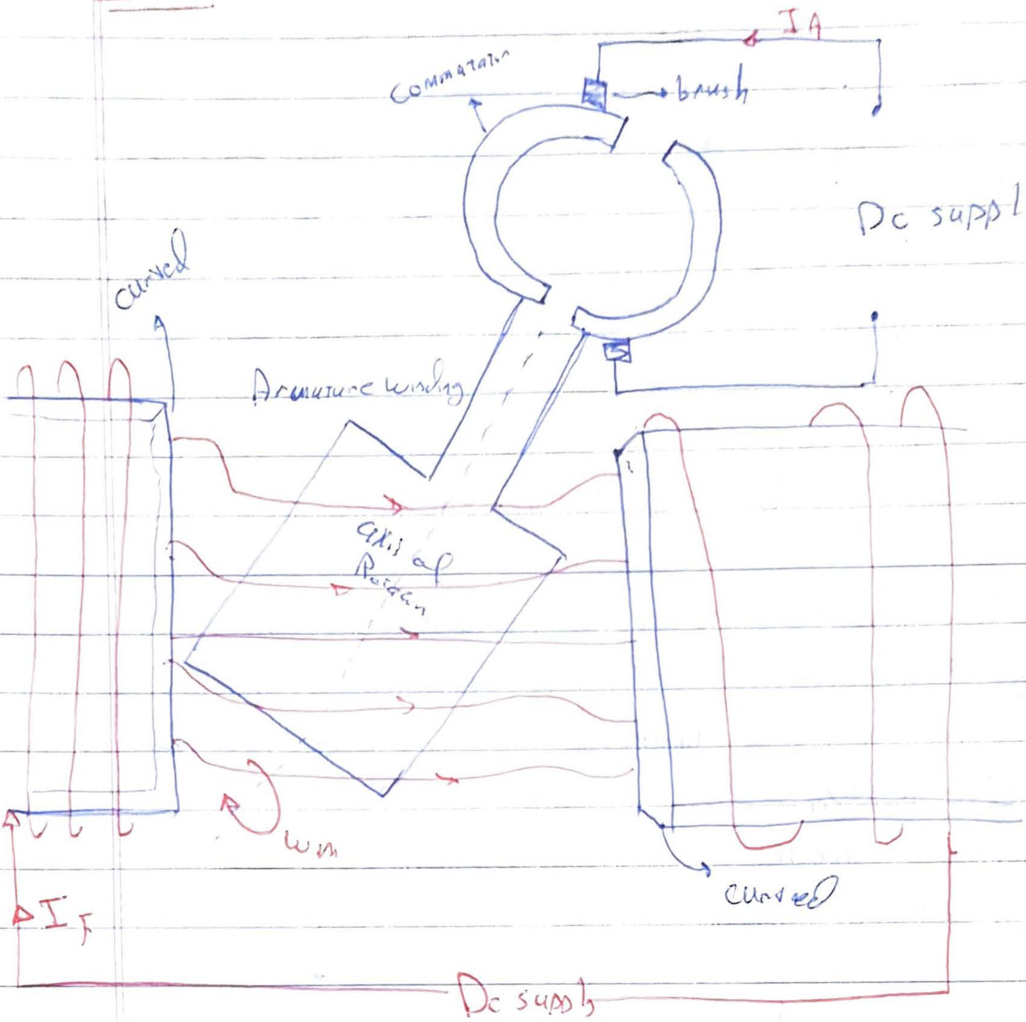
CH2: Dc Motors & Generators



⊛ الرسمة طلعت واحدة، حالت أكثر من ملف عدد كبير لأننا High Torque ع

Armature → Rotor
Field → stator
I_A: Armature current
I_F: Field current

Ac عكس ⊛

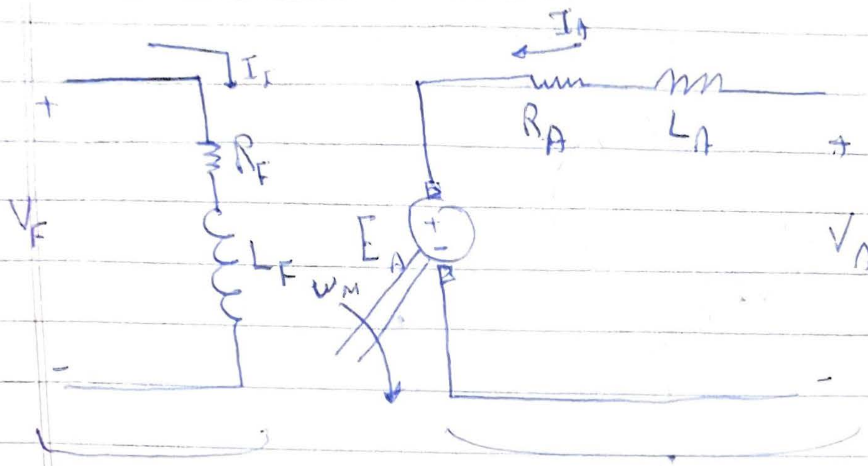
⊛ Operating principle of Dc machine (Motor Mode)

⊛ an electric current is supplied through the commutator & brushes
⊛ The current (I_A) passes through the armature windings, in the presence of magnetic field, and produces a magnetic force ($F_{ind} = I_A \vec{L} \times \vec{B}$)
⊛ The magnetic force will produces a torque which is able to rotate the Dc motor. ($T_{ind} = \vec{r} \times F_{ind}$)

⊛ Types of Dc motors:
(1) separately exited Dc motors (2) shunt Dc motor (parallel)
(3) series Dc motor (4) componant Dc motors (5) permanent magnet Dc motor

⊛ نستخدم Dc Motor للأمور التي تتطلب
• low power
• Drive is easiest than Ac induction ...

General equivalent circuit



Field circuit   Armature circuit.

R_F & L_F :- Resistance and inductance of field winding

R_A, L_A :- Resistance and inductance of armature winding

E_A :- internal voltage or induced or back emf voltage

$$E_A = K\phi\omega_m$$

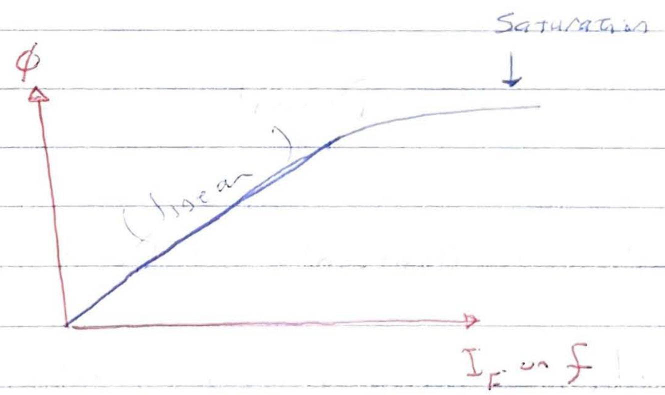
I_A :- Armature current

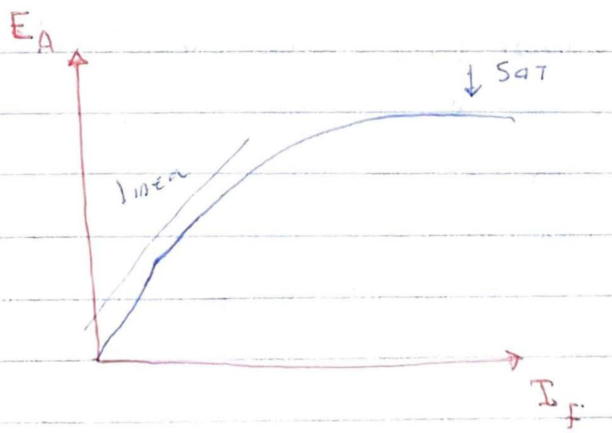
I_F :- Field current

$\phi = C I_F$

$E_A = K\phi\omega_m$, when ω_m is constant

$E_A = K'\phi$

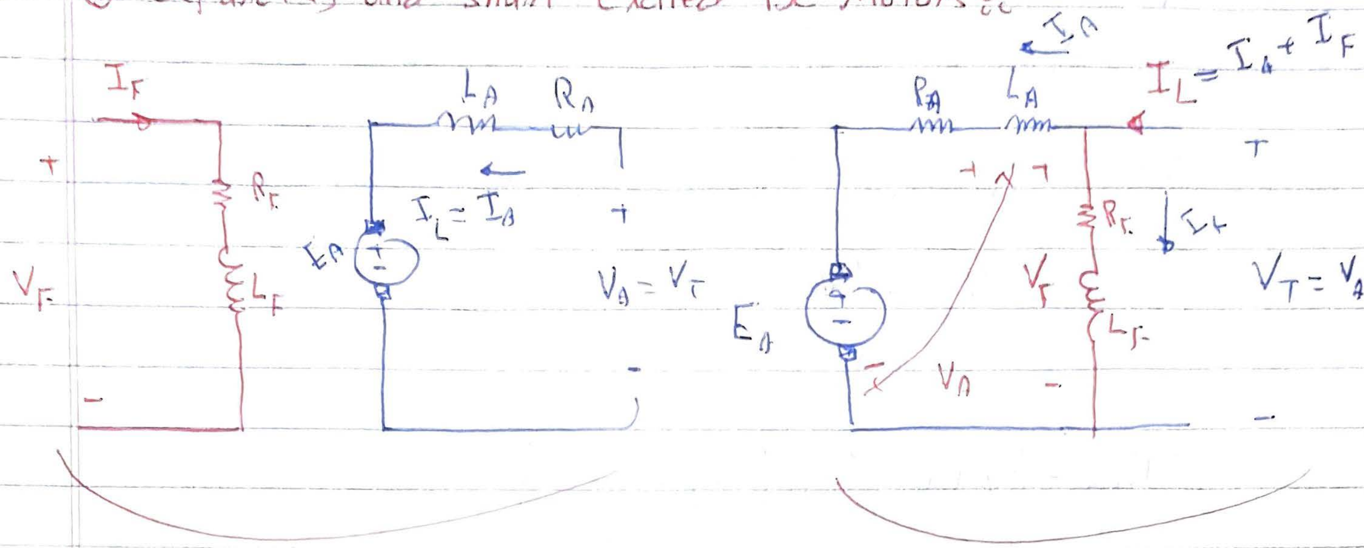




V_A :- Armature voltage

V_F :- Field voltage

① Separately and shunt excited DC Motors :



separately excited   shunt excited

V_T : Terminal or motor voltage

I_L : Motor or line current

⊛ equation of DC machine " separately & shunt excitation "

KVL in the armature circuit

- $V_T = R_A I_A + L_A \frac{dI_A}{dt} + E_A$
- Back emf voltage

  $E_A = K\phi\omega_m$
- Induced Torque

  $T_{ind} = K\phi I_A$
- Newton second law

  $T_{ind} - T_{Load} = J\frac{d\omega_m}{dT} + B\omega_m$ (B → Friction factor)

⊛ Torque speed characteristics

under steady state condition, the motor voltage is given by:

$$V_T = R_A I_A + L_A \cancel{\frac{dI_A}{dt}}^{\,0} + E_A$$

$$V_T = R_A I_A + E_A = R_A I_A + K\phi\omega_m \text{ , solve for } I_A$$

$$I_A = \frac{V_T - K\phi\omega_m}{R_A}$$

$$T_{ind} = K\phi I_A = K\phi\left(\frac{V_T - K\phi\omega_m}{R_A}\right)$$

$$T_{ind} = \frac{K\phi}{R_A}\left(V_T - K\phi\omega_m\right)$$

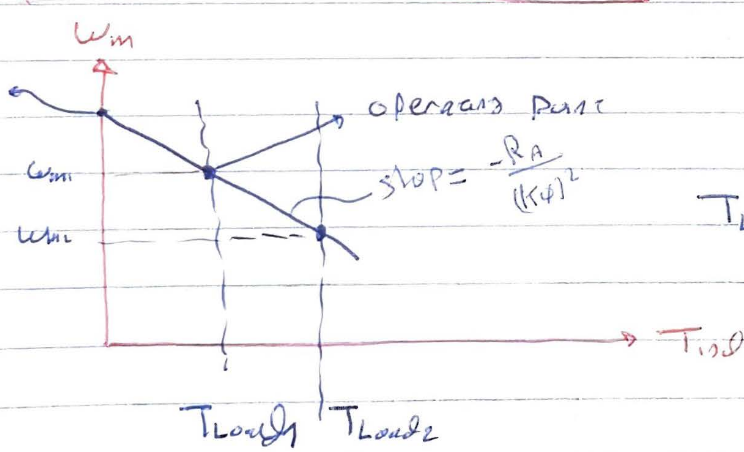
$$\frac{R_A}{K\phi} T_{ind} = V_T - K\phi\,\omega_m \Rightarrow \frac{R_A}{(K\phi)^2} T_{ind} = \frac{V_T}{K\phi} - \omega_m$$

هام

$$\boxed{\omega_m = \frac{V_T}{K\phi} - \frac{R_A}{(K\phi)^2} T_{ind}}$$

No Load speed

shunt & seperatly



$T_{Load2} > T_{Load1} \Rightarrow \omega_{m2} < \omega_{m1} < \omega_{m,No\ Load}$

$$\omega_{m,nl}\Big|_{I_A = 0} = \frac{V_T}{K\phi}$$

OR $V_T = E_A$

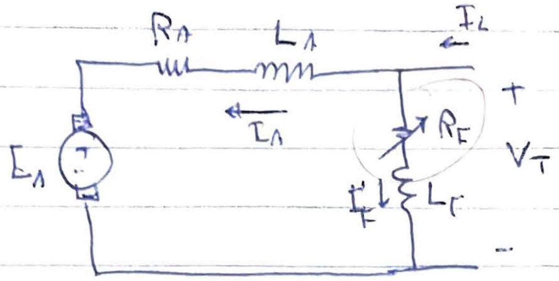
T_{ind} & T_{Load} [illegible]

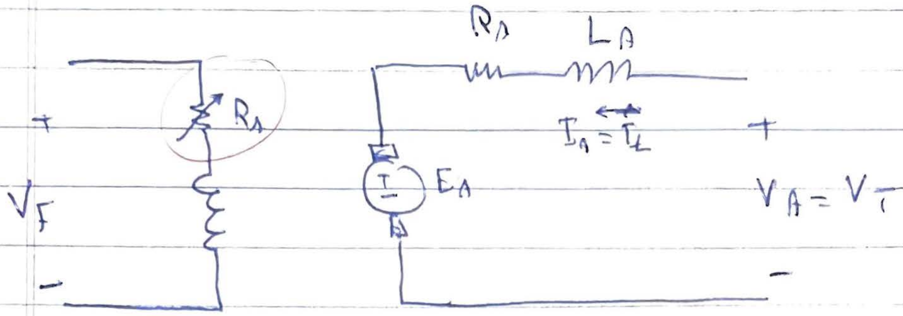
$T_{Load}\uparrow \Rightarrow \omega_m \downarrow \Rightarrow [E_A = K\phi\omega_m \downarrow]$

$\Rightarrow \left(I_A = \frac{V_T - E_A\downarrow}{R_A}\right)\uparrow \Rightarrow (T_{ind} = K\phi I_A)\uparrow$ until equals T_{Load}

Method to control the speed

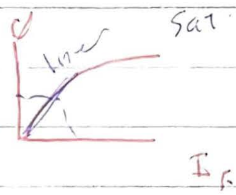
① Adjusting the Field resistor :





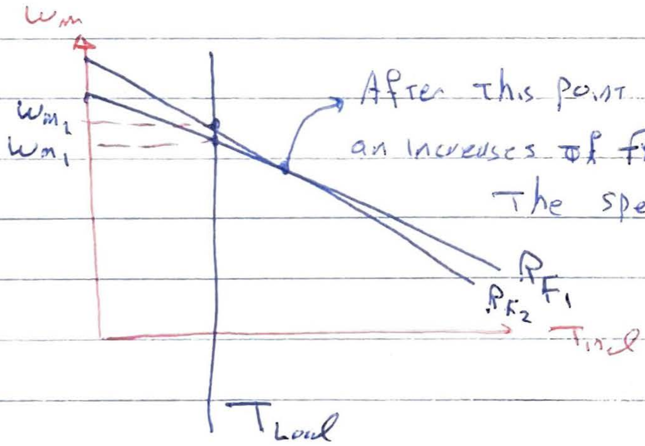
$R_A \uparrow \Rightarrow I_F \downarrow \Rightarrow \phi \downarrow$

$I_F = c\phi$



$$\omega_m = \frac{V_T}{K\phi} - \frac{R_A}{(K\phi)^2} T_{ind}$$

because $\frac{-1}{(K\phi)^2}$ slop decrease more.

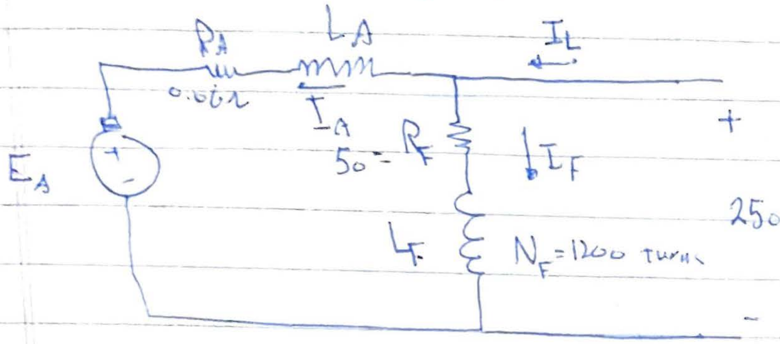


After this point an increases of RF decreases and No load ω increased the speed

⊗ منطقة التقاطع المرنة هي بالعكس
لا تقل لذلك منطقة العمل دائما
تكون قبل هذه النقطة

$R_{F_2} > R_{F_1} \Rightarrow \omega_{m2} > \omega_{m1}$ (Field weakening)

Example A 50 hp, 250 V, 1200 rpm DC shunt motor has armature resistance of 0.06 Ω. Its field circuit has a total resistance of 50 Ω which produces a no-load speed of 1200 rpm. There are 1200 turns per pole on the shunt field winding.



a) Find the speed of this motor when its ~~field~~ input current is 100 A?

بدون الحمل عند NL لا في يكون I_A يساوي صفر so $E_A = V_T$

$V_L = R_A I_A + E_A$

$I_A = I_L - I_F \quad \Rightarrow I_A = 100 - \frac{250}{50} = 95\,A$

$E_A' = 250 - 0.06(95) = 244.3\ V$

$E_A = 250\ V$ (at No Load)

$E_A = K\phi\omega_m$

$250 = K\phi\,1200$

$244.3 = (K\phi)(\omega_m')$

ϕ is Not changed since $V = 250$ constant of field circuit

$\boxed{\omega_m' = 1173}$

b) Find the speed of this motor when its input current is 300 A

$V_L = R_A I_A + E_A$

$250 = (0.06)(I_A) + E_A$

$\boxed{I_A = 295\,A}$, $\boxed{E_A = 232.3}$

$E_A = K\phi\omega_m \Rightarrow 250 = (K\phi)(1200)$ — ①

$232.3 = K\phi\,\omega_m'$ — ② $\Rightarrow \boxed{\omega_m' = 1115\ rpm}$

Seperately excited

Converted power in ~~shunt~~ Dc motors

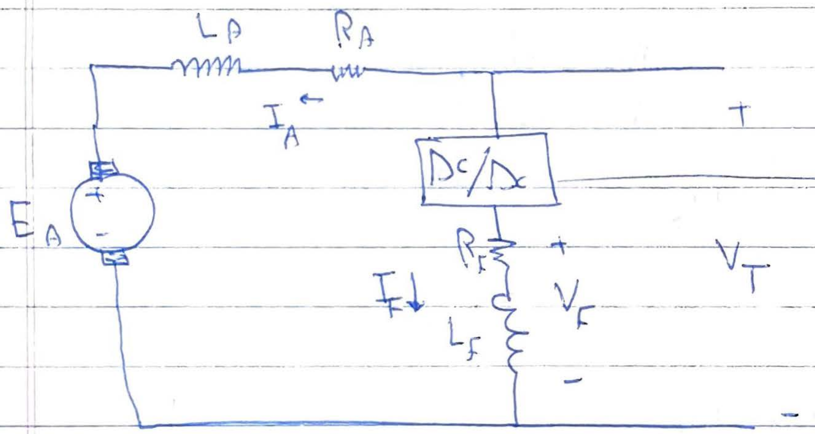
$V_L = R_A I_A + E_A$, Multiply the eq by I_A

$P_L = \underbrace{V_L I_A}_{\text{input power}} = \underbrace{R_A I_A^2}_{\text{Copper losses in } R_A} + \underbrace{E_A I_A}_{\text{Converted power}}$

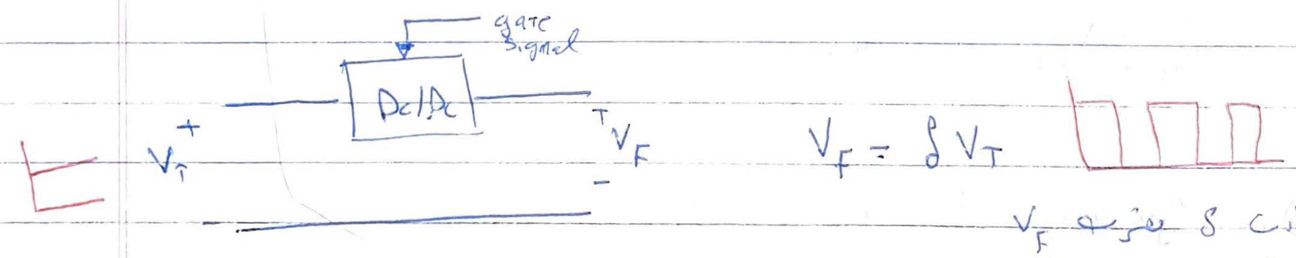
$P_{conv} = E_A I_A = T_{ind}\, \omega_m \Rightarrow \boxed{T_{ind} = \dfrac{P_{conv}}{\omega_m}}$

* Method to control the speed (Repeated)

① adjusting the field resistor or adjust the field voltage :-



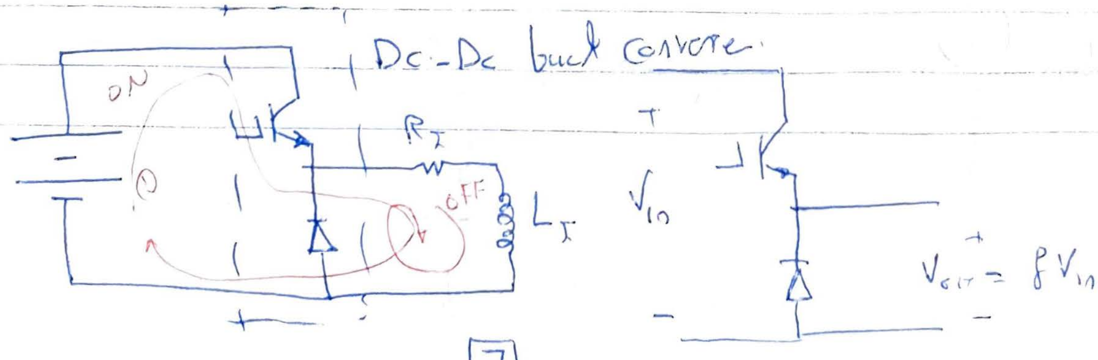
تقلل V_F بيقلل
بيقل I_F بيقل ϕ



$V_F = \delta V_T$

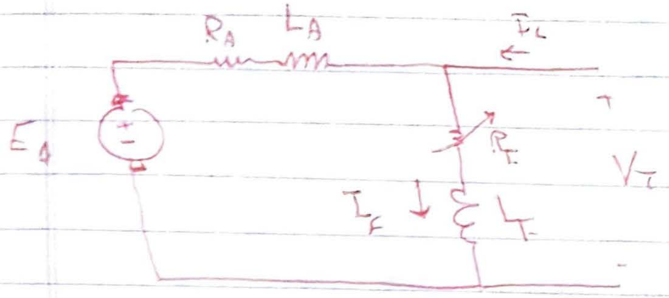
كل ما زادت δ بتقرب V_F
من V_T ويقل فترة opp

where δ is called the duty cycle $0 \leq \delta \leq 1$



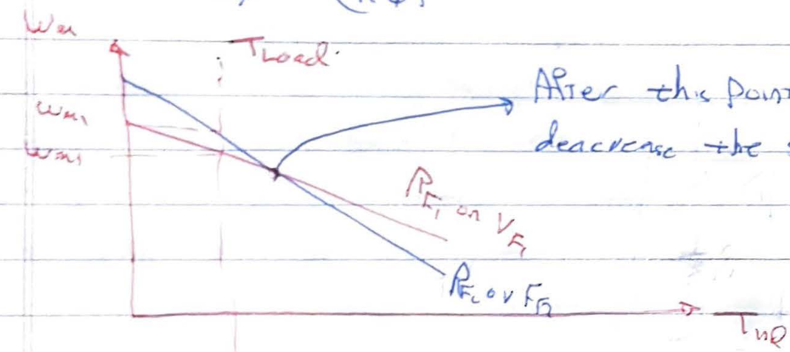
$V_F \downarrow \Rightarrow (I_F = \frac{V_F}{R_F}) \downarrow \Rightarrow (\phi = C I_\phi) \downarrow \Rightarrow \omega \uparrow$

① adjusting the field Resistor



$R_F \uparrow \Rightarrow (I_F = \frac{V_F}{R_F}) \downarrow \Rightarrow (\phi = C I_F) \downarrow$

$$\omega_m = \frac{V_T}{K\phi} - \frac{R_A}{(K\phi)^2} T_{ind}$$

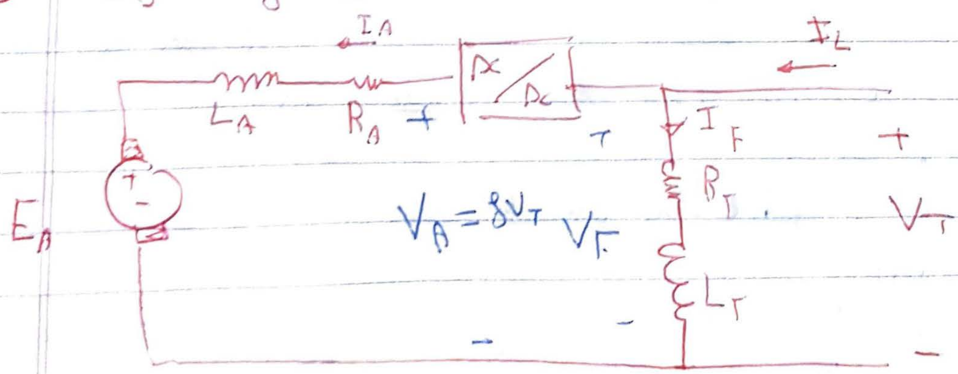


After this point an increase of R_F will deacrease the speed.

$R_{F_1} < R_{F_2} \Rightarrow \omega_{m_1} < \omega_{m_2}$

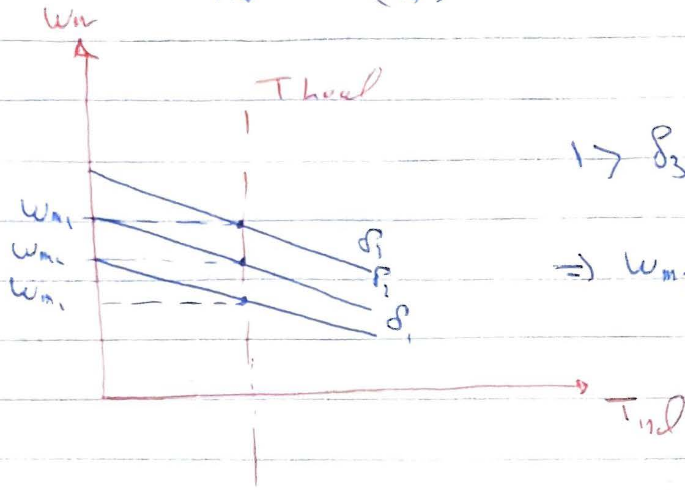
$V_{F_1} > V_{F_2} \Rightarrow \omega_{m_1} < \omega_{m_2}$

② adjusting the armature Voltage.



$V_A = \delta V_T$, δ is the duty cycle $0 \leq \delta \leq 1$

$$\omega_m = \frac{\delta V_T}{K\phi} - \frac{R_A}{(K\phi)^2} \cdot T_{ind}$$



$1 > \delta_3 > \delta_2 > \delta_1 > 0$

$\Rightarrow \omega_{m3} > \omega_{m2} > \omega_{m1}$

Note

① $V_A = R_A I_A + E_A = R_A I_A + K\phi\omega_m$

$V_A = R_A I_A + K\phi\,\omega_m$

⊛ لا يمكن رفع الـ Voltage أعلى من Rated volt ، بعد الـ full نعدل الـ ϕ لزيادة الحركة

$\phi = \phi_r$ rated flux [when $\omega_m \leq \omega_{m,r}$ where $\omega_{m,r}$ is the rated speed
$\Rightarrow$ Armature control is used $\Rightarrow V_A$ increase with ω_m (linearly)]

when $\omega_m \geq \omega_{m,r} \Rightarrow$ Field control is used

$V_A = V_{A,r}$ = rated motor voltage

$\Rightarrow \phi \propto \frac{1}{\omega_m}$ "Field weakening"

② $T_{ind} = K\phi I_A$

$P_{conv} = T_{ind}\,\omega_m$

⊛ من طرق التحكم بالحركة بعد Rated تقليل الـ ϕ
ولكن هي بتبقي V_A ثابت الدراية $\phi = \frac{c}{\omega}$
لذلك $V_A = R_A I_A + K\frac{c}{\omega}\omega$ — constant

[when $\omega_m \leq \omega_{m,r} \Rightarrow \phi = \phi_r \Rightarrow T_{ind}$ = constant
when $\omega_m \geq \omega_{m,r} \Rightarrow \phi = \phi_r \frac{\omega_{m,r}}{\omega_m} \Rightarrow T_{ind} = K\phi_r \frac{\omega_{m,r}}{\omega_m}$]

& P_{conv} = Constant

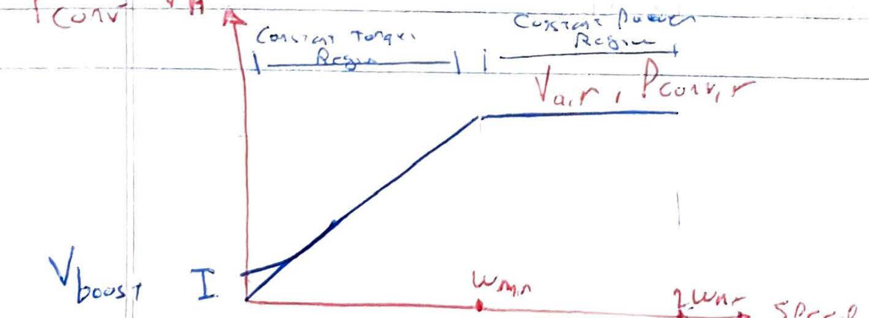
Constant $= P = K\phi_r \frac{\omega_{m,r}}{\omega_m} \cdot \omega_m$

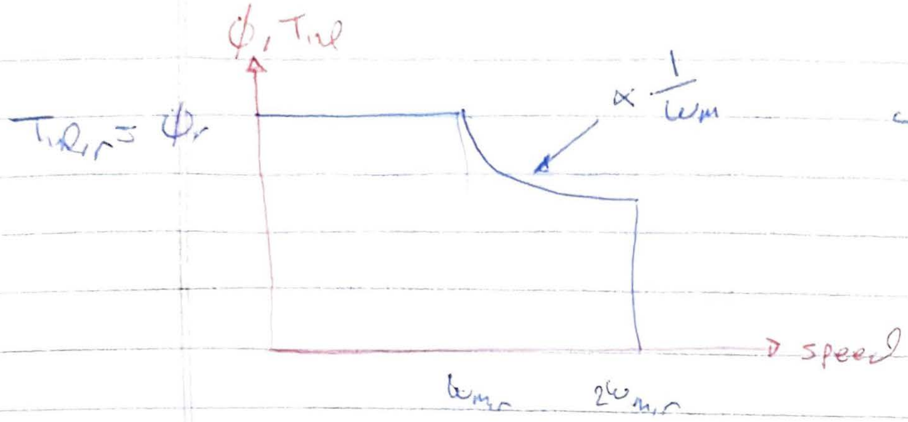
$P = T_{ind}\,\omega_m$

$T_{ind} = K\phi\,\omega_m$

$T_{ind} = K\frac{\phi}{\omega} \cdot \omega_m$ = Const

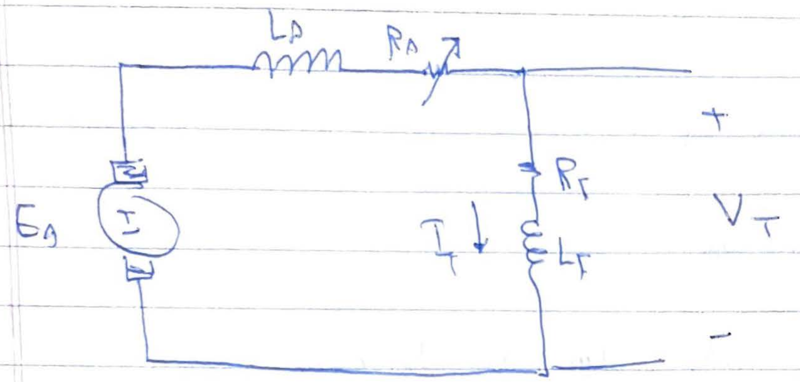
P = Constant $\cdot \omega_m$



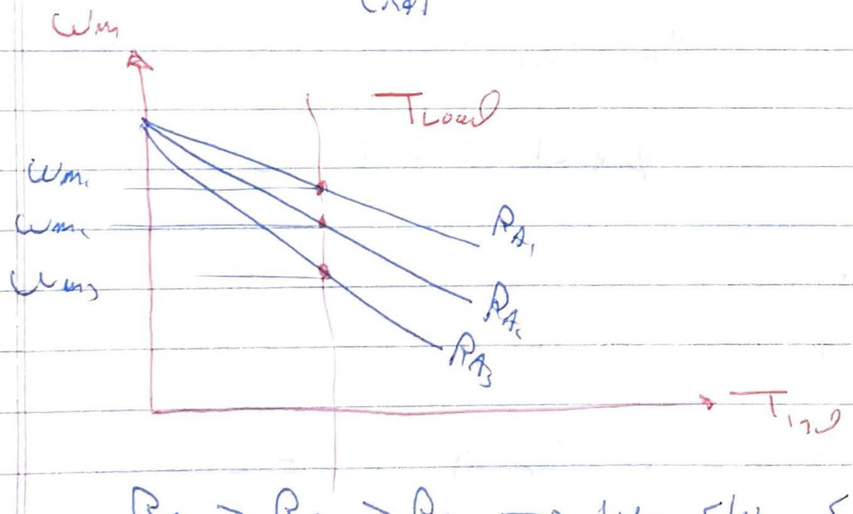


⊗ نلاحظ زيادة السرعة على حساب T_{ind} حيث أنها تقل مع $\frac{1}{\omega_m}$

③ Inserting a resistor to the armature circuit.



$$\omega_m = \frac{V_T}{K\phi} - \frac{R_A}{(K\phi)^2} \cdot T_{ind}$$



$$R_{A_1} > R_{A_2} > R_{A_3} \Rightarrow \omega_{m_3} < \omega_{m_2} < \omega_{m_1}$$

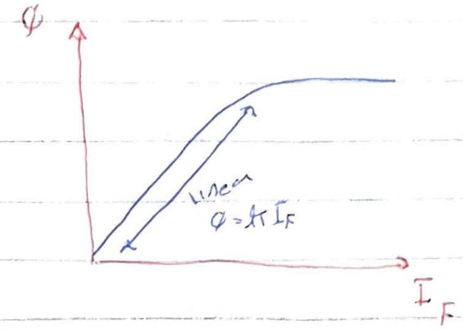
⇒ This method is insfficient because the power losses are very large ⇒ its rearly used.

Note: The direction of shunt or separately excited DC motor is reversed by switching the terminals of armature or field windings.

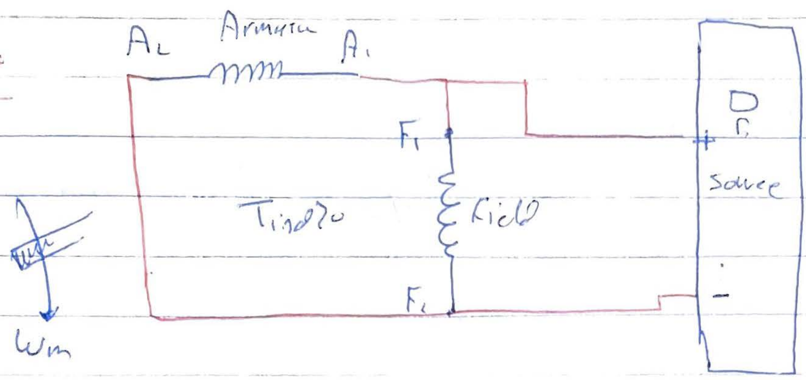
$T_{ind} = K \phi I_A$

$\phi = K I_F$ ⊕ عليك عكس احدى التيارات .

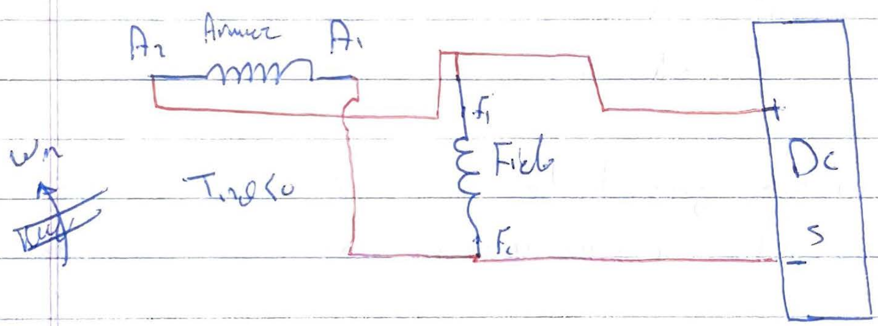
$T_{ind} = K c I_F I_A$



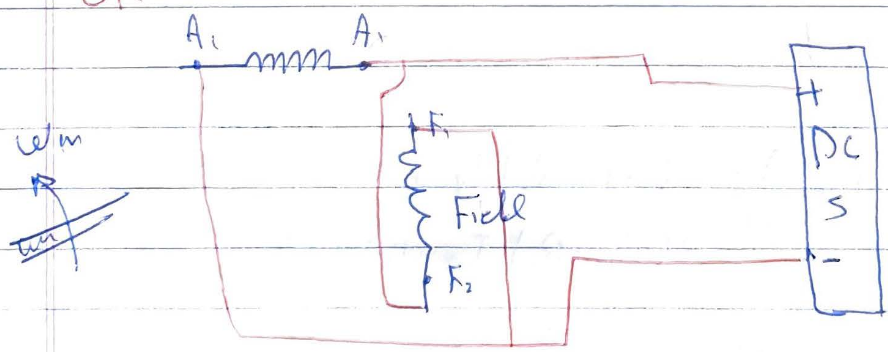
Shunt



How?



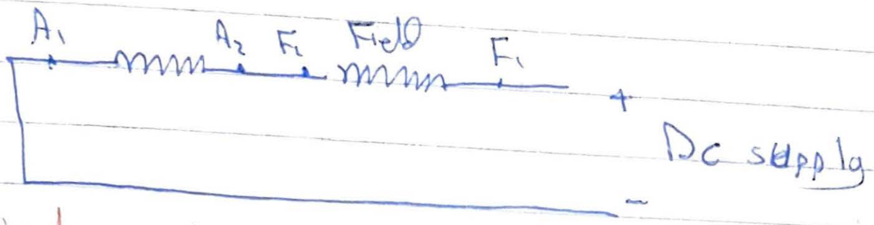
OR



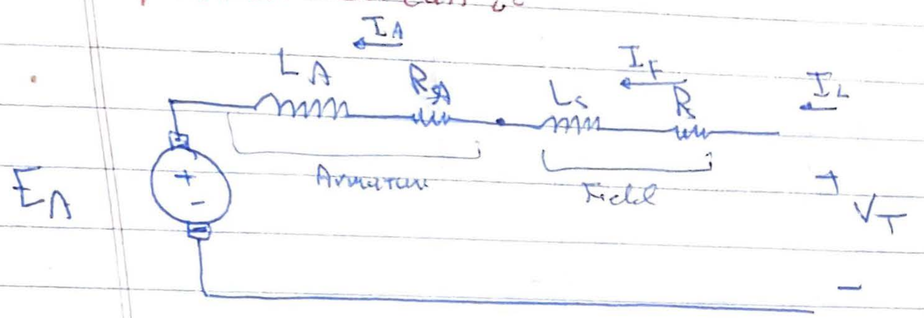
~~② Sep.~~

③ Series DC motor

The field winding is connected in series with the armature coil,



equivalent circuit :-



Motor Current = $I_A = I_F = I_L$

Induced Torque : $T_{ind} = K\phi I_A$

$T_{ind} = K c I_F I_A \quad , \quad I_F = I_A$

$T_{ind} = K c I_A^2 \Rightarrow T_{ind} \propto I_A^2$

The series Dc motor gives higher Torque / Ampere ratio than other Dc motor. It's usually used in applications requiring high Torques.

Torque speed characteristics of series Dc motor ?

KVL in the loop : $V_T = (R_A + R_S) I_A + E_A \quad , \quad E_A = K\phi\omega_m$

$V_T = (R_A + R_S) I_A + K\phi\omega_m$

$\phi = c I_F \quad , \quad I_F = I_A$

$V_T = (R_A + R_S) I_A + K c I_A \omega_m \quad \text{--- ①}$

$T_{ind} = K c I_A^2$

$\Rightarrow I_A = \frac{\sqrt{T_{ind}}}{\sqrt{Kc}} \quad \text{--- ②}$

①,② $V_T = (R_A + R_S)\frac{1}{\sqrt{K_C}}\sqrt{T_{ind}} + \frac{K_C}{\sqrt{K_C}}\sqrt{T_{ind}}\,\omega_m$

$$\frac{V_T}{\sqrt{T_{ind}}} = \frac{R_A + R_S}{\sqrt{K_C}} + \sqrt{K_C}\,\omega_m$$

$$\boxed{\omega_m = \frac{V_T}{\sqrt{K_C}} \cdot \frac{1}{\sqrt{T_{ind}}} - \frac{(R_A + R_S)}{K_C}}$$

Starting Torque:

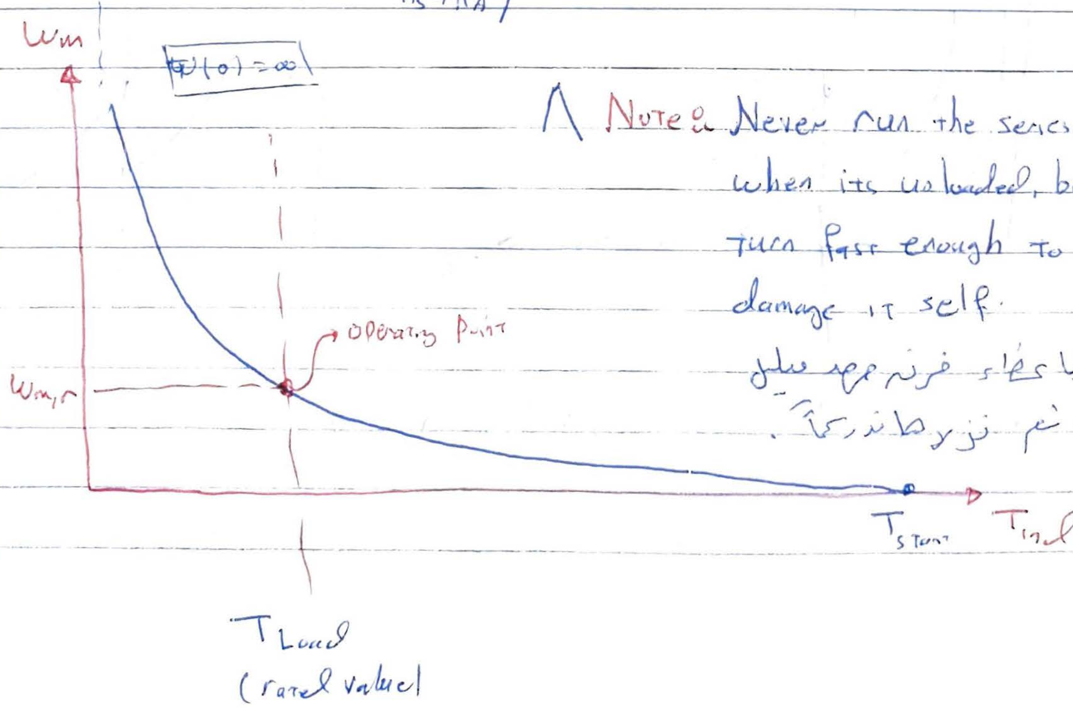
$$T_{start} = T_{ind}\Big|_{\omega=0} \Rightarrow 0 = \frac{V_T}{\sqrt{K_C}} \cdot \frac{1}{\sqrt{T_{ind}}} - \frac{(R_A + R_S)}{K_C}$$

After solving it $\Rightarrow$ $\boxed{T_{start} = \left(\frac{V_T}{(R_A + R_S)}\right)^2 K_C}$

or by $E_A = K\phi\omega_m = 0$ At starting

$$T = K_C I_A^2 \quad , \quad I_A = \frac{V_T - E_A^{\,0}}{R_A + R_S}$$

$$\therefore T_{start} = K_C\left(\frac{V_T}{R_S + R_A}\right)^2$$



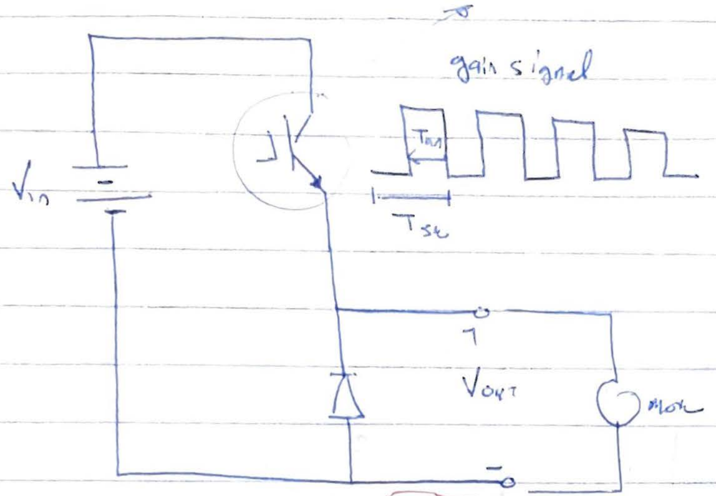
⚠ Note: Never run the series DC motor when its unloaded, because it may turn fast enough to seriously damage it self.

ممكن حلها باعطاء فرق جهد قليل
من البداية ثم نزيدها تدريجيا.

⊛ Methods to control the speed ω_0

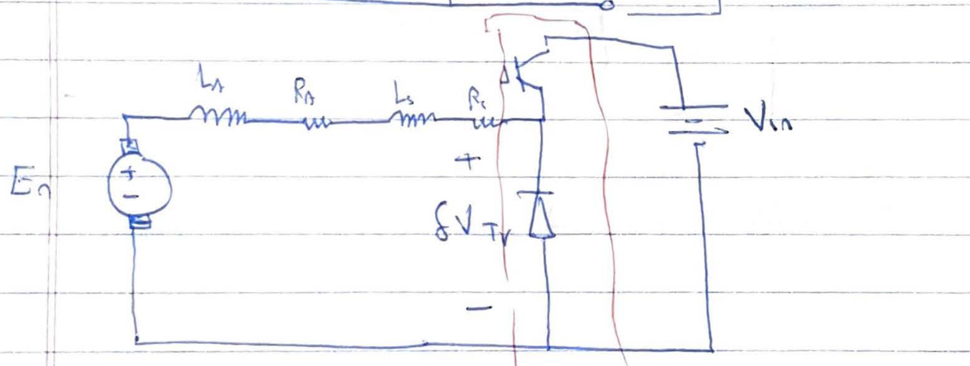
1) Adjust the motor Voltage using DC/DC buck converter (chopper circuit)

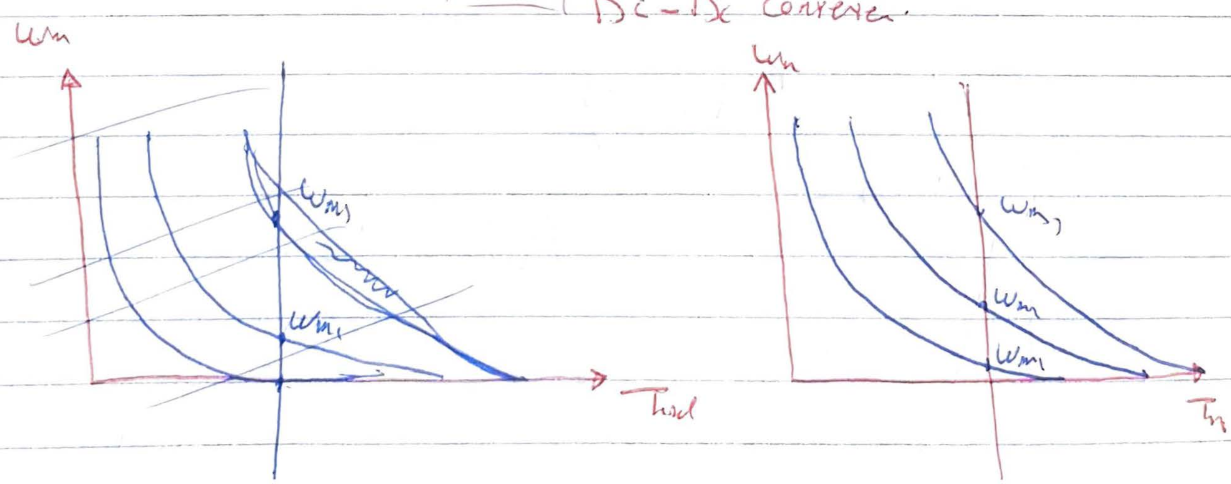
اذا اعطيته High signal بشتغل والعكس صحيح.



$V_{out} = \delta V_{in}$

$$\delta = \frac{T_{on}}{T_{sw}}$$

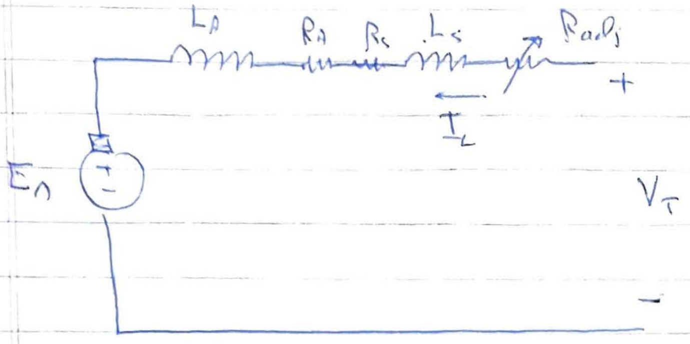




$V_1 < V_2 < V_3$, $\omega_{m_1} < \omega_{m_2} < \omega_{m_3}$

⊛ اذا بدي انزل ال Voltage بنزل ال δ ، والعكس صحيح.

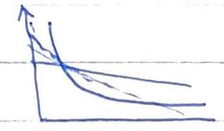
2) Adding a resistor in series with the field & armature windings.



$R_{adj} \uparrow \Rightarrow \omega_m \downarrow \Rightarrow$ This method is inefficient because the power losses are very large $\rightarrow$ its rarely used.

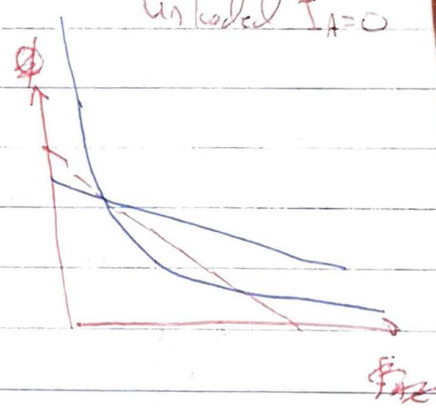
Note: This method is usually used for starting up the DC motor

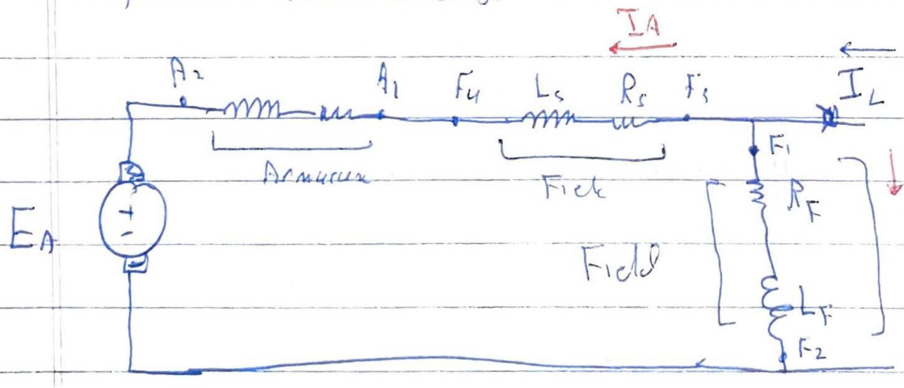
③ Compound DC Motors:



it consists of 3-windings:

1) Armature winding
2) series field windings
3) shunt field windings.





ⓧ اصلا flux بيتزيد منطقي $I_A=0$ لكن $I_F \neq 0$ لذلك بوجد ω_s

فوق للتفسير

The net mmf is giving by, $\mathcal{F}_{net} = \mathcal{F}_F + \mathcal{F}_S$

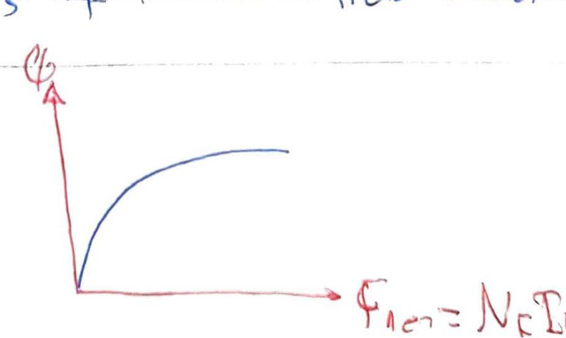
بوجد

$\mathcal{F}_{net} = N_F I_F + N_S I_A = N_F I_F^*$, I_F^*: effective field current

ϕ ودا

Constant

$$I_F^* = I_F + \frac{N_s}{N_F} \cdot I_A$$



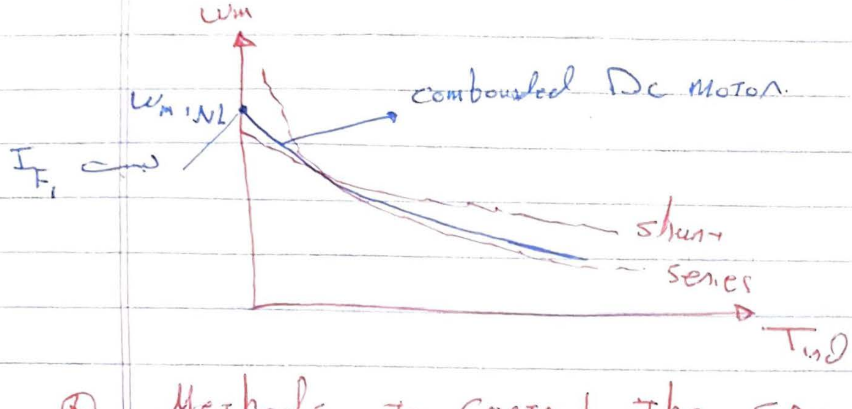
اذا No Load $I_A = 0$

$I_F^* = I_F$

⊛ its combines the best features of both series and shunt DC motors

series DC motors ⟶ high Torque

shunt DC motors ⟶ it doesn't overspeed when its unloaded.



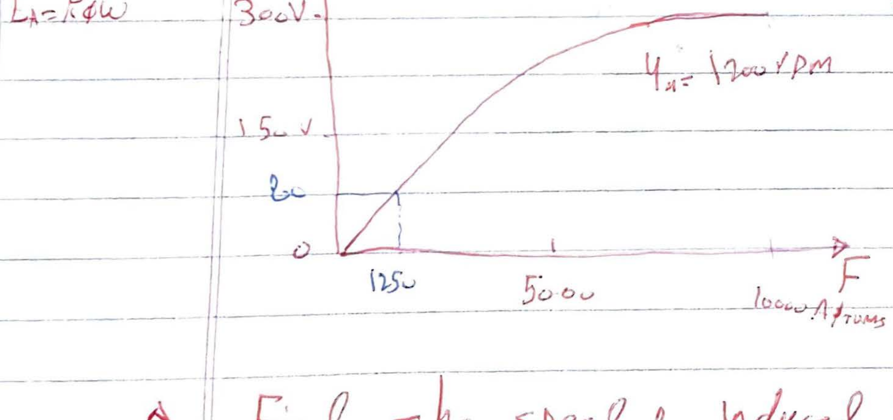
⊛ Methods, to control the speed?

1) changing the Terminal Voltage (Buck converter)
2) changing the field shunt resistor
3) changing the field series resistor

} power losses ↑

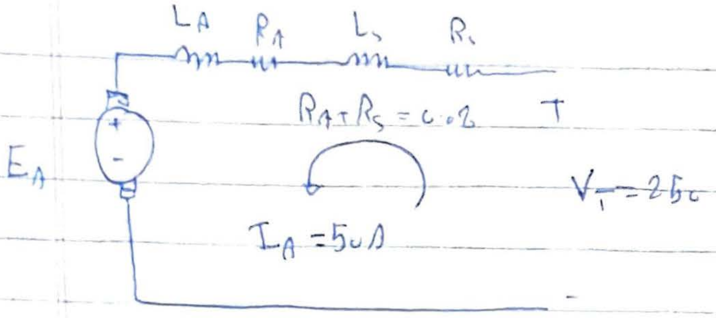
Example A 250V series DC motor has a total series resistance of 0.01Ω. The series field consists of 25 turns per-pole, with the magnetizing curve shown in Figure

$E_A = K\phi\omega$



* هذا رسمة منحنى الـ
E_A لـ حالـ KT
* صحح كل ما $K\phi$
ثم كل للسرعة الجديدة

◇ Find the speed & Induced Torque when the motor current is 50 A?



KVL in the loop ⇒

$V_T = (R_A + R_S) I_A + E_A$

$E_A = 246$ Volt

$E_A = K\phi\omega_m$

$F = N_F I_F = N_S I_A = (25)(50) = 1250$ A.turn

From magnetizing curve ⇒ $E_{A_0} = 80V = K\phi\left(\frac{1200\pi}{30}\right)$

$K\phi = \cancel{246}$, $\omega_m = 3690\frac{\pi}{30}$ rad/sec

.6369 $\quad n_m = 3690$ rpm

$T_{ind} = K\phi I_A$

or $P_{conv} = T_{ind}\,\omega_m = E_A I_A$ ⇒ $\boxed{T_{ind} = 31.8\ N.m}$

Control circuit in DC motors

Function of control circuits

1. protection against short circuit (Fuses)
2. Protection against overloading (OL heater)
3. protection against high starting current
4. speed control

Starting problems in DC motors

The armature current of the DC motor is giving by (KVL) ⇒

$$I_A = \frac{V_T - E_A}{R_A}$$ "seperately or shunt excited"

At starting $\Rightarrow \omega_m = 0 \Rightarrow E_A = K\phi\omega_m = 0 \Rightarrow I_{A,start} = \frac{V_T}{R_A}$

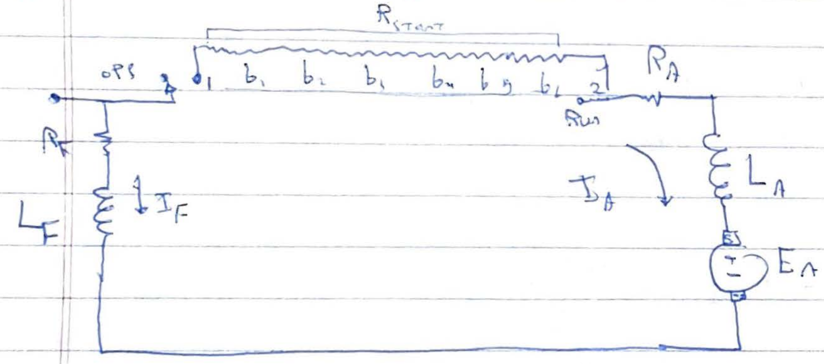
المشكلة هو عدم وجود E_A في البداية لذلك يجب اضافة R في البداية ثم ازالتها بعد زيادة E_A

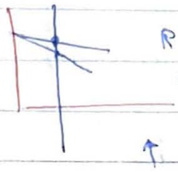
$R_A = (3\% - 6\%)$ (per-unit) (PU) $\Rightarrow I_{A,start} \approx (20-30) I_{A,rated}$

Starters of Dc motors

⊗ كل الطرق عن طريق R ، بطريقة مختلفة.

① Manual starter





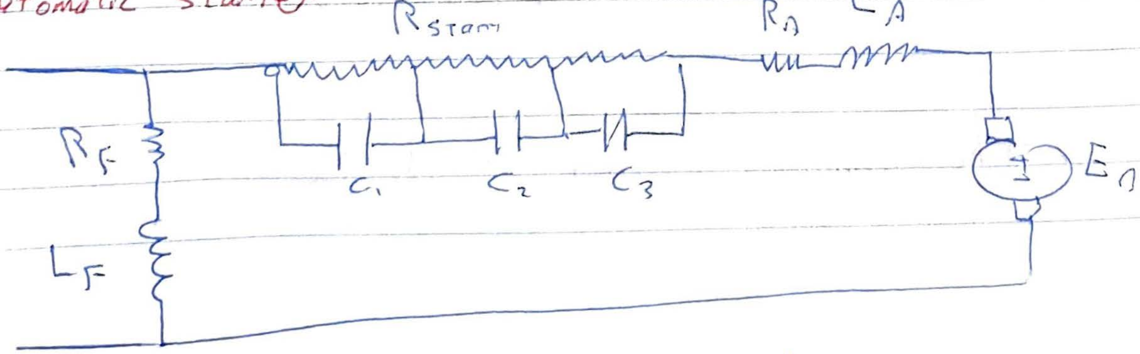
⊗ يجب ازالة R بحذر ودلك للحفاظ على الحركة حسب ↑

⊗ Continous starting resistor, which is gradually cut out of the circuit by a person moving his handle.

⊗ The handle shouldn't be moved slowly to prevent burning up the resistor

⊗ The handle shouldn't be moved quickely to prevent the resulting current of being large.

② Automatic starter



$$I_{start} = \frac{V_T - E_A \uparrow}{R_A + (R_{...}\ ...)}$$

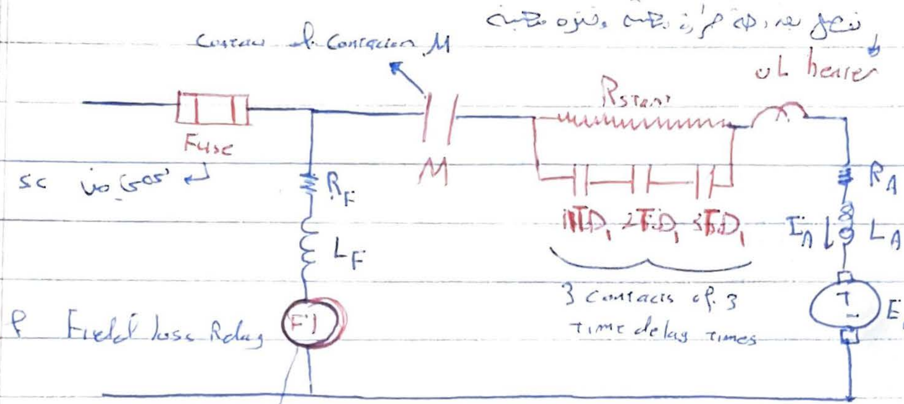
$C_1, C_2, C_3 \rightarrow$ contacts of relay C_1, C_2 & C_3 (Normally opened contacts)

The Resistor, R_{START} is divided into 3 parts, which are Removed sequentially via the contact $C_1, C_2 + C_3$

(1)

C_1, C_2 & C_3 are 3 contacts of time delay relays on armature voltage sensing relays. (2)

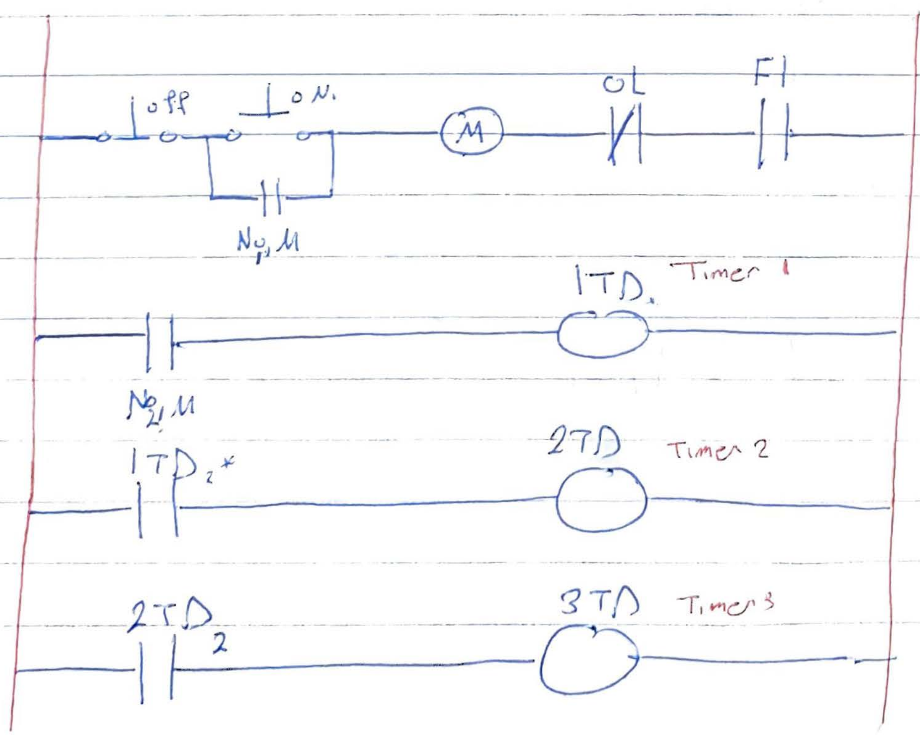
Video



shunt

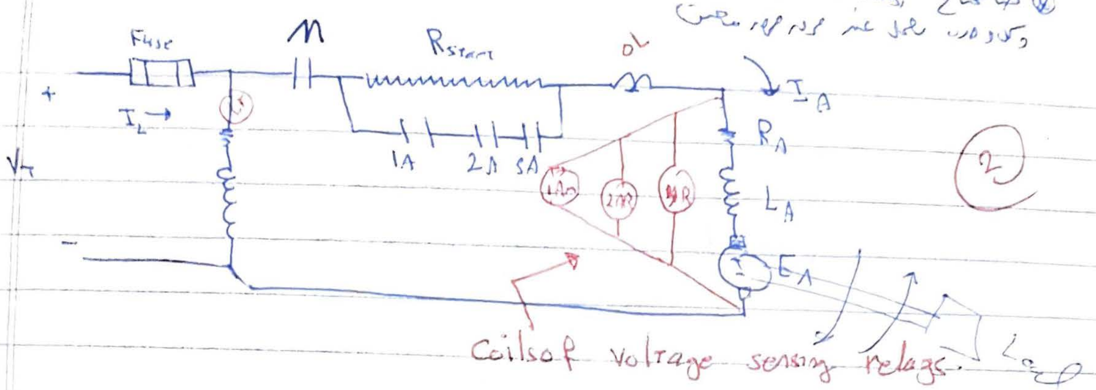
(1)

Control Circuit

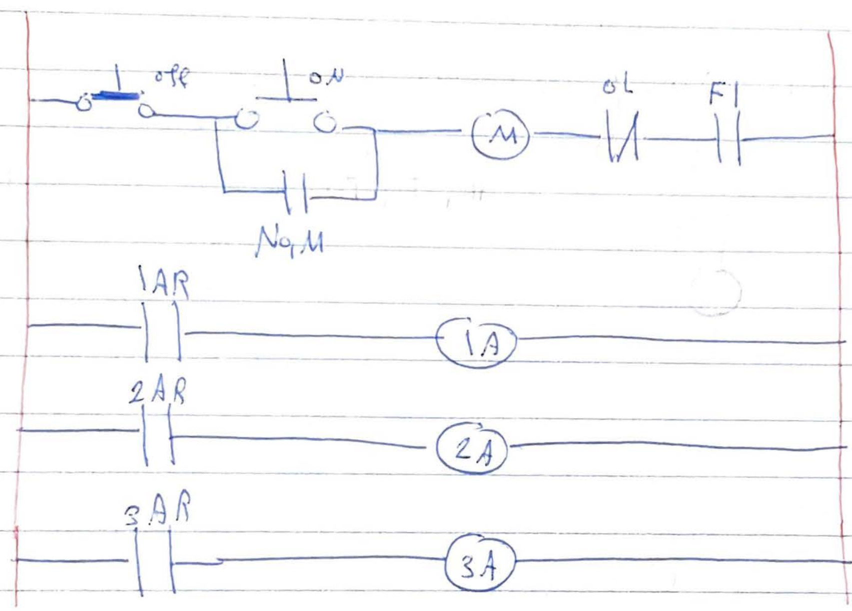


(2)

صاحبنا 3 relays لقراءة فرق الجهد
وكل واحد يعمل عند فرق جهد معين



Control circuit



Fuse: To protect the motor and the source from short circuit.

OL: Cut off the current when the Temp increased too much than Normally Temp (for long time)

chapter 8 questions 1, 2, 3, 5, 6, 8, 9, 12, 13, 14, 21