Energy conversion I

Lecture 16:

Topic 5: Induction Motors (S. Chapman ch. 7)

- **Induction Motor Construction.**
- **Basic Induction Motor Concepts.**
- The Equivalent Circuit of an Induction Motor.
- Powers and Torque in Induction Motor.
- Induction Motor Torque-Speed Characteristics
- Starting Induction Motors
- Speed Control of Induction Motor
- Determining Circuit Model Parameters

Introduction:

Induction /asynchronous machine:

the most usual industrial motor (from some tens W to tens MW from tens V to some kV).

Mainly used as motor.

Are used as generator in wind turbines.

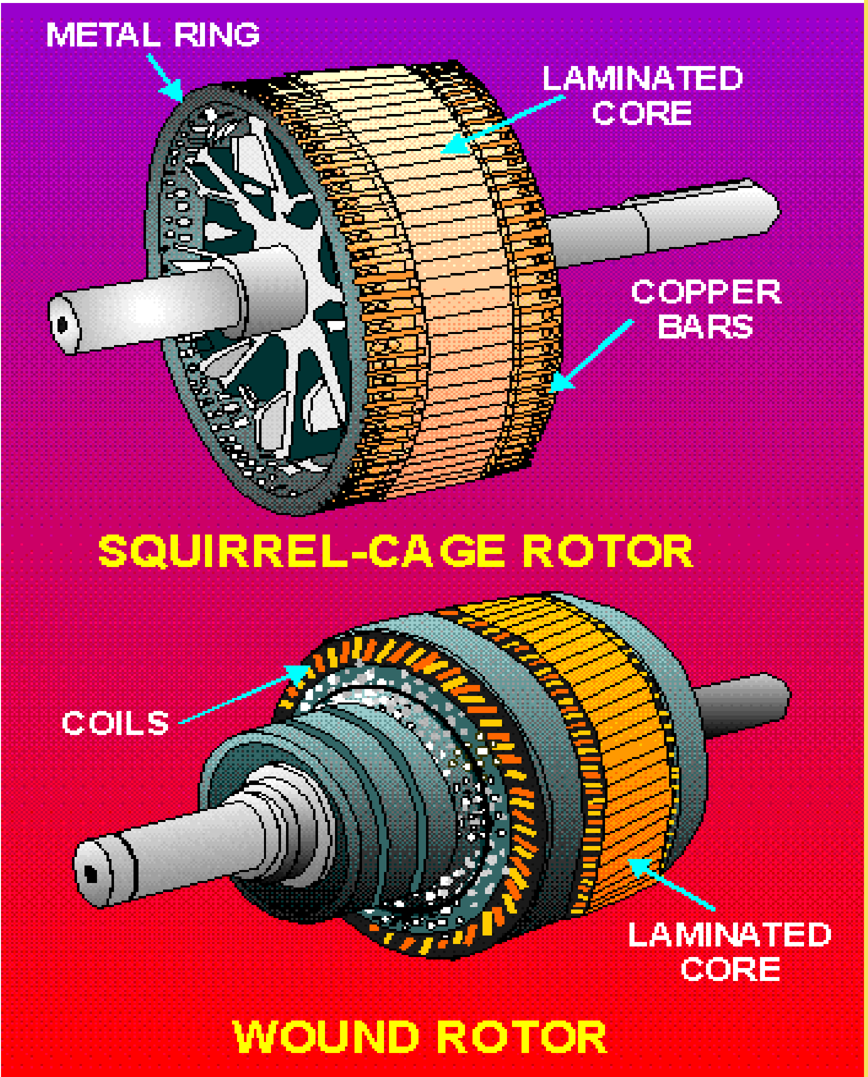
Three phase (in industry) / Single phase (home/industrial appliance).

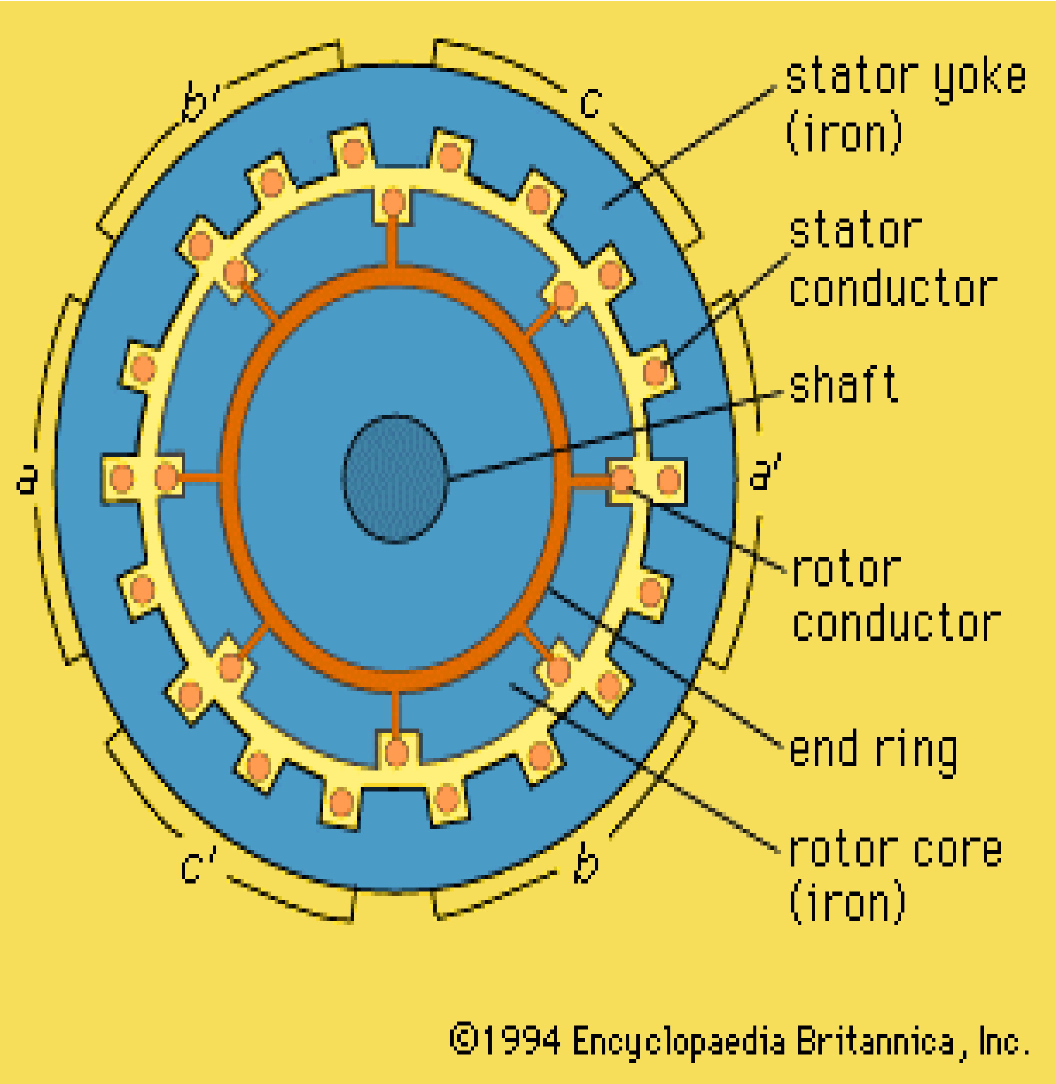
Wound rotor (/ slip ring rotor) / squirrel cage rotor.

Wound rotor are more expensive and are used mainly in high power applications.

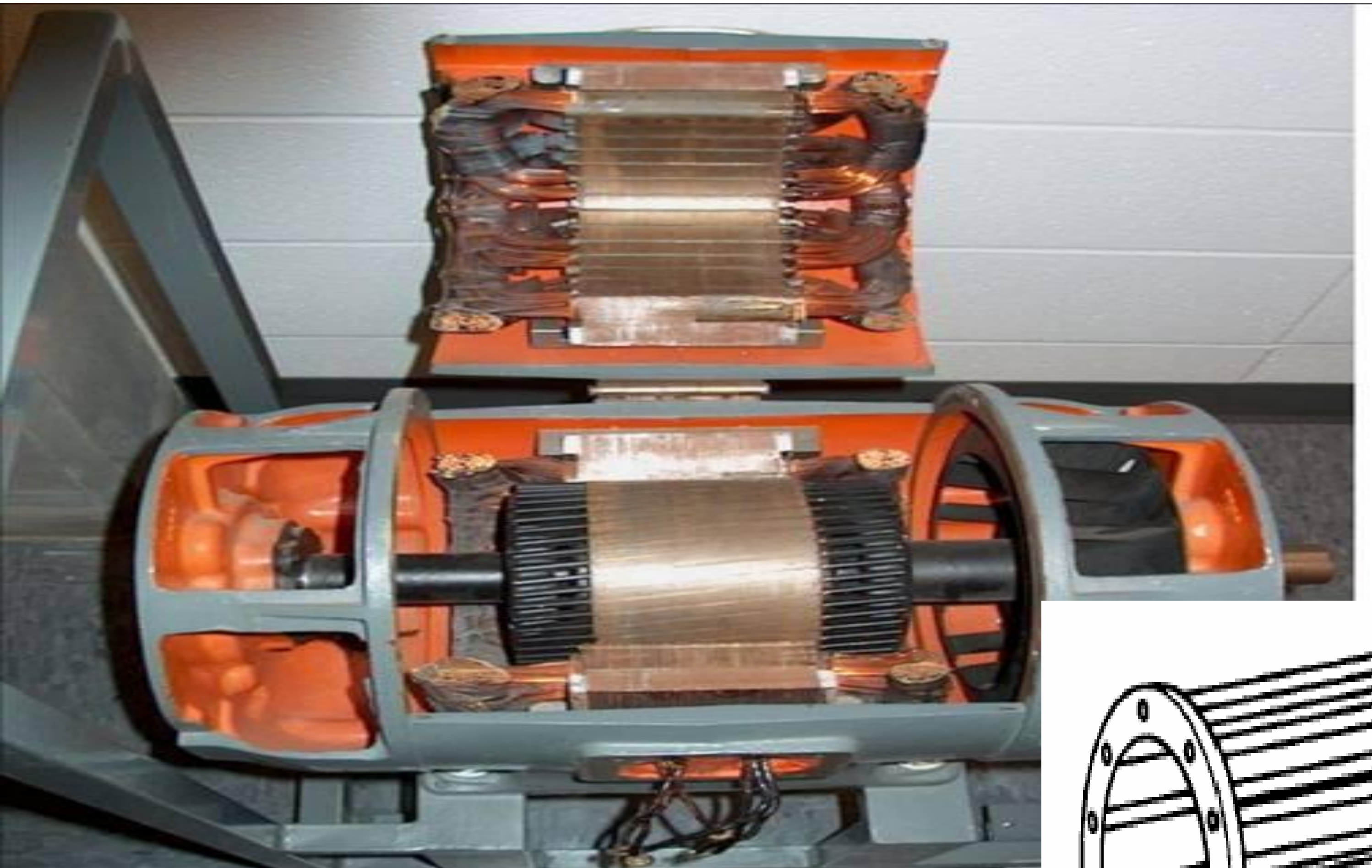
Induction Motor Construction

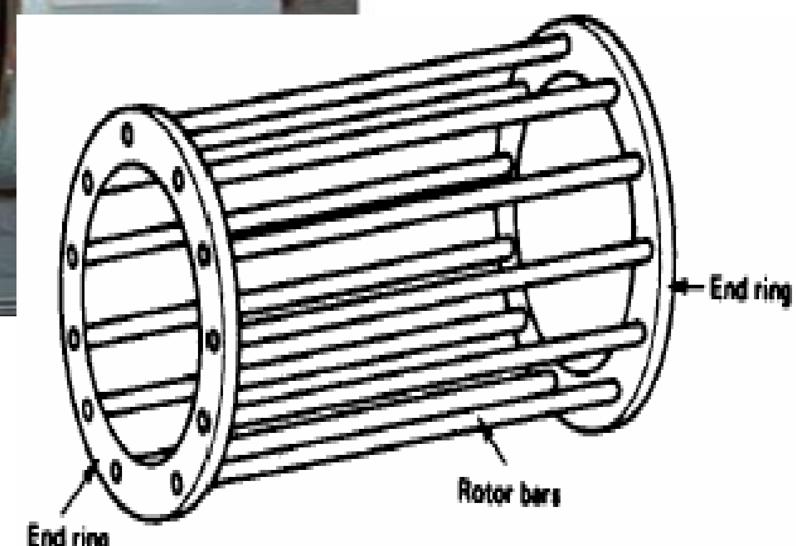
Laminated stator and rotor magnetic core
Three phase stator winding
Short circuited rotor



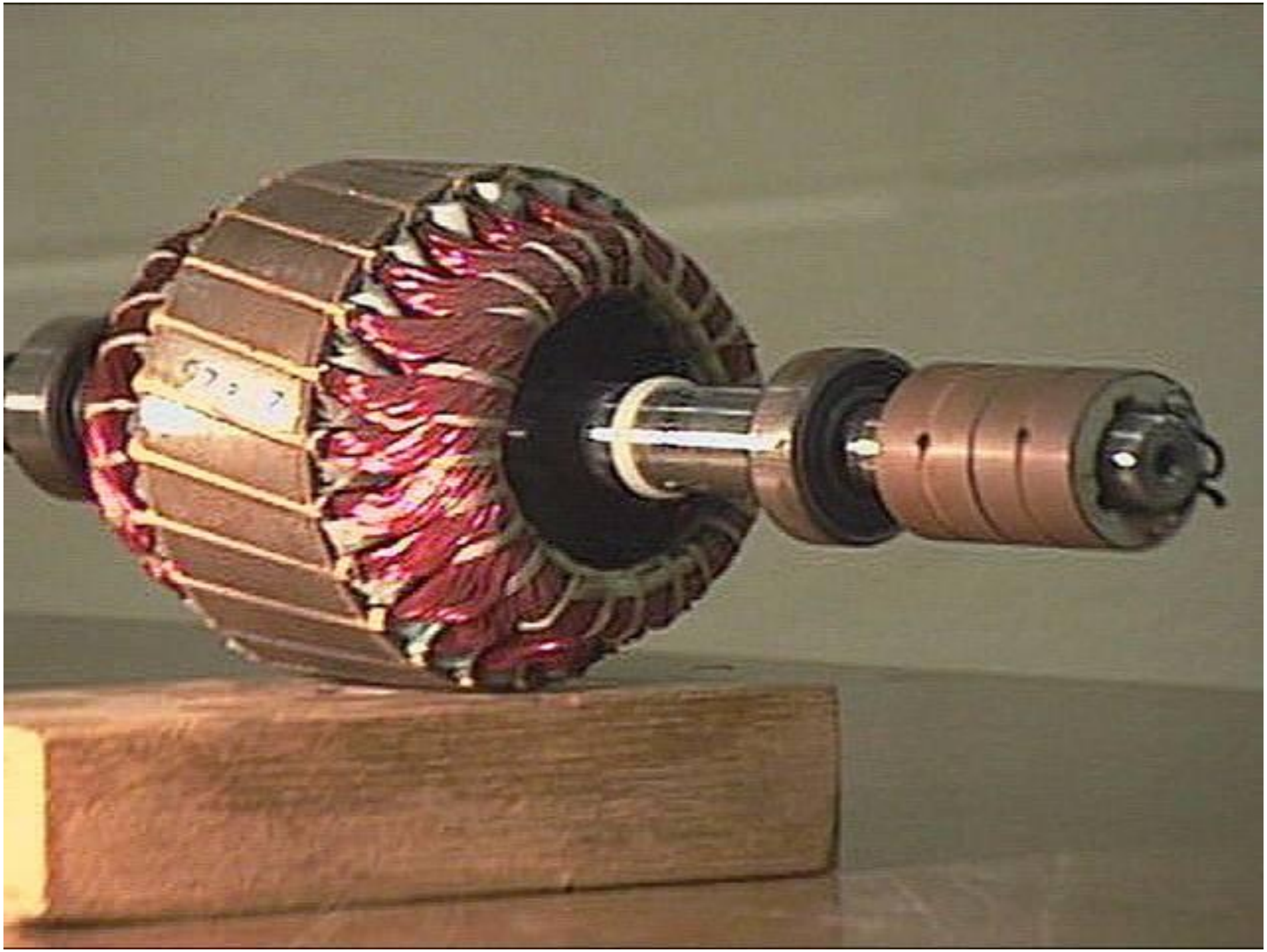


Cut-away Squirrel cage induction motor:





Wound / Slip ring rotor:



Basic Induction Motor Concepts

Stator three phase winding is fed by three phase voltage.

⇩

Stator winding generates stator rotating magnetic field.

⇩

Stator magnetic field induces voltage on short circuited rotor winding/cage. (induction motor)

⇩

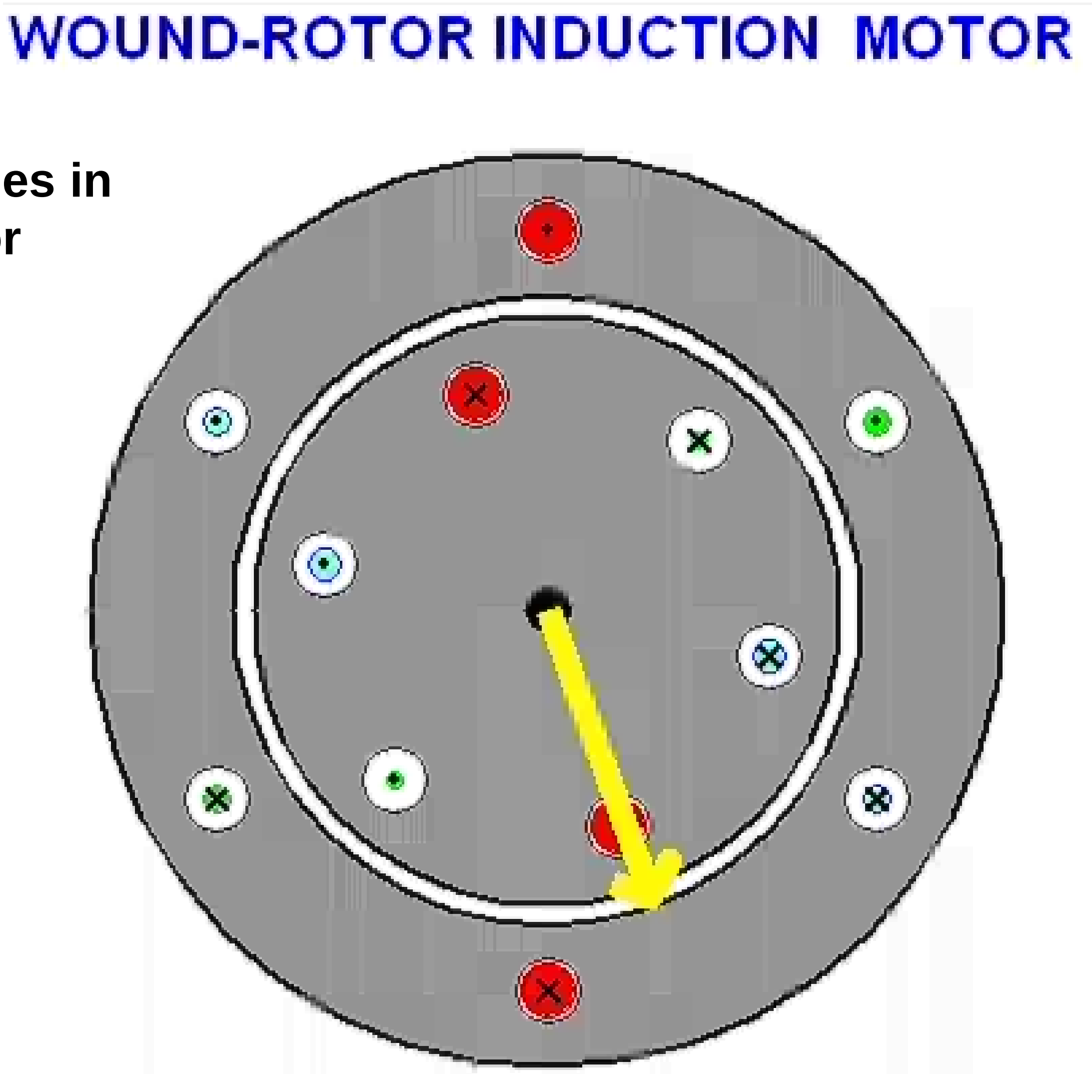
If rotor winding is not rotating with synchronous speed (asynchronous motor), induced rotor current generates rotor rotating magnetic field rotating with stator rotating magnetic field speed.

⇩

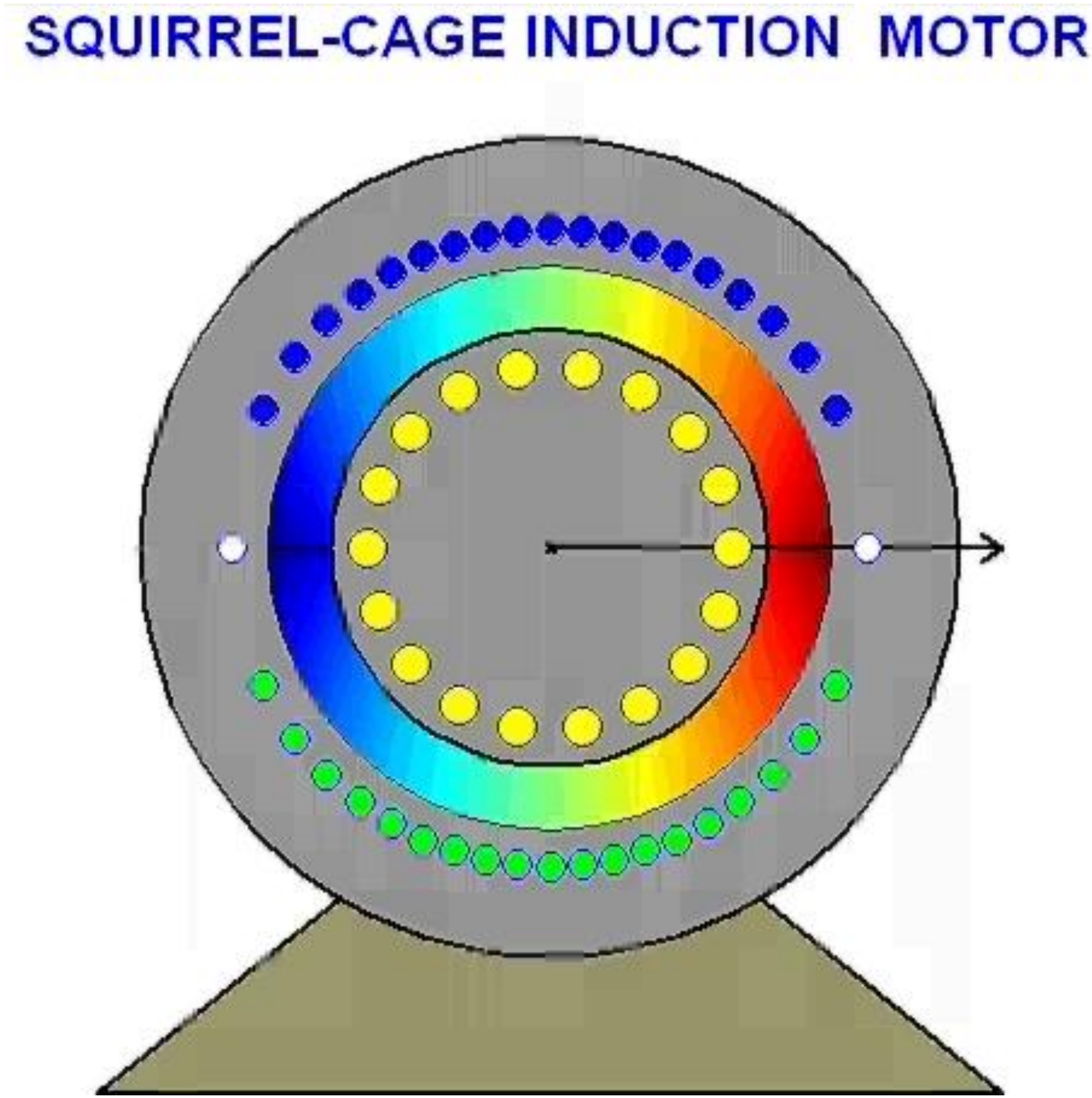
Interaction between stator and rotor rotating magnetic field produces torque.

Schematic diagram of a wound-rotor induction motor

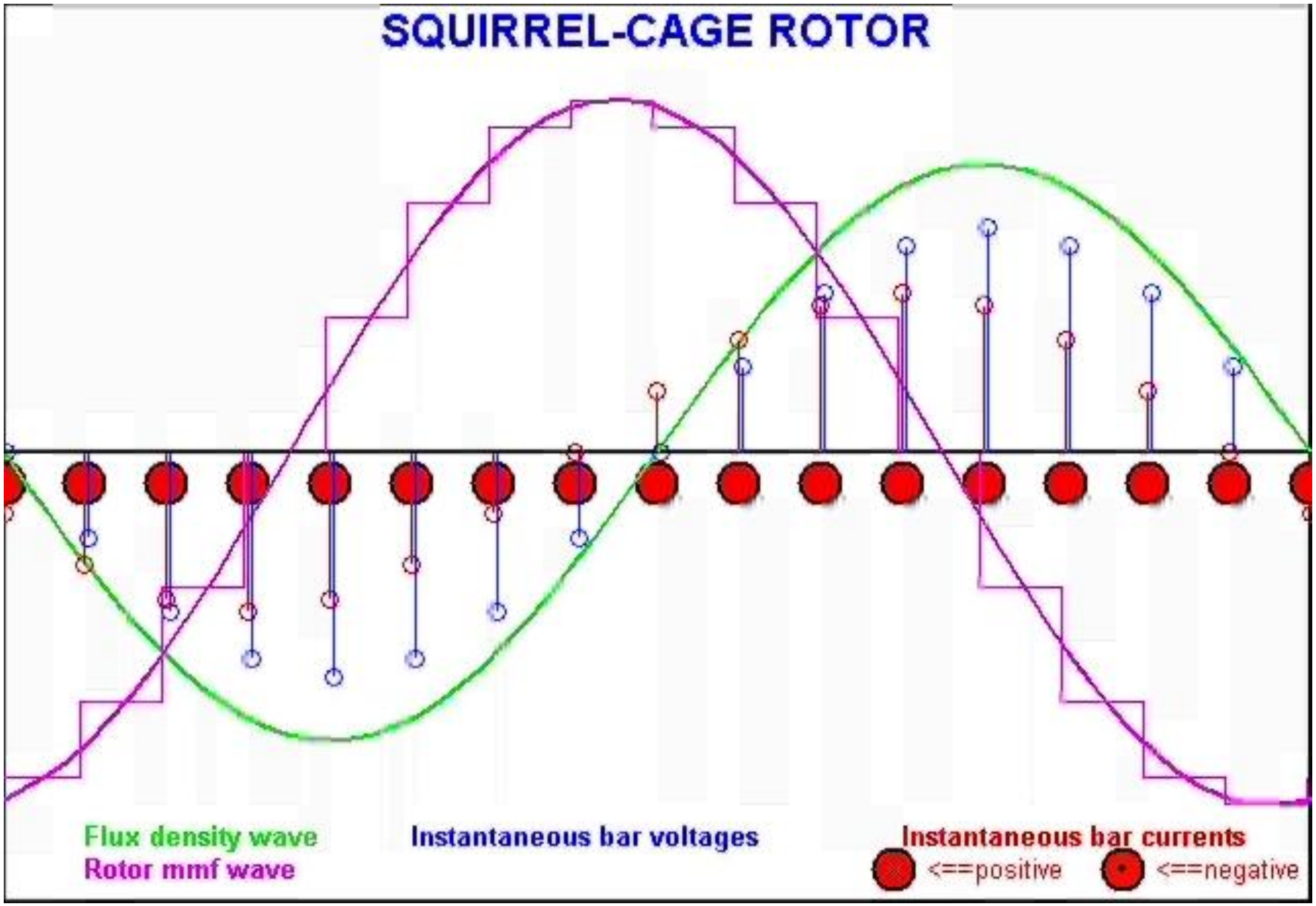
Induced voltages in rotor and stator windings



Schematic diagram of a squirrel-cage induction machine



Behavior of squirrel-cage rotor in a two-pole field seen from rotor



Special Thanks to Professor Mahmoud Riaz for animations

Rotor Slip

Asynchronous machine generates torque if rotor is not rotating synchronously with stator magnetic field

$$n_{sync} = \frac{120 f_s}{p} \text{ rpm}$$

f_s: stator voltage / current frequency

p: Number of poles

Slip speed (n_{slip}) is the difference between n_{sync} and rotor speed (n_m)

$$n_{slip} = n_{sync} - n_m$$

$$s = \frac{n_{slip}}{n_{sync}} = \frac{n_{sync} - n_m}{n_{sync}} = \frac{\omega_{sync} - \omega_m}{\omega_{sync}}$$

s: slip

From slip equation we can write:

$$n_m = (1 - s) n_{sync}$$

s(@ n= 0: start up) = 1

s(@ n=ns: synchronous speed) = 0

Electrical Frequency on the Rotor

Speed of rotation of stator magnetic field: n_{sync}

Speed of rotation of rotor n_m

Rotor winding see the variation of flux with slip frequency

$$f_r = s f_s$$

What is the speed of rotation of rotor magnetic flux compared to rotor?

Example: A 208V, 10hp, 4 pole, 60Hz, Y-connected induction motor has a full-load slip of 5%.

A- What is the synchronous speed of this motor?

B- What is the rotor speed of this motor at the rated load?

C- What is the rotor frequency of this motor at the rated load?

D- What is the shaft torque of this motor at the rated load?

Example: A 208V, 10hp, 4 pole, 60Hz, Y-connected induction motor has a full-load slip of 5%.

A- What is the synchronous speed of this motor?

$$n_{sync} = \frac{120 f_s}{p} = \frac{120 \times 60}{4} = 1800\, rpm$$

B- What is the rotor speed of this motor at the rated load?

$$n_m = (1 - s) n_{sync} = (1 - 0.05) \times 1800 = 1710\, rpm$$

C- What is the rotor frequency of this motor at the rated load?

$$f_r = s f_s = 0.05 \times 60 = 3 Hz$$

D- What is the shaft torque of this motor at the rated load?

$$T = \frac{P_o}{\Omega_m} = \frac{10 \times 746}{\frac{1710}{60} \times 2\pi} = 41.66\, N.m.$$