MACHINES

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POWERUNIT

• Chapter 1

- Machinery :- is the collection of machines that work together in order to compelete a single task or operation.
- Machine :- one machine only.

* The operation of a machine may involve the transformations of energy
- examples :-
  - Chemical energy → mechanical (Internal combustion engines)
  - electrical " → mechanical (motors)
  - Thermal → electrical (solar cells)

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electric machines
- static machines → no movement
  - ex: transformer
- Dynamic machines → mechanical
  - generators → mechanical → electrical
  - motors → electrical → mechanical

The motors move in rotary motion "rotational motion"

θ → Angular position / ω → angular velocity / α → angular acceleration
↳ rad ↳ $rad.s^{-1}$ ↳ $rad.s^{-2}$

I → Moment of inertia : ممانعة الدوران / $\tau = I\alpha$
↳ $kg.m^2$ ↳ Torque $[N.m]$

- Work $= \tau\theta$ joul. rad
- kinetic energy $= \frac{1}{2} I \omega^2$ joul. rad
- Power $= \tau\omega$ → Work مشتقة

- Magnetic Field

Ampere's law

- Current produces a magnetic field in the area around it.
- A time-changing magnetic field induces a Voltage in a Coil of wire if it passes through that coil. → transformer
- A current-carrying wire in the presence of a magnetic field has a force induced on it. → motor
- A moving wire in the presence of a magnetic field has a voltage induced in it → generator

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- Ampere's Law

H → magnetic field intensity

integral over closed surface

$$\oint \vec{H} \cdot d\vec{l} = \Sigma i = \oint H\,dl\cos\theta$$

↳ total currents

l_c → average distance of flux

$H l_c = N i$:- N = # of turns

$$H = \frac{Ni}{l_c}$$

l_c ≡ الطول

$Ni = F$ → Magnetomotive Force

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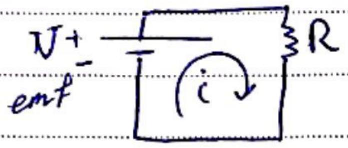
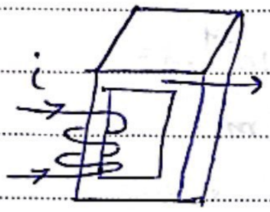


$i = \frac{V}{R}$ → depends on Length, Area, Conductivity

$R\uparrow L\uparrow$ $R\uparrow A\downarrow$ $R\uparrow \sigma\downarrow$

↳ $R = \frac{L}{A\sigma}$



Φ :- flux

$N\uparrow$ $H\uparrow$

$i\uparrow$ $H\uparrow$

$V \equiv mmf = Ni$ → Ampere's law

- reluctance ($\mathcal{R}$) → opposing the passage of magnetic flux.

↳ $\mathcal{R} \propto Lc$, $\mathcal{R} \propto \frac{1}{A}$, $\mathcal{R} \propto \frac{1}{\mu}$

↳ cross sectional Area. ↳ ~~permittivity~~ Permeability (Henry/meter)

$\mathcal{R} = \frac{Lc}{\mu A}$

- $\Phi = \frac{V}{\mathcal{R}}$ (weber ~~~~) ~~~~ $= \frac{Ni}{\mathcal{R}}$ (V → F)

- $B \equiv$ flux density $= \frac{\Phi}{A}$ (webur/m^2) (Tesla) $= \frac{Ni}{\mathcal{R}A}$ (Φ → flux, A → Area)

$B = \mu H$ #

- flux density (B) → it is a way of describing the electric field strength. ~~at any distance from the charge~~

Example 2 slide 15

- Find the flux if the flux density is 1.0T
- " " current in the coil
- " " magnetic field strength in the airgap and in the core
  ↳ H

Solution :- $B = 1\,T$, $\mu_r = 7\times10^4$, $A = 9\times10^{-4}\,m^2$
Coil length = 0.3 m , Air gap length = 0.0005 m
$N = 500$

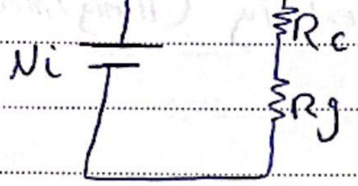
- $\Phi = BA = 1\times9\times10^{-4} = 9\times10^{-4}$ weber

$Ni = \Phi R$

Rg > Rc

$R_c = \frac{l_c}{\mu A} = \frac{0.3}{7\times10^4\times4\pi\times10^{-7}\times9\times10^{-4}} = 3789.4$ At/weber

(relative)



↳ equivalent circuit.

$R_g = \frac{l_c}{\mu A} = \frac{0.0005}{\mu_0 A} = \frac{5\times10^{-4}}{4\pi\times10^{-7}\times9\times10^{-4}} = 4.42\times10^5$

$R = R_c + R_g = 445789.4$

$mmf = 9\times10^{-4}\times445789.4 = 401.31$ At

- $I = \frac{mmf}{N} = \frac{401.31}{500} = 0.8\,A$

- $H = \frac{B}{\mu}$, $H_c = \frac{1}{7\times10^4\times4\pi\times10^{-7}} = 11.37$ At/m

$H_g = \frac{1}{4\pi\times10^{-7}} = 7.96\times10^5$ AT/m

- magnetic field strength in the air gap > magnetic field strength in the core because the voltage on air gap > the voltage on core.

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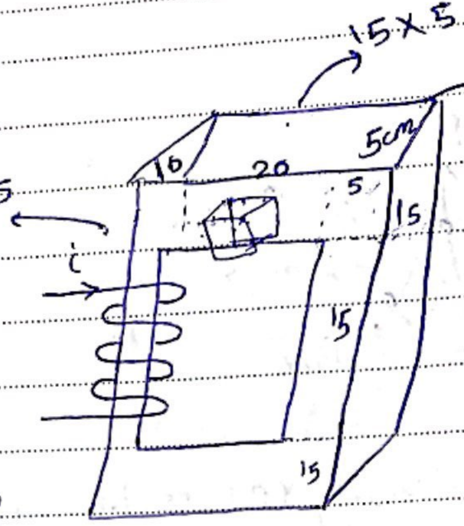
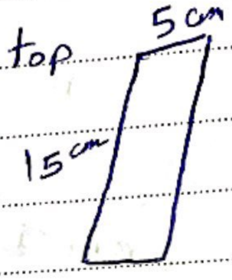
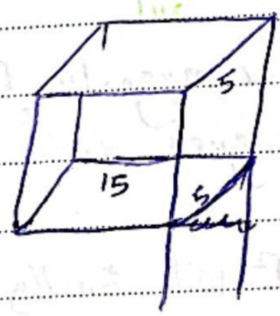
• Example 3 slide 16

$\Phi = 0.003$ Wb
$N = 500$
$\mu_{r_c} = 1000$

I, B_{top}, B_{right} ??







• $B_{top} = \dfrac{0.003}{0.15 \times (0.05)} = 0.4\,T$

• $B_{right} = \dfrac{0.003}{0.05 \times 0.05} = 1.2\,T$

$20 + \frac{1}{2}(10) + \frac{1}{2}(5)$ "up and down same R"

• $R_{u+d} = \dfrac{2 \times 0.275}{1000 \times 4\pi \times 10^{-7} \times (0.05) \times (0.15)} = 58.36\,kAt/wb$

• $R_r = \dfrac{0.3}{1000 \times 4\pi \times 10^{-7} \times 0.05 \times 0.05} = 47.75\,kAt/wb$

• $R_L = \dfrac{0.3}{1000 \times 4\pi \times 10^{-7} \times 0.05 \times 0.1} = 95.49\,kAt/wb$

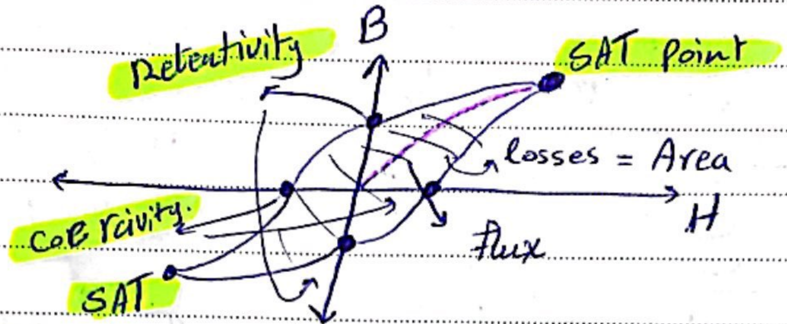
$R_{total} = R_{up+down} + R_R + R_L = 201.6\,kA.t/wb$

$mmf = \Phi R_{total} = Ni$

• $i = \dfrac{\Phi R_{total}}{N} = \dfrac{0.003\,wb \times 201.6 \times 10^3}{500} = 1.21\,A$

• Cross sectional Area ↓ R ↑

- Hysteresis



B–H curve

- The magnetic flux density (B) is increased when the magnetic feild strength (H) is increased

- B will finally reach saturation point where B is Constant.

- When B and H decrease until zero, material retains some amount of flux is called retentivity.

- when there is a decrease in H towards the negative side, flux also decreases. At point (Coercivity) the flux = 0

⇓

Due to forward and opposite direction process, the cycle is complete and it is called the hysteresis loop.

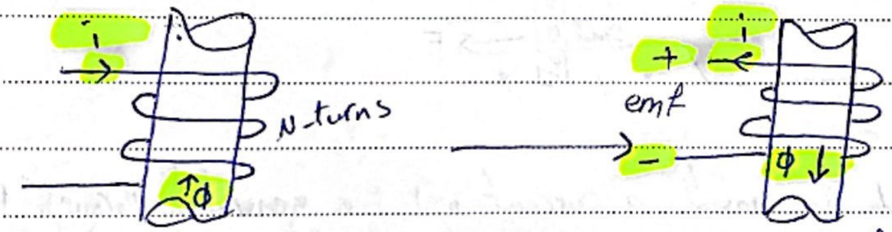
- When dealing with machines, hysteresis should be as low as possible to reduse losses.

↓ curve ↓ losses

• **Faraday's law** → induced emf due to the change in flux
↳ any change in the magnetic environment of a coil, will cause a voltage "emf" to be induced in the coil. no matter how the change is produced, the ~~change~~ voltage will be generated

• **Lenz's law** → The polarity of the induced voltage is opposite to the original field that produced it.
• if the ~~electric~~ magnetic field increases → induced emf will reduce it.

$$\text{induced Emf} = -N \frac{\Delta \Phi}{\Delta t}$$ → **derivative**



flux due to increase in the magnetic field

• the induced emf should reduce the ~~[illegible]~~ flux

• **Motor action** electrical → mechanical
flux → current → Force

$$\vec{F} = i(\vec{L} \times \vec{B}) \quad : \quad L \times B = LB\sin\theta$$ → cross product

i: current / L: length of wire / B: flux / F: Force

$$F = iLB\sin\theta$$

Left hand rule:-
Fingers → magnetic field
Palm → electrical "current"
thumbs → Force

Generator Effect

mechanical → electrical

Force → emf → current

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

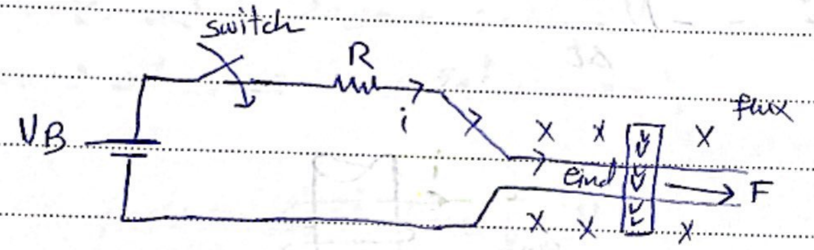
cross product ↲ ↳ Dot product

Right hand Rule :-

- fingers → flux
- Velocity → thumbs
- Palm → emf

$e_{ind} = VBl\cos\theta$

The linear DC machine



- if the switch is closed, a current will be generated through "R" "motor effect", the wire will move to the right so emf will be generated "generator effect", it will be opposite to the direction of the current that generated it according to lenz's law

- Example 4

a) max starting current at $t=0$ "with no any induced voltage"

$$i = \frac{V_B - V_{ind}}{R} = \frac{120 - 0}{0.3} = 400\ A$$

- steady-state velocity, at max value of e_{ind}

max value of $e_{ind} = 120$

~~[crossed out]~~ $V_{ss} = \frac{V_B}{BL}$

$$V = \frac{120}{0.1 \times 10} = 120\ m/s$$

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b) to reach steady-state → $F_{applied} = F_{induced}$ (in the opposite direction)

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

$$i = \frac{F}{Lb} = \frac{30}{10 \times 0.1} = 30\ A$$

$120 + 0.3 \times 30 = 129$ $V = e_{ind}$

$$V_{ss} = \frac{129}{10 \times 0.1} = 129\ m/s$$

bar ← Power $= 129 \times 30 = 3870\ W$

battery ← Power on V_B $= 30 \times 120 = 3600\ W$

$3870 - 3600 = 270\ W$ → resistor

" Generator effect "

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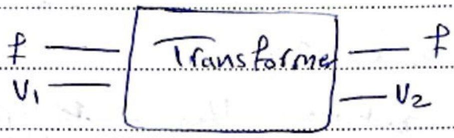
c) $i = 30$, $e_{ind} = 120 - 9 = 111$

$V = 111\ m/s$

" motor effect "

Chapter 2 Transformers

- A transformer is a device that changes ac electric power at one frequency and voltage level to ac electric power at the same frequency and another voltage level through the action of a magnetic field



The idea of Transformer : • Generation → step up → tranfer → step down → output

step up: V↑ ; step down: V↓

Transformers types (according to the core)

- Core types transformers
- shell type transformer
  - ↳ more popular

Primary turns → N_P ; secondary terms → N_S

$$\frac{N_P}{N_S} = \frac{V_P(t)}{V_S(t)} = a$$

($V_P(t)$ → AC)

↳ step up $a < 1$

step down $a > 1$

• flux in primary = flux in secondary

Dot convention

Dot ≡ +

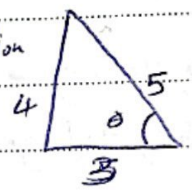
Current → flow in primary and flow out secondary

- Peak value refers to the maximum value that the current or voltage reaches in an alternating current. RMS gives an average value for current or voltage

$$V_{RMS} = \frac{V_{peak}}{\sqrt{2}} = 0.7071\, V_{peak}$$

- Capacitive load provides a leading power factor.
- Inductive load provides a lagging power factor. (current lags voltage)

$I = 4 + j3$ → complex representation

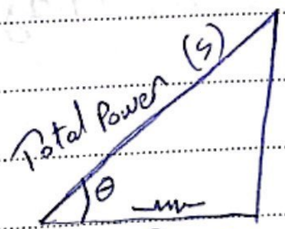


$\sqrt{4^2+3^2} = \sqrt{25} = 5$

$\theta = \tan^{-1}\frac{4}{3} = 36.6$

$I = 5 \angle 36.6$ → Phasor representation

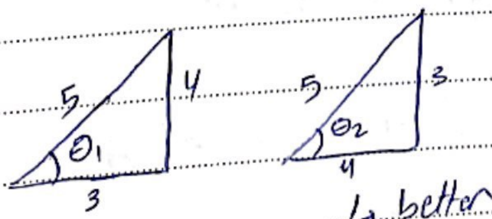
- Power consists of 2 parts
  - Power caused by resistors (P)
  - Power caused by complex loads (capacitors and inductors) (jQ)



$Q = IV\sin\theta$ (The less the better)

$P = IV\cos\theta$ (The higher the value, the better)

ex :-



where $\theta_2 < \theta_1$ (θ↓, better)

↳ better

- $\frac{P}{S}$ should equals 1 or close to

- $P_{primary} = P_{secondary}$

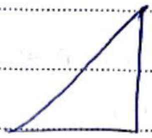
$V_p I_p \cos\theta_p = V_s I_s \cos\theta$

in ↲ ↳ out

- reactive power (Q) $= V_p I \sin\theta$

in: $= V_p I_p \sin\theta$

out: $V_s I_s \sin\theta$



Example 1 slide 10:

Primary Voltage = 2400 V
secondary Voltage = 240 V } → step down ($V_p > V_s$)

$a = \frac{V_p}{V_s} = \frac{2400}{240} = 10 > 1$ → step down

$2200\angle 0^\circ \, V \rightarrow 2200\cos\theta + j\,2200\sin\theta$ (θ → 0°)

$= \boxed{2200\,V}$

$2\angle 36.9^\circ \, \Omega \rightarrow 2\cos 36.9 + 2j\sin 36.9$

$1.6 + j1.2 = 1.6 + 1.2j \; \Omega$

a) $V_s = \frac{2200\angle 0}{10} = 220\,V$

$I_s = \frac{V_s}{Z_s} = \frac{220\angle 0}{2\angle 36.9} = 110\angle -36.9^\circ$ (→ 0 − 36.9)

b) $I_p = I_s / a = \frac{110\angle -36.9}{10} = 11\angle -0.36.9^\circ \, A$

c) $Z = \frac{V_p}{I_p} = \frac{2200\angle 0}{11\angle -36.9} = 200\angle 36.9$

d) $2200\angle 0 \times 11\angle -36.9 = 24.2\,kVA\,\angle 36.9$ — input power = output power ↳ no losses.

output → $220\angle 0 \times 110\angle -36.9 = 24.2\,kVA\,\angle 36.9$

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/ /

• impedance with respect to the primary circuit:-

$Z'_L = a^2 Z_L$ " load impedance as seen from the primary side".

• Ideal transformer → no losses (Power input = output Power)
but in Real transformers losses have to be accounted.

1) Copper losses → in the primary and secondary windings (heating losses) = I^2R
↳ Can be implemented as resistor (‑ᴡᴡ‑)

2) Eddy curren losses → can be implemented as a coil (‑ℓℓℓℓℓ‑)

3) Hysteresis → (coil symbol) coil

4) leakage flux → ‑ᴡᴡ‑ resistor

⇓

Real model : ideal model with some other components.

Other Transformers (special types of transformers)

1) current transformer (CT) → used to measure the current, designed to produce an alternating current in its secondary winding that is proportional to the current that it is measuring in its primary

$I_s = I_P / N_s$ (N_s → turns)

(I_s measured using the Ameter)

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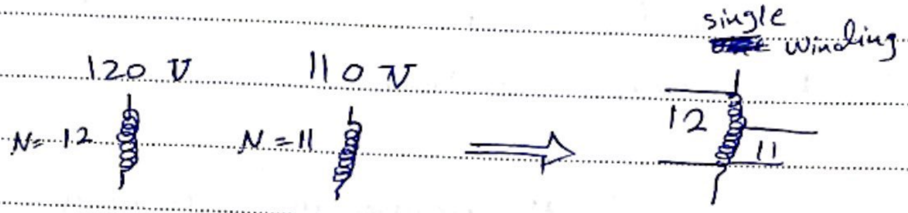
2) AUTOTransformer → "single Transformer" → only one winding on one side, same winding acts as both the primary winding and secondary winding, used to interconnect systems operating at different voltage classes.

ex:-



3) Isolation Transformer → usuall # of primary turns = # of secondary turns
↳ main idea → isolation between the 2 circuits (primary and secondary circuits)
- no step up or step down
- Provide separation from the power line ground connection.

Example 2 slide 15:-

$V = 480\angle 0 \; V$

$Z_L = 4 + 3j \; \Omega$ → Note:- imaginary part, due to capacitors and inductors in the load

a) $Z_{equ} = 0.18 + 0.24j + 4 + j3 = 4.18 + 3.24j$

$= \sqrt{4.18^2 + 3.24^2} = 5.29 \angle 37.8°$

$I_{line} = \frac{V}{Z_{equ}} = \frac{480\angle 0}{5.29\angle 37.8} = 90.8 \angle -37.8$

$V_{load} = I_{line} Z_{load} = 90.8\angle -37.8 \cdot 5 \angle 36.4$ ($5 = \sqrt{3^2+4^2}$, $36.4 = \tan^{-1}\frac{3}{4}$)

$= 454 \angle -0.9° \; V$

$Losses = I^2R = R(P) = (90.8)^2 (0.18) = 1484 \; W$

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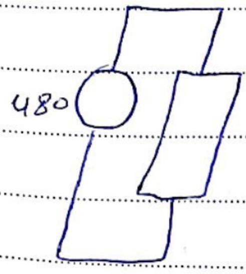
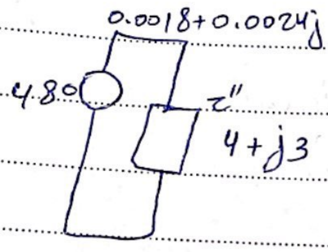
b) $z' = z_{load} \times 100 = 400 + 300j = \boxed{z_{load} \times a^2}$



$z'' = \dfrac{400 + 0.18 + 300j + 0.24j}{100}$



$I_G = \dfrac{480\angle 0}{4.0018 + 3.0024j} = \dfrac{480\angle 0}{5.003\angle 36.88°} = 95.94\angle -36.88$

$I_{line} = \dfrac{95.94\angle -36.88}{10} = 9.594\angle -36.88°$ $\qquad a = \dfrac{1}{0.1} = 10$

$I_{load} = 10\,(9.594\angle -36.88) = 95.94\angle -36.88°$

$V_{load} = 95.94\angle -36.88 \times 5\angle 37.9 = 479.7\angle -0.01\ V$ $\quad (5 = \sqrt{4^2 + 3^2})$

$R(P) = \text{losses} = I^2R = (9.54)^2(0.18) = 16.7\,W$

Chapter 3 :-

- DC motors → low current
  - ↳ hig speed / low Torque / Reversibility
    - ↳ The direction of movement may be reversed. (forward ⇄ reverse) (UP ⇄ down)

- DC Generator → (mechanical → electrical)
- DC motor → (electrical → mechanical)

- The rotor is the rotating part.
- The stator is the non-moving, fixed counterpart. (slide 5, south and north poles) contain permenent magnet → magnetic flux
  (surrounded by winding)
- The Yoke → protects the internal components (metal casing)
- Armature → set of coils ↑coils ↑Torque
  slide 5

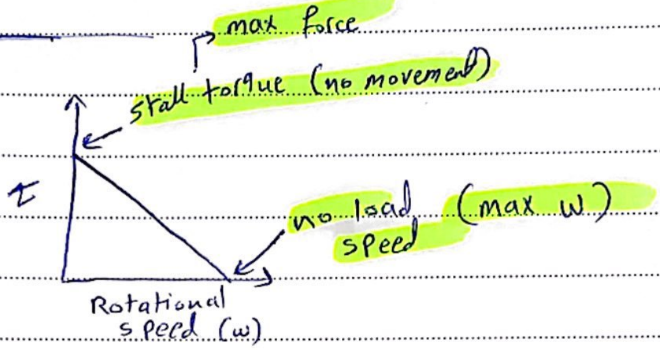
* Summary : → magetic flux result from a permenent magnet or ferromagnetic material (electromagnetic circuit) "stators" → the rotor is a group of coils → cutting the magetic flux → generate force → rotation
motors ←

- Bearing :- It makes the movement smoother

slide 6 →
- Poles is splitted into liminations to reduce eddy current.

- Commutation → the process by which the reversal of current takes place for rotation to occur. (Two forces opposite each other)
  - → reverse the polarity of the Applied Voltage using certain devices
  - → using commutator

- Torque/speed curve

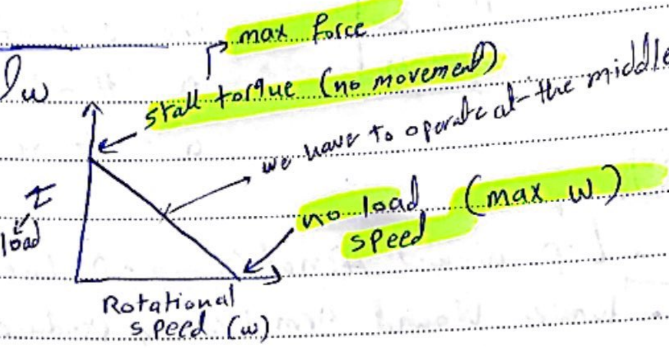


- The relationship between Torque and speed → inverse relationship

- no load → max speed / no torque
- stalled speed → zero speed / max Torque
- max current → stall torque
- max power → between stall and unloaded speed (curves intersect)
- Voltage ∝ speed

- Commutation → the process by which the reversal of current takes place for rotation to occur. (Two forces opposite each other)
  - ↱ reverse the polarity of the applied voltage using certain devices
  - ↳ using commutator

- Torque/speed curve → relationship between T and ω



- The relationship between Torque and speed → inverse relationship

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- Voltage $\propto$ speed

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generator effect

rotation $\xrightarrow{\text{generates}}$ emf

$\uparrow \omega \quad \uparrow emf$

$\uparrow \Phi \quad \uparrow emf$

emf → depends on flux and speed

$$emf = \Phi \omega K_A$$

K_A depends on the motor's geometry (ex:- width, # of wires).

- motor effect → $Torque = K_A \Phi I_A$
  - ↳ passed current ↑ Torque ↑

without losses ←

$$Power = E I_A = T\omega$$

EI_A → electrical, $T\omega$ → mechanical; ideal motor

where T :- torque

ω :- speed

- $K_A = \frac{ZP}{2\pi a}$

$N \overset{or}{=} Z$
a or M

Z :- number of conductors on rotor $= 2CN_c$
C :- # of coils on rotor
N_c :- # of turns per coil
p :- # of field poles
a :- # of parallel paths in armature winding

- Lap Wound Armatures → • Produce high current (summation of currents)
- Wave Wound Armatures → Produce high voltage and low current (summation of voltages)
- Frogleg Wound Armatures → moderate current and moderate voltages.

- $T = \frac{2}{\pi} \phi i$, $\begin{cases} K = \frac{2}{\pi} \\ P = 2 \\ a = 1 \\ Z = 2 \end{cases}$ → For single loop

- $Z = 2C\,N_c$ "in single loop $N_c = 1$"

- Example slide 11

starts as motor effect →

a) movement → generator effect → magnetic field (عكس المجال الأصلي) → enduced voltage → in steady state emf = V_B / $i = 0$ (flow current) → then it'll rotate with no load speed

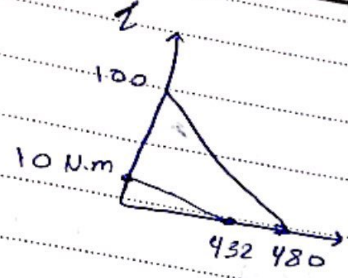
b) $\frac{V_B - V_{end}}{R} = \frac{V_B}{0.3} = \frac{120}{0.3} = 400A$ ($V_{end} \to 0$)

$\Phi = B * A$
$= B * \pi r l$
مساحة لـ نصف دائرة

- e at steady state $= 120 = K w \phi$

$120 = \frac{2}{\pi} w \phi$

$120 = \frac{2}{\pi} w B \pi r l$ $w = 480$ rad/s



$\tau = K\phi i = 100\ N.m$

c) "w" will decrease.

• steady state → motor effect

$\tau = 10\ N.m$

• $10 = \frac{2}{\pi}(1 \times \frac{1}{2} \times \frac{1}{4} \times i \times \pi) \rightarrow \boxed{i = 40\,A}$

$e_{ind} = 120 - \underset{iR}{12} = 108$

• $w = \frac{e_{ind}}{\phi K} = \frac{108}{2/\pi(1 \times 0.5 \times 0.25 \times \pi)} = 432\ rad/s$ which is less than 480

• electrical power = IV = $120 \times 40 = 4800\ W$
• mechanical power = $w\tau = 432 \times 10 = 4320\ W$ } difference → losses on battery

• motor effect " battery Produced a higher Voltage than the enduced voltage / (→) current direction which causes a loss on battery.

d) • $7.5 = \frac{2}{\pi} \times 1 \times 0.5 \times 0.25 \times \pi \times i$

$\frac{7.5}{0.25} = i \rightarrow \boxed{i = 30\,A}$

• steady state ↳ generator effect

• $e_{ind} = 30 \times 0.3 + 120 = 129\ V$

• $w = \frac{129}{2/\pi \times 1 \times 0.5 \times 0.25 \times \pi} = 516\ rad/s$ which is greater than 480

• τ in generator effect is negative.
• generator effect.

/ /

e) $\frac{120}{0.3} = 40\,A \rightarrow \omega = \frac{120}{\frac{2}{\pi}\times1\times0.5\times0.2\times\pi} = \frac{120\times10}{2} = \frac{1200}{2} = 600\ rad/s$

• $\phi\downarrow\ \omega\uparrow$ → ~~w~~ w will increase until a certain limit then the device may be damaged.

• Armature

↑loops of wires ↑Voltage → in commutator

• armature is the commutator with windings and shaft

• Armature Windings :- 3 ways

1 - lap Wound Armatures (Parallel loops)

• low voltage with high current (summation of all currents)

2 - Wave Wound Armatures (~~???~~ series loops)

• high voltage and low current
↳ (summation of all voltages)

3 - Frogleg Wound Armatures (Parallel and series together)

• (moderate current and moderate voltage)

• Armature reaction

↳ The effect ~~of~~ on the main field flux of that flux set up by the currents in the armature winding

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- Power flow and losses in DC machines

  - mechanical power ⟷ electrical power

- in ideal system → Total electricity is converted into power and vice versa (no losses)

  → but this case isn't exist.

$\frac{P_{out}}{P_{in}} \times 100\% = 100\%$

- efficiency = $\frac{\text{Power out}}{\text{Power in}} \times 100\%$ { usually $P_{out} < P_{in}$ due to losses

- five categories of losses:-

  1- resistive losses → $I^2 R$ (Field / Armature)
  2- Brush
  3- Core losses due to eddy current and hysteresis
  4- mechanical losses
  5- stray losses

  } slides

  (3–5: in all types of motors)

- slide 15 :-

  - first figure → motor (input :- electrical , output :- mech.)
  - second figure → generator (input - mechanical , output :- electrical)

Chapter 4 DC Motors and Generators

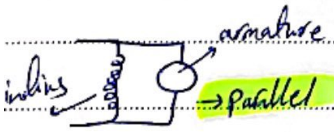
DC motors
- Brushless DC
  - ↓ no brushes
  - ↓ Permenant magnet rotates
- Brushed DC → disadvantage :- you always need to do maintanance
  - ↓ Slide 3

Brushed DC motors
- Permenant magnet ↑ flux is fixed
  - ↓ for small motors (low τ)
- electromagnet → field winding
  - slide 3
  - → large DC motors

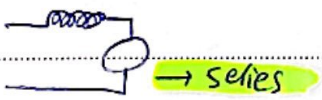
- **Field winding** (How the field is connected to the motor)
  ↳ **separately Excited** → whose field winding is supplied by an independent external DC source (like a battery) "separate from the armature"

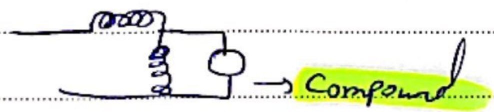
Shunt ≡ Parallel

- **self Excited** → the field winding is wired parallel (shunt) or series to the armature winding



- **Compound excited** → two field windings (shunt and series)
  - Differential Compound
  - Comulative Compound





- Speed Regulation (SR) → كل ما كانت اقل كل ما كانت افضل.

$$SR = \frac{\omega_{no\,load} - \omega_{full\,load}}{\omega_{f.l}} \times 100\%$$

كل ما كان الفرق بين $\omega_{n.l}$ و $\omega_{f.l}$ اقل تكون افضل

- ⊕ SR → ↑load ↓speed — بتشتغل لما يكون ال motor
- ⊖ SR → ↑torque (load) ↑speed → "Generator effect" — كانه generator
  ↳ "load with the same direction"

- R_F → resistor of the field / R_{adj} → adjustable to control the strength of the magnetic field → control the flux
  $\phi\uparrow$ $T\uparrow$ to control speed
- How to control the speed (regulation)? in separately excited
  ↳ by controlling ϕ (adjust R_{adj})

  $\downarrow R_{adj}$ $\uparrow\phi$ → when $R_{adj} = 0$ → max flux

- we assume R_F and R_{adj} are ~~kept~~ lumped together and called R_F

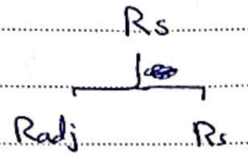
- المعادلات سلايد ٦.
- بالعادة ما يكون التركيز على separately Excited

- Speed Torque characteristics.

$$\omega_m = \frac{V_T}{K\phi} - \frac{R_A}{(K\phi)^2}\tau_{ind}$$ → for DC shunt motor

↳ linear relationship between speed and torque

- **Series DC motor**



- $\tau_{ind} = K\phi I_A$ / $\phi = C I_A$ so → $\tau_{ind} = KC I_A^2$ where I_A → armature current

- $\omega = \frac{V_T}{\sqrt{KC}} \frac{1}{\sqrt{\tau_{ind}}} - \frac{R_A + R_S}{KC}$

- **Compound DC motor**
  - series → low speed gives high torque
  - shunt → reaches rated speed → constant voltage with fixed current on windings

- $V_T = E_A + I_A(R_A + R_S)$
- $I_A = I_L - I_F$
- $I_F = \frac{V_T}{R_F}$

- $F_{net} = F_F \pm F_{SE} - F_{AR}$ (F_F → shunt, F_{SE} → series, F_{AR} → ignored)

(+) → cumulatively compound

(−) → differentially compound

- **Torque speed characteristic**

↳ higher starting torque than a shunt motor but lower starting torque than a series motor

- doesn't over speed at no load

- $(r/min)/60 * 2\pi = rad/s$

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• Example slide 11

large motor → = 37.5KW   • 1hp = 750 W

• 50-hourse power / 250 V / $\frac{1200 r/min \times 2\pi}{60}$ / Compensating winding ↳ armature reaction is negligible

$R_A = 0.06\ \Omega$ / $R_{adj} + R_F = 50\ \Omega$

no load speed = 1200 r/min / N = 1200

input current (I_L) $I_F = \frac{250}{50} = 5A$ / $I_A = 95A$

a) $E_{ind} = K\phi w$ I↑ ↓E w↓

or $E_1 = \bar{K}\phi n_1$

$E_2 = \bar{K}\phi n_2$ where n = speed (r/min)

• Voltage when no load speed = 250 ↳ (no losses)

$\rightarrow \frac{E_1}{E_2} = \frac{n_1}{n_2} \rightarrow \frac{250}{250 - 0.06 \times 95} = \frac{1200}{n_2} = \frac{250}{244.3} = \frac{1200}{n_2}$

$n_2 = 1173$ rpm

b) $250 - 0.06 \times 195 = 238.3$ V

$n_2 = \frac{1200 \times 238.3}{250} = 1144$ r/m

c) $250 - 0.06 \times 295 = 232.3$ V

$n_2 = \frac{1200 \times 232.3}{250} = 1115$ r/m

d) $I_P = OP$

$I_A V_A = W\tau$

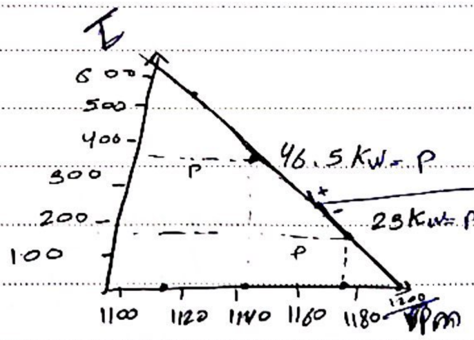
$\tau_a = \frac{I_A V_A}{\omega_1} = \frac{95 \times 244.3}{1173/60 \times 2\pi} = 140$ N.m / Power = 23208.5 = 23Kw

$\tau_b = \frac{I_A V_A}{W_2} = \frac{195 \times 238.3}{1144 \times 2\pi/60} = 388$ N.m / Power = 46.5 kw

$\tau_c = \frac{295 \times 232.3V}{\frac{1115}{60} \times 2\pi} = 587$ N.m / Power = 68.5 kw

/ /

D)

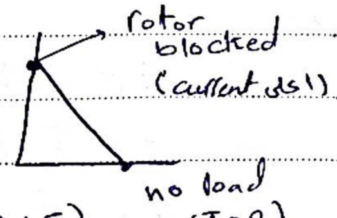


• no load speed $I = 0$

• power $= \omega T$

works here
50 hp = 38 KW

• Example 2 slide 12



a) $R_A = \frac{10.2}{170} = 0.06\ \Omega$ / $I_L = 175\ (170+5)$

motor ↖ $P_{out} = P_{in} - P_{losses}$

$= I_L \times V - P_{losses}$ | $P_{in} = 43750\ W$

$= 43750 - P_{losses}$

$P_{losses} \rightarrow I^2R = (170)^2 \times 0.06 + 5^2(50) = 1734 + 1250 = 2984\ W$

↳ brushes losses $= VI = 2 \times 170 = 240\ W$

↳ stray losses $= 0.01 \times 43750 = 437.5\ W$

↳ mechanical losses + core losses $= V_{nL} \times I_{nL} = 240 \times 13.2 = 3168\ W$

$P_{out} \rightarrow 43750 - (2984 + 340 + 437.5 + 3168)$

$P_{out} = 36820\ W$

↳ بنقارنها بقيمة
hp

$T = \frac{1200}{P_{out}}$

$50 \times 746 = 37300$

b) effi. $= \frac{36820}{43750} \times 100\% = 84.2\%$ → $\text{effi.} = \frac{P_{out}}{P_{in}} \times 100\%$

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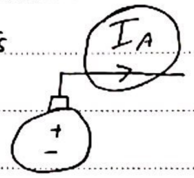
- DC Generators



⇒ Armature produces the current in generators

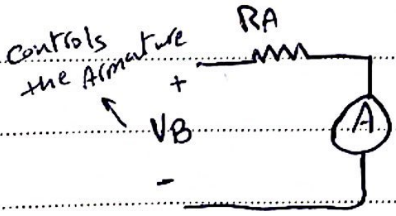
mechanical → electrical.

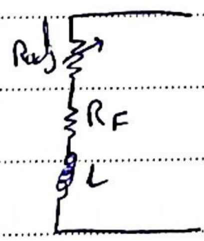
- Brushed DC Motor type Comparison

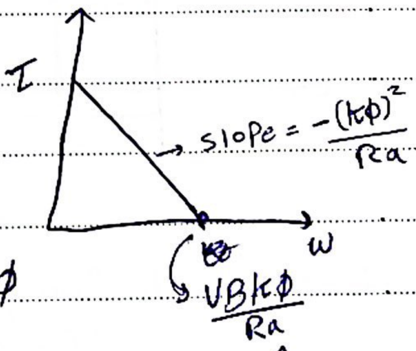
Brushed DC Motor
- Permanent Magnet
- electromagnet
  - shunt
  - series
  - compound

Refer to slide 15. (table)

- The speed of the DC motor can be changed by using the following methods :-
  1) Field control method (R_{adj})
  2) Armature resistance control method (R_A)
  3) Armature voltage control method (V_F / V_T)
     - ↳ in some motors it is the same as field voltage
     - ↳ series / compound.



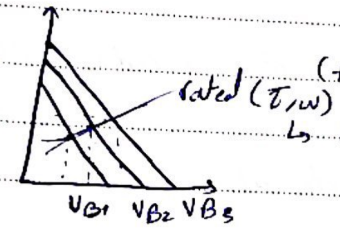




$$V_B = IR_a + V_{end} = I_a R_a + K\phi w = \frac{I}{K\phi} R_a + Kw\phi$$

$$\frac{IR_a}{K\phi} = -Kw + V_B \longrightarrow I = \frac{V_B K\phi}{R_a} - \frac{(K\phi)^2 w}{R_a}$$

• Changing V_B → The x-section changes



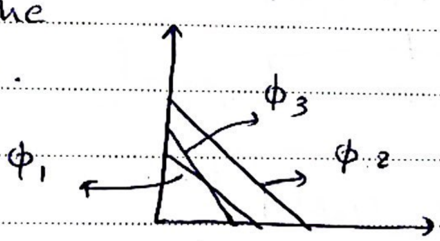
(the slope is fixed)
↳ it'll work on diff. ω and τ when you change the armature voltage

$V_{B3} > V_{B2} > V_{B1}$

• Changing R_F (Radj) → V_B here is fixed and $\underline{\underline{\phi}}$ is variable through Radj

↳ slope will change as well as the cross section.

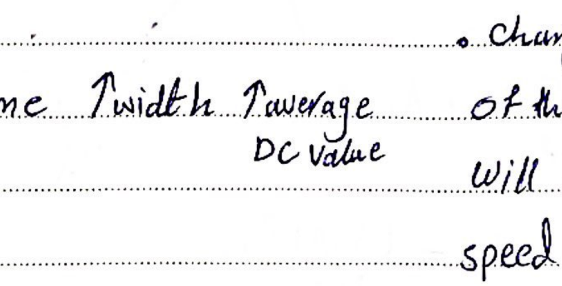
• العلاقة بين Φ والمقاومة علاقة عكسية



$\phi_2 > \phi_3 > \phi_1$

• different curves gives different rating to work on (τ, ω)

• Pulse width modulation (PWM) → to control the speed of the motor.



$$\text{Duty cycle} = \frac{T_{on}}{T} \times 100\%$$

$$f = \frac{1}{T}$$

T_{on} time ↑ width ↑ average DC value

• Changing "on" value by changing the width of the pulse, so the average DC voltage will change too. When the voltage increase the speed of the motor will increase too.

- Single direction control through Switches (on / off) or PWM ↳ to control current (speed) / transistor
- Dual-direction control through H-bridge (to control direction).

→ so:- Control of DC Motors :-

1) Switch ON-OFF → Trans.
2) Speed → PWM
3) Direction → H-Bridge

- Flywheel diode → to reduce motor runaway effect
  - ↳ في حالة switch off بيعمل path في لل current (يتناقص العيش)
  - ↳ used in windings types

Flywheeling diode is used to protect the circuit from abrupt reduction in the current (this reduction causes sudden voltage spike).

- L293D H Bridge → Dual H-Bridge (2 motors)

Control M1

0	0	→	(off)
0	1	→	Forward / Reverse
1	0	→	Forward / Reverse
1	1	→	(hold)

Forward / Reverse → depends on the connection

Brushless DC Motors → more reliable and efficient.

- stator is the Permanent magnet
- rotor → coils

} → in the Brushed DC Motor.

- stator → coils
- rotor → Permanent Magnet

} → in the Brushless DC Motor

/ /

- Brushless DC Motor applications:-
  - CPU cooling fans → out runner (to reduce elect. noise and to extend fan life)
  - outrunner ← CD/DVD players → motor is used in spinning
  - electric automobiles → high speed / high efficiency / low maintenance / instantaneous control of speed and torque.

- Hall effect sensor → used to distinguish if there is a current or not, and to know the direction of the current.
  → able to distinguish between the positive and negative charge

→ Controlling the Brushless motor is harder than controlling the Brushed DC motor especially the sensorless one.

- Notes:-
  - Armature reaction:- The current flowing through the armature Conductors creates a magnetic flux. This armature flux distorts and weakens the magnetic flux produced by the main poles. (armature flux affects the main flux).
  - How to reduce the armature reaction effect?
    1- Interpoles:- set interpoles between the main poles of the DC motor. The interpole windings are connected in series with the armature so that respective fluxes rise and fall together with the changes in the current.
    * (the polarity of the ~~pole~~ interpole must be that of the main pole).

    2- Adjust the Brush position

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3- Compensating winding → auxiliary winding embedded in the slots of the main poles. The compensating windings produce a flux equal and opposite to the armature flux and thus completely neutralise the armature reaction.

3- Compensating winding → auxiliary winding embedded in the slots of the main poles. The compensating windings produce a flux equal and opposite to the armature flux and thus completely neutralise the armature reaction.

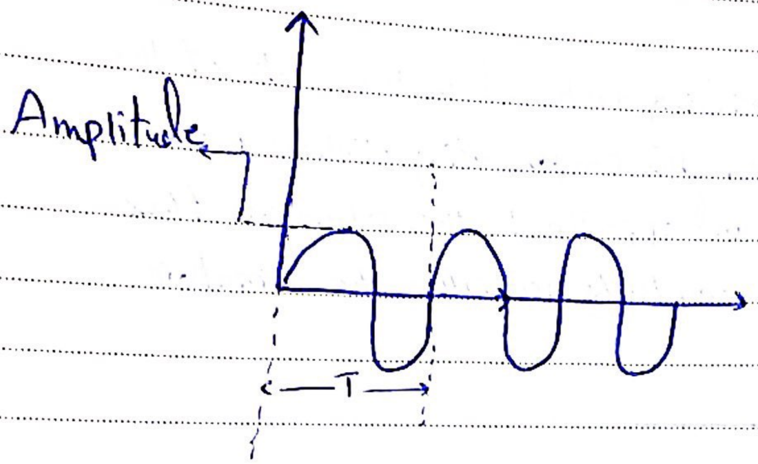
• Chapter 5 AC machinary fundementals.

- Motors
  - DC → easy to control than AC
  - AC
    - synchronous
    - asynchronous
      - ↳ induction motor (most popular)

• VFC → Variable frequency controller → used to control the speed of the AC motor which makes it easy to control too. (botho Voltage and frequency must be adjusted)
↳ high cost

• AC power is connected only to the motor's stator field windings (no brushes)

• why it is called induction motor?
because the rotor gets its power by electromagnetic induction, a Process that doesn't require physical electrical contact, which means longer life time



- Controlling AC → control Amplitude and frequency

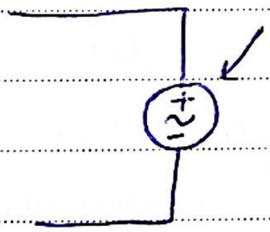
$$\text{Frequency} = \frac{1}{T} \quad \text{(Hertz)}$$

T ↳ Periodic Time

$$\omega = 2\pi f \quad \text{(rad/sec)}$$

ω ↳ rotational speed

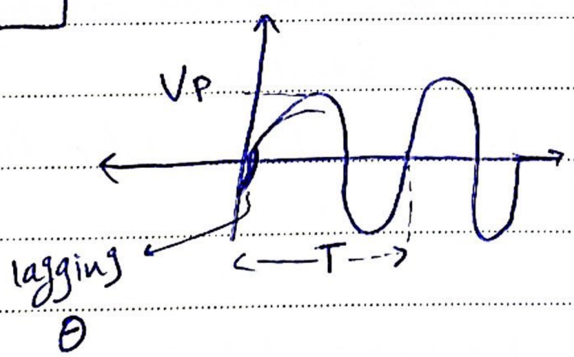
f ↳ frequency



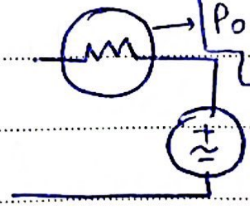
$$v(t) = V_p \sin(\omega t + \theta)$$

V_p → Vpeak

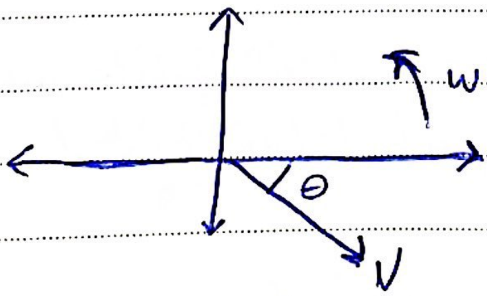
θ → phase shift



$$V_{rms} = \frac{V_{peak}}{\sqrt{2}}$$



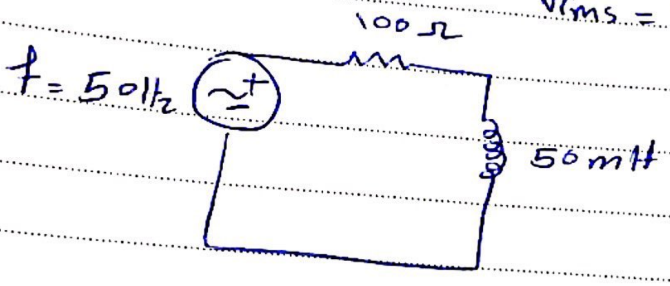
$$\text{Power} = \frac{V_{rms}}{R}$$



lagging

Example

$V_{rms} = 100V$



calculate the current in phasor form and time forme.

$V = 100 \angle 0$ → Phasor

$V(t) = 100\sqrt{2} \sin(314t + 0)$ → time form

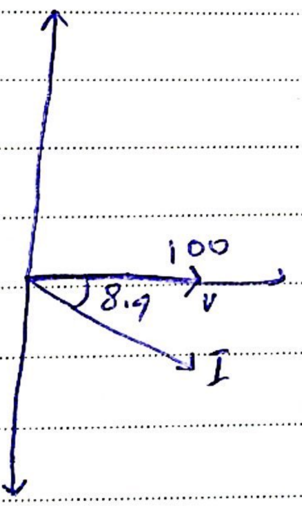
Vpeak ↲

$I = \frac{V}{Z} = \frac{100\sqrt{2}\sin(314t + 0)}{100 + j15.7\,\Omega}$ → $\omega L = 314 \times 50 \times 10^{-3}$

$X_L = 15.7\,\Omega$

Phasor ←

$I = \frac{V}{Z} = \frac{100 \angle 0}{101 \angle 8.9} \approx 1 \angle -8.9$ → lagging

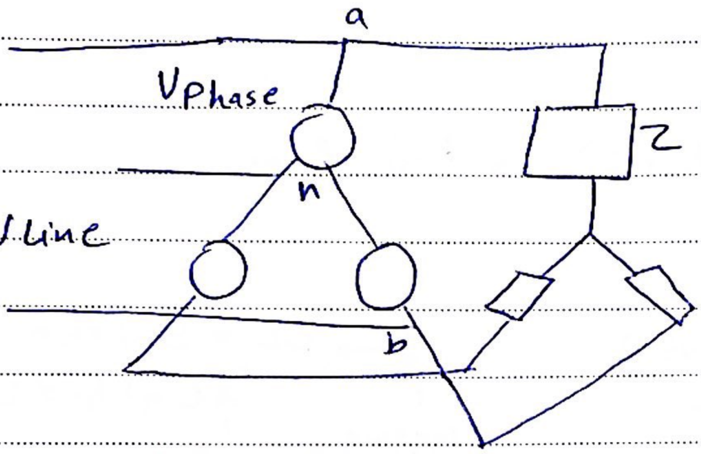


I lags the Voltage

- Three phase circuit :-
  - 3 AC Voltage sources
  - All have same (ω) but different Phase shift $(360° \div 3)$ ↳ $120°$

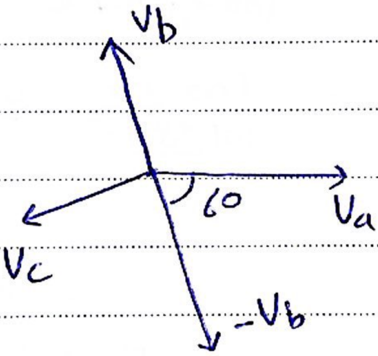
- 3 Phase can be connected in 2 ways:
  1- Star
  2- Delta

- Star Connection



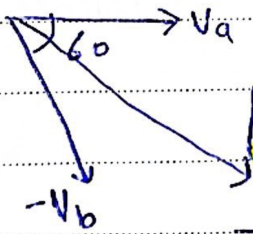
Vphase → between a and neutral Point

Vline → between a and b.



$V_L = V_a - V_b$

→ $V_L = V_a + (-V_b)$



$V_L = \sqrt{3}\, V_{ph}$

V_L leads V_{ph} 30°

$I_L = I_{ph}$

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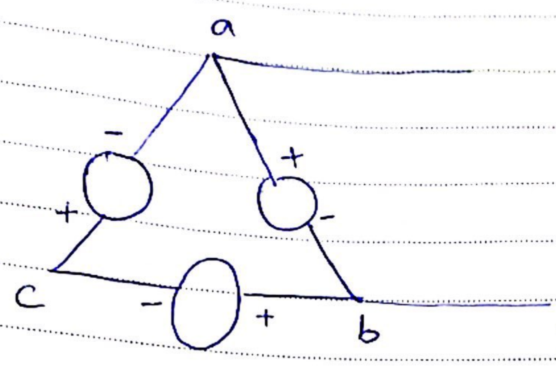
• Delta Connection



$I_a = I_{ab} - I_{ca}$

$V_L = V_{ph}$

$I_L = \sqrt{3}\, I_{ph}$

• I_{line} lags I_{ph} by 30°

$P = I_{ph} V_{ph} \cos\theta$

$= 3 I_{ph} V_{ph} \cos\theta$

$= 3 I_L \frac{V_L}{\sqrt{3}}$

either star or delta → $P = \sqrt{3}\, I_L V_L \cos\phi$ → angle between I_L and V_L.

• Nameplate → contains information about the construction characteristics and performance of the motor like number of phases, connection, rating and the type.

• How AC motor work?

revolving magnetic field created in the stator by AC current, with an opposing magnetic field either induced in the rotor or provided by a separate DC current source. → Torque which can be coupled to desired loads

/ /

- A rotating magnetic field with constant magnitude is produced, rotating with a speed

$$n_{sync.} = \frac{120 f_e}{P} \quad (rpm)$$

sync. speed ↲

f_e :- supply frequency with drive the stator.

P :- number of poles

- note :- # of poles in 3phase = 6
  " " " in single phase = 2

- Construction of an AC motor :-

  - Flang bracket → covers the internal components
  - stator → made from electromagnetic steel liminated plates, to reduce eddy current.
  - Motor case → made from die cast aluminium.
  - Rotor
  - output shaft
  - Ball bearing → reduce friction
  - lead wires → make constant magnetic field.
  - Painting → that tolerates heat.

Chapter 6 Induction Motors

↳ asynchronous Motors / AC electric motor
"rotates at a speed less than the speed
of rotating magnetic flux inside the motor."

- No dc field current is required to run the machine.
  - ↳ "on the rotor."
  - ↳ the current in the rotor is induced current

- usually induction machines referred to as induction motors because Induction generator has many disadvantages and low efficiency.

- it has the same stator as the synchronous motor, but a different rotor

- rotor types:-

1- squirrel Cage rotor

↳ the stator windings produces a rotating magnetic field. This RMF causes Voltage induced in the rotor bars, so that current induced. "short circuit current" which causes force then motion

- squirrel cage is more popular because it needs less maintenance, more reliable, and efficient, cheap.
- squirrel cage has less copper losses.

2- Wound rotor → also known as slip ring-rotor motor

↳ the rotor windings are connected through slip rings to external resistance. adjusting the resistance allows control of the speed.

stator magnetic flux speed ← $n_{sync} = \frac{120 f_e}{P}$ where f_e : frequency of AC source

P :- # of Poles

In the rotor ← $e_{ind} = (V \times B) \cdot l$

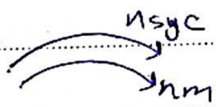
$\tau_{ind} = k B_R \times B_s$

- Generator effect at the ~~begining~~ begining → induced current → Torque → motion

---

- n_{slip} → difference between synch. speed and actual speed ↳ rotor speed.

rpm ← $n_{slip} = n_{sync} - n_m$ ↳ السرعة الضائعة



$S = \frac{n_{slip}}{n_{syn}} \times 100\%$ ↳ Value of slip

↓nslip ↑efficiency.

- upper limit to the motor speed = n_{sync}. (if ↑ n_{sync} [speed equals] → Torque = 0 and $e_{ind} = 0$)
- ~~ng~~ n_{sync} ≡ no load.

⇓

- if $n_{sync} - n_m = 0$ ($n_{sync} = n_m$) → no emf and current / I = 0

- Torque speed charcteristic
  - locket rotor torque → torque the electrical motor develops at standstill (starting torque) or zero speed.
  - Breakdown torque → highest torque available
  - Pull up torque → minimum torque when accelerated from standstill to the speed at which breack down torque occures.

- $f_{rotor} = s f_e$ where $s \rightarrow$ slip
  $f_e \rightarrow$ frequency of emf / magnetic field / stator

- the frequency of the current and EMF in the rotor (f_r) depends upon the difference between the synch. speed and the rotor speed ("on the slip").

- if the rotor of a motor is locked so that it cannot move, the rotor will have the same frequency as the stator.
- if $n_m = n_{sync} \rightarrow$ slip $= 0 \rightarrow f_r = 0$

- power flow in induction motor

(line, phase; angle between current and voltage)

- $P_{in} = \sqrt{3} V_L I_L \cos\theta = 3 V_{ph} I_{ph} \cos\theta$

(losses on wires) (3 phases (loss on each phase))

- $P_{SCL} = 3 I^2 R \rightarrow$ electrical (stator copper losses (R_1))

- $P_{core} \equiv$ leakage $\rightarrow$ electrical on (R_c)
  ↳ due to eddy current / Hystrisis

→ primary losses
↳ stator

- $P_{AG} = P_{in} - (P_{SCL} + P_{core})$. where PAG is the power that will be converted

(losses of PAG)

- $P_{RCL} = 3 I_2^2 R_2 \rightarrow$ losses on ($\frac{R_2}{s}$) on the figure (cage)
  Note (P_{RCL} = slip)
  (P_{conv} = 1 - slip)

- assume PAG = 100 W, slip = 5%, then P_{RCL} 5% of 100 W = 5 and P_{conv} = 95

→ $P_{conv} = P_{AG} - P_{RCL}$ (will be converted from electrical to mechanical)

→ $P_{out} = P_{conv} - (P_{F+W} + P_{stray})$

. $efficiency = \frac{P_{out}}{P_{in}} \times 100\%$

. eff. ↑ 85% better

. Example slide 9

1) $n_{sync} = \frac{120 * f_e}{P} = \frac{120 * 60}{4} = 1800$ rpm

2) rated load → slip = 0.05 (full load)

$s = \frac{1800 - x}{1800} \times 100\%$

$1800 - 5 * 18 = x$

$x = 1710$ rpm → motor speed

3) $f_r = f_e * s$

$= 60 * 0.05 = 3Hz$ → سرعة ال roto بالنسبة لل stator

4) $P = 10 * 746 = 7460 W$

$P = \omega \tau$

$\tau = \frac{P}{\omega} = \frac{7460}{179} \approx 41.7$ N.m

. Example 2 slide 13

1) $P_{AG} = P_{in} - (P_{SCL} + P_{core})$ → $\cos\theta = PF$

$P_{in} = \sqrt{3}\,(480)\,(60)$ ~~cos θ~~ $(0.85) = 42400$ W

$42400 - (2000 + 1800) = 38600$ W

2) $P_{conv} = P_{AG} - P_{RCL}$

$38600 - 700 = 37900$ W

3) $P_{out} = 37900 - 600 - 0 = 37300\ W = 50hp$

4) $\eta = \frac{P_{out}}{P_{in}} \times 100\% = \frac{37300}{42400} = 88\%$

Example 3 slide 13

- $slip = \frac{P_{RCL}}{P_{AG}} \times 100\%$

1) $slip = \frac{700}{38600} \times 100\% \approx 2\%$

2) $n_{syn} = \frac{120 f_e}{P} = \frac{120 * 60}{4} = 1800\ rpm$

$slip = n_{syn} - n_{m}$

$0.02 = 1800 - n_r$

$n_r = 1784\ rpm$ → operating speed

$w_r = \frac{1764 * 2\pi}{60} = 184.7\ rad/s$

3) $P = w\tau$

$\tau_{ind} = \frac{P_{conv}}{w_r} = \frac{37400}{184.7} = 205.2\ N.m$

Note :- developed torque (P_{conv})
output torque P_{out}

4) $\tau_{ind} = \frac{P_{out}}{w_r} = \frac{37300}{184.7} = 201.4\ N.m$

according
- Class → ↑ relationship between speed and torque

  - Class A and B → general use
  - Class C → higher starting torque
  - Class D → highest starting torque, wide stable speed range but low efficiency

---

- Starting Induction motor :-

  - The starting current of the induction motor is very large
  - The purpose of a starter is not to just start the motor, but it reduces the heavy starting current.
  - star delta starter → method of starting three-phase induction motor, the motor runs at delta-connected stator windings
  - during starting the supply is given from star connection because (high torque), then from delta connection during driving (when it reaches steady state speed)

the starter current reduces by $1/\sqrt{3}$ times than the delta connection

---

- Variable-speed control → controlling speed by controlling frequency or # of poles (usually by controlling the frequency only)

fixed frequency → converter (AC → DC) → PWM → inverter (DC → AC)

- Inverter → used to control the frequency then controlling the speed.

/ /

Note :- in inverter type air conditioners, temperature is adjusted by changing motor speed without turning the motor ON and OFF. It has less power loss.

- Single phase Induction motor → not self starting. (needs a starting mechanism).
  - ↳ Produces low starting torque
  - types

① split phase induction motor → the stator is provided with a starting or auxiliary winding, and main or running winding. The auxiliary winding is displaced by 90° from the main winding. The auxiliary winding operates only during the brief period when the motor starts up.

then produce the rotating magnetic flux

- switch by default closed → when the rotor reach 80% of the rated ω → open switch → continue working
- it has small Torque, so capacitor star induction motor is used.

because phase = 90°

② Capacitor start induction motor → ↑phase shift

↳ the starting torque is produced by using a starting capacitor

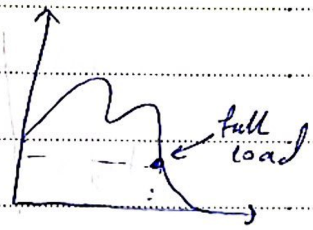
③ Capacitor start capacitor run induction motor → There are two capacitors in this method, one is used at the time of starting, the other is used for continous running.

• Problems

① A slip-ring Induction motor runs at 290 rpm at full load, when connected to 50Hz supply. Determine the number of poles and slip.

$f = 50\,Hz$

$n_r = 290$ rpm



. Assume $n_{sync} = 300$ (it should be greater than n_r)

• $slip = \frac{300 - 290}{300} \times 100\% = \boxed{3.3\%}$

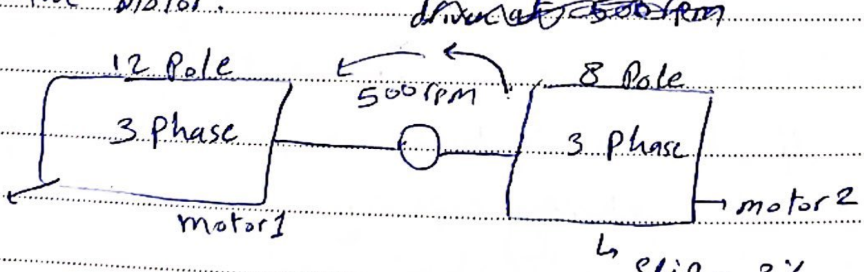
• $300 = \frac{120(50)}{P} \rightarrow \boxed{P = 20 \text{ Poles}}$

---

② A 12-pole 3-phase Alternator motor driven at speed of 500 rpm, supplies power to 8-pole 3-phase Induction motor, if the slip of the motor at full load is 3%. calculate the full speed of the motor.

↳ $= n_{sync}$

~~driven at 500 rpm~~



sync speed motor 1 بتساوي 500 rpm

$f = \frac{120 \times 500}{12} = 50\,Hz$

$slip = \frac{n_{sync} - n_m}{n_{sync}} =$, $n_{sync} = \frac{120 \times 50}{8} = 750$ rpm

↳ $n_m = 727.5$ rpm

Chapter 7 "Synchronous Machines"

- remember → (Asynchronous) → rotor and stator were rotating at different speeds where ($n_r < n_{syn}$)
  (stator → = generated magnetic field)

- In Synchronous machines ($n_r = n_{syn}$) → rotor and stator (magnetic field) rotate at the same speed.
  machines ↓ generator and motor.

- AC machines are more used than DC machines because it is less expensive to produce and transmit AC current than DC current

- Synchronous motors → gives constant speed regardless of the load (up to certain load).

- Stator in both synchronous and Asynchronous (induction) is the same. But different rotors.

- rotor in synchronous machines has field winding (→ that produce a rotating magnetic field) and poles and Brushes or slip Rings to provide current to the rotor

---

Synchr. speed →

$$n_s = \frac{120 f_e}{P} \text{ (r.p.m)}$$

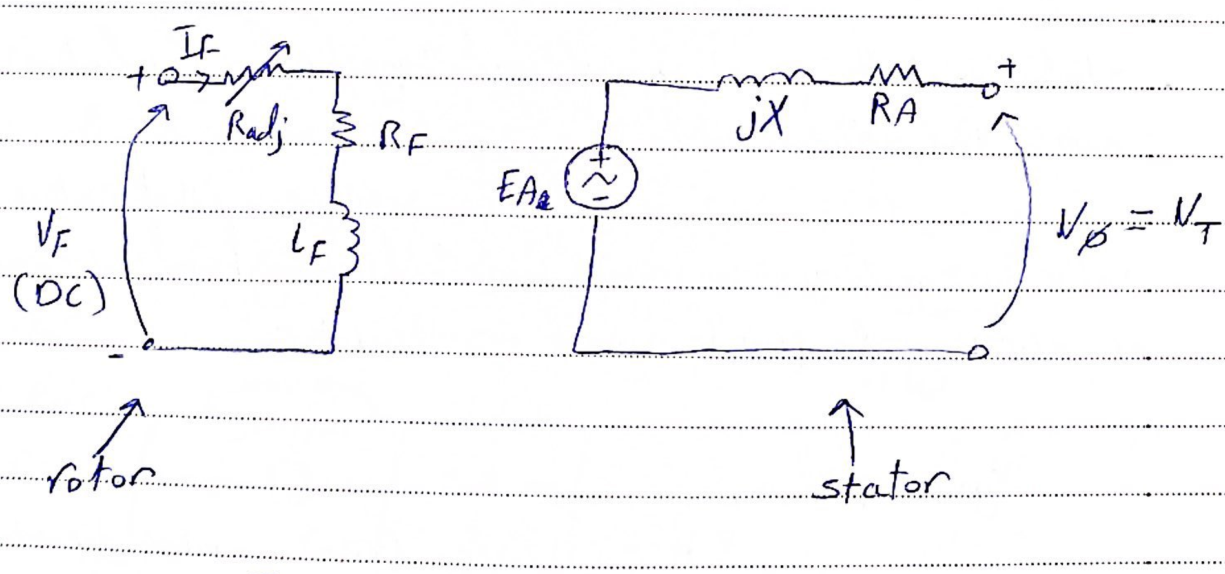
where the rotating air gap field and the rotor rotate at the same speed $= n_s$

- Synchronous motor
  - ↳ stator is connected to AC source
  - ↳ rotor is connected to DC source

- Synchronous generator → the rotor is rotating and produce field in the stator.
  using external mechanical load called prime mover.

- There are two types of rotors used in Synchronous machines :-
  1) Cylindrical (or round) rotors :- used in higher speed higher power applications such as turbogenerators
  2) salient pole rotor :- in low mechanical speed applications
     ↳ less expensive than round rotor

- Equivalent circuit of Synch. machine :-



- motor (EA) ← I∠θ
- generator (EA) → I∠θ

} V_T and EA polarity don't change but the losses will change from motor to generator according to current direction

$V\phi = EA - jX_s IA - RA IA$ → generator

$V\phi = EA + jX_s IA + RA IA$ → motor

• Basic synch machine concept :-

Motor *

↳ current on stator will produce magnetic field in the stator with speed equals to n_{synch}.

↳ DC supply on the rotor will produce magnetic field, so it'll rotate following the n_{sync} with a shift between them

(stator leads the rotor)

• Generator

↳ ~~the~~ rotor will produce magnetic field in the coils of the stator ⟶ 3 phase output voltage (rotor leads the stator)

$$P_{out} \approx \frac{3 V_{\phi} E_A \sin \delta}{X_s}$$

δ → angle between stator and rotor fields

• by controlling δ ⟶ from leading to lagging or vice versa.

• in synch. motors → speed regulation = 0 → because it rotates at the same speed.

Chapter 8 Special-purpose motors

- **Universal motor** → can operate on either AC or DC power
  - ↳ it is Brushed series DC motor (Armature current = Field current)
  - ↳ it is often referred to as an AC series motor (need rotating magnetic flux)
  - ↳ used in home applications (household appliances)
- advantages ↳ high starting torque / high speed / lightweight / compact
- disadvantage ↳ Very noisy / It cannot be used for continuous use or for a long time / short lifetime
  - ↳ due to brushes worn.

- The universal motor is modified in several ways **to allow for proper AC supply operation**
  - ↳ ① - There is a compensating winding added
  - ② - laminated pole pieces (DC) to reduce eddy current
  - ③ - The armature typically has far more coils and plates, and hence fewer windings per coil.

- **Reluctance motor** → AC motor (need rotating magnetic flux)
  - ↳ stator is the same as the stator of induction motor and synch. motor.
  - ↳ used in some cars (electrical cars motors)
  - ↳ rotor doesn't have winding
  - ↳ no slip ($n_m = n_{synch}$) → (synch. reluctance)

• Universal motor → • when fed with a DC supply, it works as a DC series motor, when current flows in the field winding. The same current also flows from the armature conductors. when a conductor is placed in an electromagnetic field, it experiences a mechanical force, due to this mechanical force the rotor starts to rotate.

it produces an electromagnetic field.

• when fed with AC supply, it still produces unidirectional torque because, armature winding and field winding are connected in series, they are in the same phase. Hence, as polarity of AC changes periodically, the direction of current in armature and field winding reverses at the same time. Thus, direction of magnetic field and the direction of the armature current reverses, so the force remains same.

• Reluctance motor → induces non-permanent magnetic poles on the ferromagnetic rotor. the rotor doesn't have any winding it generates torque through magnetic flux.

↓
less core losses
(higher efficiency)

• The working principle of reluctance motor is, whenever a magnetic material is located within the magnetic field, then it always brings into line in the less reluctance way.

• higher speed than induction motor

- **Hysteresis motors** → silent motors

↳ Synch. motor with a uniform air gap. The torque in a hysteresis and eddy current induced in the rotor by the action of the rotating flux of the stator windings.

↳ Depends on the presence of high hysteresis

↳ when stator is energized with AC supply, rotating magnetic field is produced in stator, so secondary voltage is induced in the rotor by stator rotating magnetic field. Hence eddy current is generated to flow in the rotor. Hysteresis torque in the rotor develops as the rotor magnetic material is with high hysteresis loss property and high retentivity. When the rotor starts to rotate when its speed reaches near about n_{synch} the stator pulls the rotor into synchronism where there is no difference between rotor and stator speed, hence no eddy current to generate in the rotor. The high hysteresis enables the continuous magnetic locking between stator and rotor and thus the rotor continue rotates at synch. speed (due to external conducting material)

↳

- **Stepper Motors**

↳ special electrical machine because it rotates in a discrete angular steps (not contin.)

↳ Digital motor

↳ Controlled using microcontroller

↳ unique type of DC motors

Stepper motors

- divides a full rotation into a number of equal steps. the motor's position can be commanded to move and hold at one of these steps without any position sensor (an open-loop controller).
- used in floppy disk for positioning the read, write head.
- can be controlled directly (speed control)

stepper motors (according to the rotor)

- Permanent magnet
- Variable Reluctance → low reluctance materials in the core.
- Hybrid → permanent + variable

stepper motors (according to the stator windings)
→ طريقة تعطيل ال wind. ال rotor

- Unipolar → a center tap added.
- Bipolar → harder to control → عملية عكس التيار الصعب

4 modes of operation in stepper motor

1) 1 phase ON → # of required steps to complete $(360)^\circ$
   → = 360 / size of step.
2) 2 phase on → " " " " = 360 / size of step — higher torques
3) 2-1-2-1-Phase-ON → " = 360 / size of step (↑ half step)
4) Micro-stepping → to control number of pulses, rev.

• Phase angle ⇒ $\Delta\theta = \theta_s - r\theta_r$ where θ_s → stator = 360/# of poles

or, θ_r → rotor = 360/# of poles rotor

$\theta_{larger} - \theta_{smaller}$

~~[illegible]~~

• Micro-stepping → Control divides each full step into smaller steps to help ~~[illegible]~~ smooth out the motor's rotation especially at low speed.

↳ achieved by using PWM

• Example slide 15

~~[illegible]~~

# of steps = 360/15 = 24

64 - 12 = 52 CW

52 - 2(24) = 4 rev. + 4 more steps

↳ 60° from original position

• Servo motors

↳ Control system that control machine as issued commands

↳ Control speed, position, torque or more than one at a time

↳ DC or AC motor (closed loop controller)

• linear motor

Force = length × current × B (B → flux density)

↓ has had its stator and rotor unrolled.

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· Chapter 9 Motor Sizing principles

· Sizing an electric motor goes a long way to improve reliability and performance while making equipment cost-effective

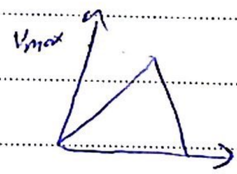
· size shouldn't be much larger than torque needed to drive the system

· when the motor is sized, controlling the mechanical components is much easier

· over sizing the motor is more common than under sizing
↳ it'll not work correctly

· slide 6
if the input (drive) has more teeth than the output
↳ more speed but less torque
O.W
↳ torque ↑ but slower

· motion profile → velocity vs time
↳ slide 7 → trapezoidal motion profile

· triangular motion profile
↳ 

Slide 11 :-

Horse power = 10
Voltage = 230 / 460
Amps = 13.5 | Full load = 27
Nema Design → class A
RPM : → MAX = 4200 / rated = 1774 / 3540 (actual)

n_{syn}: $\omega = \frac{120 \times Fr}{P} = 1800$

slip = 26

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