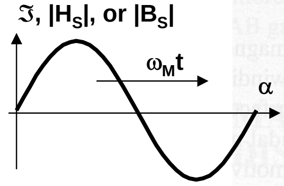
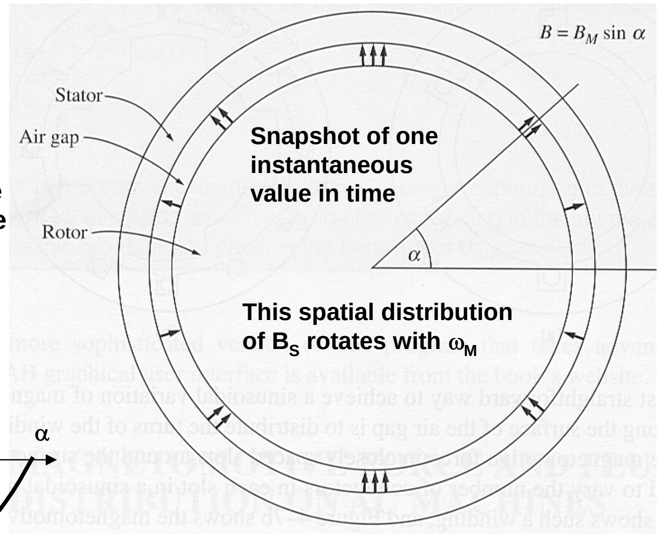
Magnetomotive Force and Flux Distribution

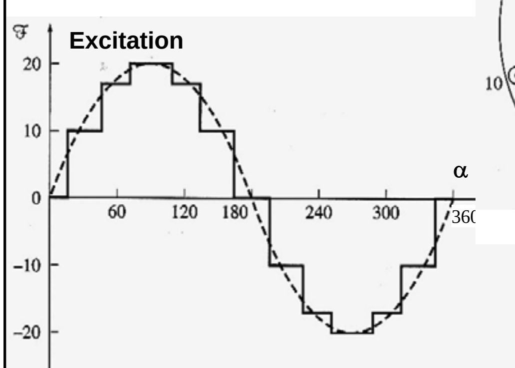
- **The magnetic field used to induce sinusoidal voltages (in the stator) has to be distributed sinusoidal along the circumference of the stator/rotor (air gap)**

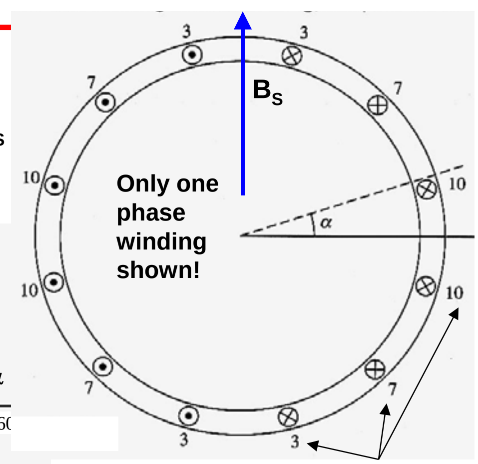




Practical Winding Considerations

- **Distributed stator winding with varying number of turns per slot**
- **Generates space harmonics of B_S (can be reduced by more slots and/or fractional-pitch windings)**





Number of turns per phase and slot vary, total number of turns per slot stay constant

Induced Voltage in Stator Loop – 2 Poles

- **Rotor field B_R rotates CCW with $\omega_M t$ => equivalent to conductors moving through $\vec{B}$ with velocity $\vec{v}$**

$$e_{ind} = \left(\vec{v} \times \vec{B}\right) \cdot \vec{l} \qquad |\vec{v}| = \omega_m r$$

Rotor system

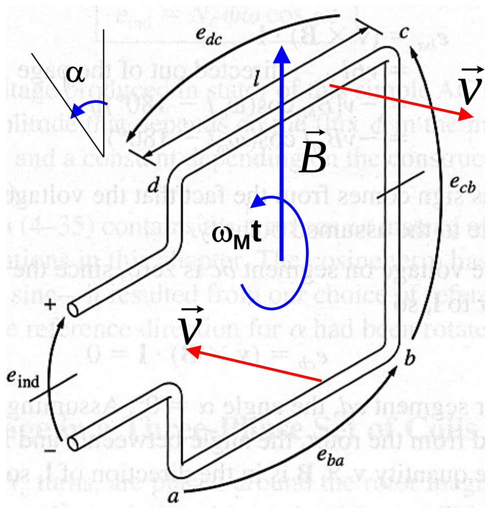
$$B = B_M \cos(\alpha)$$

Stator system

$$B = B_M \cos(\omega_m t - \alpha)$$

- **With sinusoidal field distribution the total induced voltage becomes**

$$e_{ind} = 2rl\omega_m B_M \cos(\omega_m t)$$



Induced Voltage in Stator Coil – 2 Poles

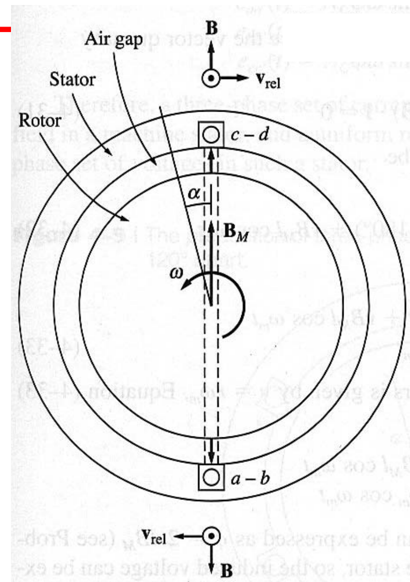
- **With total flux passing through a full stator conductor loop**

$$\phi = 2rlB_M$$

$$e_{ind} = \phi\,\omega_m \cos(\omega_m t)$$

- **For an entire winding with N_C turns the induced voltage becomes**

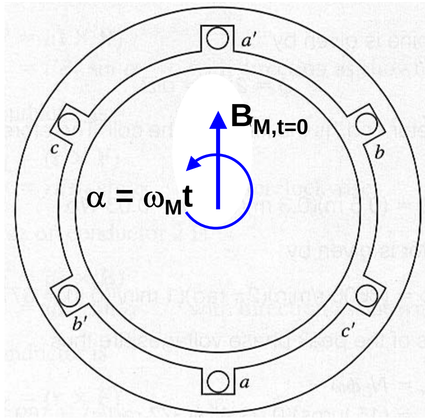
$$e_{ind} = N_C \phi\,\omega_m \cos(\omega_m t)$$



Induced Voltage in Three Stator Coils

- **In a set of three windings spatially displaced by 120°**

$$E_M = N_C \phi \omega$$
$$e_{aa'}(t) = E_M \cos(\omega t)$$
$$e_{bb'}(t) = E_M \cos(\omega t - 120°)$$
$$e_{cc'}(t) = E_M \cos(\omega t - 240°)$$



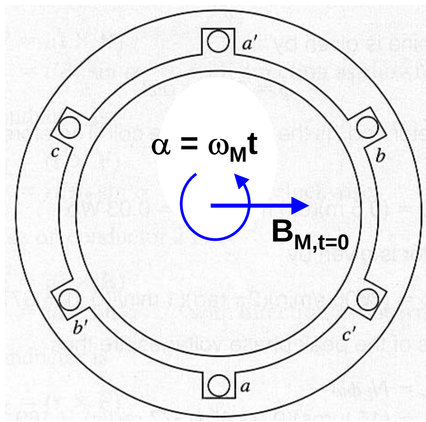
- **The per-phase RMS voltage becomes**

$$E_{\phi,RMS} = \frac{E_M}{\sqrt{2}} = \frac{N_C \phi 2\pi f}{\sqrt{2}} = \sqrt{2}\pi N_C \phi f = 4.44 N_C \phi f$$

Induced Voltage in Three Stator Coils – sin(ωt) Reference (corresponding to book)

- **In a set of three windings spatially displaced by 120°**

$$E_M = N_C \phi \omega$$
$$e_{aa'}(t) = E_M \sin(\omega t)$$
$$e_{bb'}(t) = E_M \sin(\omega t - 120°)$$
$$e_{cc'}(t) = E_M \sin(\omega t - 240°)$$

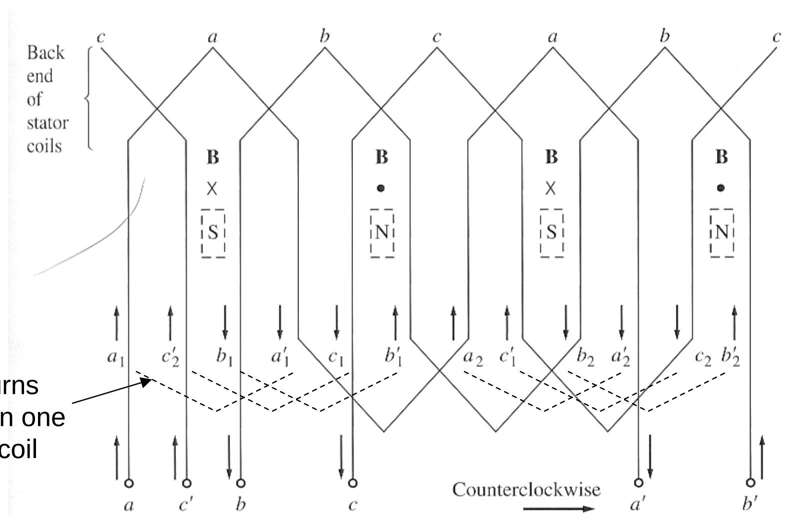


- **Whether sin(ωt) or cos(ωt) only depends on the chosen reference at t=0**

Example 4-2 (Book)

- **Additional questions**
  - d) What is the induces RMS voltage of this machine in Europe (50 Hz)?
  - e) Discuss the design of this machine for a 4-pole configuration (same power frequency and voltage). Which parameters will change?

4-pole Winding Arrangement



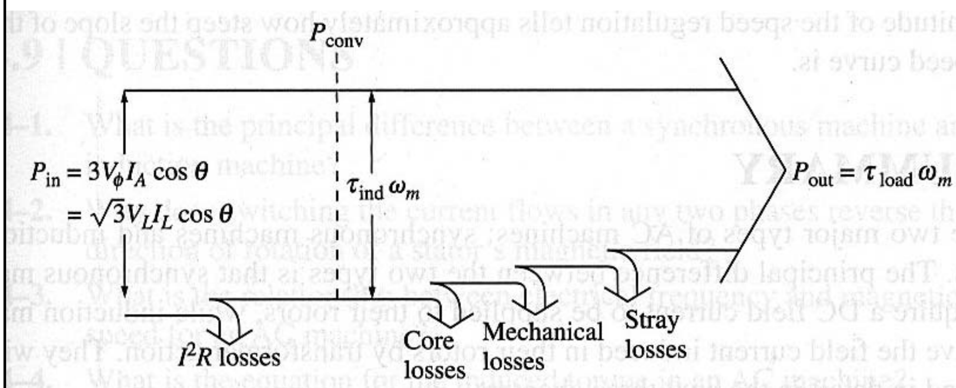
Returns within one sub-coil

Example 4-2 (Book)

- **Additional questions**
  - d) $E_{\phi,RMS} = 4.44 N_C \phi f \Rightarrow E_{50Hz} = E_{60Hz}\dfrac{50}{60} = 100 V_{L-N}$

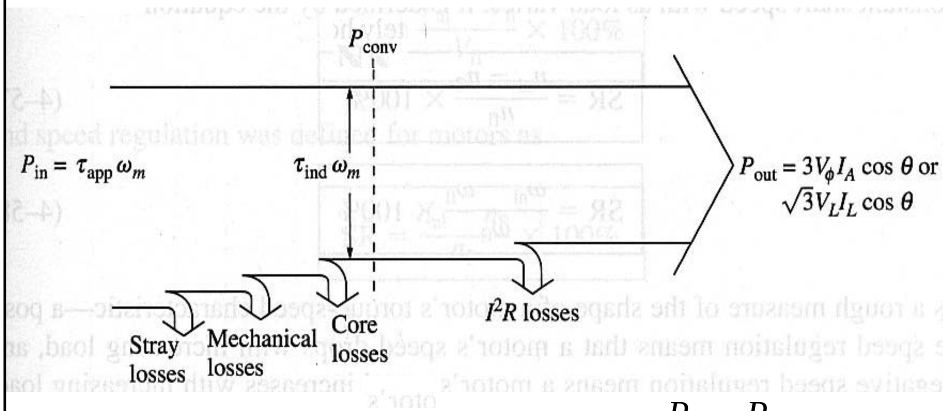
    $n_{50Hz} = n_{60Hz}\dfrac{50}{60} = 3000\, rpm$
  - e) For the same electrical frequency the rotational speed will be 1800 rpm. Keeping the (peak) flux density the same, the flux per pole will remain the same (proof?). However, since the angular (mechanical) frequency is reduced by 50%, the voltage per sub-winding will only be half of the voltage before. The two sub-windings are connected in series finally resulting in the same total voltage as before.

AC Machines Power Flows - Motor



$$\eta = \frac{P_{out} - P_{in}}{P_{in}}$$

AC Machines Power Flows - Generator



$$\eta = \frac{P_{out} - P_{in}}{P_{in}}$$

HW5

- **Problems 4-2, 4-3, 4-5**