Energy conversion I

Lecture 11:

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

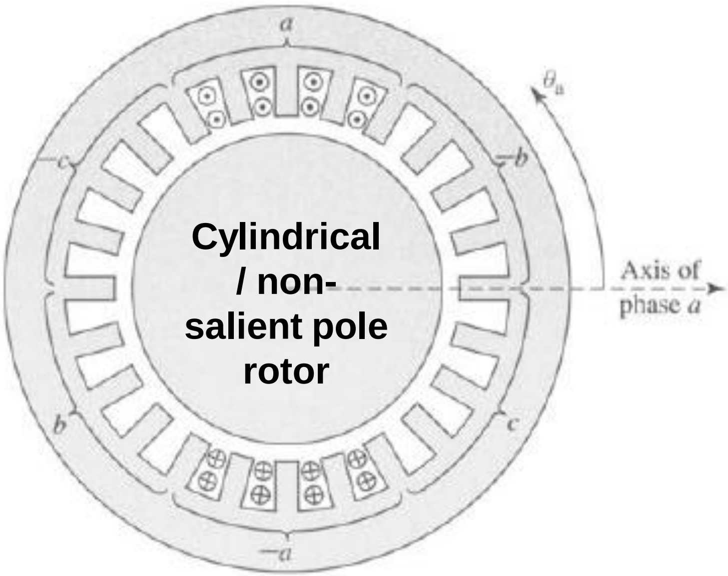
Real AC machine

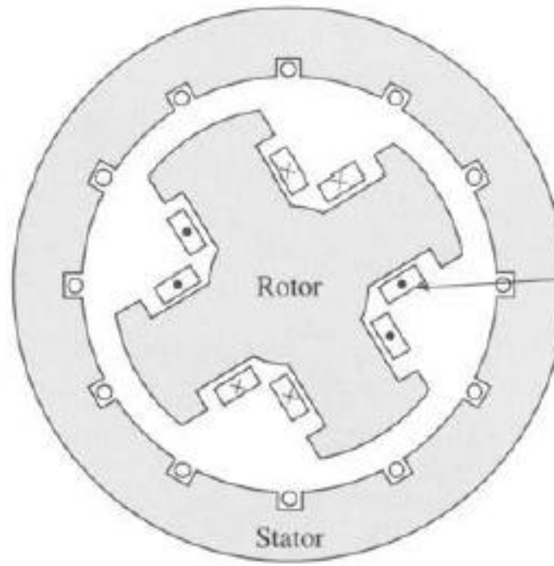
In real **AC** machines flux behavior is different due to:

Ferromagnetic rotor in the **center** of the machine (**Salient** / non-salient)

Flux density(**B**) is **perpendicular** to the **rotor** and **stator** (**Radial Flux**)

Therefore: **V and B are perpendicular**!

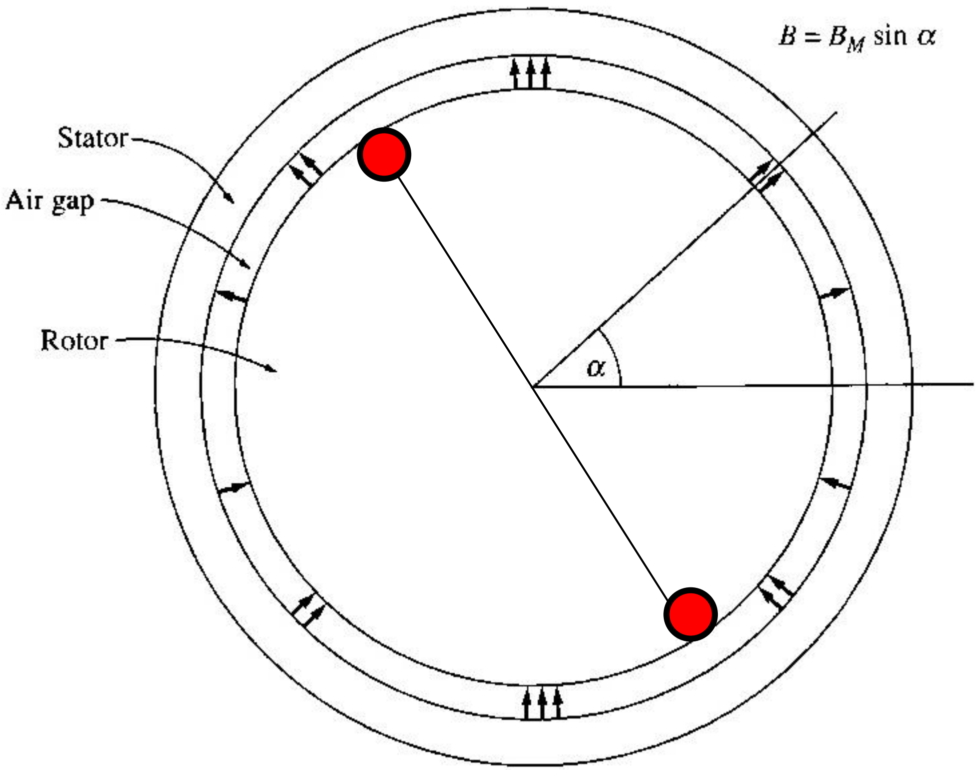




In this case to produce **sinusoidal voltage,** the magnitude of the **flux density vector** must vary in a **sinusoidal** manner**.**

Cylindrical AC machine

Induced **sinusoidal voltage** needs **sinusoidal flux density.**



$(V \times B) \bullet l = V B_M \sin\alpha\, l$

$\alpha = \omega t$

$e_{ind,loop} = \varphi_{max}\, \omega \sin \omega t$

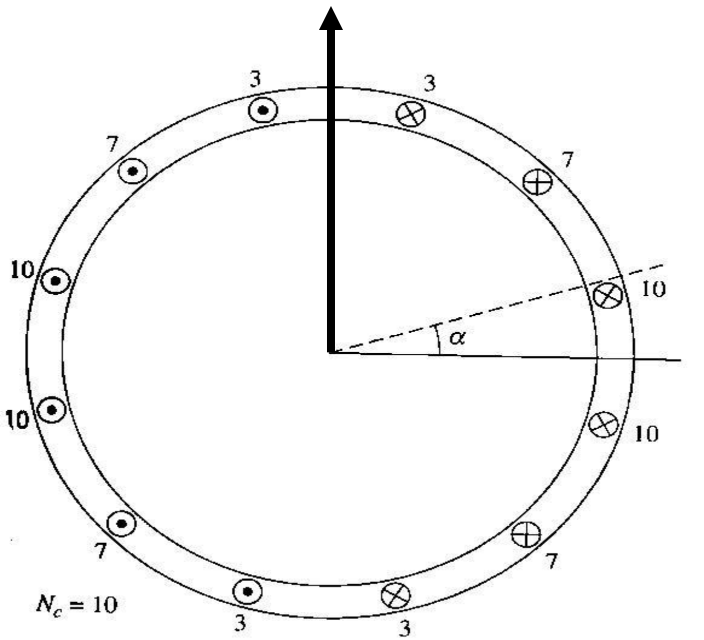
Sinusoidal induced voltage

In **cylindrical rotor** machines **reluctance** of the air-gap is **constant.**

Sinusoidal flux density can be produced by **sinusoidally distributed magnetic intensity (H) / sinusoidaly distributed mmf**

Sinusoidal MMF in AC machines

sinusoidally distributed mmf needs **sinusoidally distributed conductors!!**

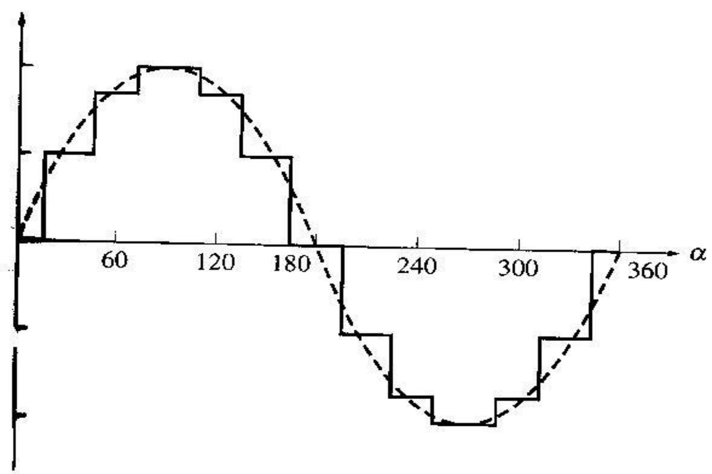


$n_c = N_c/2 \cos \alpha$
Nc: Number of coils

Practically impossible!

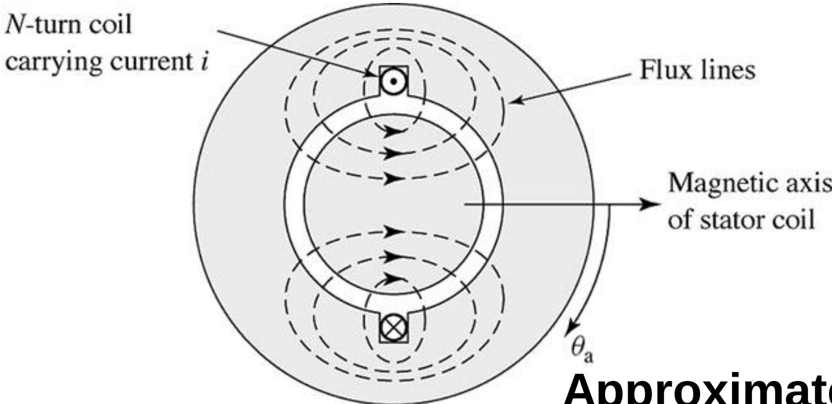
More Practical:

Different number of conductors in slots!

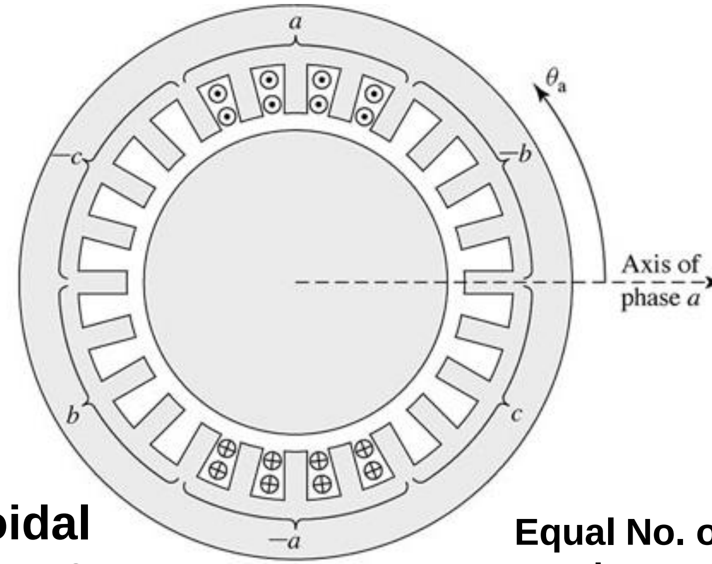


MMF in practical AC machines

Two type of windings: concentrated windings**, distributed** winding

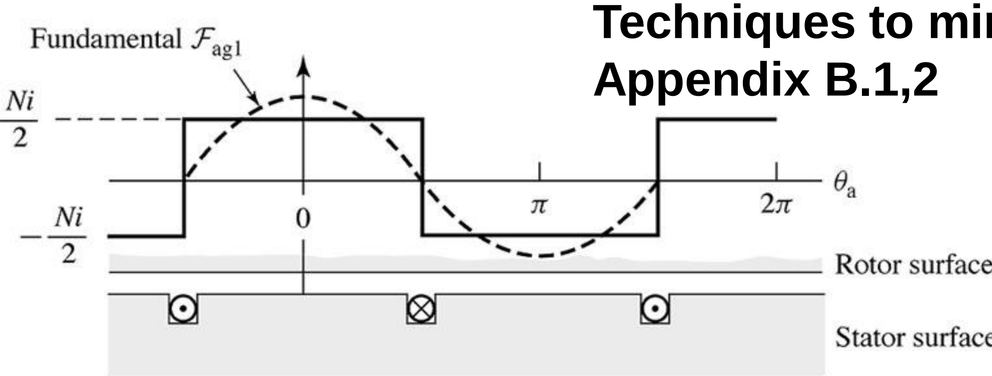


(a)

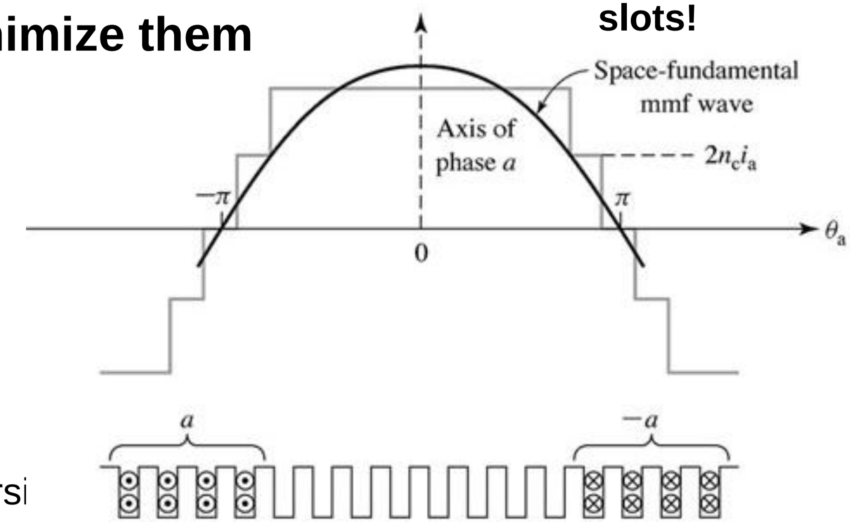


Approximately Sinusoidal
Higher order harmonics &
Techniques to minimize them
Appendix B.1,2

Equal No. of conductors in slots!



(b)

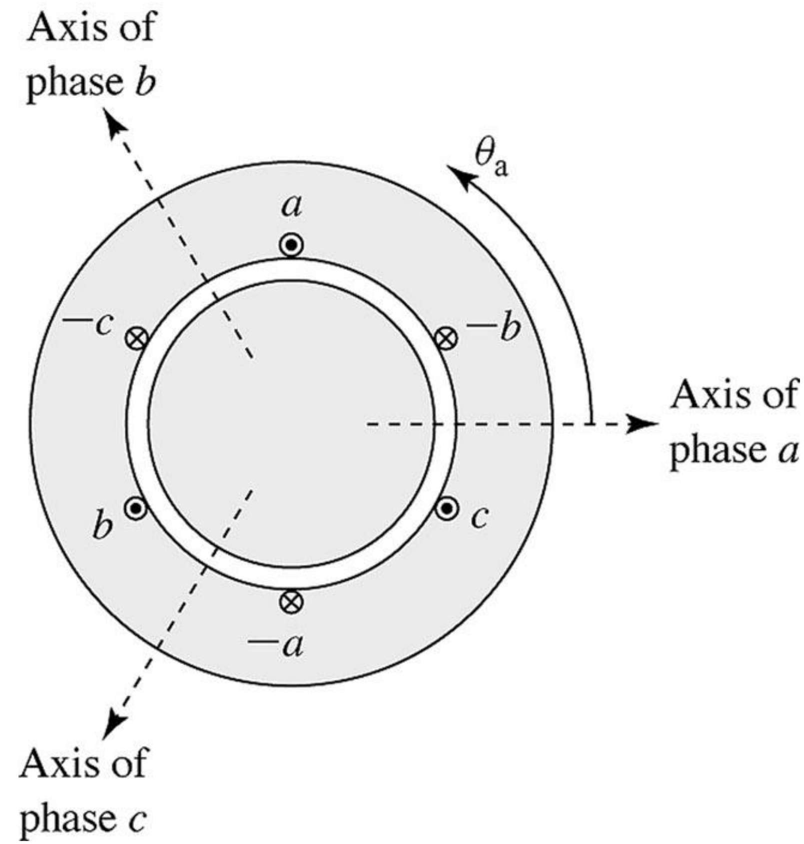


(b)

MMF in 3 phase AC machines

Using first harmonic approximate of the MMF

Having three phase windings displaced 120º



$F_{aa'} = F_a \cos\theta_a$

$F_{bb'} = F_b (\cos\theta_a - 120^o)$

$F_{cc'} = F_c (\cos\theta_a + 120^o)$

$F_a = N_{se}/2\ I_a,\ F_b = N_{se}/2\ I_b,\ F_c = N_{se}/2\ I_c$

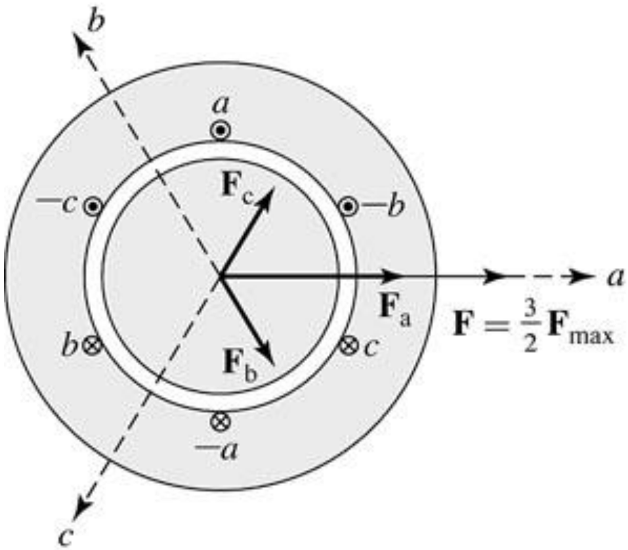
$I_{aa'} = I_m \cos\omega t$

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

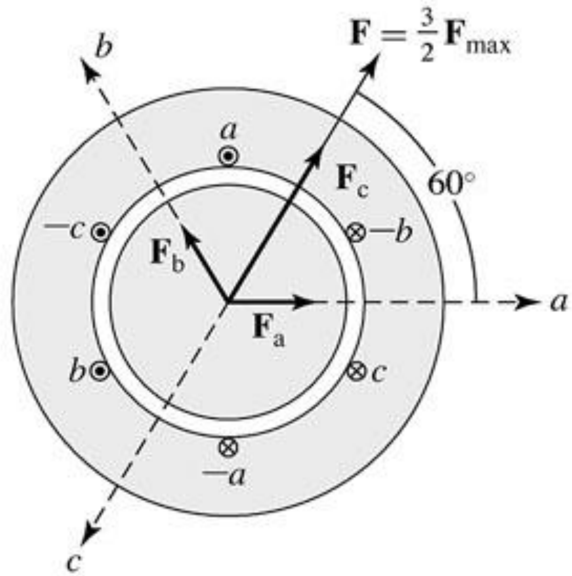
$I_{cc'} = I_m \cos(\omega t + 120^o)$

$F = F_{aa'} + F_{bb'} + F_{cc'} = 3/2 \times N_{se}/2 \times I_m \cos(\omega t - \theta_a)$ **: Sinusoidally distributed rotating MMF**

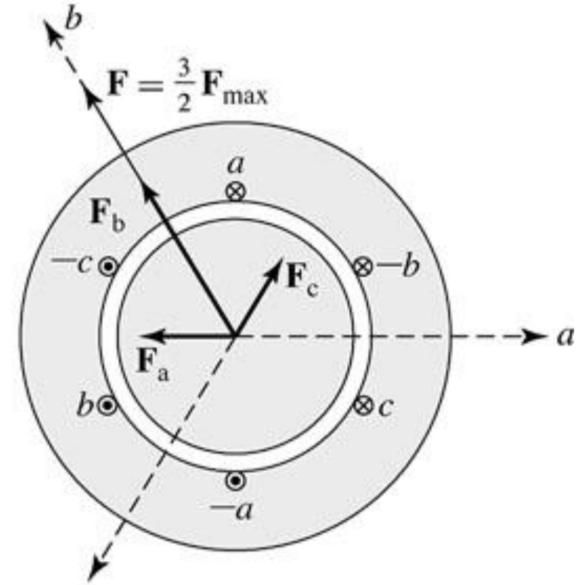
Rotating magnetic field



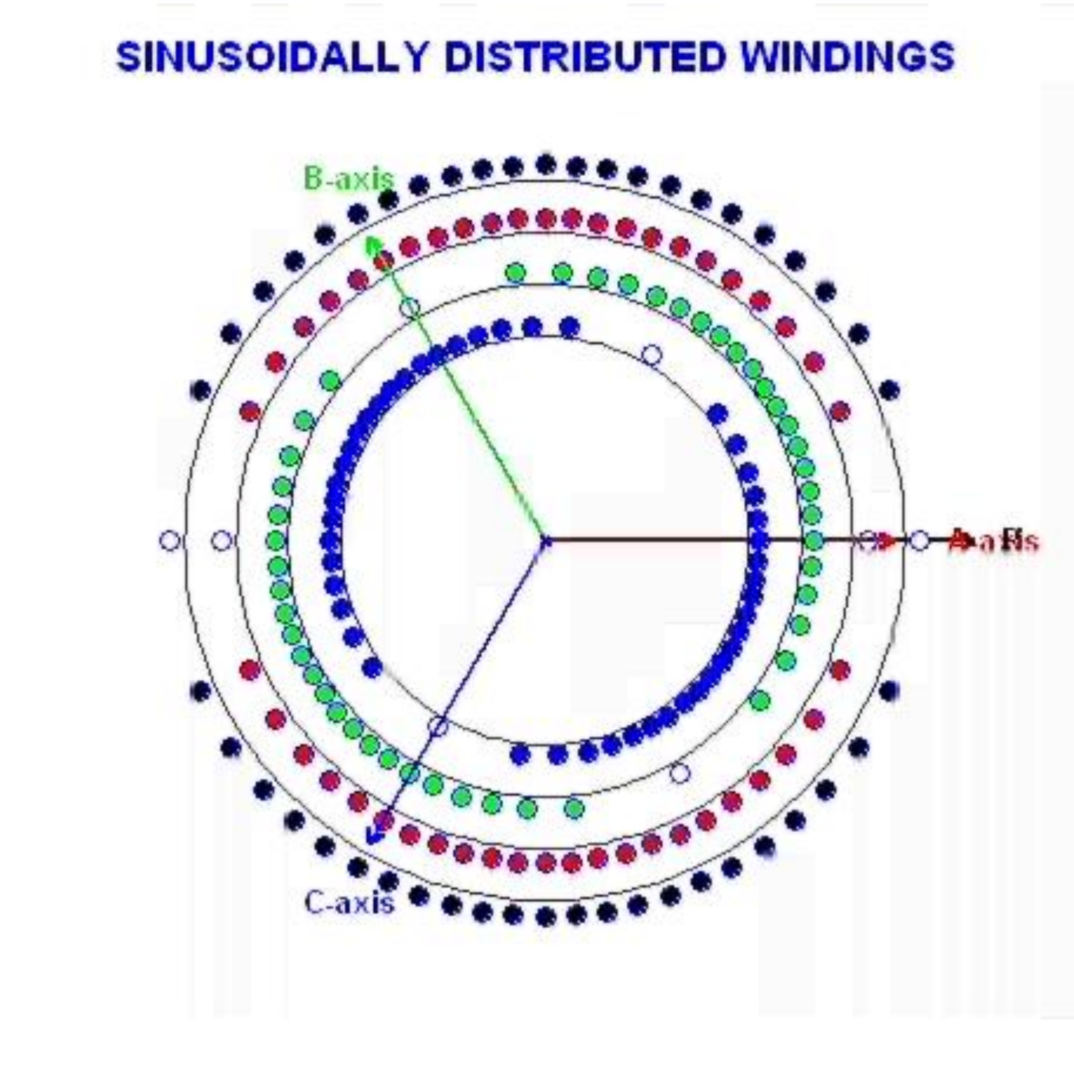
$\omega t = 0^o$



$\omega t = 60^o$

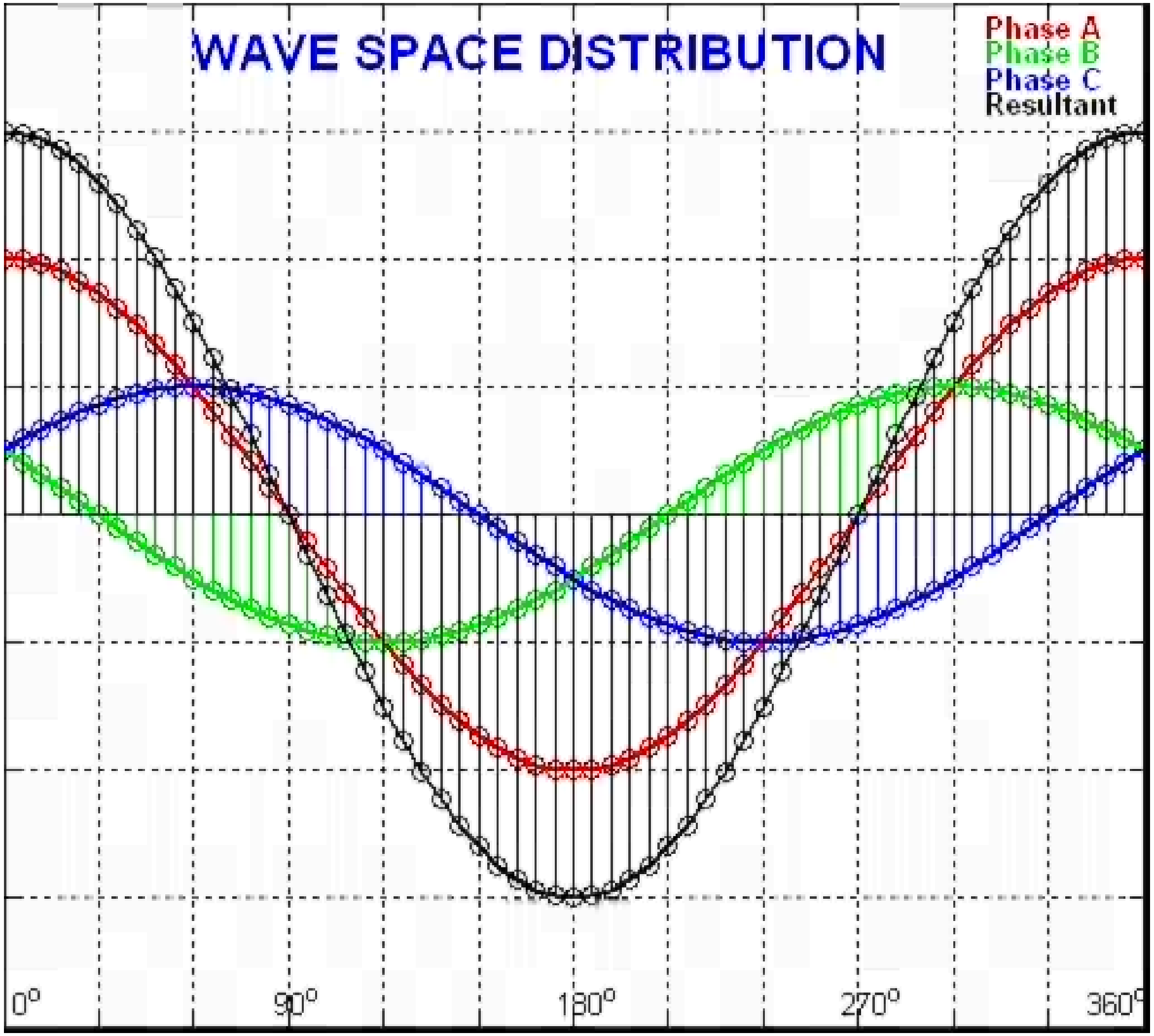


$\omega t = 120^o$

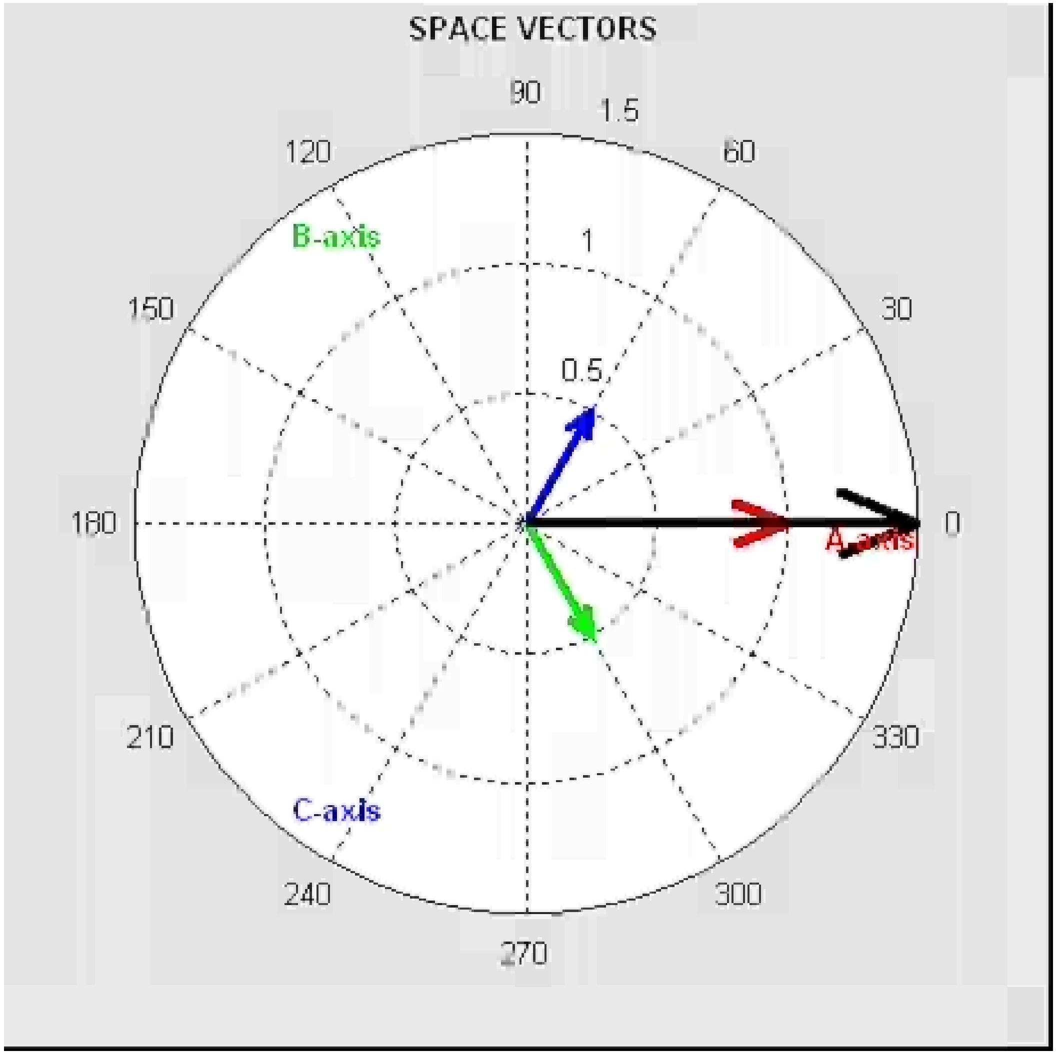


Thanks to Dr Mahmoud Riaz from University of Minnesota

Sinusoidal space distributions of MMF under balanced three-phase excitation



Motion of space vectors in a three-phase excitation system



Induced voltage due to rotating flux

<u>Rotating magnetic flux</u> in the air gap induces voltage in the stator coils

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

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

B: Sinusoidally distributed rotating flux density

B: radial

V is perpendicular to B

$\mathbf{V} \times \mathbf{B} = \mathbf{VB}$ **in the direction of ba(/dc) for** $\mathbf{l_{ba}}(/\ \mathbf{l_{dc}})$

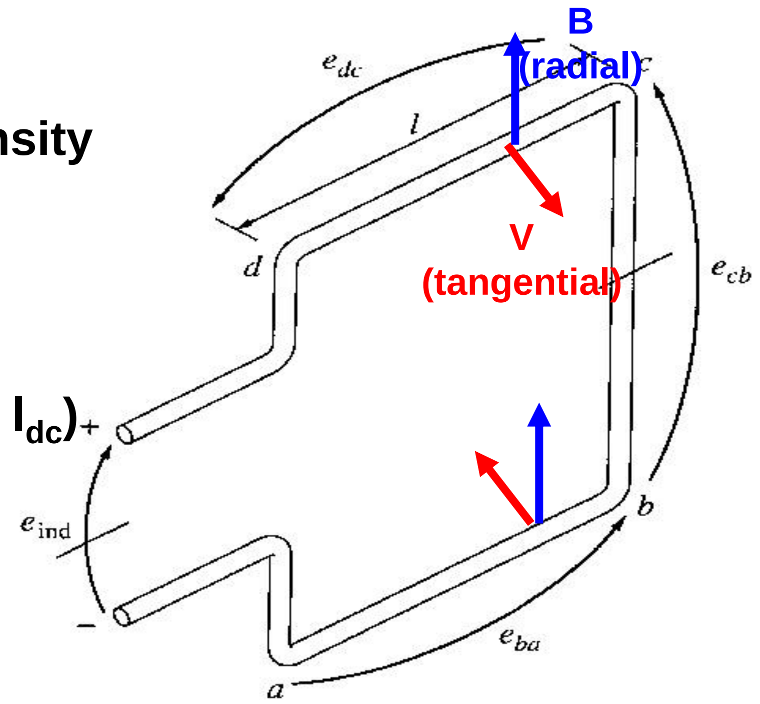
$\mathbf{B = B_M \cos(\omega t - \theta_a)}$

$e_{ba} = e_{dc} = \mathbf{v\, l\, B_M \cos(\omega t - \theta_a)}$ **!!**

$\mathbf{V} \times \mathbf{B}$**: cb (/ad) for lcb(/lad) : ecb = ead = 0**

$e_{ind,loop} = 2\mathbf{v\, l\, B_M \cos(\omega t - \theta_a)}$

$\mathbf{v = r\omega}$: $e_{ind,loop} = 2\mathbf{r\omega\, l\, B_M \cos(\omega t - \theta_a)}$



(a)

θ_a : angle between coil and phase a axis

How it modifies if the coil is rotating!!