Energy conversion I

Lecture 10:

Topic 3: Fundamentals of AC machines steady state operation (S. Chapman, ch. 4)

- **Introduction**
- **Voltage of a loop in a uniform magnetic Field.**
- **Torque of a loop in a uniform magnetic Field.**
- **Rotating magnetic field.**
- Magnetomotive force and flux distribution in AC machines.
- Induced voltage in AC machines.
- Induced torque in AC machines.

Introduction

Electric machines:

Electromechanical converters

Main AC Machines

DC Machines

Synchronous Machines

Induction Machines (asynchronous)

Magnetic field current is supplied by a separate dc power source(/Permanent Magnet)

Field current is supplied by magnetic <u>induction</u> (transformer action) into their field windings.

The field circuits are located on their rotors.

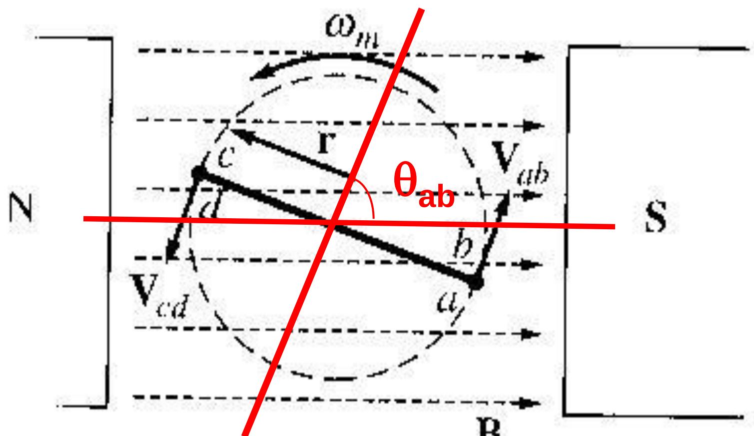
Rotor: Rotating part of the machine

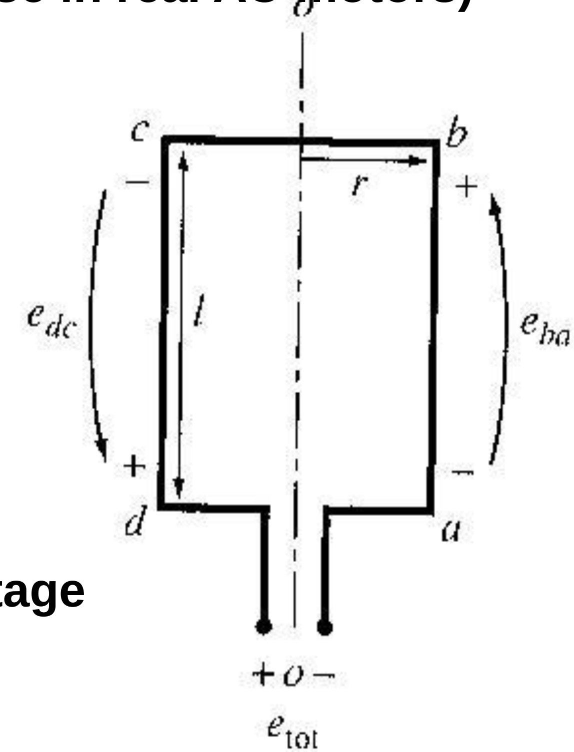
Stator: Stationary part of the machine

Voltage of a loop in a uniform magnetic Field

Induced Voltage:

Moving loop in a uniform magnetic filed (not the case in real AC motors)





(b)

Moving conductor in a magnetic field : induced voltage

$$e_{ind} = (\,\mathbf{V} \times \mathbf{B}\,) \bullet \mathbf{l}$$

$$e_{ind,loop} = e_{ba} + e_{cb} + e_{dc} + e_{ad}$$

V × B: is in the direction of ba(/dc) for l_{ba}(/ l_{dc}) :$e_{ba} = e_{dc} = v\, B\, l \sin\theta_{ab}$

V × B: is perpendicular to cb (/ad) for l_{cb}(/l_{ad}) : $e_{cb} = e_{ad} = 0$

Voltage of a loop in a uniform magnetic Field

Induced Voltage:

$e_{ind,loop} = e_{ba} + e_{cb} + e_{dc} + e_{ad} = 2\mathbf{v\ B\ l\ sin\theta_{ab}}$

$v = r\omega$, $\theta_{ab} = \omega t$ (rotating loop) $\Rightarrow$ **$e_{ind,loop} = 2\ r\omega\ B\ l\ \sin \omega t$**

Loop Area: $A = 2\ r\ l$ $\Rightarrow$ **$e_{ind,loop} = A\ B\ \omega \sin \omega t$**

$\varphi_{max} = A\ B$ $\Rightarrow$ **$e_{ind,loop} = \varphi_{max}\ \omega \sin \omega t$**

$\Downarrow$

Sinusoidal Induced voltage with a magnitude that depends on machine flux, and speed of rotation (similar to real AC machines)

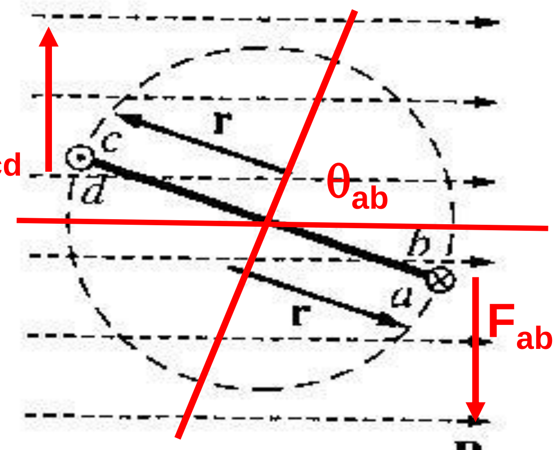
Think about: what happens if the loop (coil) is constant and flux rotates!!

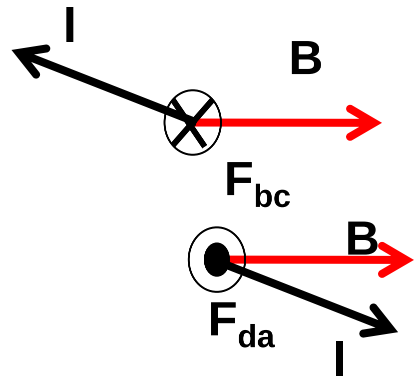
what happens if we had several coils located in different positions while flux rotates!!!

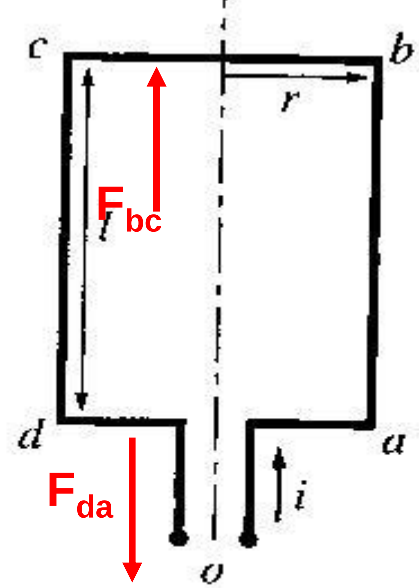
Torque of a loop in a uniform magnetic Field

Induced torque in a current-carrying loop:

current-carrying loop in a uniform magnetic field (not the case in real AC motors)







current-carrying conductor in a magnetic field : Force (/torque)

$$\mathbf{F} = i(\,\mathbf{l} \times \mathbf{B}\,)$$

$\mathbf{l} \times \mathbf{B}$: is perpendicular to the surface including conductor ba(/dc) and B :

$F_{ab} = -F_{cd} = i\, l_{ab}\, B$ (can produce torque)

$\mathbf{l} \times \mathbf{B}$: is perpendicular to the surface including conduct cb(/da) and B :

$F_{bc} = -F_{da} = i\, l_{bc}\, B$ (no torque)

Torque of a loop in a uniform magnetic Field

Induced torque :

$F_{ab} = -F_{cd} = i\ l_{ab}\ B \Rightarrow \Gamma_{ab} = \Gamma_{cd} = r\ i\ l\ B \sin\theta_{ab}$

$\Gamma_{ind,loop} = \Gamma_{ab} + \cancel{\Gamma_{bc}} + \Gamma_{cd} + \cancel{\Gamma_{da}} = 2\ r\ i\ l\ B \sin\theta_{ab}$

Alternative way to present torque:

$B_{loop} = \mu i / G$, G (in general a function of the geometry of the loop)

Loop Area: $A = 2\ r\ l$, replacing for i: $\Rightarrow \Gamma_{ind,loop} = AG/\mu\ B_{loop}\ B_s \sin\theta_{ab}$

B_s is stator flux density (B)

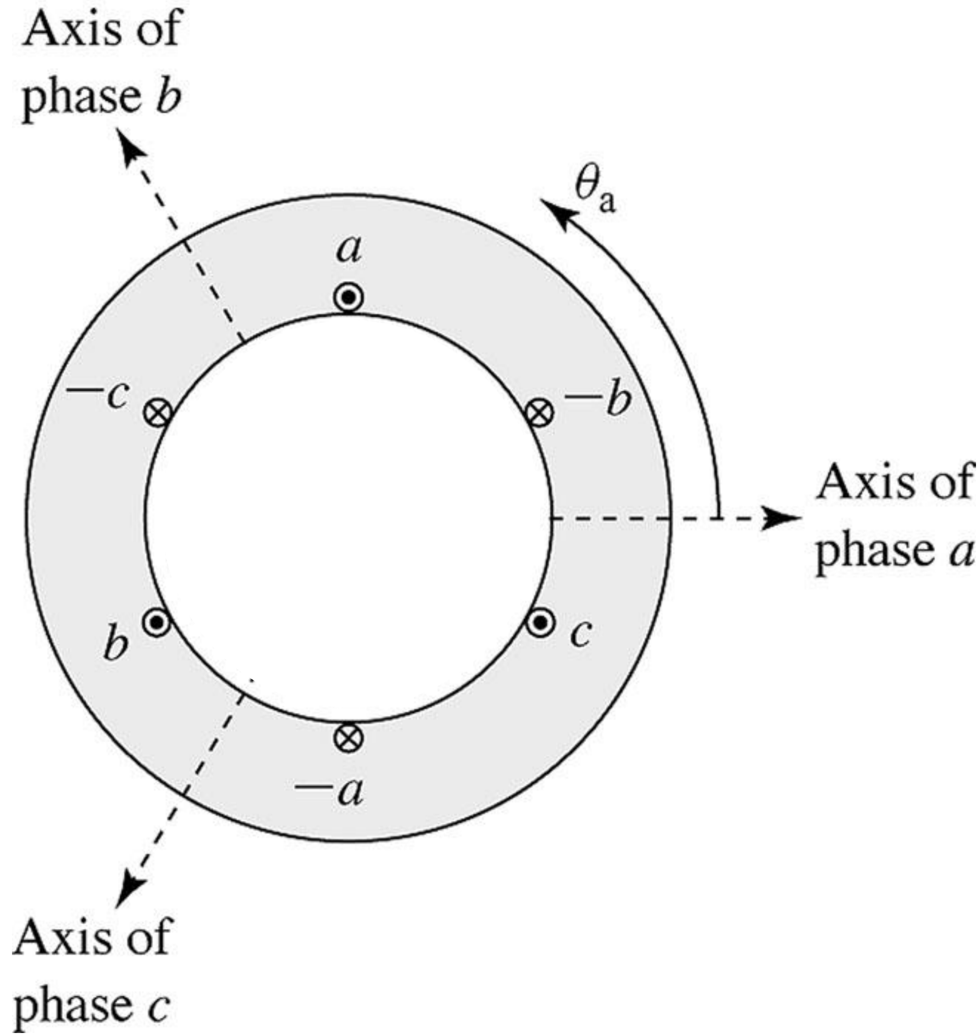
$$\Gamma_{ind,loop} = k\ B_{loop}\ B_s \sin\theta_{ab}$$

- **Induced torque depends on rotor magnetic field, stator magnetic field and the angle between them, plus a constant coming from the machine geometry.**
- **Induced torque intends to align the magnetic fields**

What is the conditions to have a constant torque while rotor is rotating !!

Rotating magnetic field

While rotor is rotating to have a constant torque stator magnetic field should rotate!!



Solution1: Three phase winding conducting three phase current

$I_{aa'} = I_m \cos\omega t$

$I_{bb'} = I_m \cos(\omega t - 120^o)$

$I_{cc'} = I_m \cos(\omega t + 120^o)$

$H_{aa'} = H_m \cos\omega t \angle 0^o$

$H_{bb'} = H_m \cos(\omega t - 120^o) \angle 120^o$

$H_{cc'} = H_m \cos(\omega t + 120^o) \angle -120^o$

Rotating magnetic field

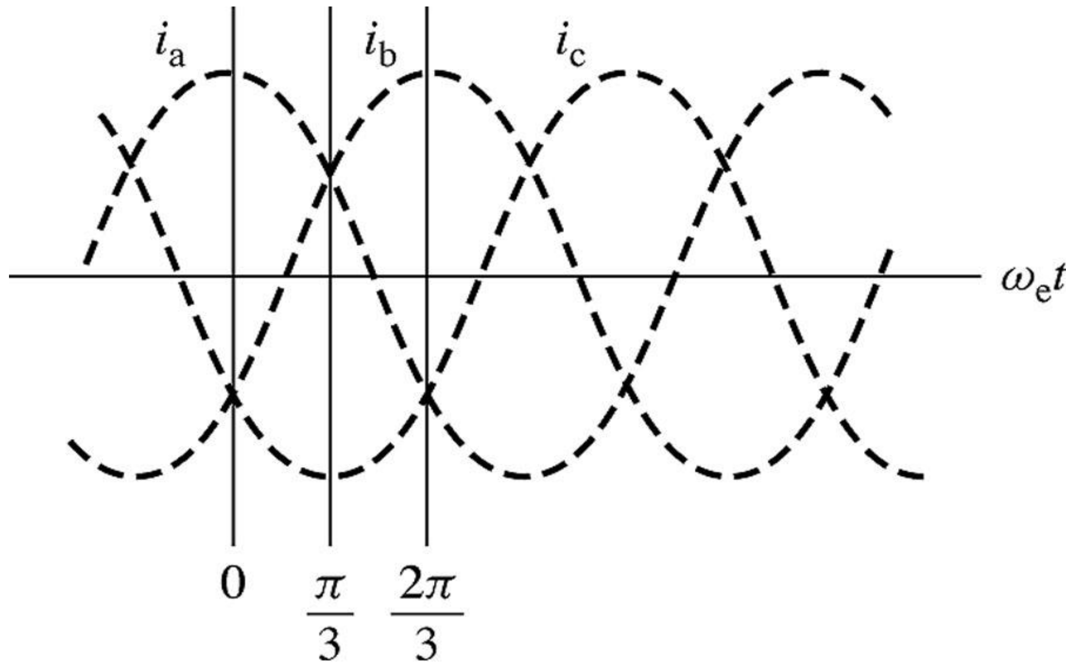
Solution1: Three phase winding

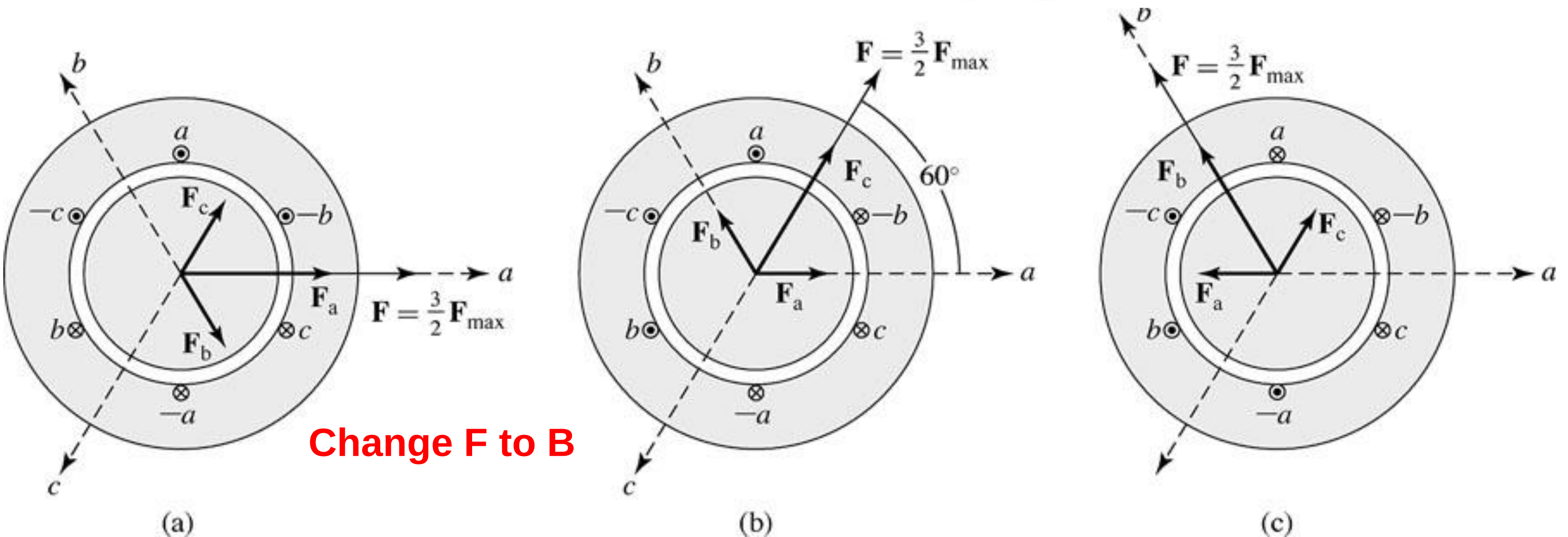
$B_{aa'} = B_m \cos\omega t \angle 0^o$

$B_{bb'} = B_m \cos(\omega t - 120^o) \angle 120^o$

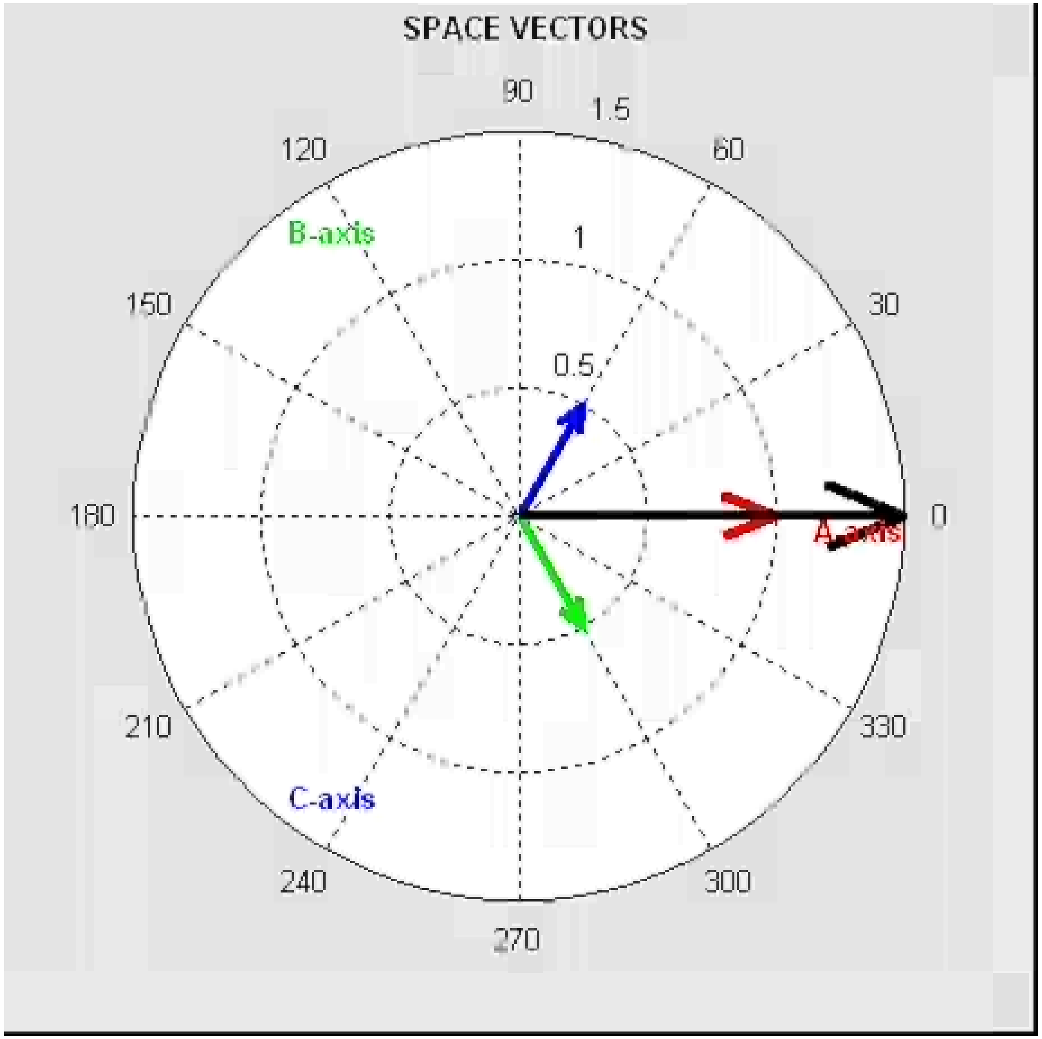
$B_{cc'} = B_m \cos(\omega t + 120^o) \angle -120^o$

$B_{s,net} = B_{aa'} + B_{bb'} + B_{cc'}$





Change F to B



Thanks to Dr Mahmoud Riaz from University of Minnesota

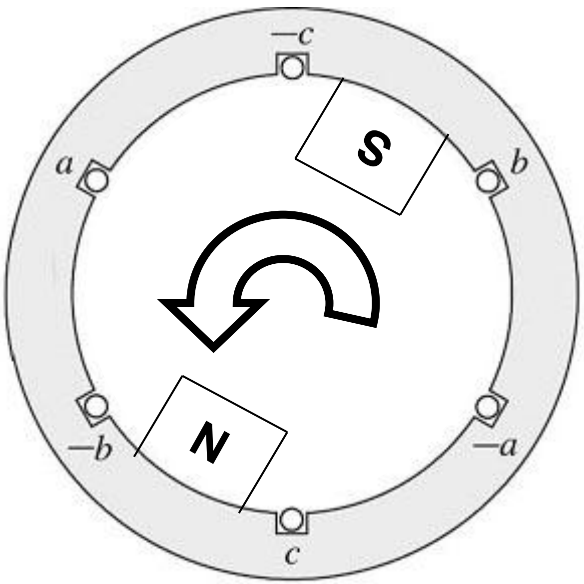
Effect of pole-pairs in magnetic field rotation speed

In 2 poles machines magnetic field rotates once every period of current:

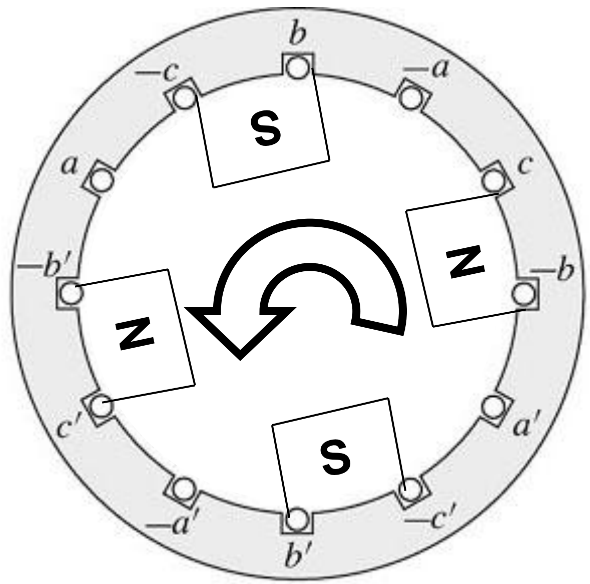
$\omega_e = \omega_m$ (ω_e frequency of current, ω_m frequency of rotation of magnetic field)

In 4 poles machines magnetic field rotates once every two period of current:

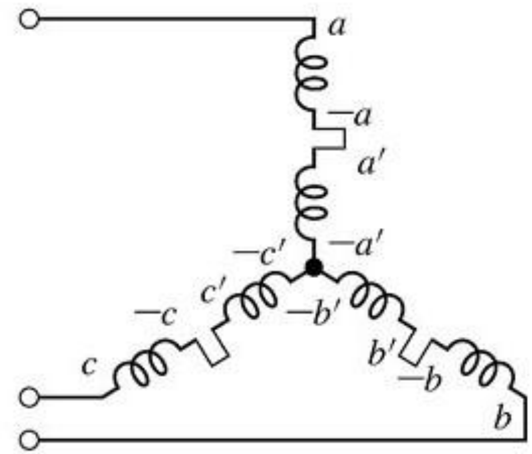
$\omega_e = 2\omega_m$



2 poles



4 poles



Winding connection

In general: $\omega_e = \dfrac{p}{2}\omega_m$ $\qquad \theta_e = \dfrac{p}{2}\theta_m$ $\qquad n_m = \dfrac{120 \times f_e}{P}$

P: Number of poles