AC Machine

AC machines : generators that convert mechanical energy to AC electrical energy and motors that convert AC electrical energy to mechanichal energy
- field circuits are located on their rotors

Classes of AC Machine

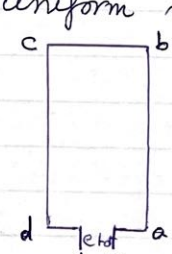
- Synchronous
  - ▷ Magnetic field current is supplied by a separate DC power source

- Induction
  - ▷ Magnetic field current supplied by magnetic Induction into their field windings (transformer Action)

Sinosoidal AC Voltage

To produce a sinusoidal AC voltage:-

Rotating ↳ A loop of wire is put in a uniform magnetic field



The rotating part is the rotor
The stationary part is the Stator

The rotation will enduce a voltage in the wire loop. = $(e_{ind})_{total}$

Velocity → إبهام!

Magnetic field → سبابة

e → الوسطى

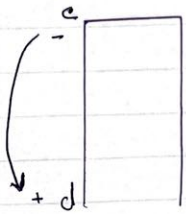
②

① Segment cd

Between V, B

$(e_{ind})_{cd} = (\vec{V} \times \vec{B})\, l = VBl \sin\theta_{cd}$

out of page



لما نلف الـ wire
تتقطع خطوط
المجال وبالتالي
بينشأ عنا فرق
جهد وتيار

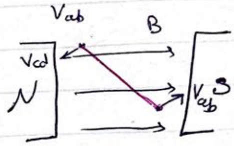
② segment ab:

اليمين

Beetween V, B

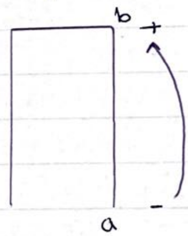
$e_{ab} = VBl \sin\theta_{ab}$

الأعلى



So $(e_{ab})_{ind}$ is into the page → so positive polarity

③ segment ad, cb



$e_{bc} = e_{ad} = 0$

l, $V \times B$ are perpendicular and so

$e = 0$

Total $e = e_{ab} + e_{cd} + e_{ad} + e_{cb}$

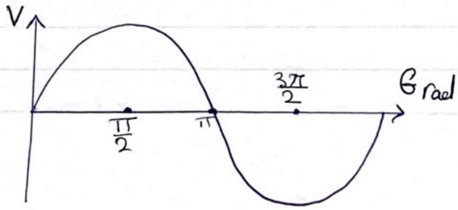
$= 2\,VBl\,(\sin\theta_{ab} + \sin\theta_{cd})$

$\theta_{ab} + \theta_{cd} = 180 \longrightarrow \sin\theta_{ab} = \sin(180 - \theta_{cd})$

$\sin\theta_{ab} = \sin\theta_{cd} = \sin\theta$

$e_{tot} = 2VBl \sin\theta$

Sinosoidal Voltage



Area of loop = $2rl = A$
Rotational Speed = ω = constant

so $\theta = \omega t$

We know that V is tangential

so $V = r\omega$

so $e_{ind} = 2VBl \sin\theta = 2(r\omega)Bl \sin\omega t$

$= 2r\,\omega Bl \sin\omega t$

$= \underbrace{AB}_{\phi_{max}}\,\omega \sin\omega t$

$= \phi_{max}\,\omega \sin\omega t$

so e_{ind} depends on
- l, Mater: Machine constants (Geometry)
- V : Speed of rotation
- B : flux level

loop with a Passing Current

- IF a current is Passing through the loop, a Force will appear on the segments

$$F = i\,(l \times B)$$

$$\tau = r F \sin\theta$$

Between r and Force

⊙ (داخل) خارج منحني

⊗ جاي لعندي

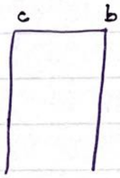
Magnetic field → سبابة
current → وسطى
result (F) → إبهام

① Segment ab

$F = i l B$ down

$\tau_{ab} = F\, r\, \sin\theta_{ab}$ → clock wise

② segment bc



$F = i\,(l)\,B$
into the page

r, l are parallel so $\tau = 0$

③ segment cd

$F = ilB$ up

$\tau_{cd} = F\, r\, \sin\theta_{cd}$ → Clockwise

④ Segment da
$F = i l B$ out of page
$\tau = 0$

$$\tau_{total} = \underbrace{2ril}_{A} B_s \sin\theta$$

B_s : $\Rrightarrow$ Stator Magnetic field

$$\theta_{ab} = \theta_{cd} = \theta$$

τ → max : plane of loop parallel to B

τ → zero : plane of loop perpendicular to B

$A = 2rl$

- The current passing through loop generates a magnetic field :-

$B_{loop} = \frac{\mu i}{G}$ — G: factor depends on geometry of loop

Assuming $K = \frac{AG}{\mu}$ =

- $\tau = \boxed{(A)\left(\frac{G}{\mu}\right.} \underbrace{\left. B_{loop}\right) (B_s) \sin\theta}$

So $\tau = K(\vec{B}_{loop} \times \vec{B}_s)$

τ affected by
- Strength of rotor magnetic field
- " " Stator " "
- Angle Between B_s, B_{loop}
- Machine constants

The Rotating Magnetic field

→ When the stator magnetic field is rotated, torque will cause the rotor to chase the rotating stator magnetic field (wire is stationary)

How to create a rotating stator magnetic field?

→ 2 . Pole Winding

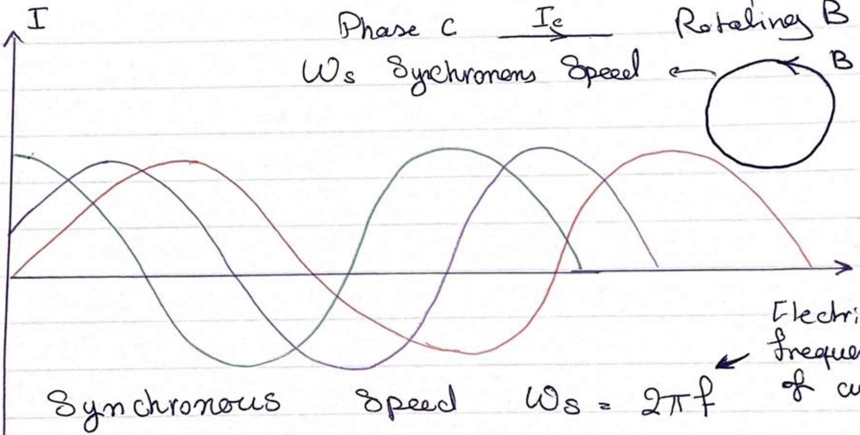
- A three phase windings (120° between each two) is used

Phase a $\xrightarrow{I_a}$

Phase b $\xrightarrow{I_b}$ → محصلة لعزم

Phase c $\xrightarrow{I_c}$ Rotating B

ω_s Synchronous Speed ←



Electrical frequency of current

Synchronous speed $\omega_s = 2\pi f$

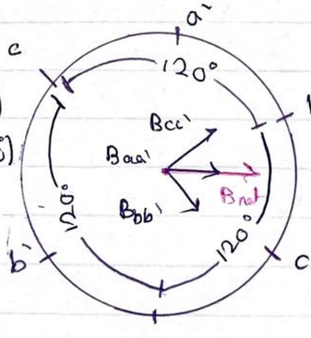
يعني متزامنة مع تردد التيار f

- Magnitude of B is constant and Rotating

$i_{aa'} = I_M \sin \omega t$

$i_{bb'} = I_M \sin(\omega t - 120°)$

$i_{cc'} = I_M \sin(\omega t - 240°)$



$H_{aa'} = H_M \sin \omega t \angle 0°$

$H_{bb'} = H_M \sin(\omega t - 120°) \angle 120°$

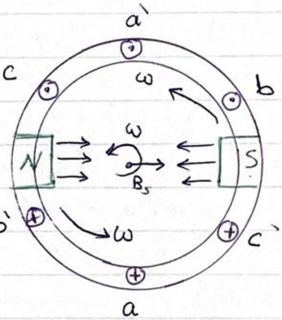
$H_{cc'} = H_M \sin(\omega t - 240°) \angle 240°$

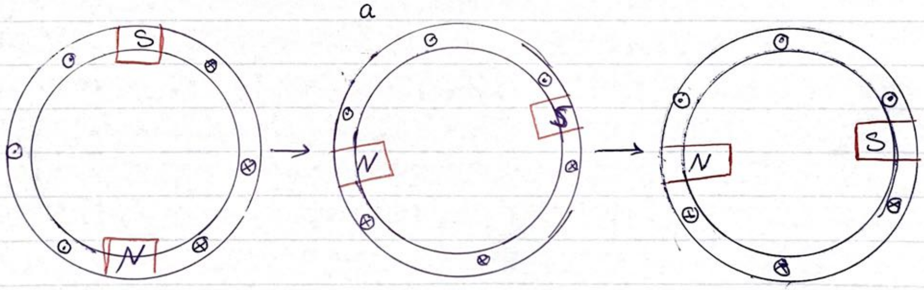
Resultant

Remember:-
$B_M = \mu H_M$

$B_{aa'}(t) = B_M \sin \omega t \angle 0^\circ$
$B_{bb'}(t) = B_M \sin(\omega t - 120^\circ) \angle 120^\circ$
$B_{cc'}(t) = B_M \sin(\omega t - 240^\circ) \angle 240^\circ$

$B_{resultant} = B_{aa'} + B_{bb'} + B_{cc'}$
if $\omega t = 180^\circ$ $\quad B_{net} = \boxed{1.5\, B_M} \angle 90$
if $\omega t = 0^\circ \longrightarrow B_{net} = \boxed{1.5\, B_M} \angle -90^\circ$
if $\omega t = 90^\circ \longrightarrow B_{net} = \boxed{1.5\, B_M} \angle 0^\circ$
if $\omega t = 270$ $\quad B_{net} = \boxed{1.5\, B_M} \angle 180$
constant





→ 4 Pole winding Speed $= \frac{1}{2}$ (2 Pole winding)

$$\omega_s = \frac{4\pi f}{P} = \frac{4\pi f}{4} = \pi f$$

number of Poles

In Motors: $2 \leq \text{Poles} \leq 14$ But no more due to the space (limited)

$$f_e = \frac{n_m P}{120}$$ n: number of rotation

Generally Speaking

Mechanical speed for rotor

$$\omega_e = \frac{P}{2} \omega_m$$

$\omega_m = 2\pi f_m$, $\omega_e = 2\pi f_e$, f_m : $\underline{RPS} = \frac{n_m}{60}$

$$f_e = \frac{P}{2} f_m$$

$$f_e = \frac{P}{2} \frac{n_m}{60} = \frac{n_m P}{120}$$ ✓

- This result is important since it connects mechanical speed to electrical frequency → rotating magnetic field with produced torque

Note:
A pole moves only half way around the stator surface in one electrical cycle

$$\text{So} \rightarrow \underset{360°}{\theta_{se}} = \underset{180°}{2\theta_{sm}}$$

Reversing Direction of Magnetic field rotation

To reverse direction of rotation we swap 2 out of 3 coils in the rotor

Magnetomotive force and flux distribution on AC machines

Rotor

- cylindrical
  non salient pole
- salient pole
  pole faces projecting out from it's surface
  → larger air gap.

Induced Voltage in AC machines (Real life)

* e_{ind} equation does not apply for rotating Magnetic field

* to apply it, we need to be in a frame of reference where the magnetic field appears to be stationary ⟶ we sit on the magnetic field
sides of the coil will appear to go by V_{rel}

$e_{ind} = e_{ba} + e_{dc} = 2VB_M\, l \cos \omega_m t$
↳ on stator (Windings) on each winding and phase shift of 120° between them.

$V = r\omega_m$

$\phi = 2rlB_m$

$e_{ind} = \phi\, \omega \cos\omega t$

Taking number of turns of windings

$e_{ind} = N_c K \phi\, \omega \underbrace{\cos \omega t}_{\text{same as } \sin \omega t}$

It can be represented as $e_{ind} = N_c K \phi\, \omega \sin \omega t$

$$\left.\begin{aligned} e_{aa'} &= N\phi\,\omega \sin \omega t \\ e_{bb'} &= N\phi\,\omega \sin(\omega t - 120°) \\ e_{cc'} &= N\phi\,\omega \sin(\omega t - 240°) \end{aligned}\right\}$$ constant in magnitude But with phase shift

Sinosoidal Signal

rms Voltage at the 3phase Stator

$E_A = \sqrt{2}\pi N_c \phi$ (line to line)

voltage

Induced torque in AC machines

There are 2 magnetic fields
1. B from rotor circuit } interaction produces the
2. B from Stator circuit } torque in the machine

$$\tau_{indu} = K H_r \times B_s \sin\alpha = K \frac{B_r}{\mu} \times B_s \sin\alpha$$ Between B_r, B_s

$$\boxed{\tau_{ind} = K(B_r \times B_s)}$$ Direction by right hand rule :

$B_{net} = B_r + B_s$ دعك B_s , سابقة B_r ← النتيجة لوا أولا بالتالي

counterclockwise Clockwise

So : $\tau_{ind} = K\ B_r \times (B_{net} - B_s) = K[(B_r \times B_{net}) - 0]$

$$\boxed{\tau_{ind} = K(B_r \times B_{net})} = K(B_r B_{net}) \sin\delta_r$$ Between B_r, B_{net}

Notes:-

$P_{generated}$ by loop → Inst $P(t) = e_{ind}\, i$

→ Avg $P_{avg} = \frac{1}{T}\int_T P(t)\, dt$

$(P_{consumed})_{mechanical} = \tau_{ind}\, \omega$