

INDUCTION MACHINES

Electrical Machines – Elective Course for ELC

Induction Machines

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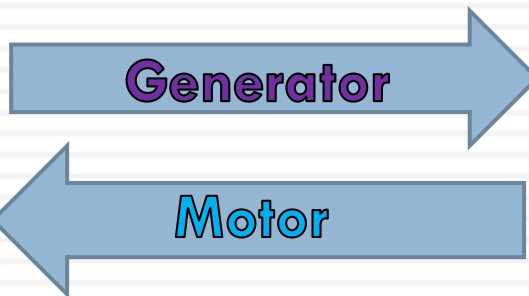
- Introduction to Electrical Rotating Machines
- Construction
- Magnetic Field Production and Distribution
- Generated Voltage and Torque Production
- Principle of Operation
- Equivalent Circuit
- Power Flow
- Torque-Speed Characteristics
- Loading & Stability
- Induction Machine Modes of Operation
- Testing

Electrical Rotating Machines

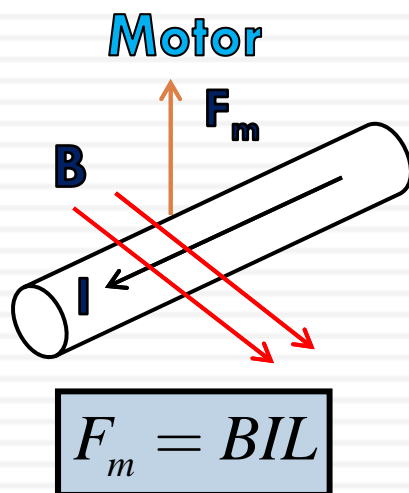
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An electrical machine is a device which converts mechanical energy into electrical energy or vice versa.

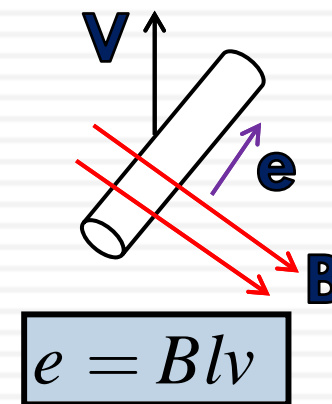
**Mechanical
Energy**



**Electrical
Energy**



Generator

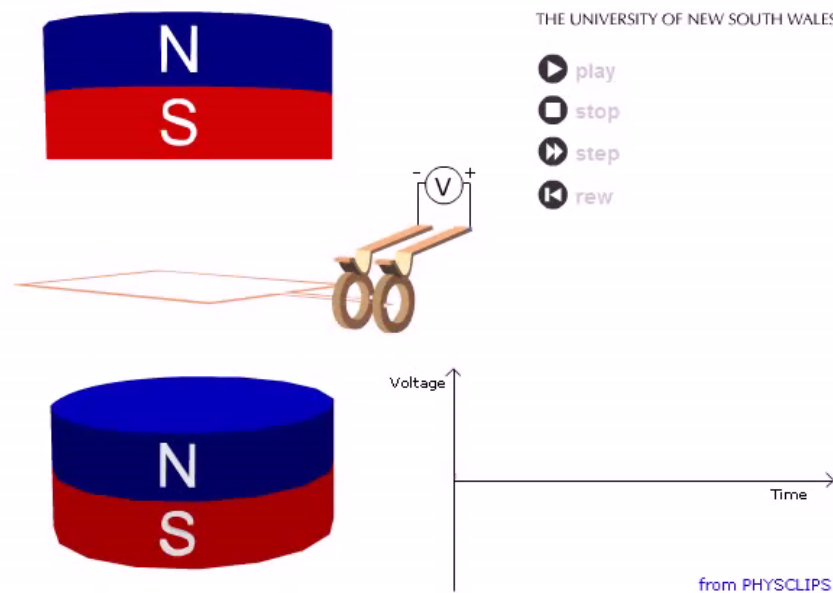


Electrical Rotating Machines

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Generator

Generators have generally two basic parts named "Stator" and "Rotor". Mechanical energy is provided to the rotor by means of a prime mover (i.e. a turbine). Turbines are of different types like steam turbine, water turbine, wind turbine etc. Mechanical energy can also be provided by internal combustion engines.



Electrical Rotating Machines

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Generator

Video 1

Electrical Rotating Machines

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Generator

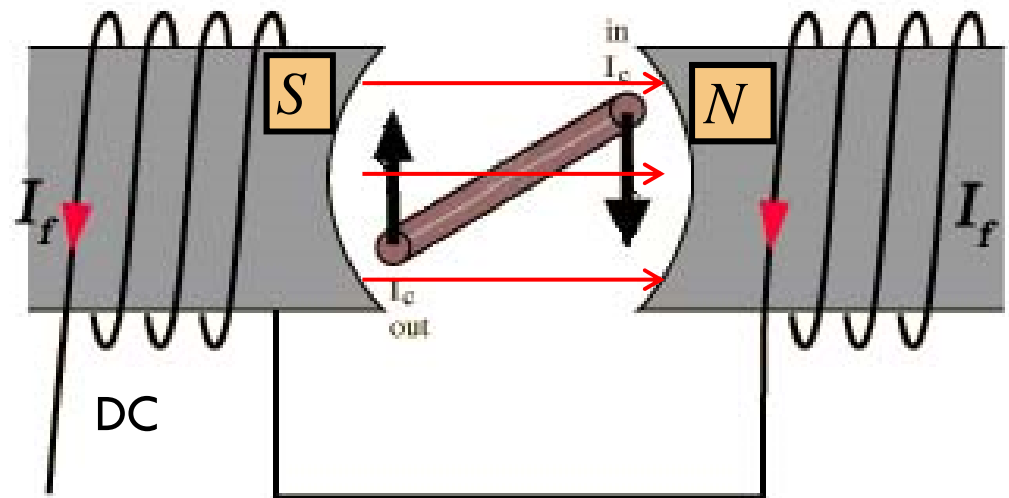
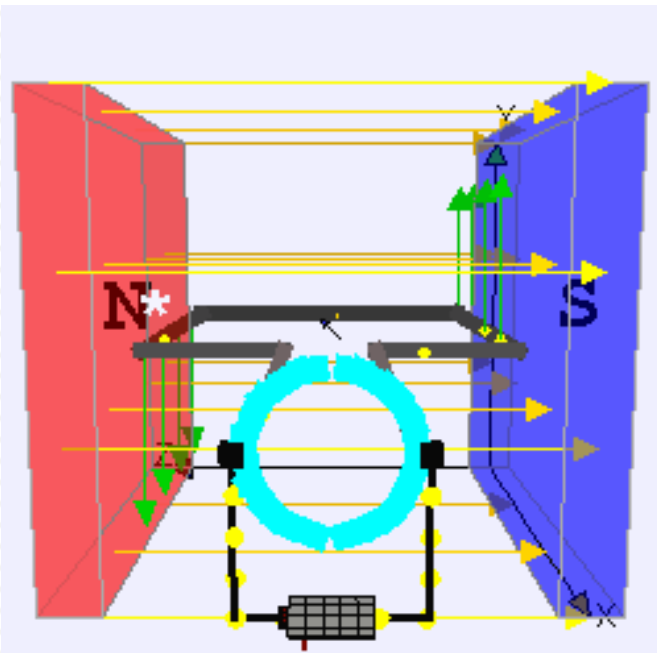
Video 2

Electrical Rotating Machines

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Motor

Motors also consists two basic parts, stator and rotor. In a motor, we give electric supply to both the stator and rotor windings which causes a mechanical force between the stator and rotor. This force causes the rotor to rotate.



Electrical Rotating Machines

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Motor

Video DC Motor

Electrical Rotating Machines

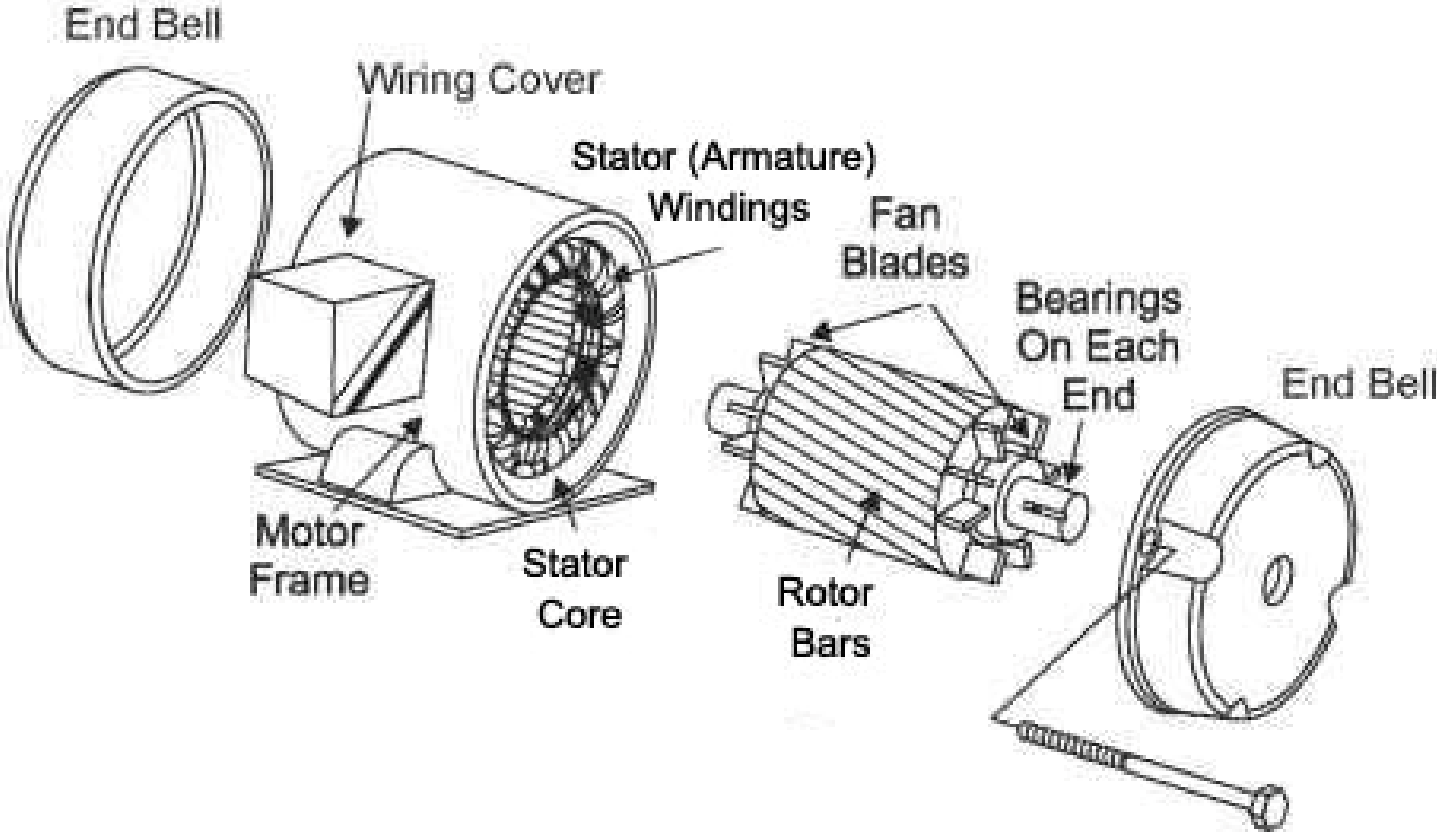
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Motor

Video Induction motor

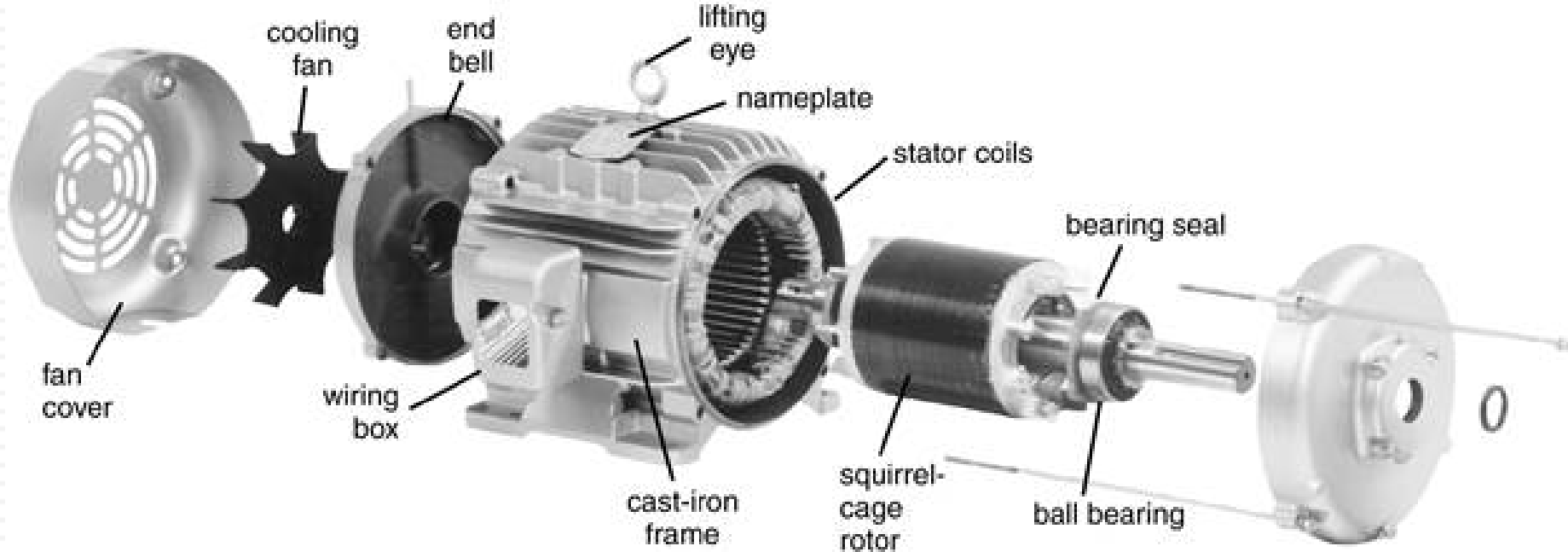
Induction Machines: Construction

10 Squirrel Cage Machine



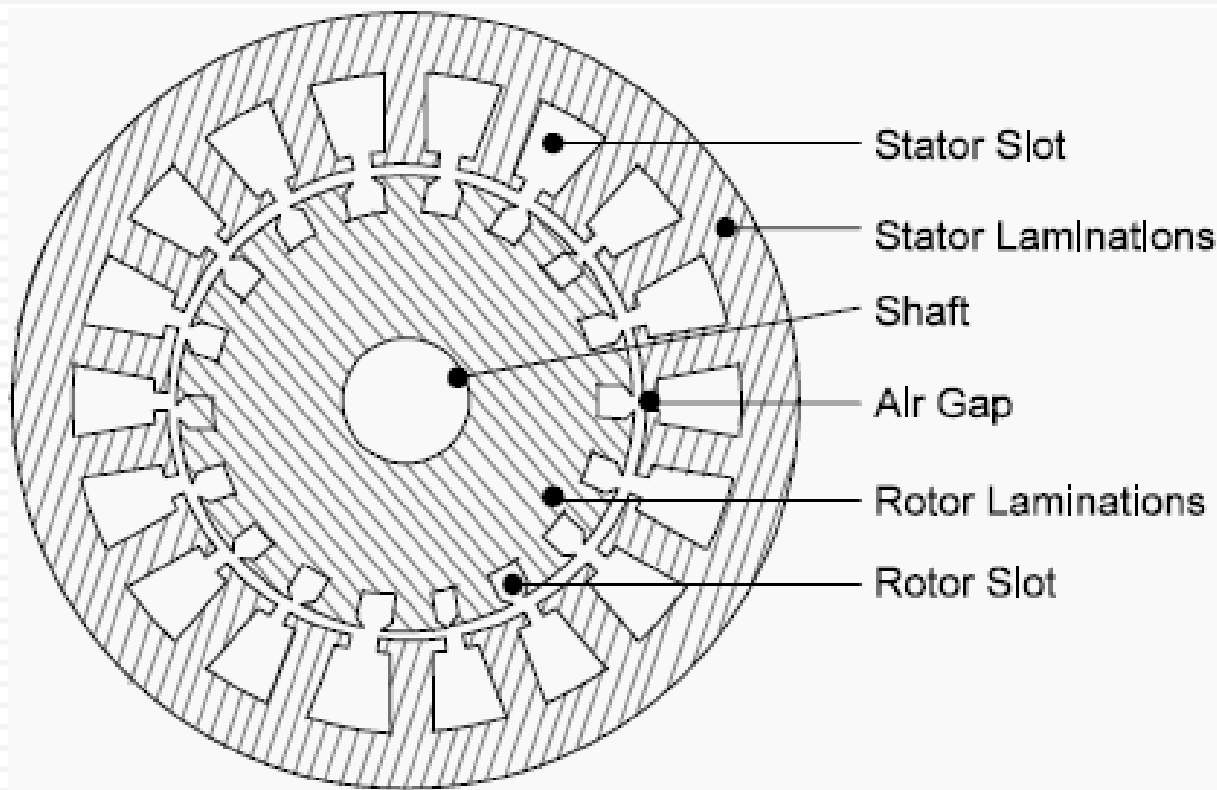
Induction Machines: Construction

11 Squirrel Cage Machine



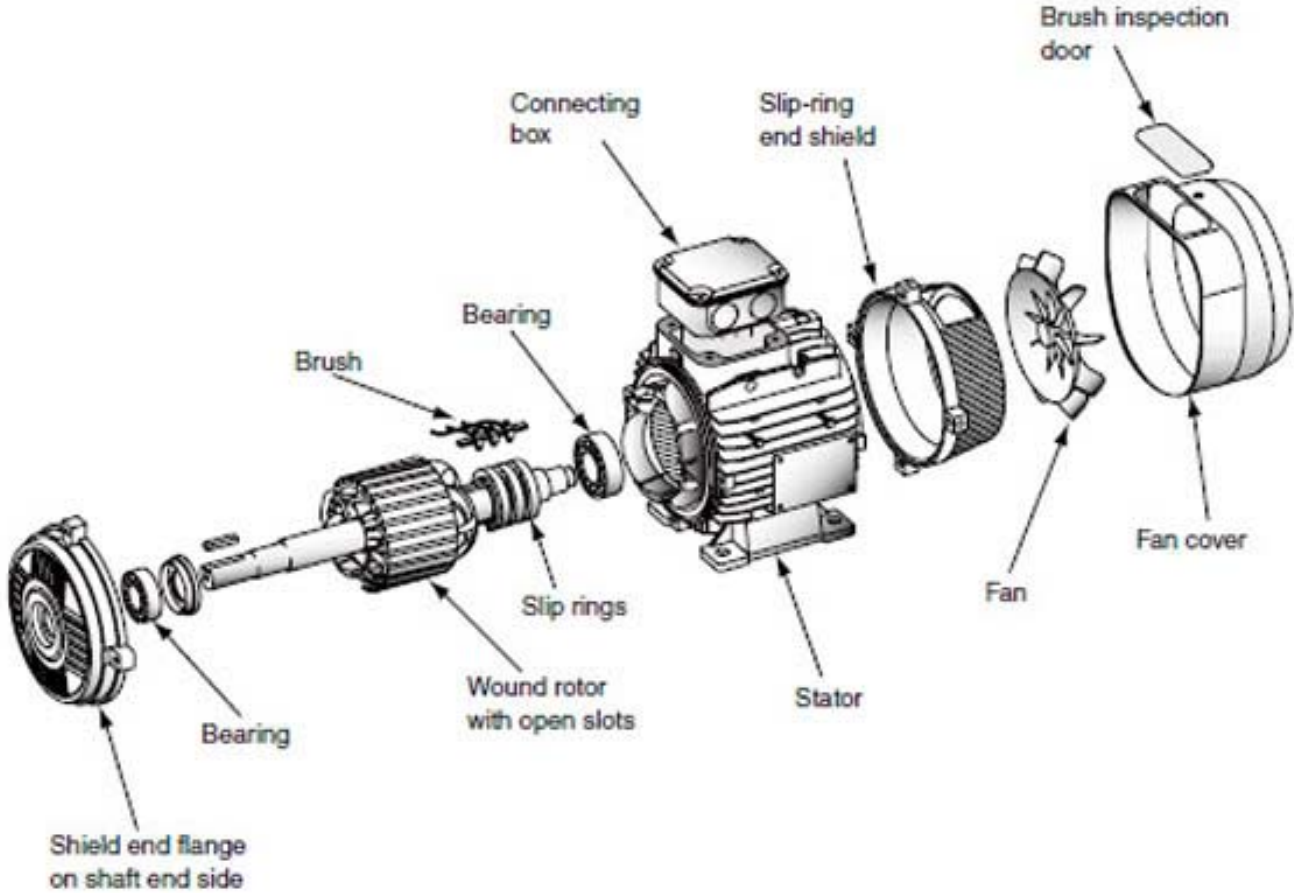
Induction Machines: Construction

12 Squirrel Cage Machine



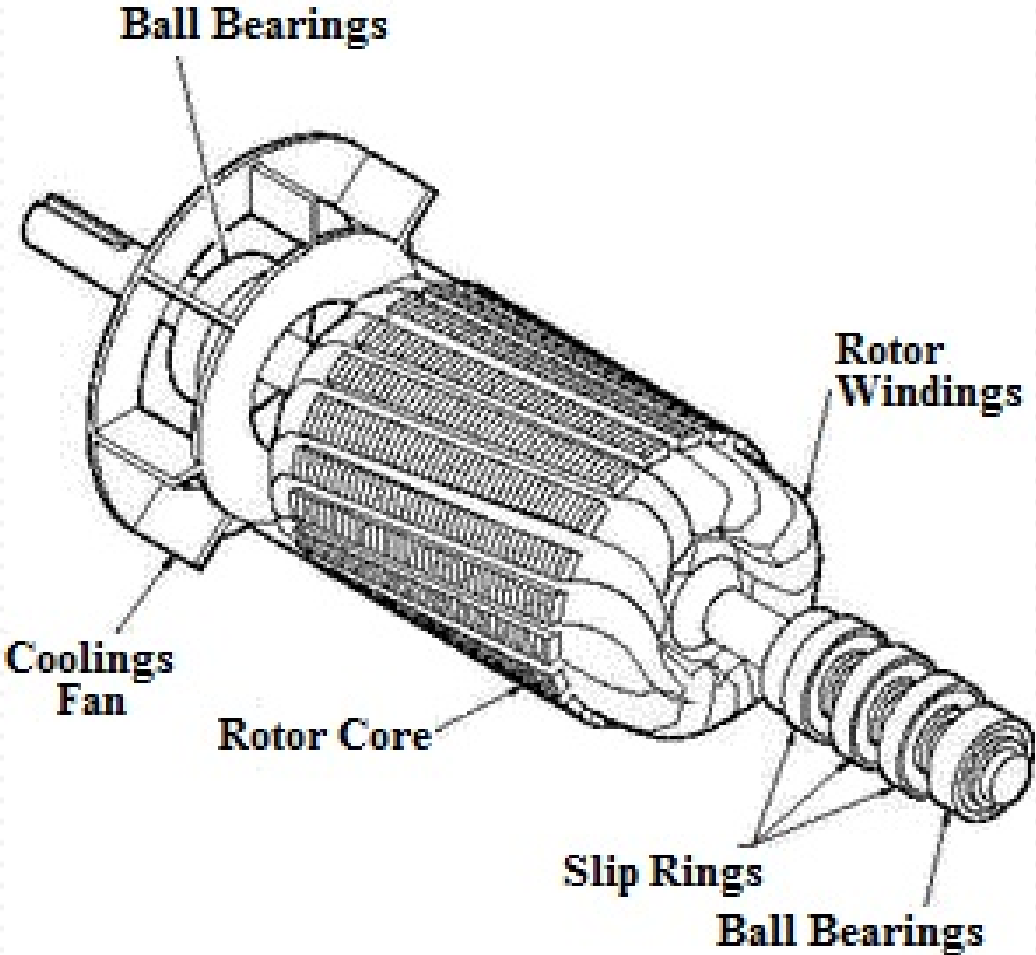
Induction Machines: Construction

13 Wound Rotor Machine



Induction Machines: Construction

14 Wound Rotor Machine



Magnetic Field Production & Distribution

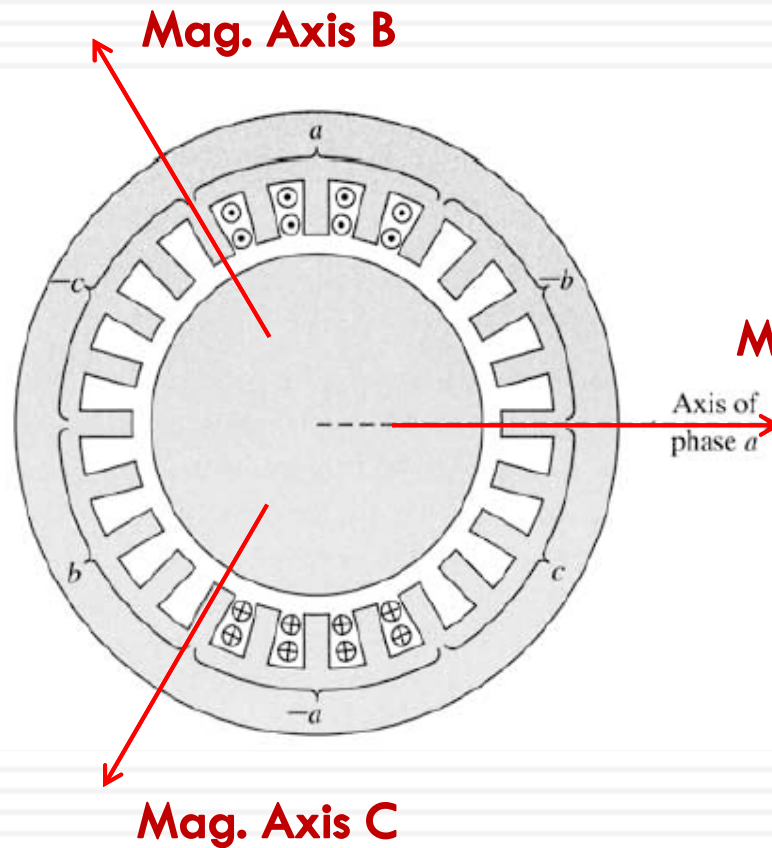
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Induction Machines

Three-phase machines

**Two
Magnetic
Poles**

**Armature
Windings
Distributed
Windings**



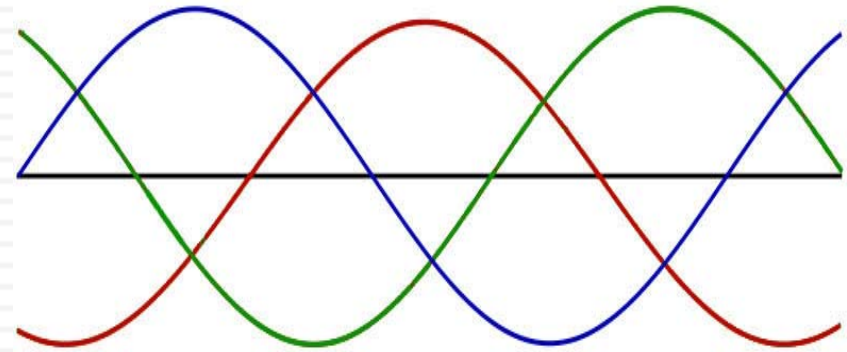
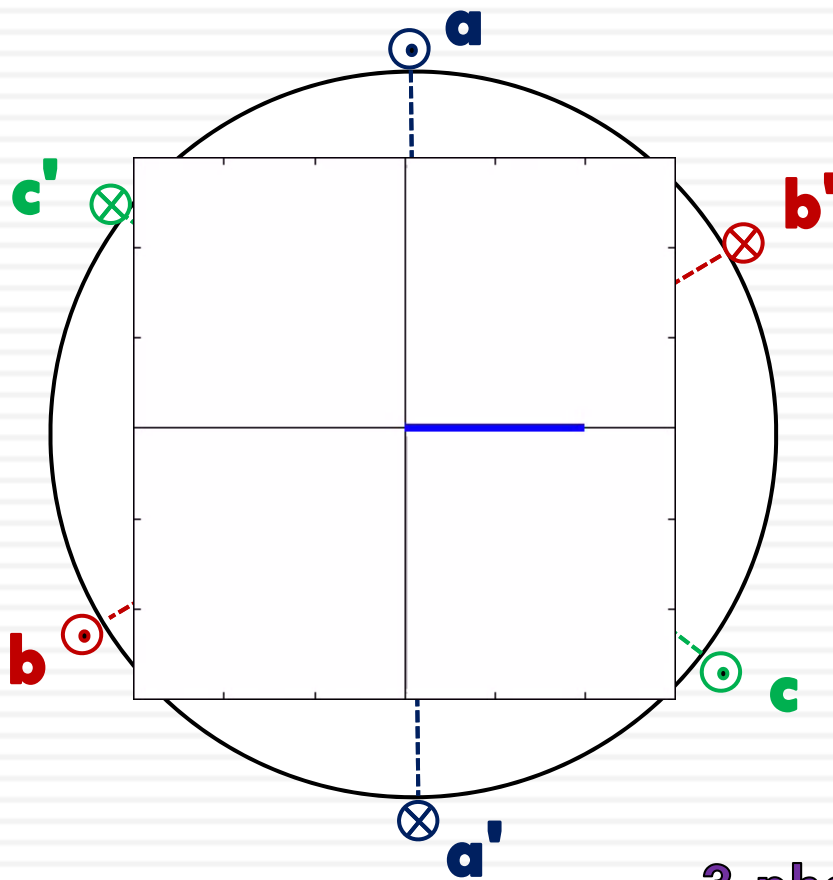
**Non-Salient
Poles**

Magnetic Field Production & Distribution

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Induction Machines

Three-phase machines



$$i_a = I_m \cos(\omega_e t)$$

$$i_b = I_m \cos(\omega_e t - 120)$$

$$i_c = I_m \cos(\omega_e t + 120)$$

3-phase Current



Rotating Field

Magnetic Field Production & Distribution

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Induction Machines

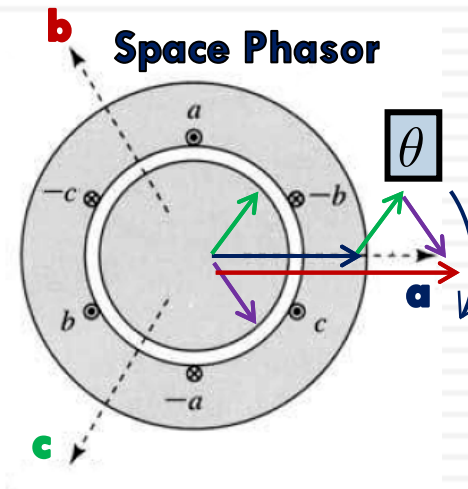
Three-phase machines

$$i_a = I_m \cos(\omega_e t)$$

$$i_b = I_m \cos(\omega_e t - 120)$$

$$i_c = I_m \cos(\omega_e t + 120)$$

$$M_{fund. max.} = \frac{4 N i}{\pi 2}$$



$$M_t = \frac{3}{2} \frac{4 N}{\pi 2} I_m$$

At $\omega_e t = \text{zero}$

$$i_a = I_m$$

$$M_a = \frac{4 N}{\pi 2} I_m$$

$$i_b = -0.5 I_m$$

$$M_b = \frac{4 N}{\pi 2} (-0.5 I_m)$$

$$i_c = -0.5 I_m$$

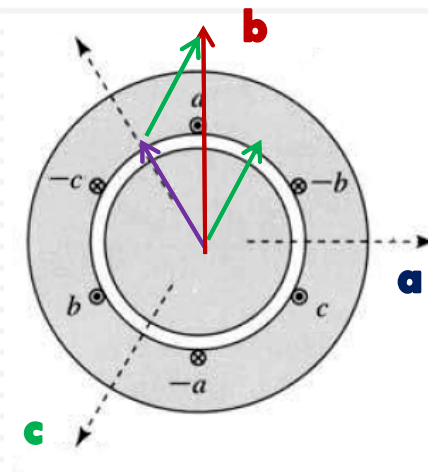
$$M_c = \frac{4 N}{\pi 2} (-0.5 I_m)$$

Magnetic Field Production & Distribution

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Induction Machines

Three-phase machines



$$M_t = \frac{3}{2} \frac{4N}{\pi} \frac{I_m}{2}$$

At $\omega_e t = 90^\circ$

Space Phasor

$$i_a = 0$$

$$M_a = 0$$

$$i_b = \frac{\sqrt{3}}{2} I_m$$

$$M_b = \frac{4N}{\pi} \frac{I_m}{2} \left(\frac{\sqrt{3}}{2} \right)$$

$$i_c = -\frac{\sqrt{3}}{2} I_m$$

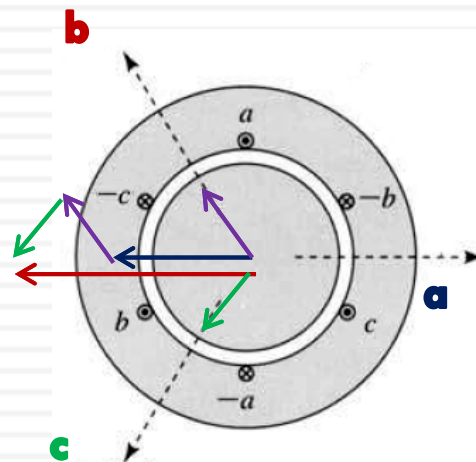
$$M_c = \frac{4N}{\pi} \frac{I_m}{2} \left(-\frac{\sqrt{3}}{2} \right)$$

Magnetic Field Production & Distribution

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Induction Machines

Three-phase machines



$$M_t = \frac{3}{2} \frac{4N}{\pi} \frac{I_m}{2}$$

Space Phasor

At $\omega_e t = 180^\circ$

$$i_a = -I_m$$

$$M_a = \frac{4N}{\pi} \frac{I_m}{2} (-I_m)$$

$$i_b = 0.5I_m$$

$$M_b = \frac{4N}{\pi} \frac{I_m}{2} (0.5I_m)$$

$$i_c = 0.5I_m$$

$$M_c = \frac{4N}{\pi} \frac{I_m}{2} (0.5I_m)$$

Magnetic Field Production & Distribution

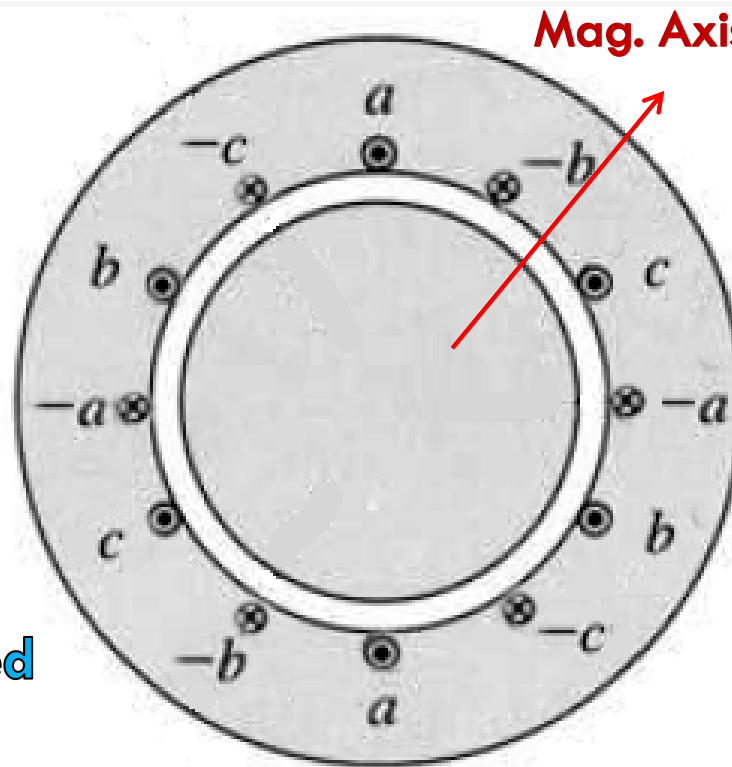
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Induction Machines

Three-phase machines

**Four
Magnetic
Poles**

**Armature
Windings
Concentrated
Windings**



**Non-Salient
Poles**

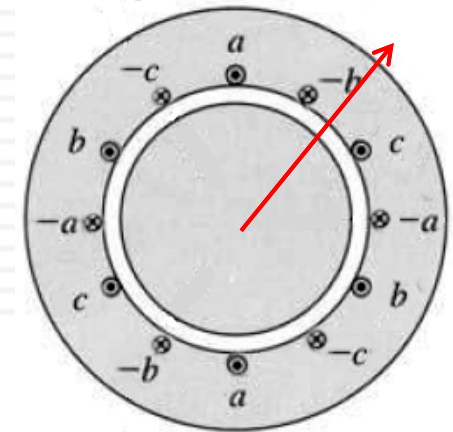
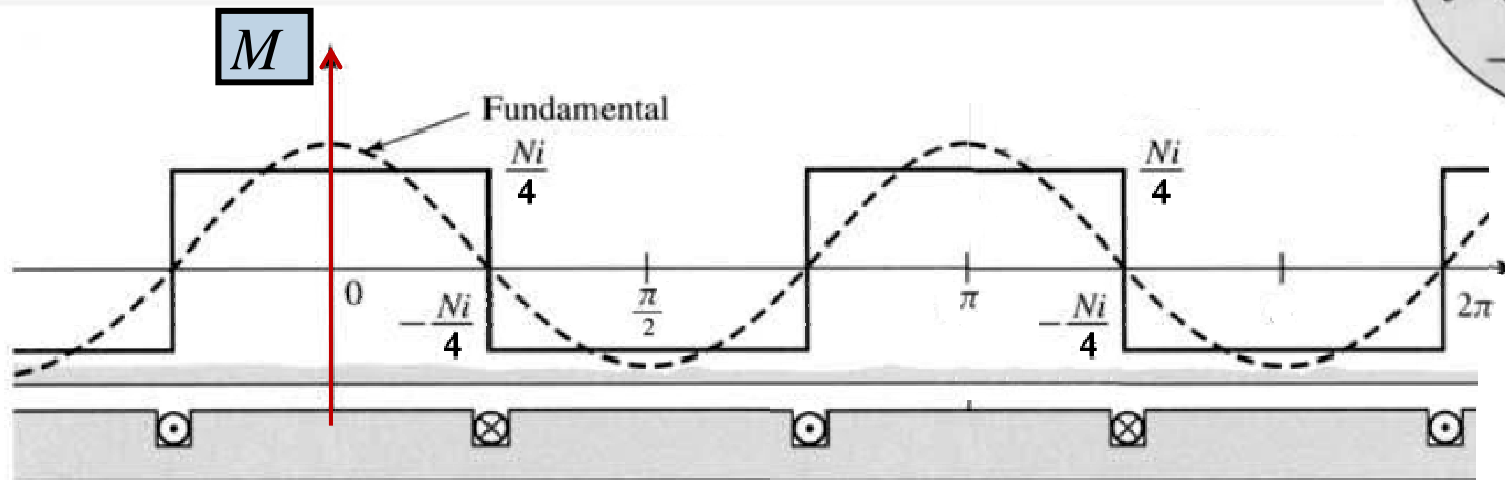
Magnetic Field Production & Distribution

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Induction Machines

Three-phase machines: Four magnetic poles

Space Phasor



MMF Space Distribution

Magnetic Field Production & Distribution

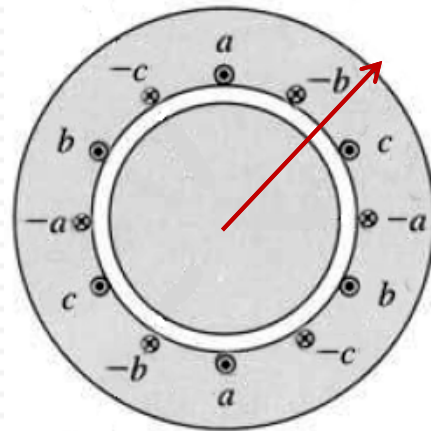
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Induction Machines

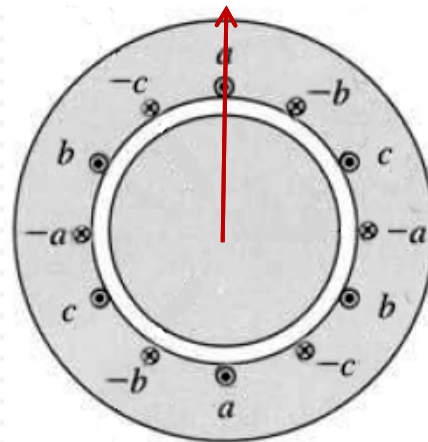
Three-phase machines: Four magnetic poles

Space Phasor

At $\omega_e t = \text{zero}$



At $\omega_e t = 90^\circ$



$$M_t = \frac{3}{2} \frac{4}{\pi} \frac{N}{4} I_m$$

Magnetic Field Production & Distribution

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Induction Machines

Speed of the Rotating Field

No. of poles	Elect. Angle	Mech. Angle
	No. of time cycles ($\omega_e t = \theta_e$)	No. of mech. Revolutions ($\theta = \theta_m$)
2	1 (2π)	1 (2π)
4	1 (2π)	$1/2$ (π)
6	1	$1/3$
$2p$	f	f/p

$$\theta_e = p\theta_m$$

p = no. of pair poles

Synchronous Speed

$$n_s = \frac{60f}{p}$$

rpm

$$\omega_s = \frac{n_s}{60} 2\pi = \frac{2\pi f}{p}$$

Rad/s

Magnetic Field Production & Distribution

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Induction Machines

The Rotating Field Equation

$$i_a = I_m \cos(\omega_e t)$$

$$i_b = I_m \cos(\omega_e t - 120)$$

$$i_c = I_m \cos(\omega_e t + 120)$$

$$M_a = \frac{4 N}{\pi 2p} i_a \cos p\theta$$

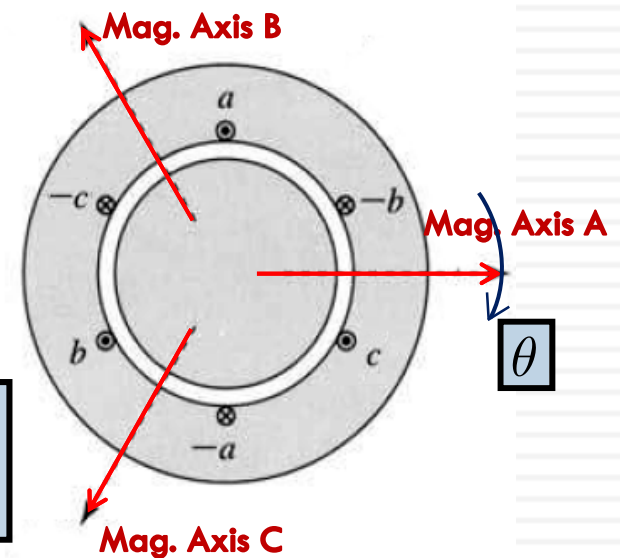
$$M_a = \frac{4 N}{\pi 2p} I_m \cos(\omega_e t) \cos p\theta$$

$$M_b = \frac{4 N}{\pi 2p} i_b \cos(p\theta - 120)$$

$$M_b = \frac{4 N}{\pi 2p} I_m \cos(\omega_e t - 120) \cos(p\theta - 120)$$

$$M_c = \frac{4 N}{\pi 2p} i_c \cos(p\theta + 120)$$

$$M_c = \frac{4 N}{\pi 2p} I_m \cos(\omega_e t + 120) \cos(p\theta + 120)$$



Magnetic Field Production & Distribution

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Induction Machines

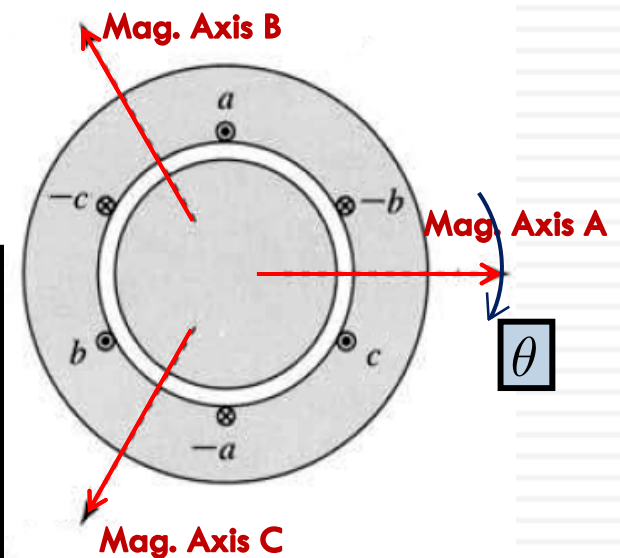
The Rotating Field Equation

$$M_t = M_a + M_b + M_c$$

$$M_t = \frac{4}{\pi} \frac{N}{2p} \frac{I_m}{2} [\cos(\omega_e t - p\theta) + \cos(\omega_e t + p\theta) + \cos(\omega_e t - p\theta) + \cos(\omega_e t + p\theta - 240) + \cos(\omega_e t - p\theta) + \cos(\omega_e t + p\theta + 240)]$$

$$M_t(\theta, t) = \frac{3}{2} \frac{4}{\pi} \frac{N}{2p} I_m \cos(\omega_e t - p\theta)$$

Rotating
Field



Magnetic Field Production & Distribution

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Induction Machines

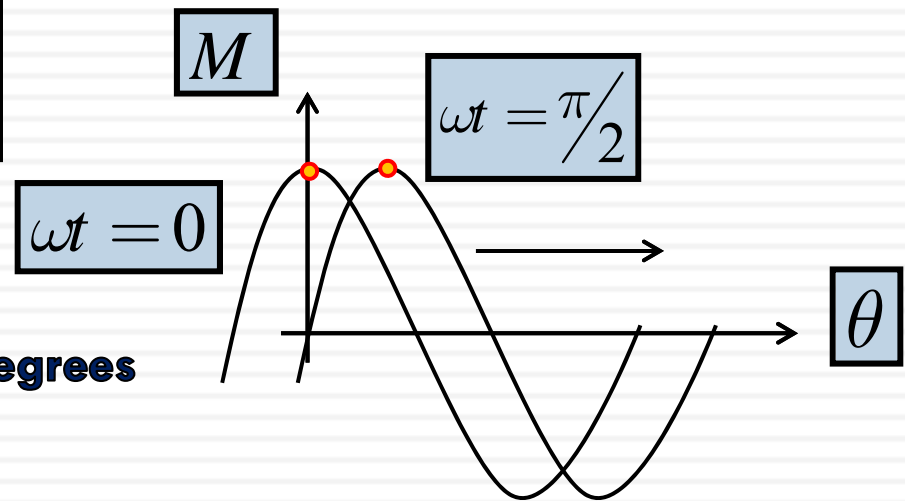
Speed of the Rotating Field

$$M_t(\theta, t) = \frac{3}{2} \frac{4}{\pi} \frac{N}{2p} I_m \cos(\omega_e t - p\theta)$$

For a particular point:

$$\omega_e t - p\theta = \text{const.}$$

Electrical degrees



$$\omega_e - p \frac{d\theta}{dt} = \text{zero}$$

$$\text{Speed} = \frac{\omega_e}{p} = \frac{2\pi f}{p}$$

Rad/sec

$$n_s = \frac{60f}{p}$$

rpm