

Induction Machines

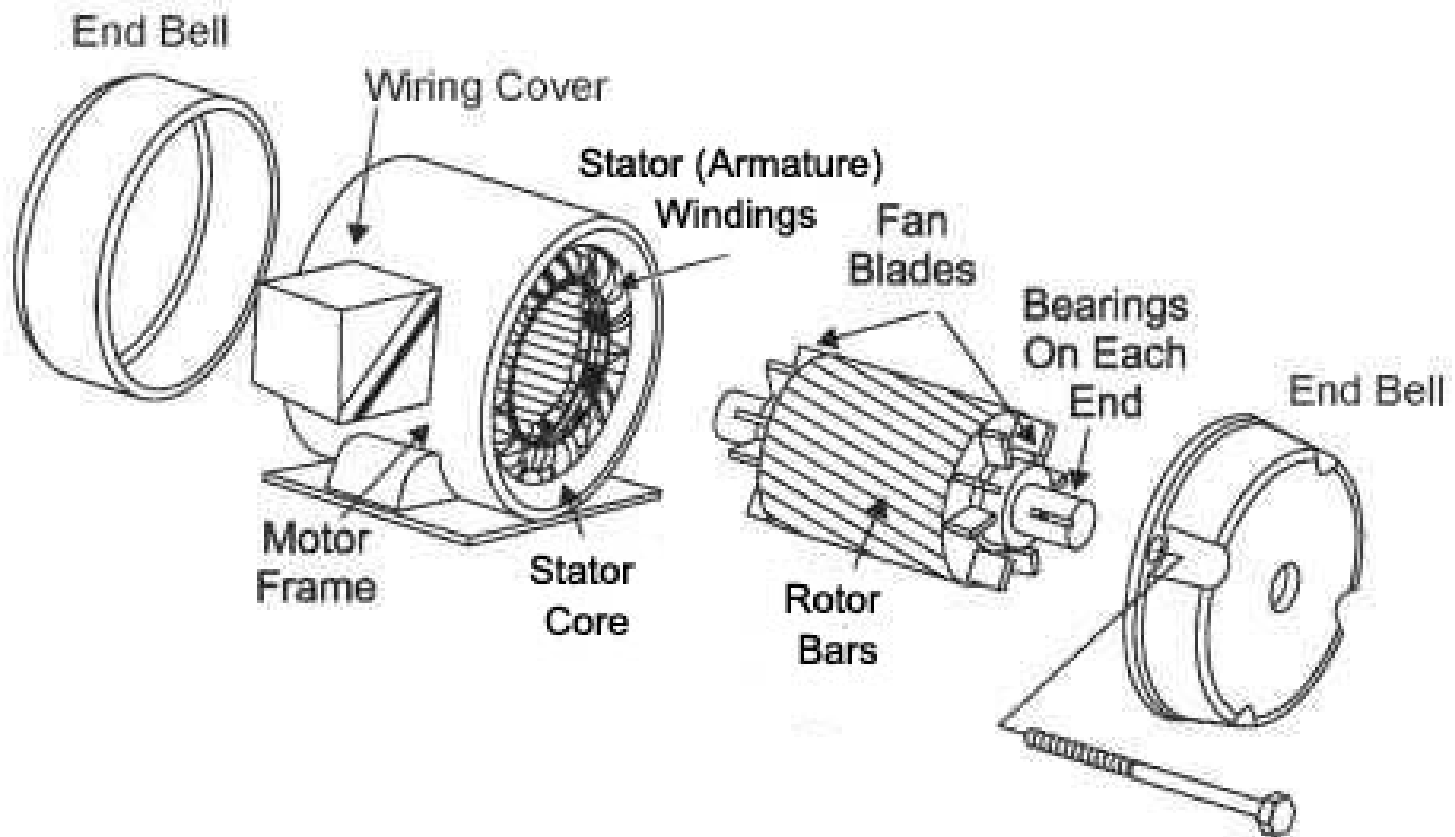
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- Construction
- Principle of Operation
- Equivalent Circuit
- Power and Torque
- Torque-speed characteristic
- Loading & Stability
- Induction Machine Modes of Operation
- Starting of Induction motors
- Braking of Induction Motors
- Testing
- Practical Motors (Lab)

Induction Machines: Construction

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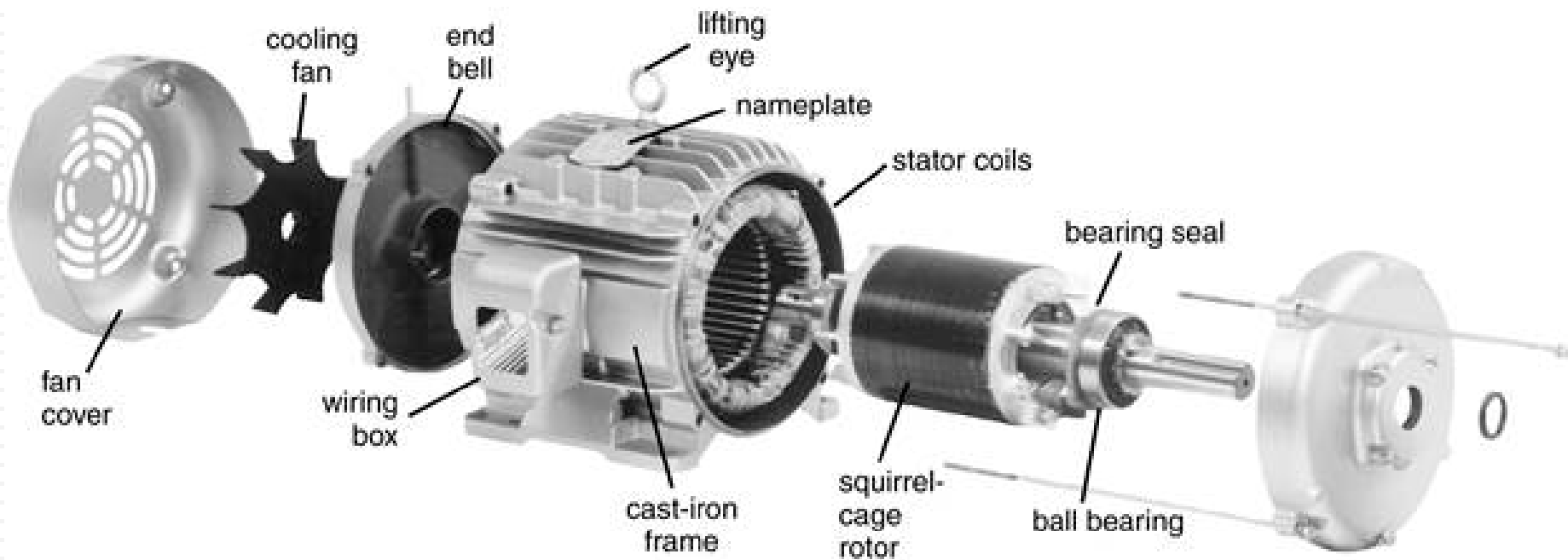
Squirrel Cage Machine



Induction Machines: Construction

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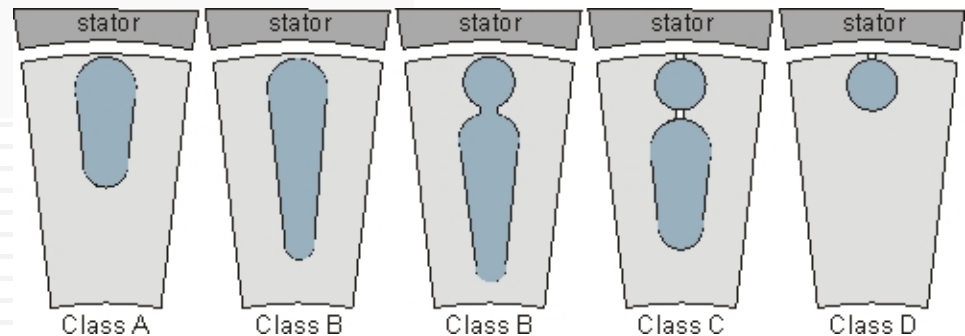
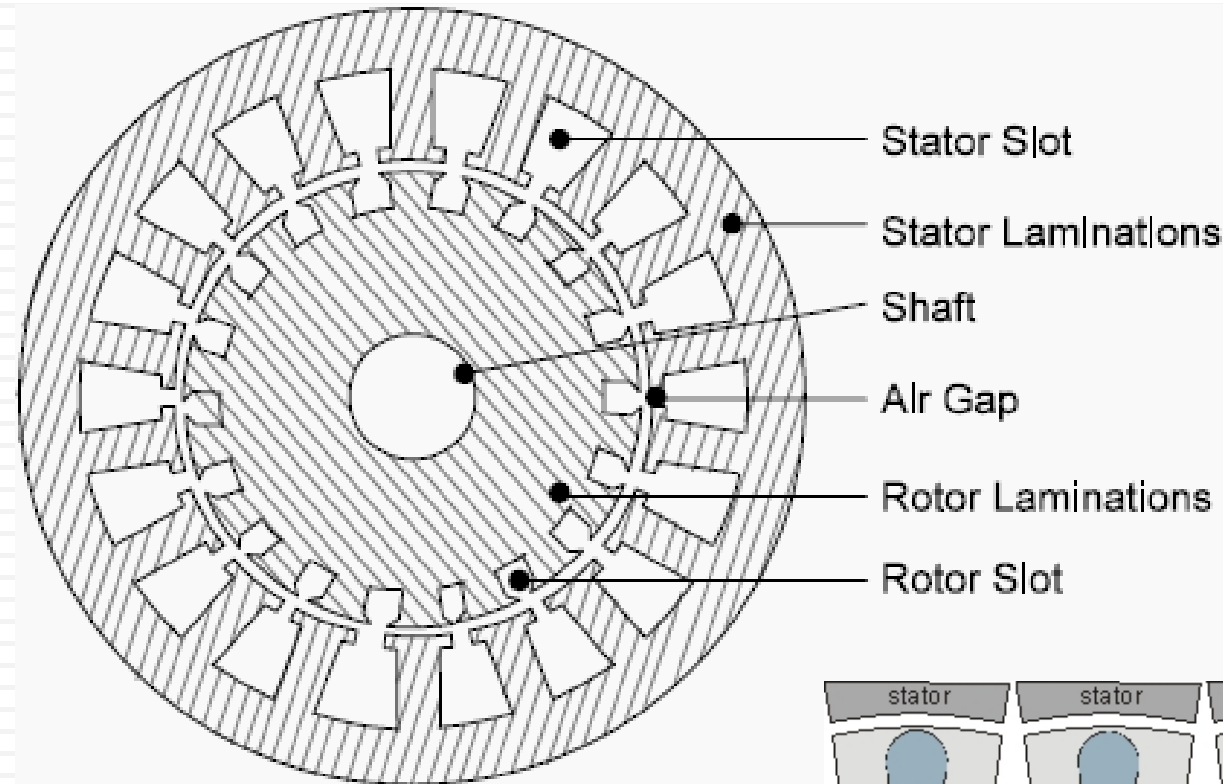
Squirrel Cage Machine



Induction Machines: Construction

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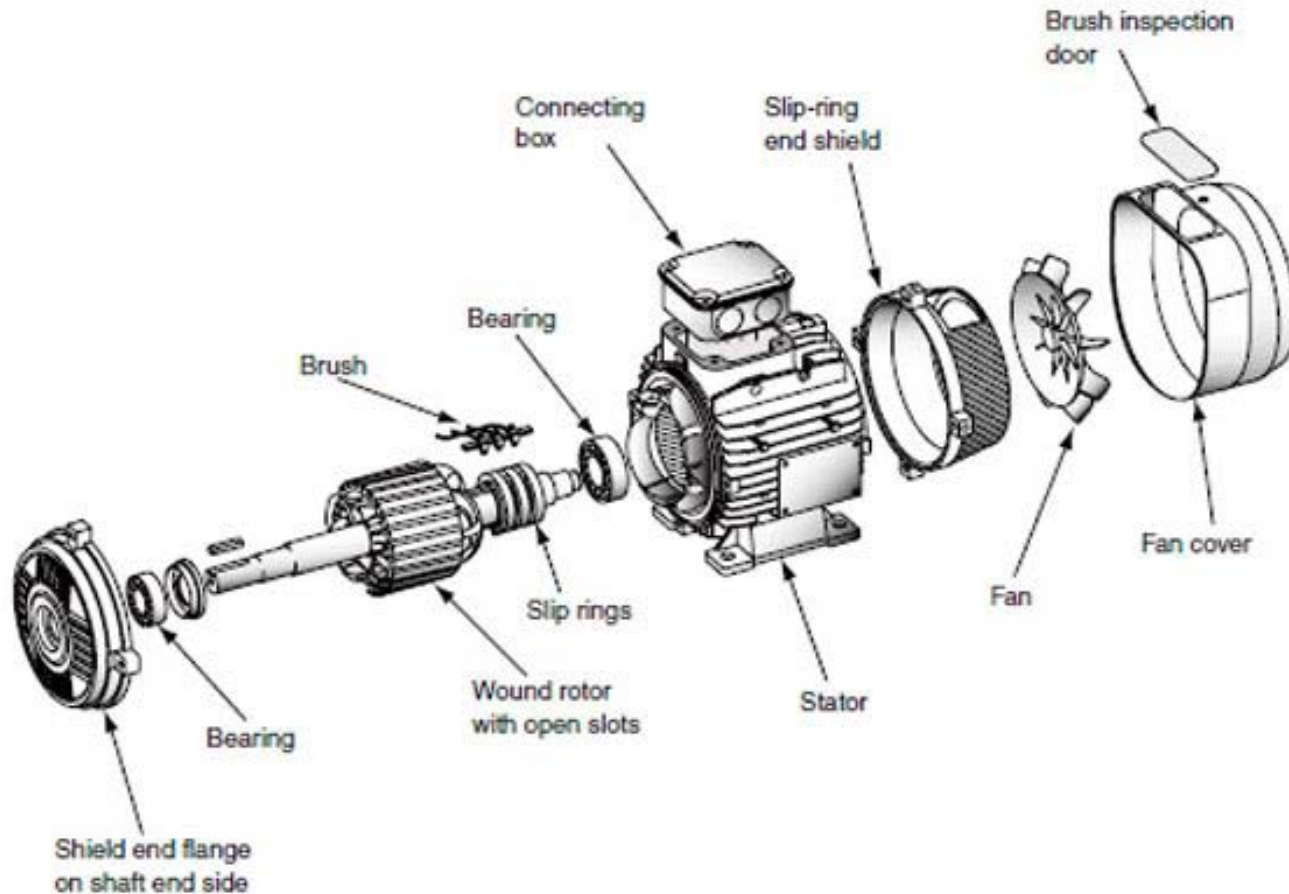
Squirrel Cage Machine



Induction Machines: Construction

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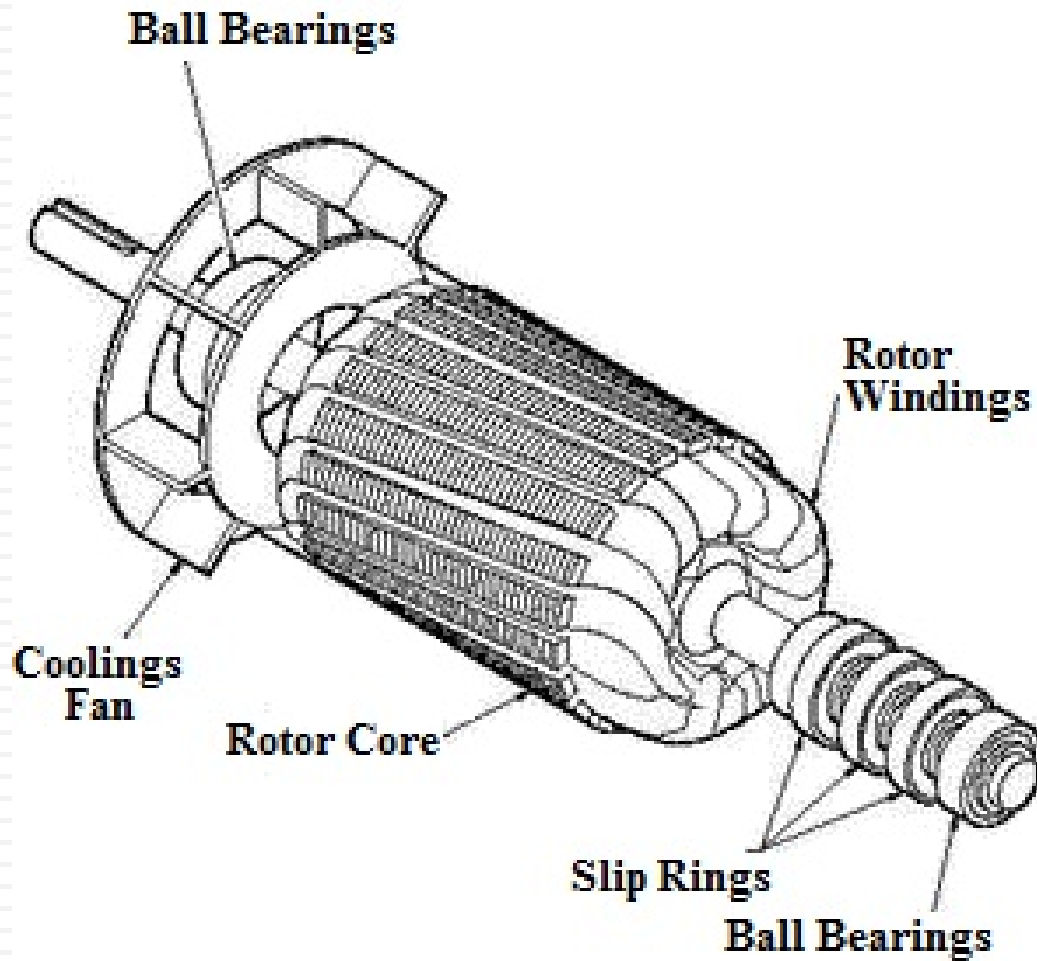
Wound Rotor Machine



Induction Machines: Construction

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Wound Rotor Machine

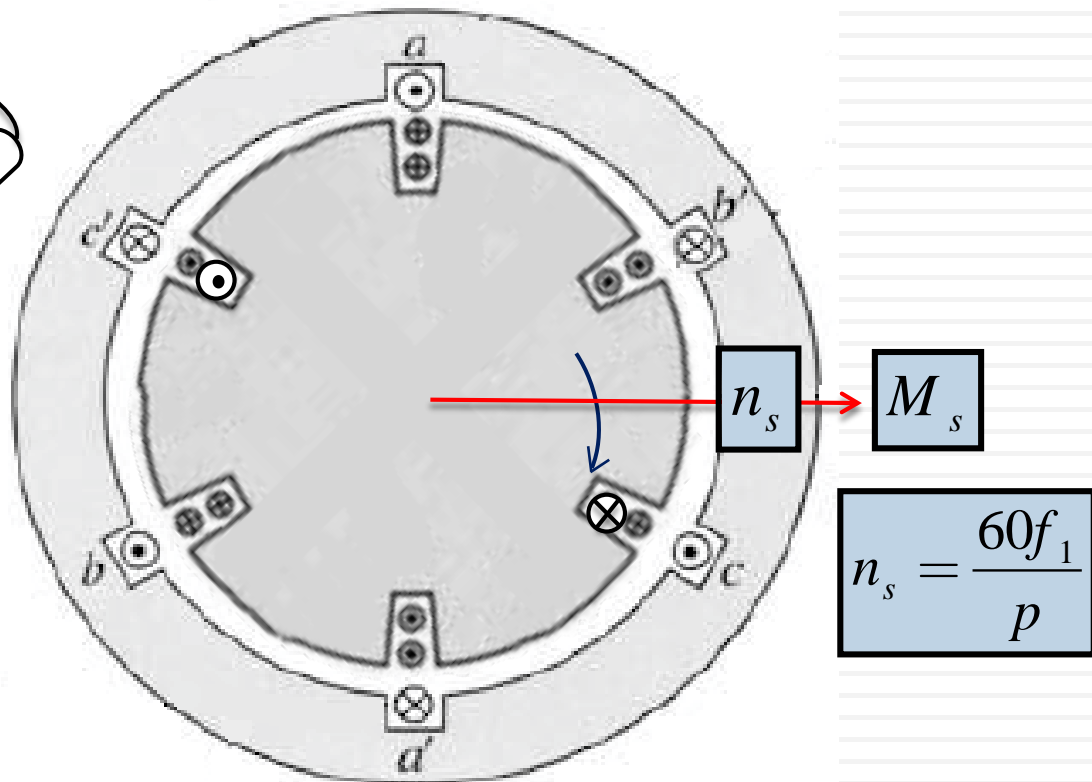
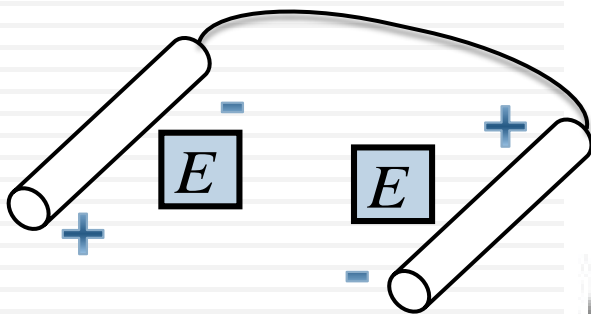


Induction Machines: Principle of Operation

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A. Motor at standstill with rotor open circuited

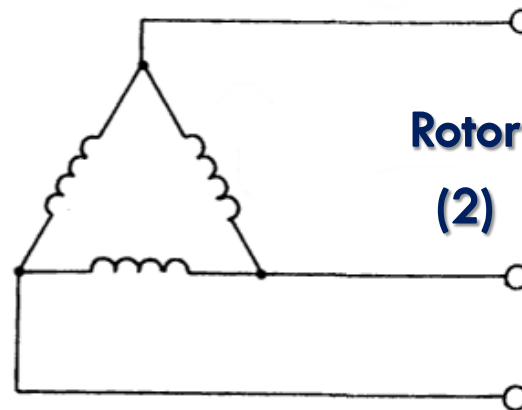
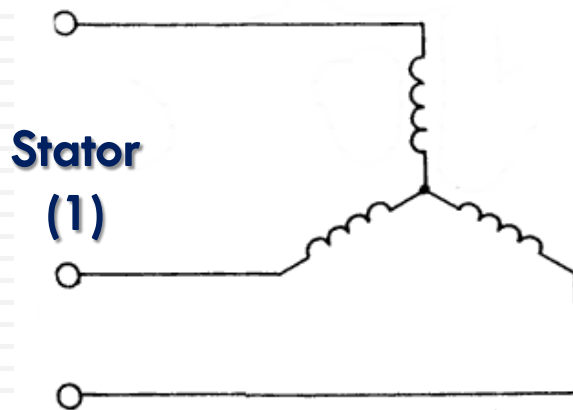
Induced Voltage



Induction Machines: Principle of Operation

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A. Motor at standstill with rotor open circuited



Wound Rotor

$$E_{1 \text{ phase}} = 4.44 f_1 \phi N_1 \frac{k_{w1}}{m}$$

$$E_{2 \text{ phase}} = 4.44 f_1 \phi N_2 \frac{k_{w2}}{m}$$

$$\frac{E_{1 \text{ phase}}}{E_{2 \text{ phase}}} = \frac{N_1 k_{w1}}{N_2 k_{w2}} = a_{\text{eff}}$$

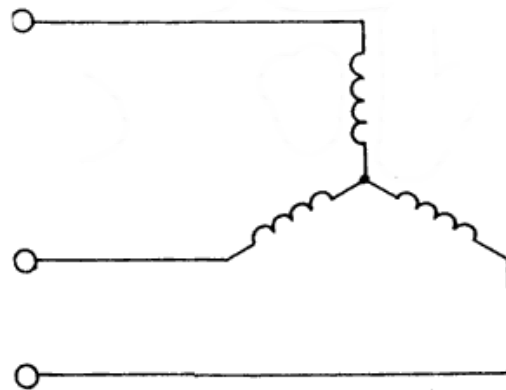
Effective turns ratio

$$E_{2 \text{ oc}} = 4.44 f_1 \phi N_2 \frac{k_{w2}}{m}$$

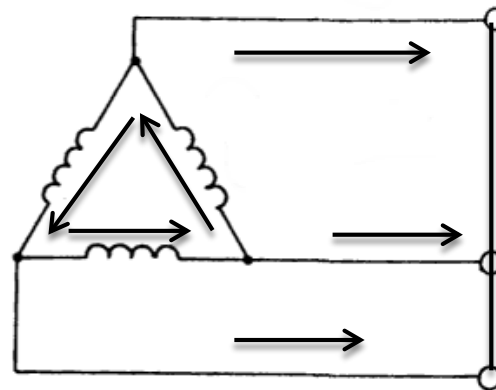
Induction Machines: Principle of Operation

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B. Motor at standstill with rotor short circuited

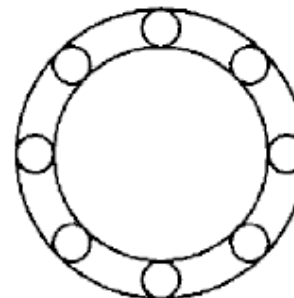
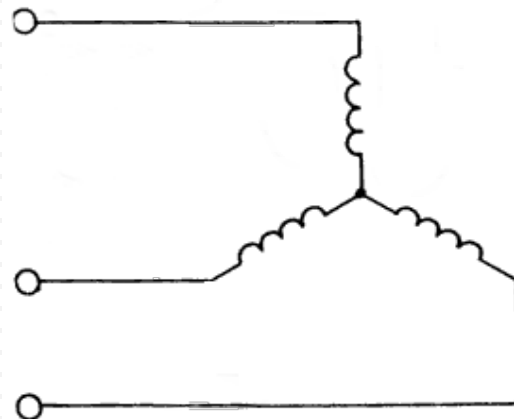


Stator



Rotor

**Wound
Rotor**



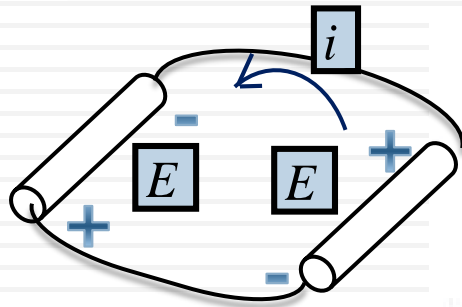
**Squirrel
Cage
Rotor**

Induction Machines: Principle of Operation

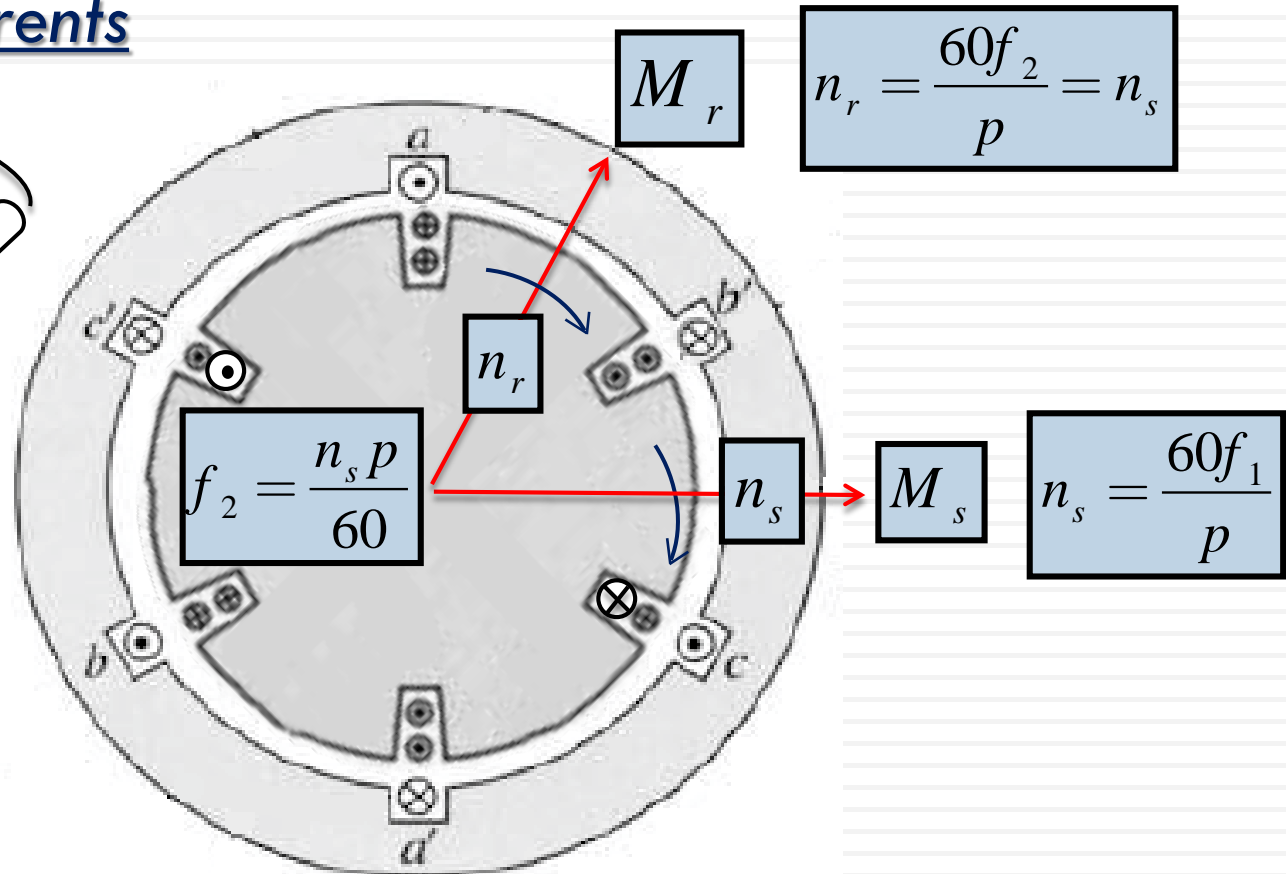
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B. Motor at standstill with rotor short circuited

Induced Currents



$$f_2 = f_1$$



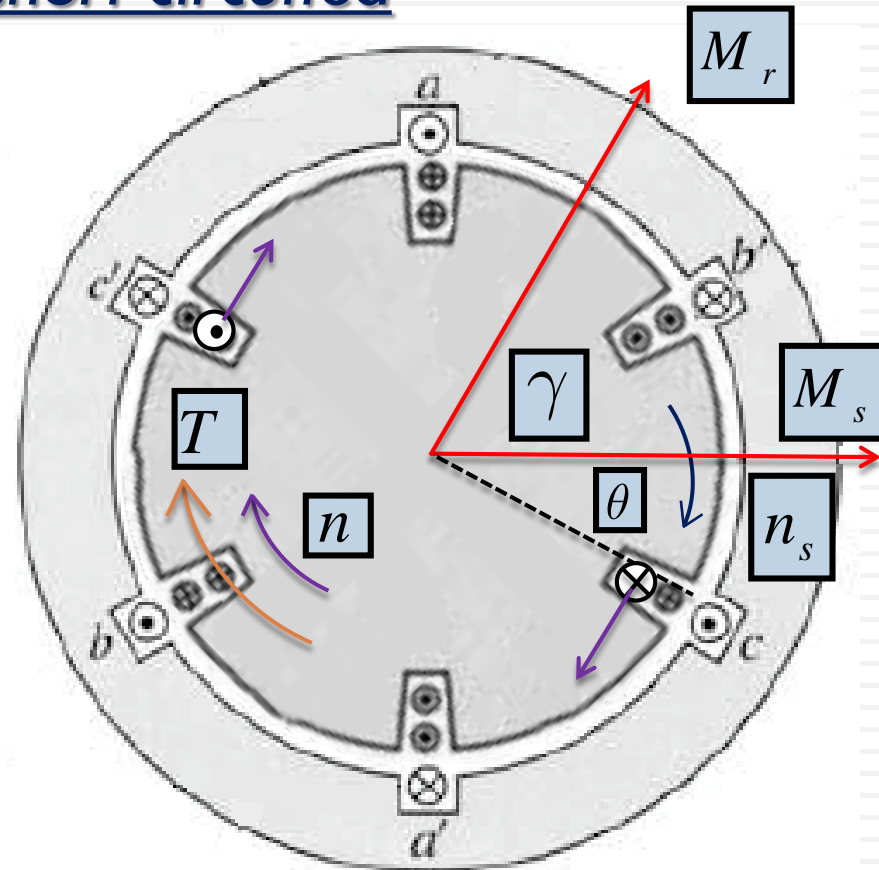
Induction Machines: Principle of Operation

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C. Motor running with rotor short circuited

Torque Production

$$T = k B_s B_r \sin \gamma$$



Induction Machines: Principle of Operation

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C. Motor running with rotor short circuited

Rotor Rotating Field Speed

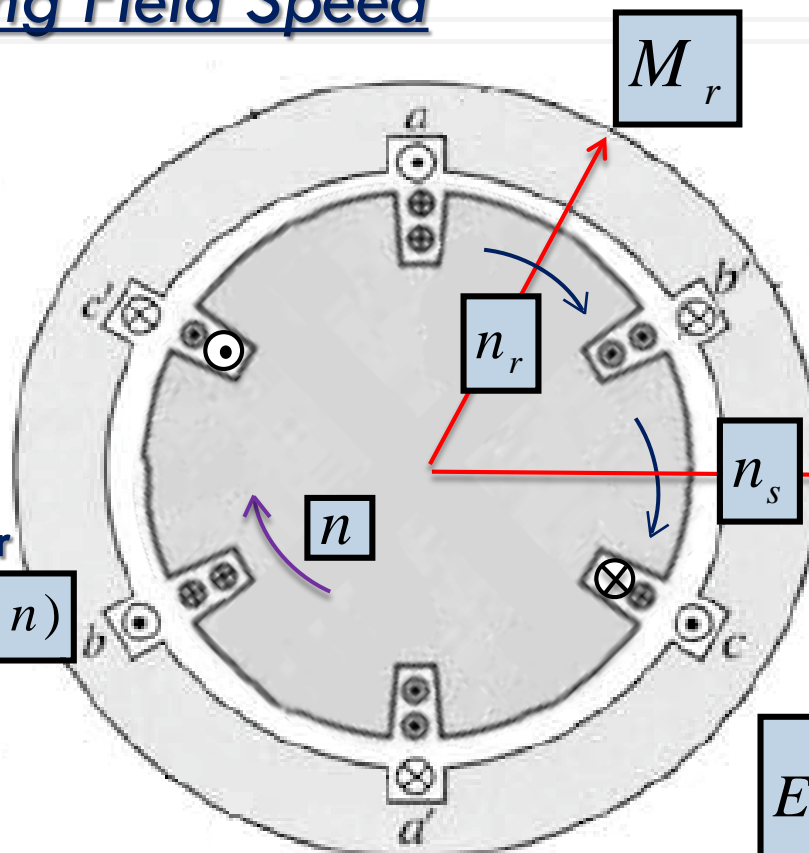
With Respect to Rotor

$$n_r = \frac{60f_2}{p}$$

With Respect to Stator

$$n + n_r = n + (n_s - n)$$

$$n_s$$



Slip

$$f_2 = \frac{(n_s - n)}{60} p$$

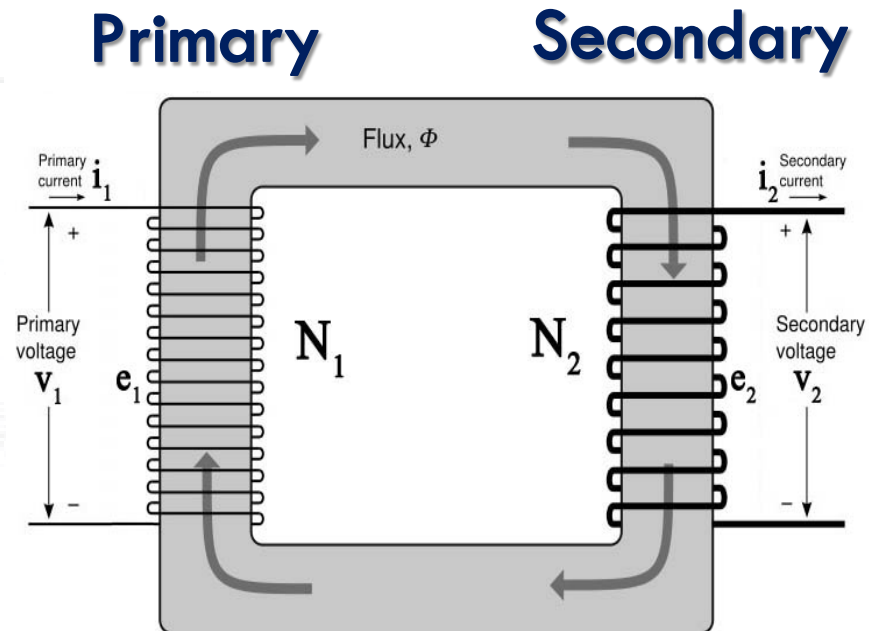
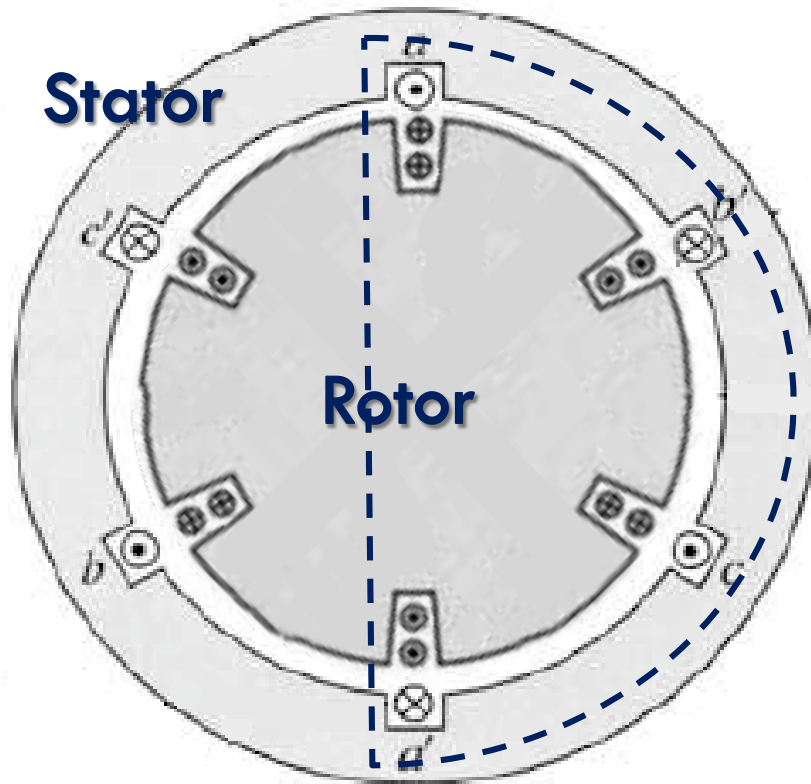
$$n_s = \frac{60f_1}{p}$$

$$E_{2 \text{ run}} = 4.44f_2\phi N_2 \frac{k_w 2}{m}$$

Induction Machines: Equivalent Circuit

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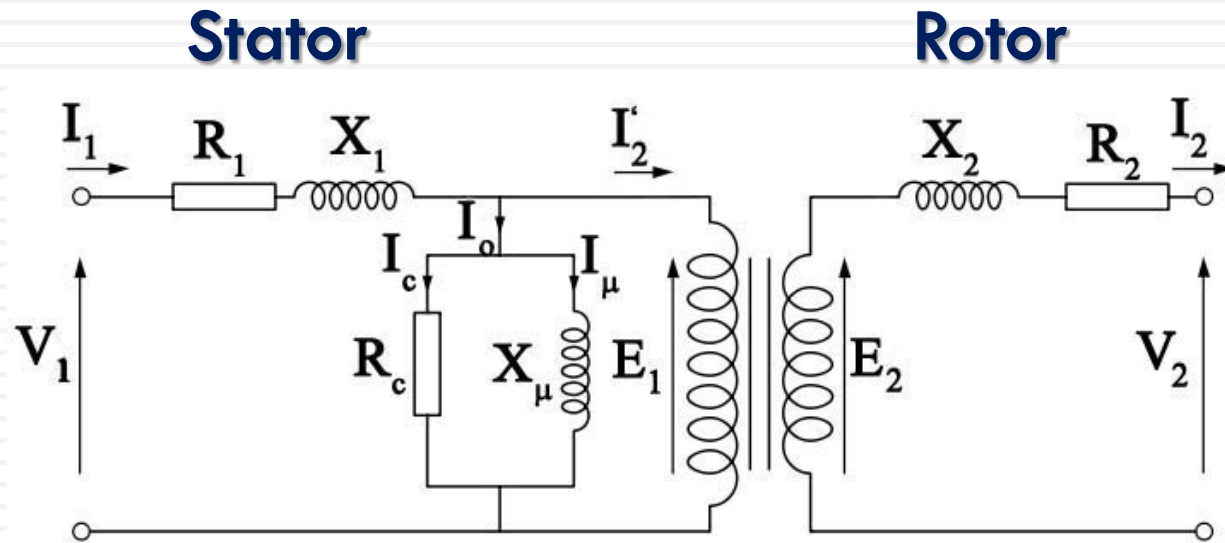
A. Rotor open circuited (standstill)



Induction Machines: Equivalent Circuit

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A. Rotor open circuited (standstill)



$$E_1 = 4.44f_1\phi N_1 \frac{k_{w1}}{m}$$

$$E_2 = 4.44f_1\phi N_2 \frac{k_{w2}}{m}$$

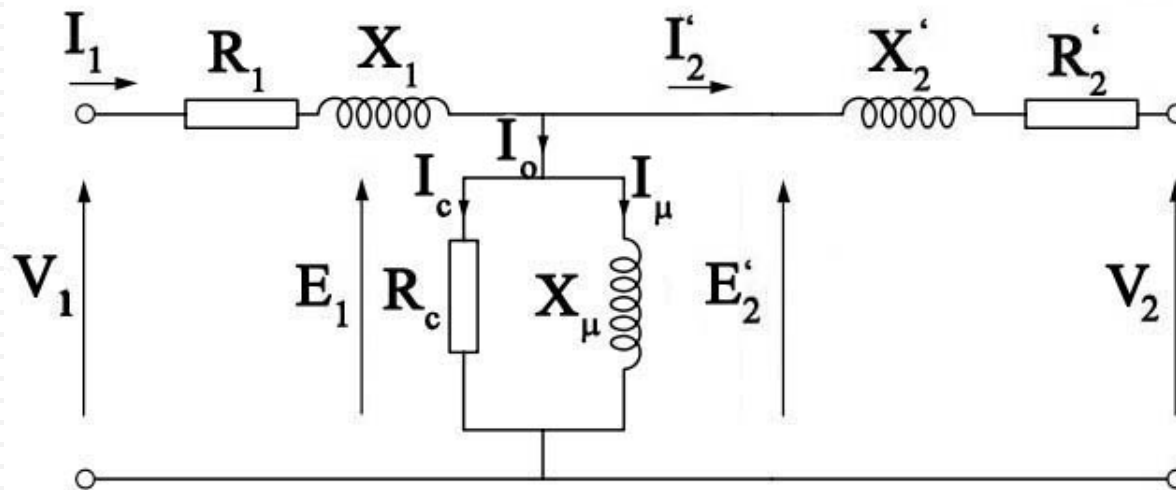
$$\frac{E_1}{E_2} = \frac{N_1 k_{w1}}{N_2 k_{w2}} = a_{eff}$$

$$E_{2\ oc} = 4.44f_1\phi N_2 \frac{k_{w2}}{m}$$

Induction Machines: Equivalent Circuit

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A. Rotor open circuited



$$E'_2 = E_1$$

$$\frac{E'_{2\ oc}}{E_{2\ oc}} = \frac{N_1 k_{w1}}{N_2 k_{w2}}$$

$$R'_2 = R_2 \left(\frac{N_1 k_{w1}}{N_2 k_{w2}} \right)^2$$

$$X'_2 = X_2 \left(\frac{N_1 k_{w1}}{N_2 k_{w2}} \right)^2$$

Induction Machines: Equivalent Circuit

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B. Rotor running at speed n

When Rotor is stationary:

$$E_{2\ oc} = 4.44f_1\phi N_2 \frac{k_w 2}{m}$$

$$\frac{E_{2\ run}}{E_{2\ oc}} = \frac{f_2}{f_1} = \frac{n_s - n}{n_s} = s$$

X_2 = rotor leakage reactance at f_1

$$X_2 = 2\pi f_1 L_2$$

At f_2

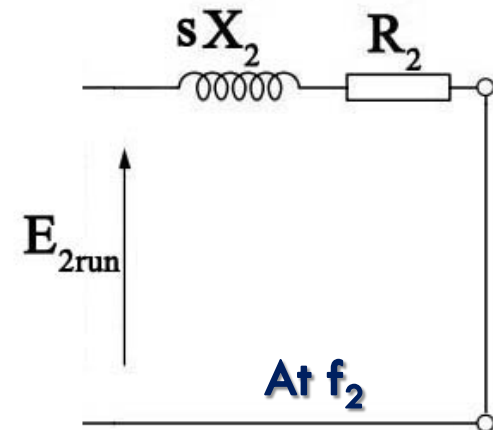
$$X_{2f_2} = 2\pi f_2 L_2 = X_2 \frac{f_2}{f_1} = sX_2$$

When Rotor is running:

$$E_{2\ run} = 4.44f_2\phi N_2 \frac{k_w 2}{m}$$

$$s = \frac{n_s - n}{n_s}$$

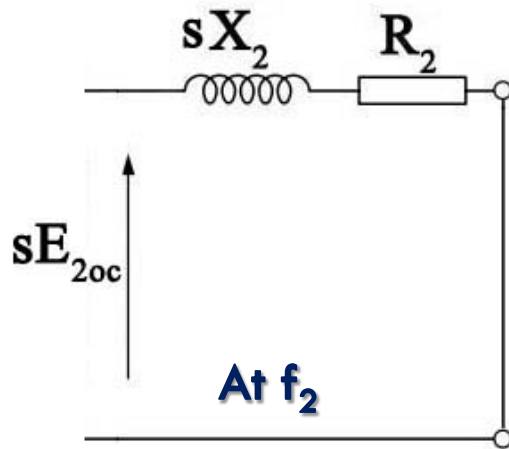
Per-unit Slip



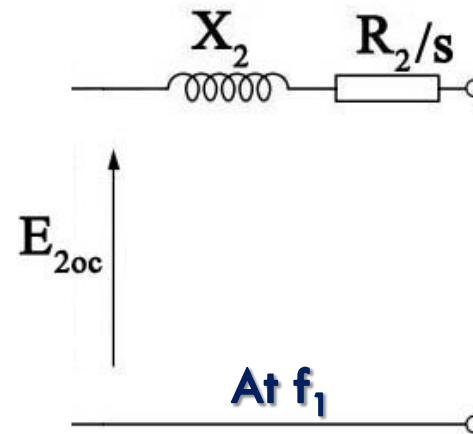
Induction Machines: Equivalent Circuit

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B. Rotor running at speed n



$$E_{2\ run} = sE_{2\ oc}$$



$$sE_{2\ oc} = I_2(R_2 + jsX_2)$$

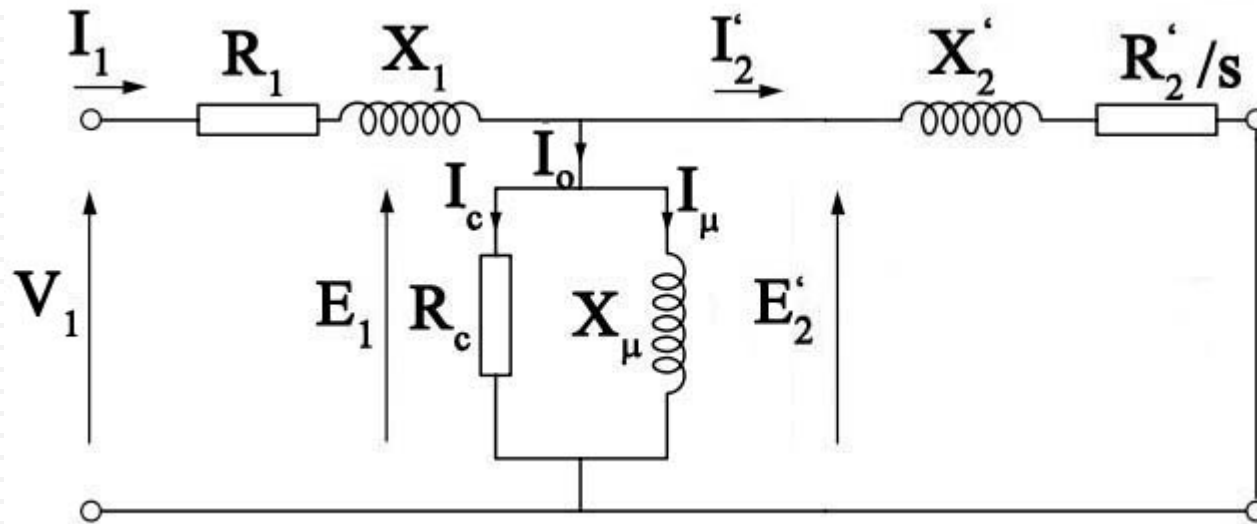
$$E_{2\ oc} = I_2\left(\frac{R_2}{s} + jX_2\right)$$

$$E'_{2\ oc} = I'_2\left(\frac{R'_2}{s} + jX'_2\right)$$

Induction Machines: Equivalent Circuit

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B. Rotor running at speed n



$$E_1 = E_2' = E$$

$$s = \frac{n_s - n}{n_s} \times \frac{2\pi}{60}$$

$$s = \frac{\omega_s - \omega}{\omega_s}$$

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

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

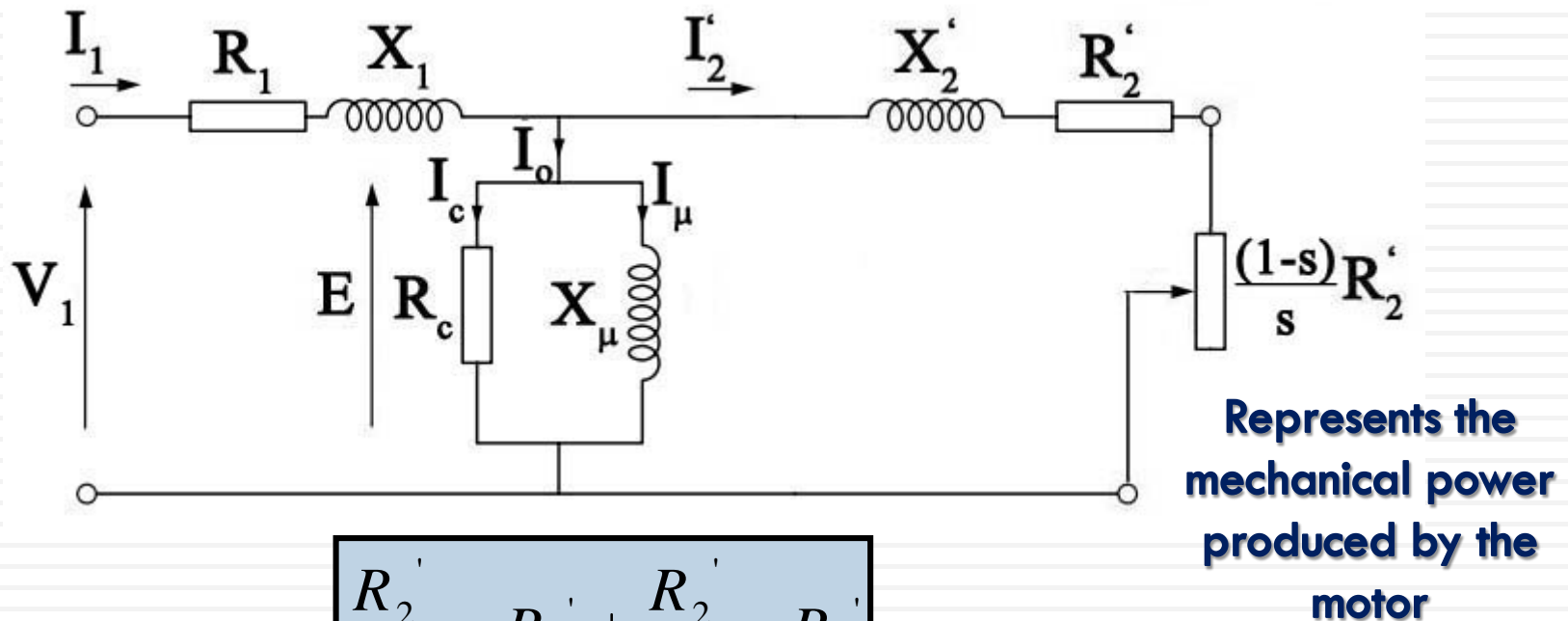
$$n_s = \frac{60f_1}{p} \times \frac{2\pi}{60}$$

$$\omega_s = \frac{2\pi f_1}{p}$$

Induction Machines: Equivalent Circuit

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B. Rotor running at speed n



$$\frac{R_2'}{s} = R_2' + \frac{R_2'}{s} - R_2'$$

$$\frac{R_2'}{s} = R_2' + \left(\frac{1-s}{s}\right)R_2'$$

Induction Machines: Power Flow

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$$P_{in} = \sqrt{3} V_L I_L \cos \phi$$

$$P_{cu1} = 3 I_1^2 R_1$$

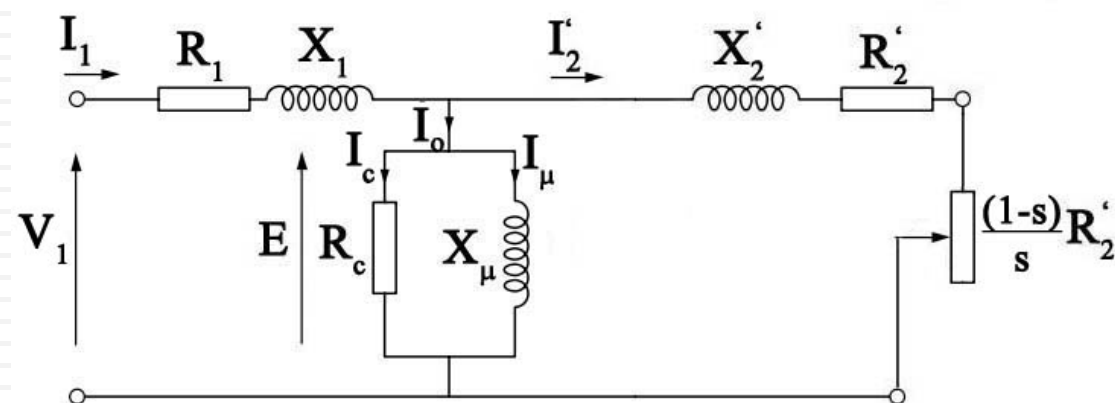
$$P_{iron} = 3 I_c^2 R_c$$

$$P_g$$

$$P_d$$

$P_{mech losses}$

$$P_{out} = T_{out} \omega$$



$P_g =$ air-gap power

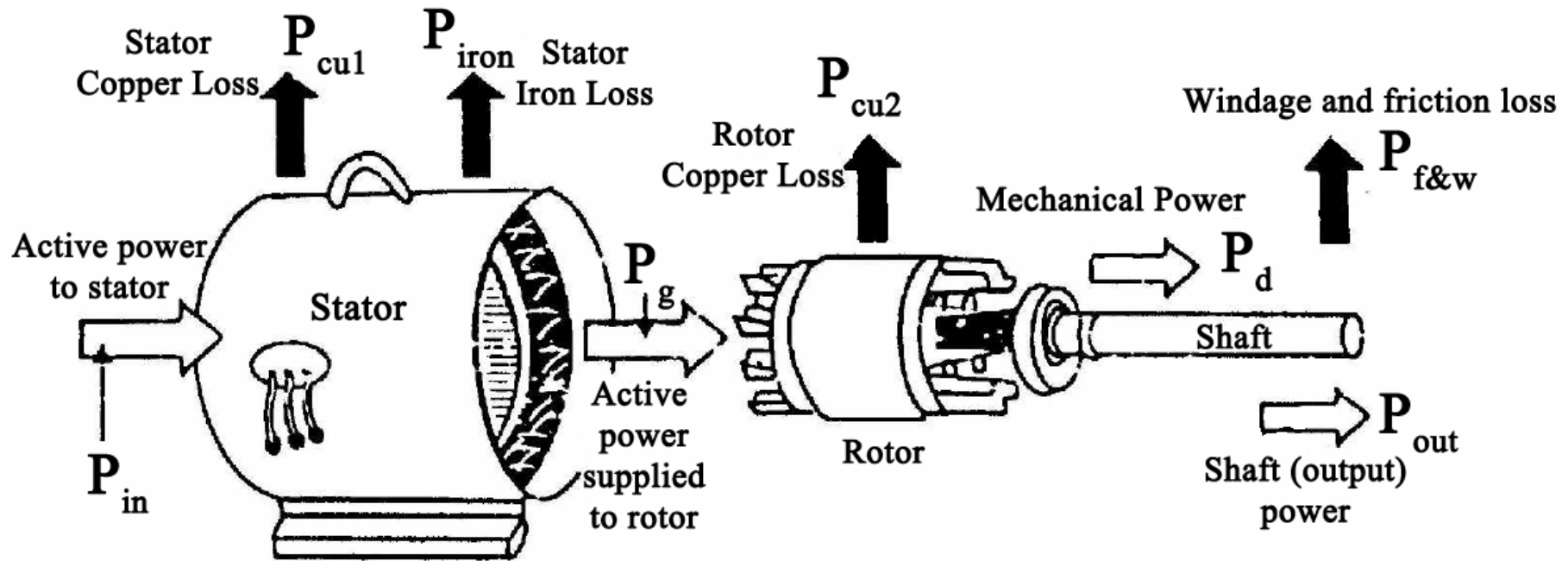
$P_d =$ developed mech. power

$$P_g = 3 I_2'^2 \frac{R_2'}{s} = P_{in} - P_{cu1} - P_{iron}$$

$$P_d = 3 I_2'^2 \frac{(1-s)}{s} R_2' = P_g - P_{cu2}$$

Induction Machines: Efficiency & Torque

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Induction Machines: Efficiency & Torque

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