High
Maintenance	Low	High
Speed Control	Poor	Good
Efficiency on startup	Poor	Good
Efficiency during operation	Good	Poor
Heat regulation	Good	Poor
In rush current & torque	High	Low

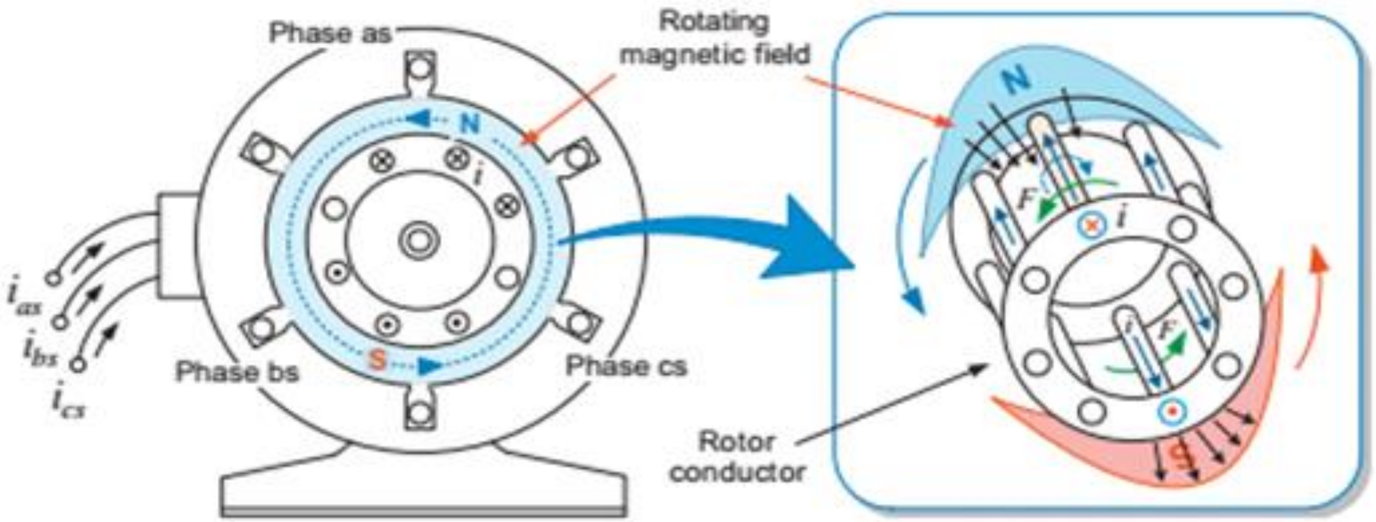


Figure 9 Rotation of an induction motor

Fundamentals of induction motors (Rotating magnetic field)

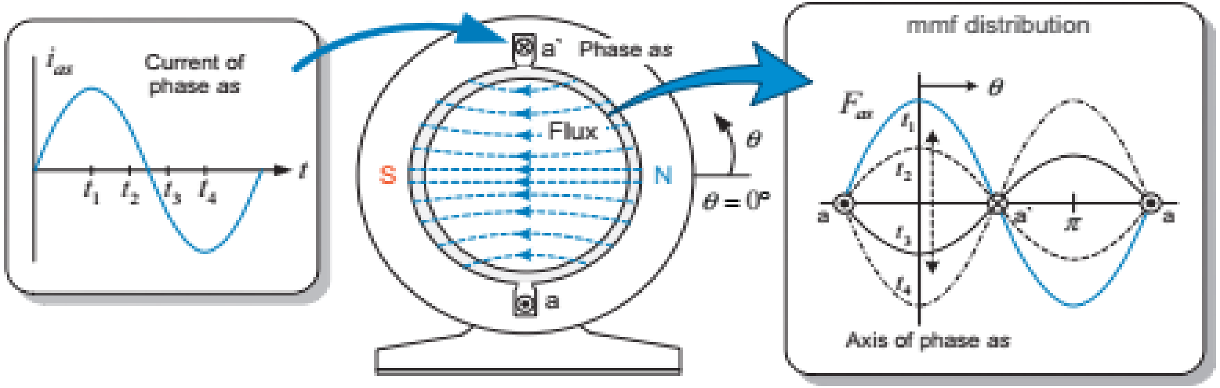
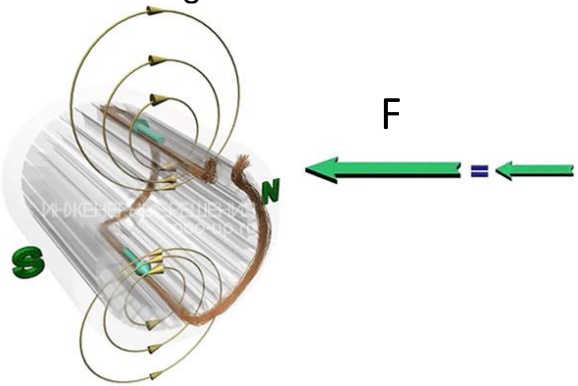


Figure 10 Phase as current and mmf



Fundamentals of induction motors (Rotating magnetic field)

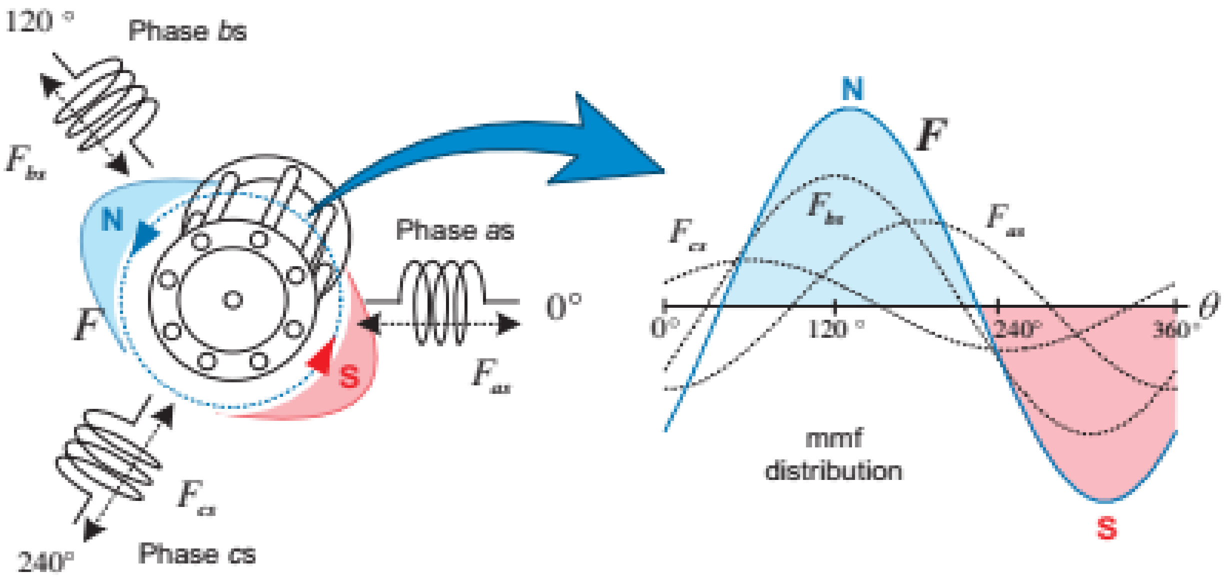
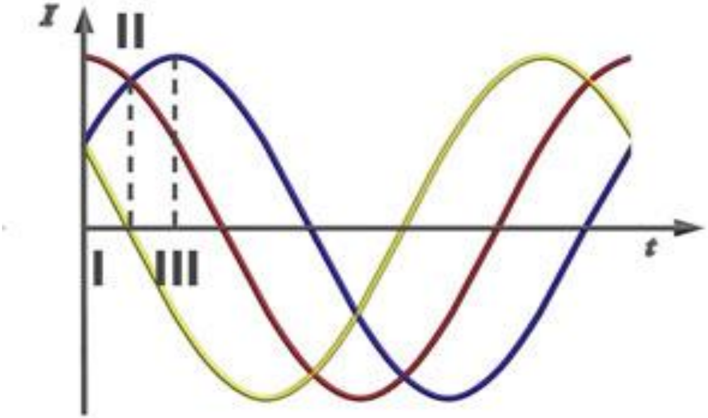


Figure 11 Resultant air-gap mmf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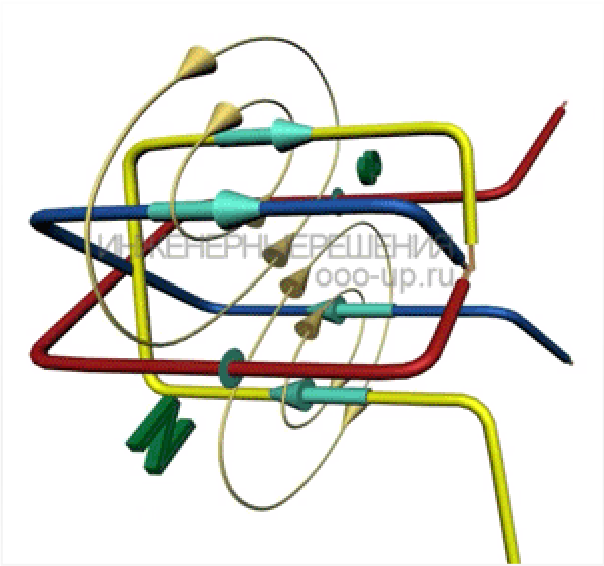
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Fundamentals of induction motors (Rotating magnetic field)

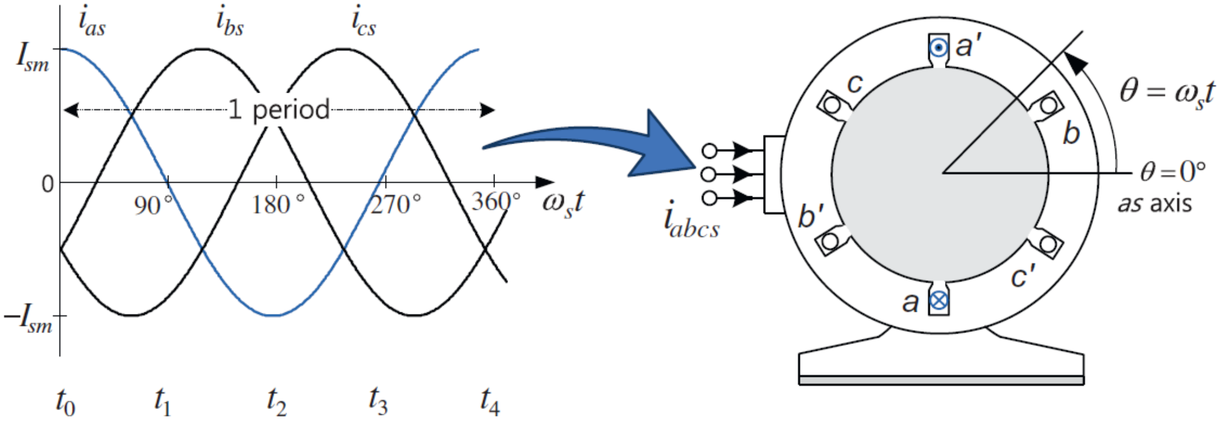


Figure 12 Three-phase windings and currents

$\omega_s (= 2\pi f_s)$ is the angular frequency of the currents and f_s is the frequency of the currents.

$$i_{as} = I_{sm} \cos \omega_s t$$

$$i_{bs} = I_{sm} \cos\left(\omega_s t - 120^o\right)$$

$$i_{cs} = I_{sm} \cos\left(\omega_s t + 120^o\right)$$

$$F_{as}(\theta) = N_s i_{as} \cos \theta$$

$$F_{bs}(\theta) = N_s i_{bs} \cos(\theta - 120^o)$$

$$F_{cs}(\theta) = N_s i_{cs} \cos(\theta + 120^o)$$

$$F(\theta) = F_{as}(\theta) + F_{bs}(\theta) + F_{cs}(\theta) = N_s I_{sm}[\cos \omega_s t \cos \theta + \cos(\omega_s t - 120^o) \cos(\theta - 120^o)] +$$

$$+ \cos\left(\omega_s t + 120^o\right) \cos(\theta + 120^o) = \frac{3}{2} N_s I_{sm} \cos(\omega_s t - \theta)$$ resultant air-gap mmf

Fundamentals of induction motors (Rotating magnetic field)

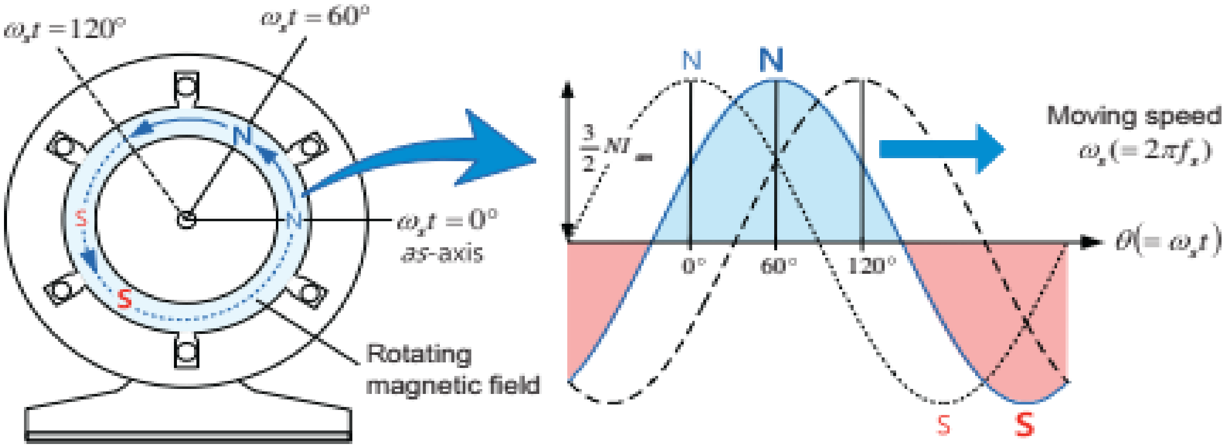


Figure 13 Resultant mmf

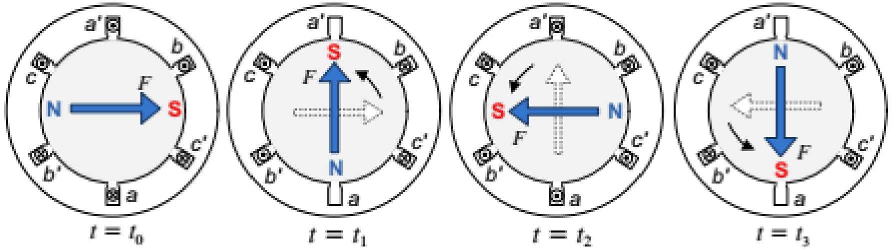
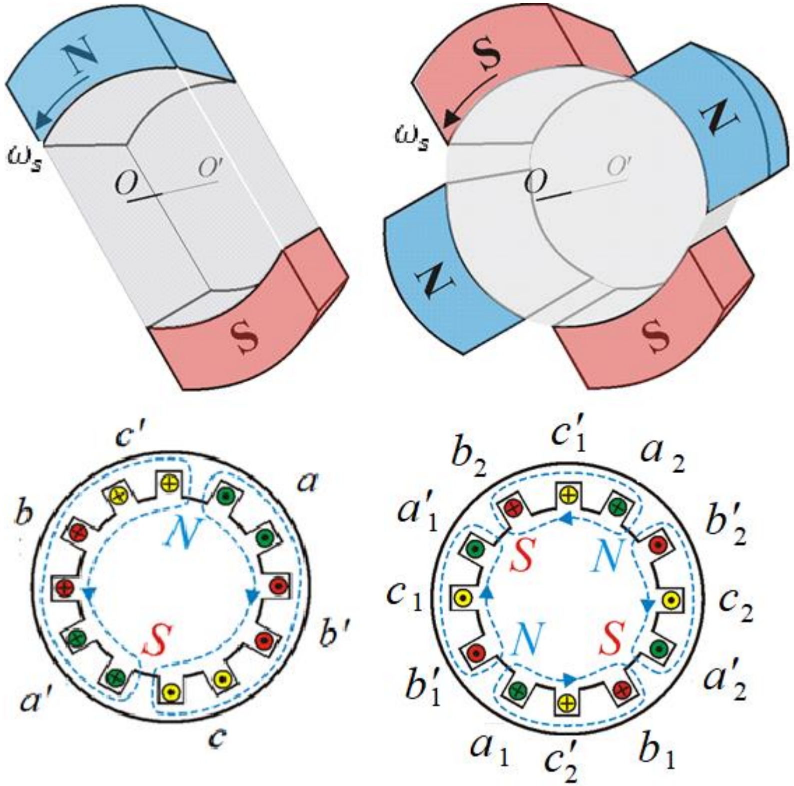


Figure 14 Movement of the resultant air-gap mmf per cycle of the current (the number of magnetic poles is two P=2)

Fundamentals of induction motors (Rotating magnetic field)

two-pole
windings
(the number of
magnetic poles
is two P=2)



four-pole
windings
(the number of
magnetic poles
is two P=4)

Fundamentals of induction motors (Rotating magnetic field)

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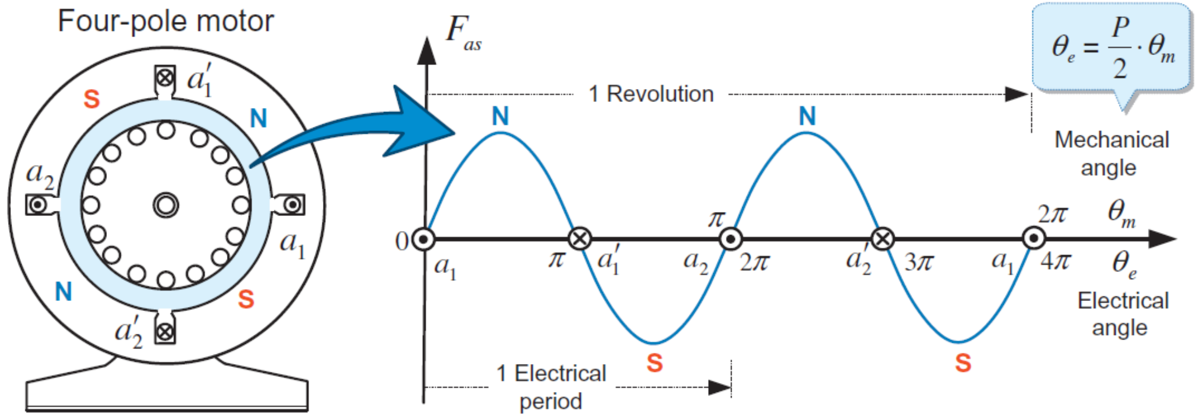

Figure 15 mmf Distribution by phase as current in the four-pole motor

A relationship between the mechanical angle θ_m and the electrical angle θ_e (for P-pole motor) as

$$\theta_e = \frac{P}{2} \cdot \theta_m$$

The rotating speed n_s of the mmf by the three-phase currents with a frequency f is expressed in terms of revolution per minute (r/min) as

$$n_s = \frac{2}{P} \cdot f \cdot 60 = \frac{120f}{P} (r/min)$$

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Thank you!

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