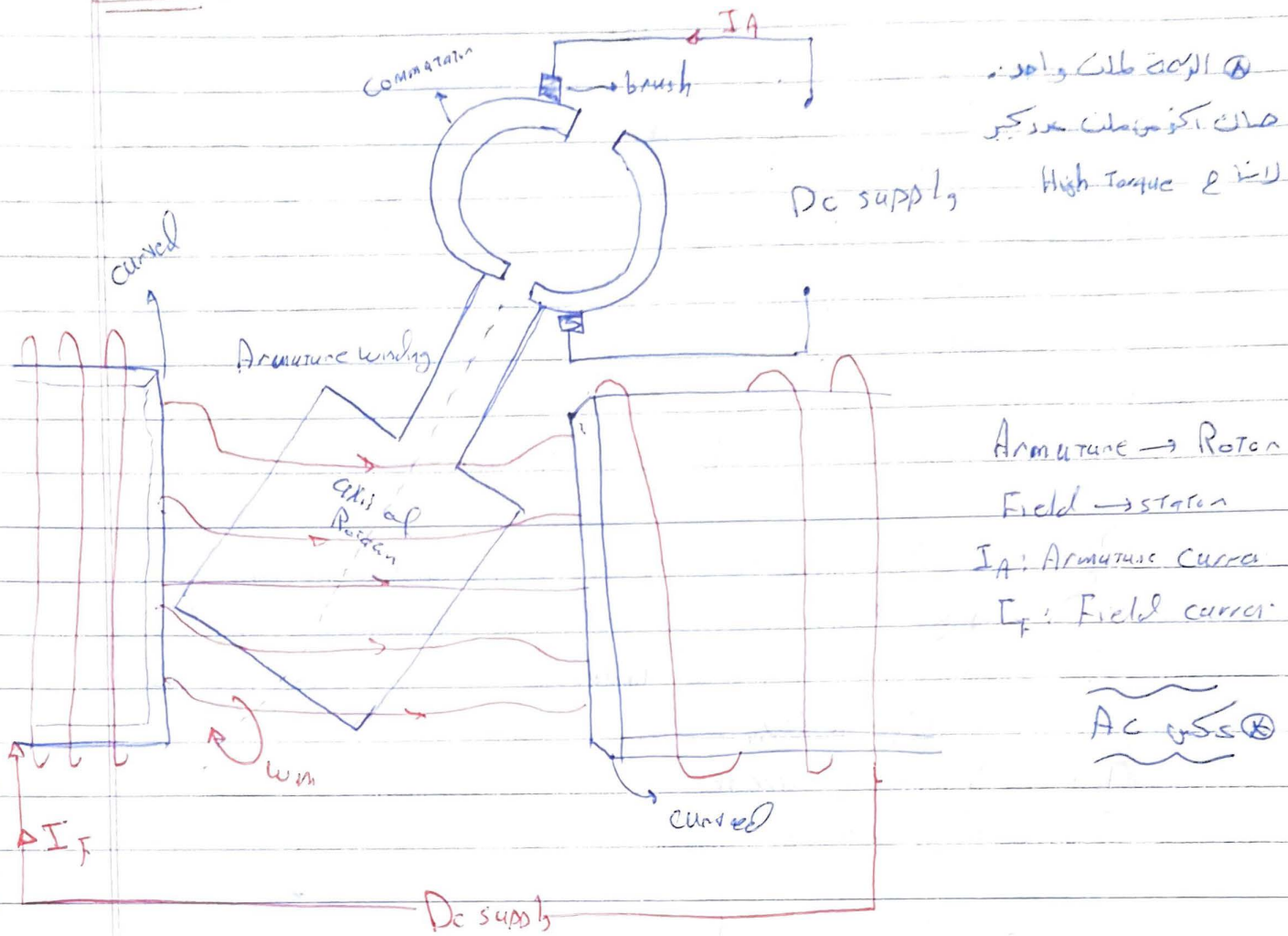


CH2 :- Dc Motors & Generators



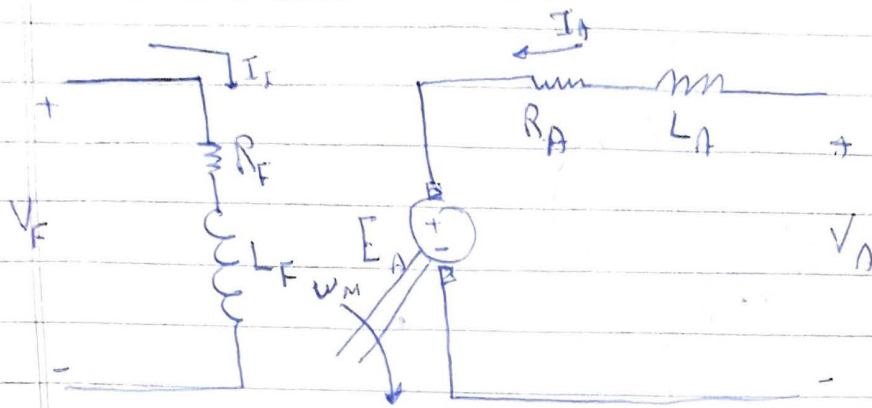
⊗ Operating principle of Dc machine (Motor Mode)

- ⊗ 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 produce a torque which is able to rotate the Dc motor. ($T_{ind} = \vec{r} \times F_{ind}$)

⊗ Types of Dc motors, (parallel)

- ① Separately excited Dc motors
- ② shunt Dc motor
- ③ series Dc motor
- ④ compound Dc motors
- ⑤ permanent magnet Dc motor

General equivalent circuit



Field circuit

Armature circuit.

R_F, L_F $\Rightarrow$ Resistance and inductance of field winding

R_A, L_A $\Rightarrow$ Resistance and inductance of armature winding

E_A $\Rightarrow$ internal voltage or induced or back emf voltage

$$E_A = K \Phi \omega_m$$

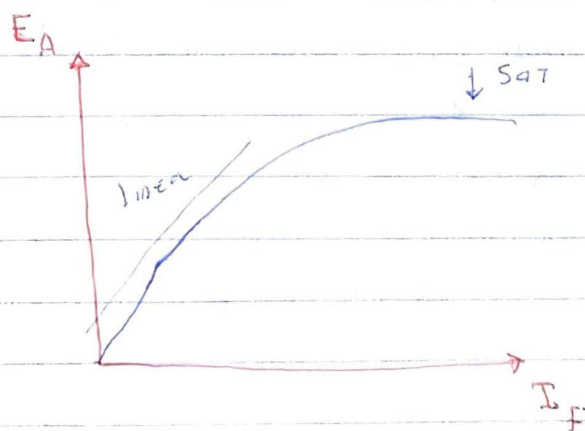
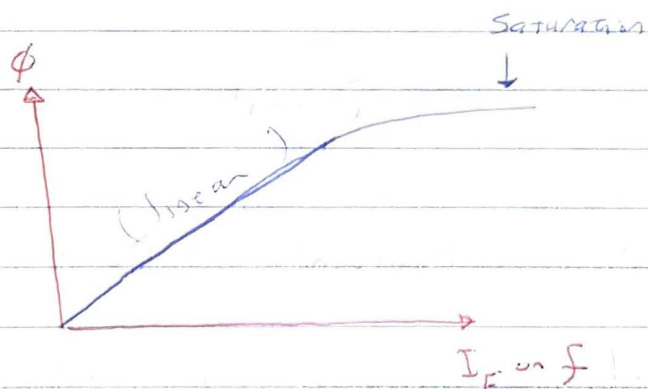
I_A $\Rightarrow$ Armature current

I_F $\Rightarrow$ Field current

$$\Phi = C I_F$$

$$E_A = K \Phi \omega_m, \text{ when } \omega_m \text{ is constant}$$

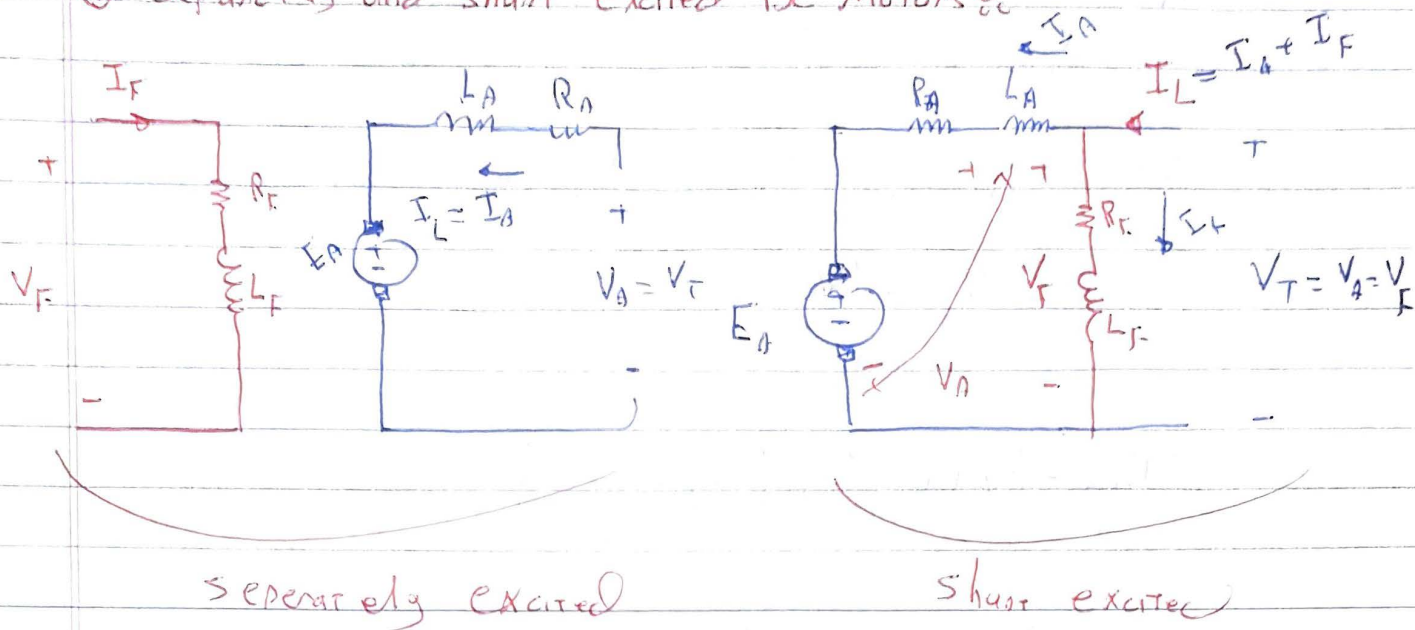
$$E_A = K' \Phi$$



V_A $\Rightarrow$ Armature voltage

V_F $\Rightarrow$ Field voltage

① Separately and shunt excited DC Motors etc



V_T is Terminal or motor voltage

I_L is Motor or line current

② 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

$$T_{ind} - T_{load} = J \frac{d\omega_m}{dt} + B \omega_m$$

Friction factor

③ Torque speed characteristics

under steady state condition, the motor voltage is given by $V_T = R_A I_A + L_A \frac{dI_A}{dt} + E_A$

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

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

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

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

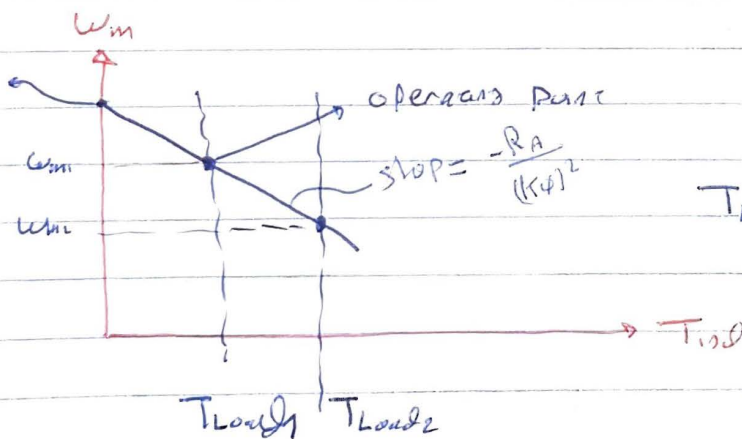
$$\frac{R_A}{K\phi} T_{ind} = V_T - K\phi\omega_m \Rightarrow \frac{R_A}{(K\phi)^2} T_{ind} = \frac{V_T}{K\phi} - \omega_m$$

Derive

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

No Load speed

shunt separately



$$T_{load2} > T_{load1} \Rightarrow \omega_{m2} < \omega_{m1}$$

$\leftarrow \omega_{m, \text{No Load}}$

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

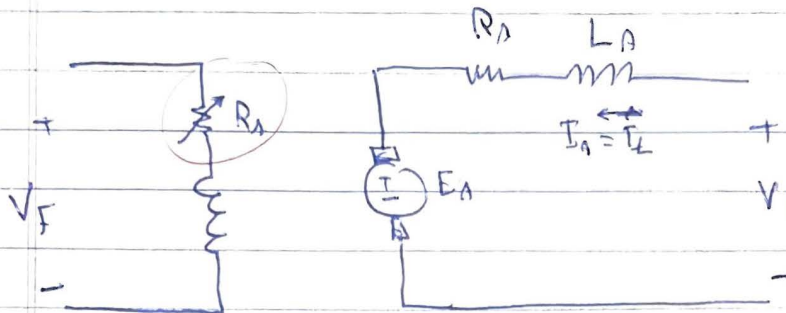
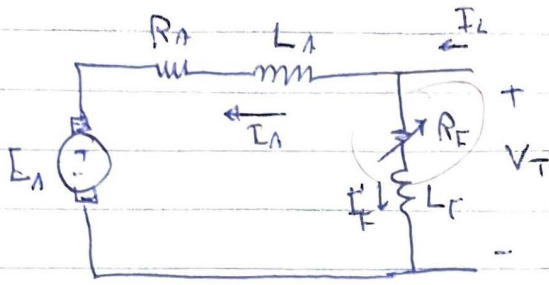
$$\text{OR } V_T = E_A$$

$$T_{load} \uparrow \Rightarrow \omega_m \downarrow \Rightarrow (E_A = K\phi\omega_m \downarrow)$$

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

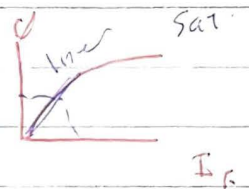
Method to control The speed

① Adjusting The Field resistor &

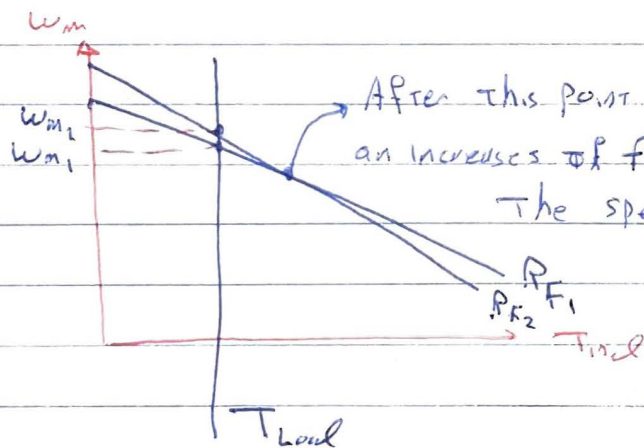


$$R_A \uparrow \Rightarrow I_F \downarrow \Rightarrow \phi \downarrow$$

$$I_F = c\phi$$



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



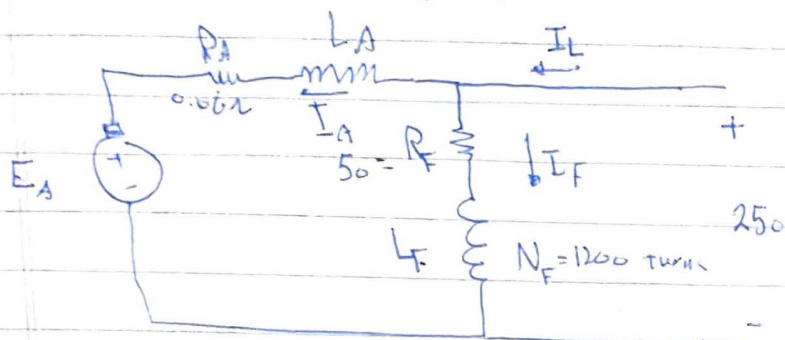
because $\frac{-1}{(K\phi)^2}$ slope becomes more.

After this point an increase of R_F decreases and No load ω increased The speed

عند زيادة المقاومة الحثية في الدارة الحثية
تقل التيار الحثي وتقل القوة الحثية
وتزداد السرعة

$$R_{F2} > R_{F1} \Rightarrow \omega_{m2} > \omega_{m1} \text{ (Field weakening)}$$

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?

$$V_L = R_A I_A + E_A$$

$$I_A = I_L - I_F \rightarrow I_A = 100 - \frac{250}{50} = 95 \text{ A}$$

$$E_A = 250 - 0.06 \times 95 = 244.3 \text{ V}$$

$$E_A = 250 \text{ V (at No Load)}$$

$$E_A = K \phi \omega_m$$

$$250 = K \phi (1200)$$

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

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?

$$V_L = R_A I_A + E_A$$

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

$$\boxed{I_A = 295 \text{ A}}$$

$$\boxed{E_A = 232.3}$$

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

$$232.3 = K \phi \omega_m' \Rightarrow \boxed{\omega_m' = 1115 \text{ rpm}}$$

separately excited

Converted power in ~~shunt~~ Dc motors

$$V_L = R_A I_A + E_A \quad , \text{ Multiply the eq by } I_A$$

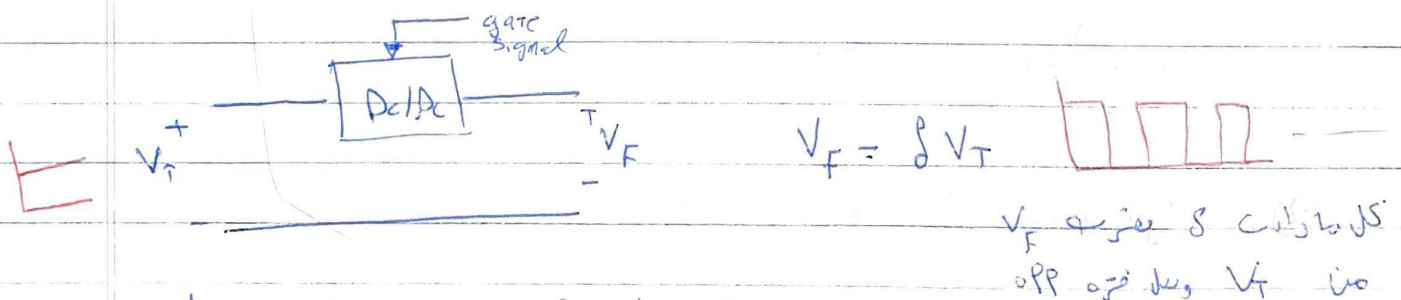
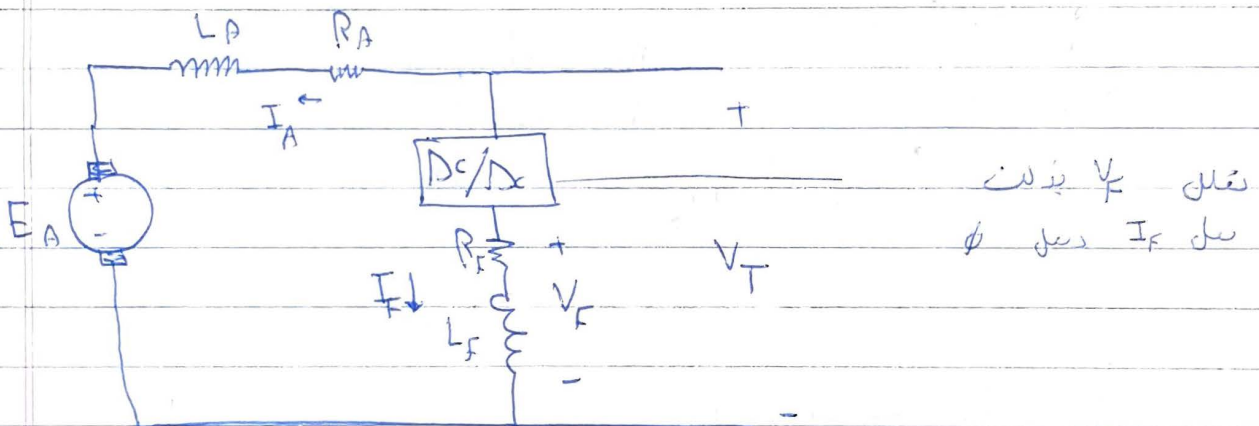
$$V_L I_A = R_A I_A^2 + E_A I_A$$

$\downarrow$ input power $\downarrow$ Copper losses in R_A $\rightarrow$ converted power

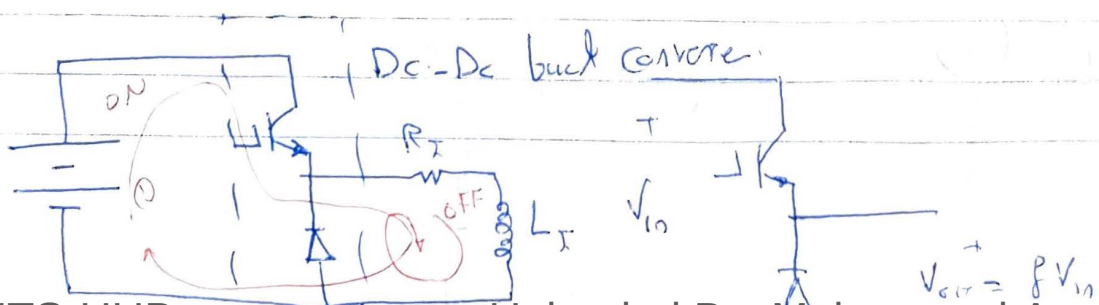
$$P_{conv} = E_A I_A = T_{ind} \omega_m \Rightarrow T_{ind} = \frac{P_{conv}}{\omega_m}$$

⊛ Method to control the speed (Repaired)

- ① adjusting the field resision or adjust the field voltage.

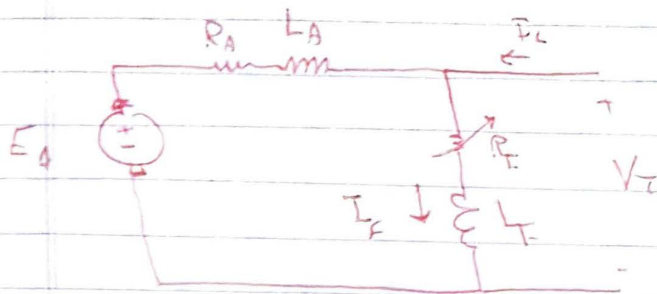


where f is called the duty cycle 0.5, 0.75



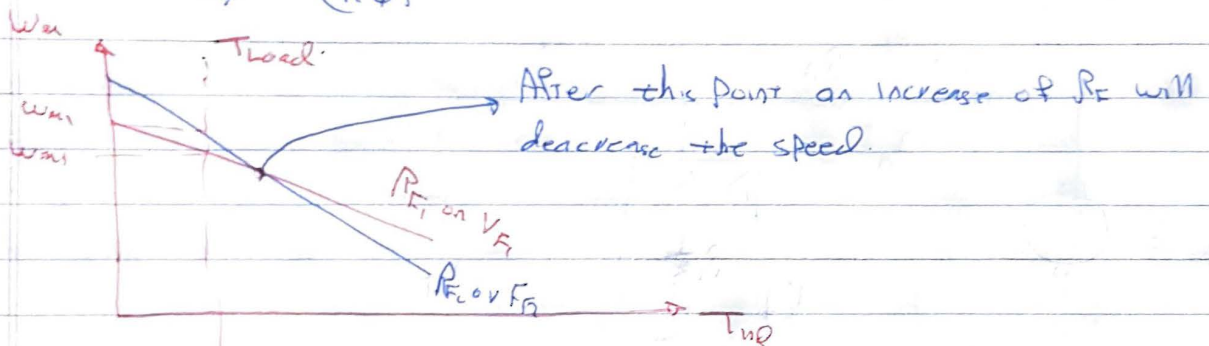
$$V_F \downarrow \Rightarrow \left(I_F = \frac{V_F}{R_F} \right) \downarrow \Rightarrow (\phi = C I_F) \downarrow \Rightarrow \omega \uparrow$$

① adjusting the field Resistance



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

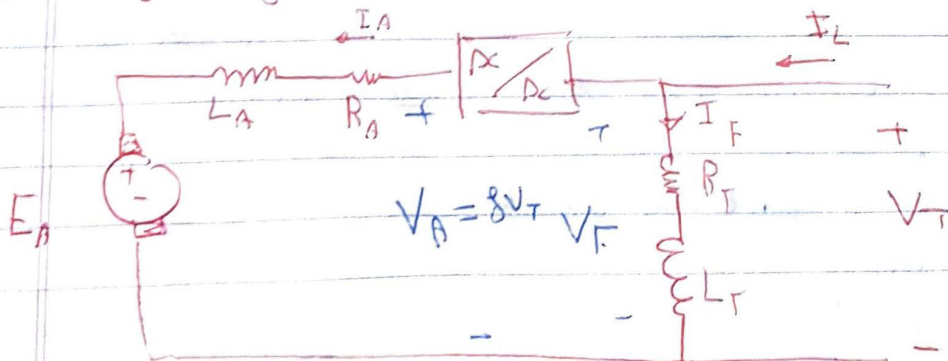
$$\omega_m = \frac{V_T}{K\phi} - \frac{R_A}{(K\phi)^2} T_{inD}$$



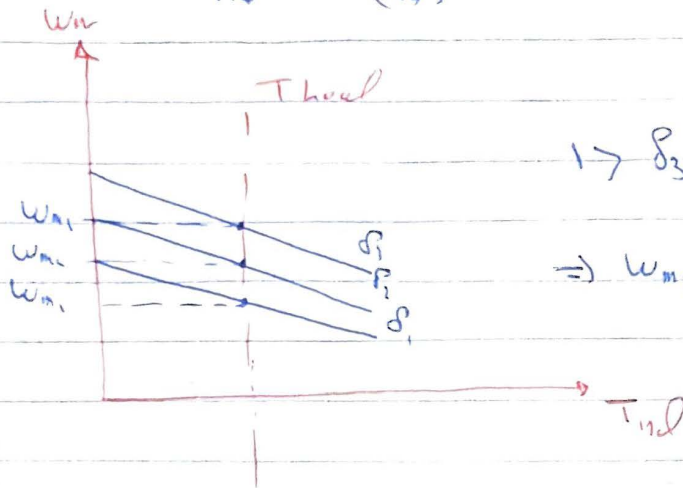
$$R_{F1} < R_{F2} \Rightarrow \omega_{m1} > \omega_{m2}$$

$$V_{F1} > V_{F2} \Rightarrow \omega_{m1} < \omega_{m2}$$

② adjusting the armature Voltage.



$$\omega_m = \frac{8 V_T}{K \phi} - \frac{R_A}{(K \phi)^2} \cdot T_{ind}$$



$$\Rightarrow \phi_3 > \phi_2 > \phi_1 > 0$$

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

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

⊗ V_A Voltage الجهد الكهربي

Full volt. rated volt. الجهد الكامل، الجهد المسموح به

تزداد مع زيادة السرعة

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

Ⓛ $\phi = \phi_n$
 $\Rightarrow$ 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 $\omega_m > \omega_{m,r} \Rightarrow$ Field control is used

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

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

Ⓜ $T_{ind} = K \phi I_A$
 $P_{conv} = T_{ind} \omega_m$

⊗ ϕ is the rated flux الجهد المسموح به

$\phi = \frac{c}{\omega}$ V_A is constant الجهد الكهربي ثابت

$$\text{Constant } V_A = R_A I_A + K \phi \omega_m$$

Ⓛ when $\omega_m \leq \omega_{m,r} \Rightarrow \phi = \phi_n \Rightarrow T_{ind} = \text{constant}$
 $\omega_m > \omega_{m,r} \Rightarrow \phi = \phi_n \frac{\omega_{m,r}}{\omega_m} \Rightarrow T_{ind} = K \phi_n \frac{\omega_{m,r}}{\omega_m}$

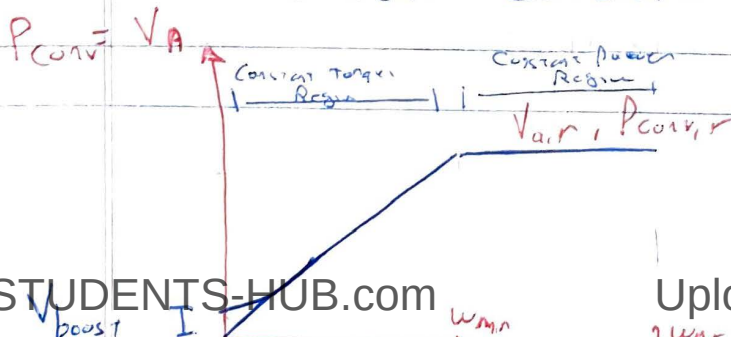
$$P_{conv} = \text{constant}$$

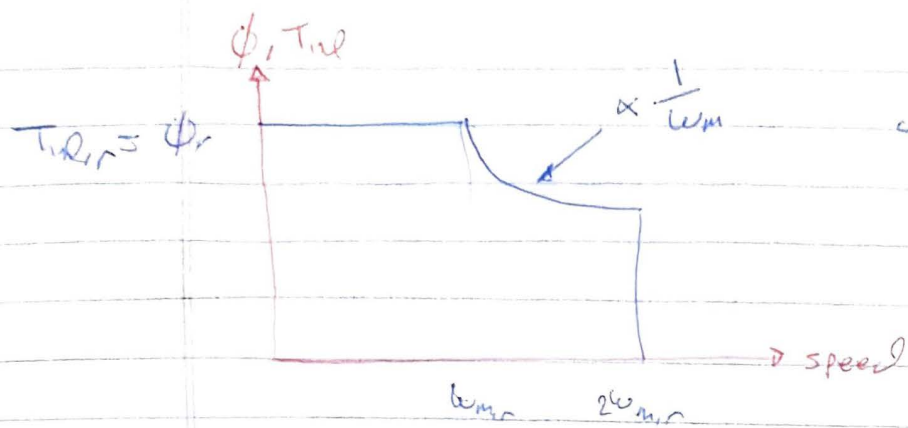
$$\text{Constant } P = K \phi_n \frac{\omega_{m,r}}{\omega_m} \cdot \omega_m$$

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

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

$$P = T_{ind} \omega_m = K \phi \omega_m^2 \leq \text{const}$$



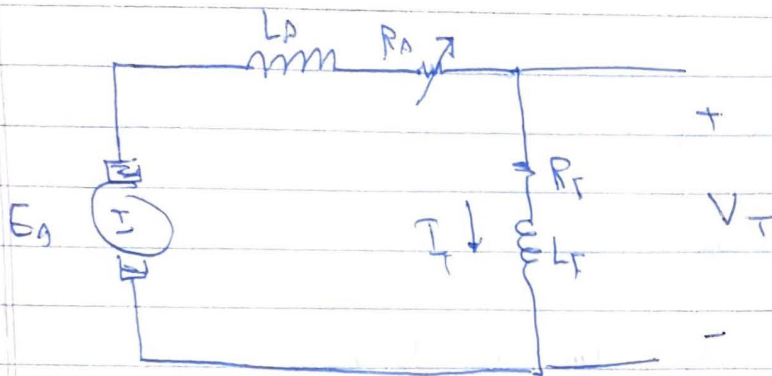


المحرك يعمل كمولد في هذه الحالة

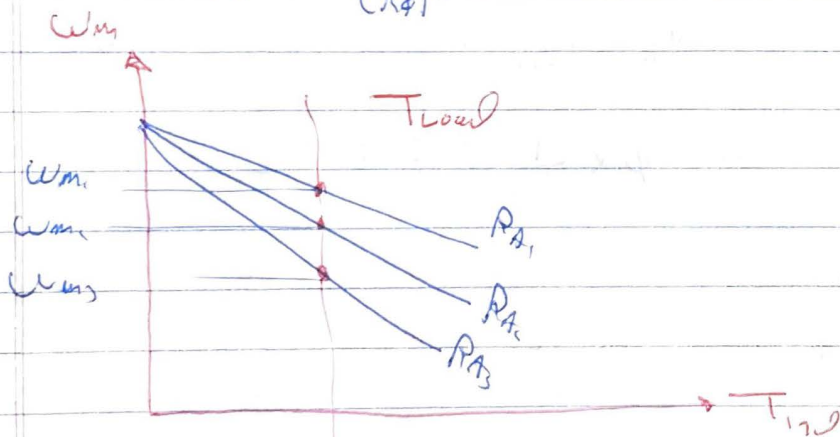
T_{ind}

$\frac{1}{\omega_m}$ - decreasing

③ Inserting a resistor to the armature circuit.



$$\omega_m = \frac{V_T}{k\phi} - \frac{R_A}{k\phi} \cdot T_{ind}$$



$$R_{A1} > R_{A2} > R_{A3} \Rightarrow \omega_{m3} < \omega_{m2} < \omega_{m1}$$

$\Rightarrow$ This method is inefficient because the power losses are very large $\Rightarrow$ its rarely used.

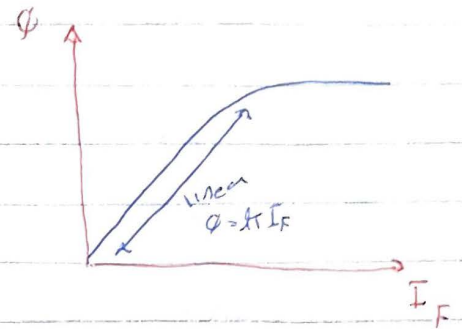
Note: The direction of shunt on separately excited Dc motor is reversed by switching the terminals of armature or field windings

$$T_{ind} = K \phi I_A$$

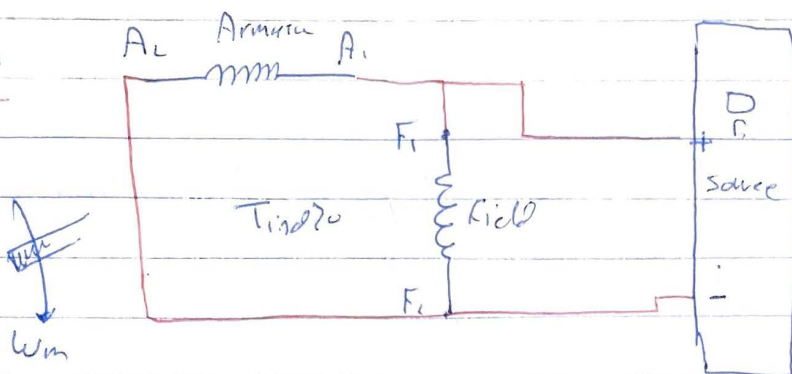
$$\phi = K_f I_F$$

$$T_{ind} = K_c I_F I_A$$

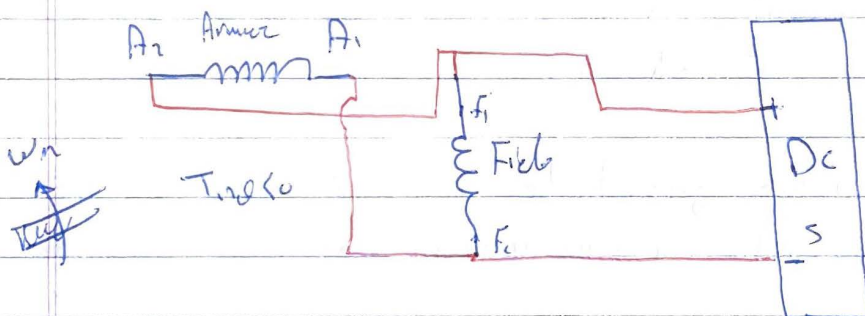
∴ additional k_c & k_f @



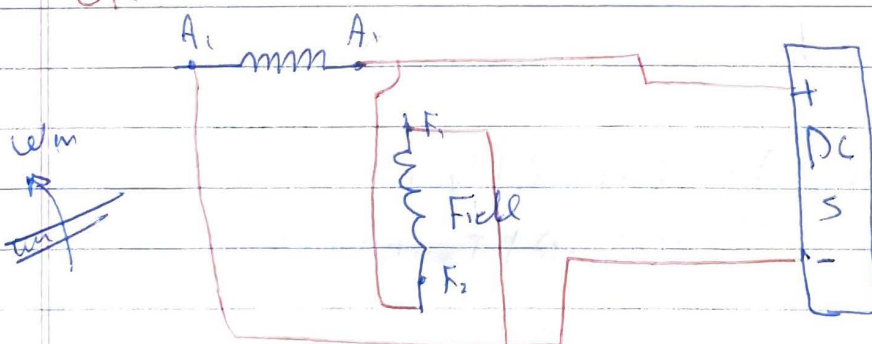
Shunt



How?



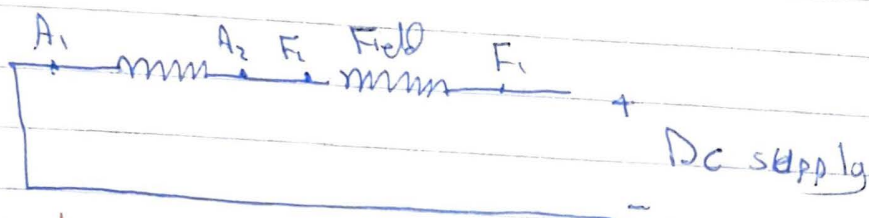
OR



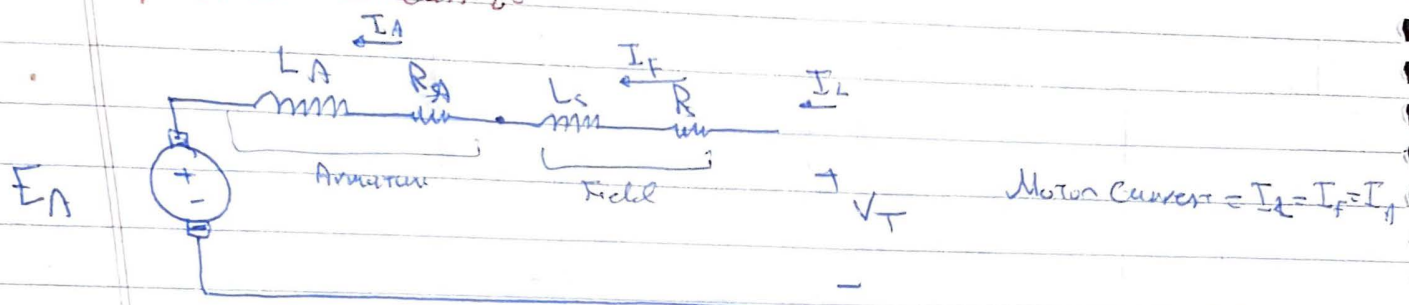
② SCA:

② Series Dc motor

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



equivalent circuit :-



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

$$T_{ind} = K_c I_F I_A \rightarrow I_F = I_A$$

$$T_{ind} = K_c I_A^2 \rightarrow T_{ind} \propto I_A^2$$

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

Torque speed characteristics of series DC motor?

Kvl in the loop $\therefore V_T = (R_A + R_S) I_A + E_A \rightarrow E_A = K\phi \omega_m$

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

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

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

$$T_{ind} = K_c I_A^2$$

$$\Rightarrow I_A = \frac{T_{ind}}{\sqrt{K_c}} \cdot \sqrt{T_{ind}} \quad \text{--- (2)}$$

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

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

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

Starting Torque

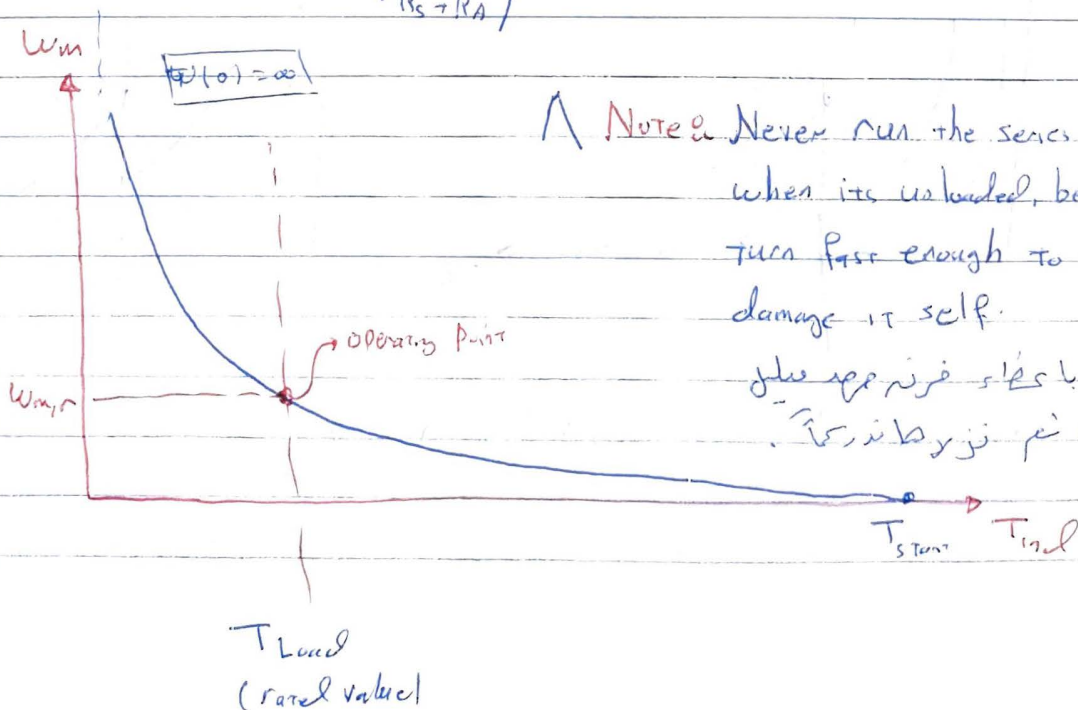
$$T_{start} = T_{ind} \Big|_{\omega=0} \Rightarrow 0 = \frac{V_T}{\sqrt{K_c}} \cdot \frac{1}{\sqrt{T_{ind}}} - \frac{(R_A + R_S)}{K_c}$$

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

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

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

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



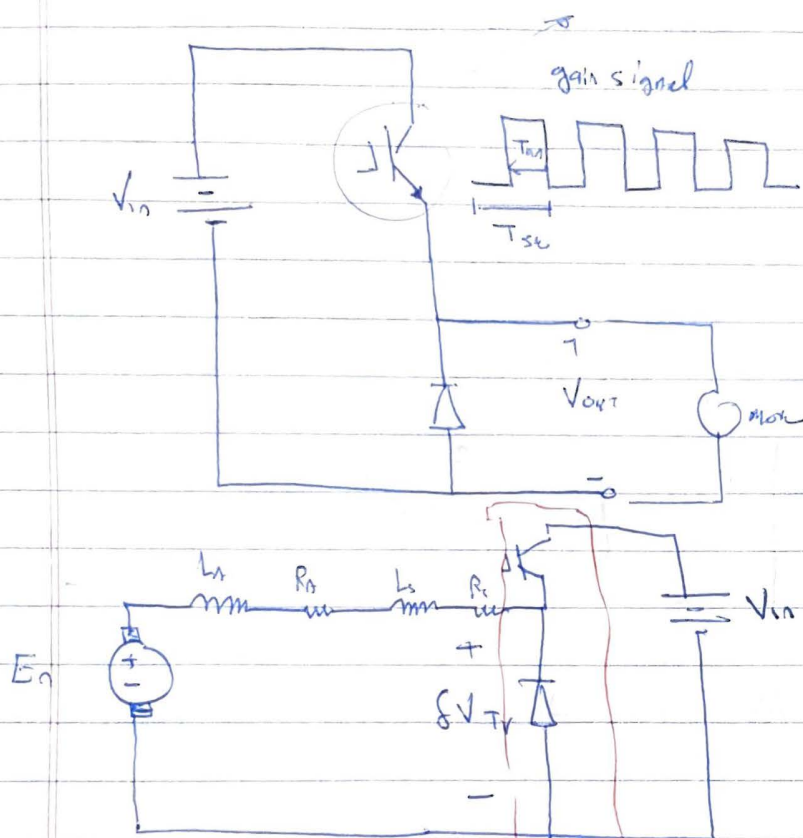
⚠ **Note:** Never run the series DC motor when its unloaded, because it may turn fast enough to seriously damage it self.

المحرك سيرى يلف بسرعة كبيرة جداً
في حالة الحمل الزائد

② Method to control the speed

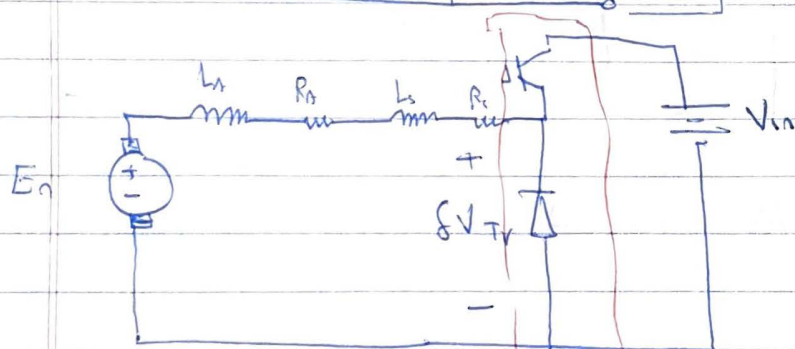
1) Adjust the motor voltage using Dc/Dc buck converter (chopper circuit)

مثال: High speed 1

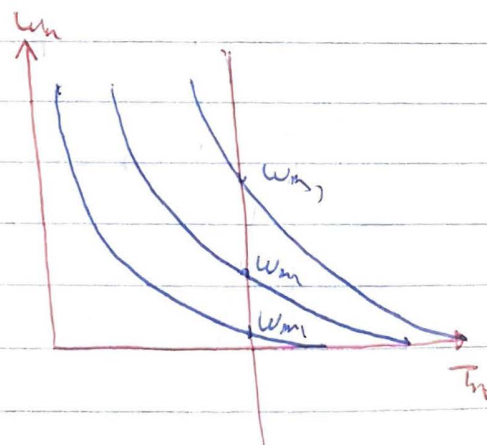
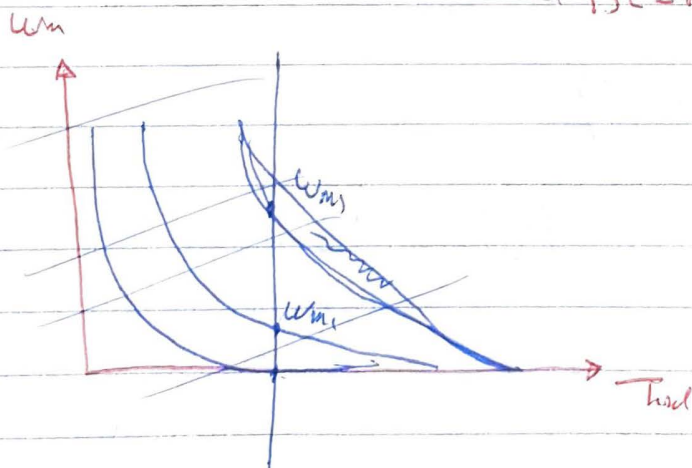


$$V_{out} = \delta V_{in}$$

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



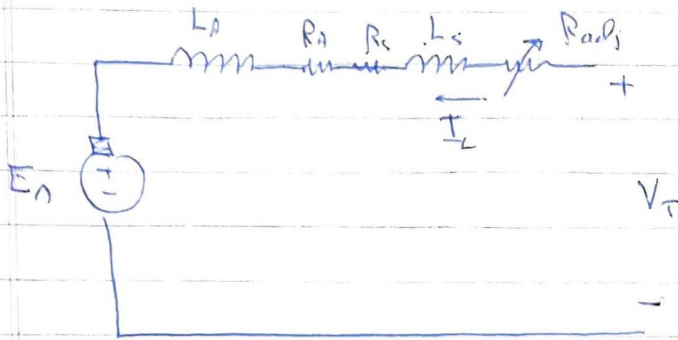
DC-DC Converter



$$V_1 < V_2 < V_3, \quad \omega_{m1} < \omega_{m2} < \omega_{m3}$$

⊗ إذا بدي انزل في voltage بوزني δ ، الفكرة صحيحة.

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



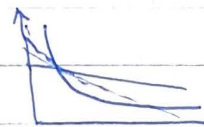
$R_{adj} \uparrow \Rightarrow \omega_m \downarrow \Rightarrow$ This method is inefficient because the power losses are very large $\rightarrow$ its rarely used.

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

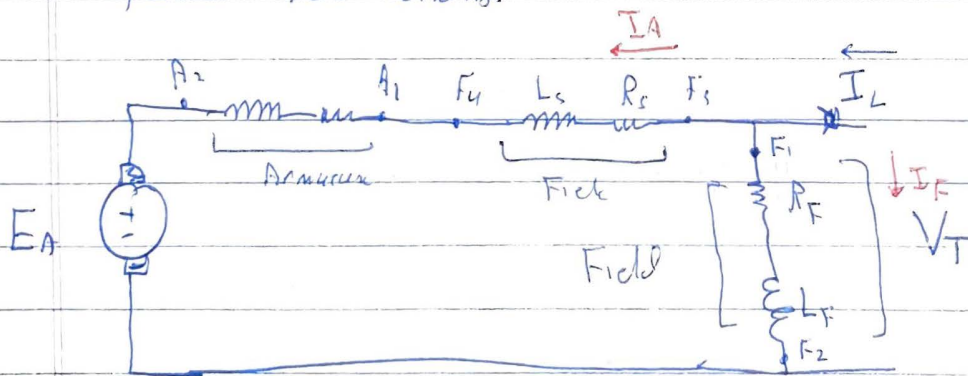
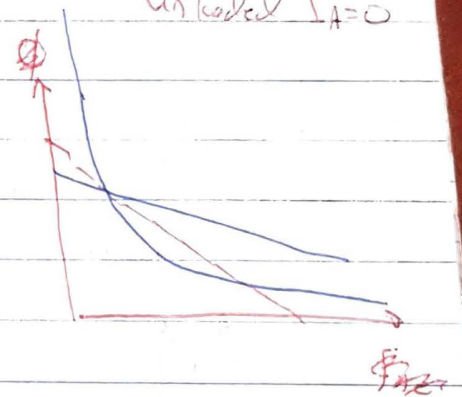
③ Compound DC Motors

it consists of 3 windings.

- 1) Armature winding.
- 2) Series field winding.
- 3) shunt field winding.



unloaded $I_A = 0$

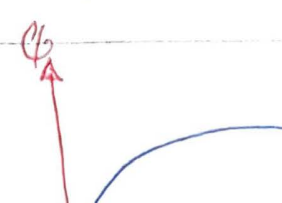


Compound flux ϕ
 $\phi \propto I_A + I_F$
 $I_F = I_A \frac{R_s}{R_F}$
 $\omega_m \propto \phi$

The net mmf is giving by $F_{net} = F_F + F_s$

$F_{net} = N_F I_F + N_s I_A = N_F I_F^*$, I_F^* : effective field current

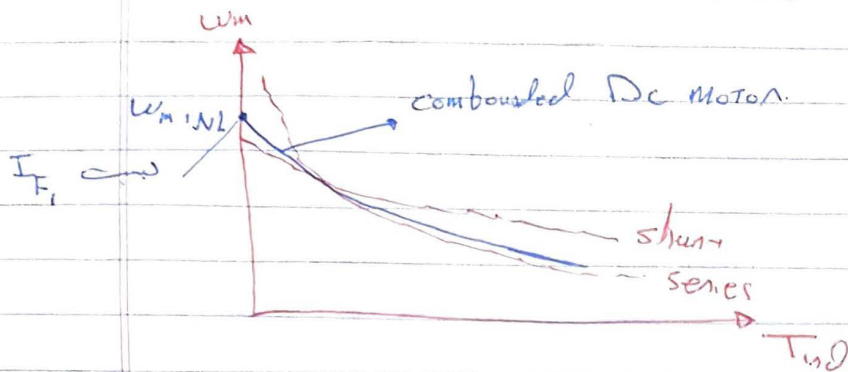
$$I_F^* = I_F + \frac{N_s}{N_F} \cdot I_A$$



- ⑧ It combines the best features of both series and shunt DC motors

Series DC motor $\rightarrow$ high Torque

Shunt DC motor $\rightarrow$ it doesn't overspeed when its unloaded.

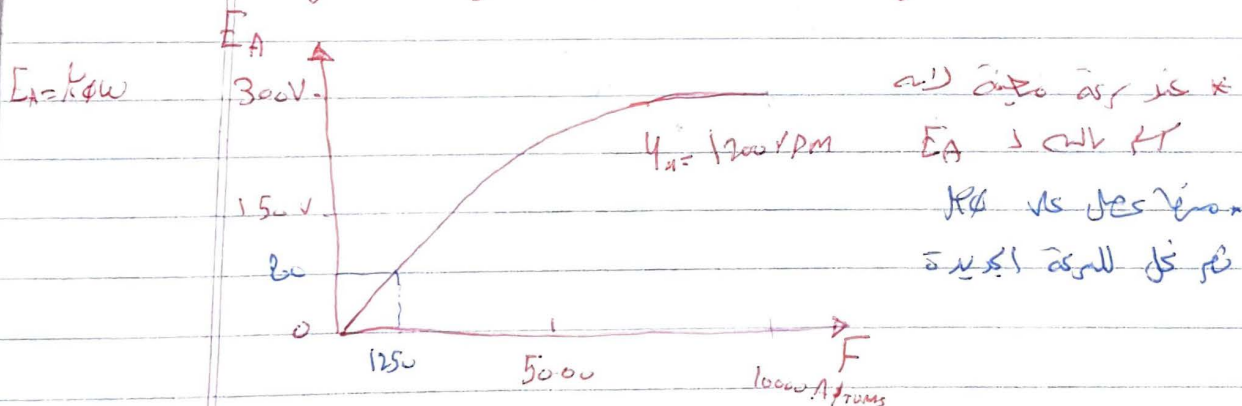


- ⑨ Methods, to control the speed?

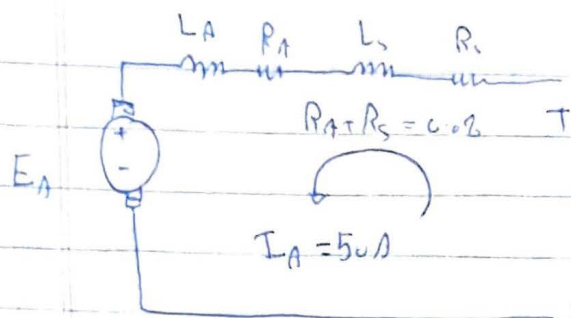
- 1) changing the terminal voltage (Buck converter)
 - 2) changing the field ^{shunt} resistance
 - 3) changing the field series resistance
- } Power losses $\uparrow$

Example

A 250V series DC motor has a total series resistance of 0.02Ω. The series field consists of 25 turns per-pole, with the magnetizing curve shown in Figure



- ⑩ Find the speed & induced Torque when the motor current is 50 A?



KVL in the loop

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

$$E_A = 246 \text{ Volt}$$

$$E_A = K\phi\omega_m$$

$$F = \frac{N_F I_F}{N_A} = N_S I_A = (25)(50) = 1250 \text{ A.turn}$$

$$\text{From magnetizing curve} \Rightarrow E_{A0} = 250 \text{ V} = K\phi \left(\frac{1250}{30} \right)$$

$$K\phi = \frac{246}{6369}, \quad \omega_m = 3696 \frac{\pi}{30} \text{ rad/sec}$$

$$\gamma_m = 3690 \text{ rpm}$$

$$T_{ind} = K\phi I_A$$

$$\text{or } P_{conv} = T_{ind} \omega_m = E_A I_A \Rightarrow T_{ind} = 31.8 \text{ N.m}$$

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 given by I_A (KV/A)

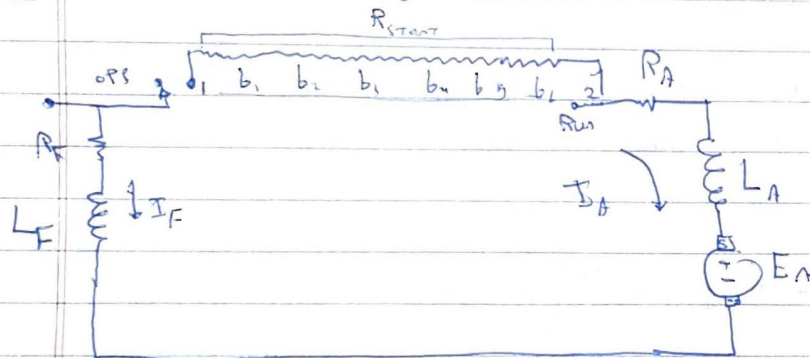
$$I_A = \frac{V_T - E_A}{R_A} \quad \text{"separately or shunt excited"}$$

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

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

STARTERS of DC MOTORS

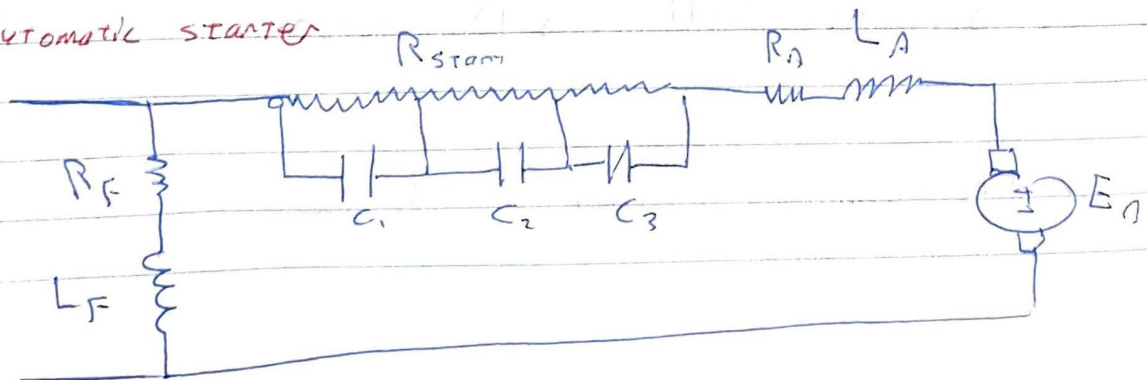
① Manual starter



⊗ R ممانعة
بواسطة
المحرك
التي تزداد
مع السرعة

- ⊗ Continuous 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 quickly to prevent the resulting current of being large.

② Automatic starter

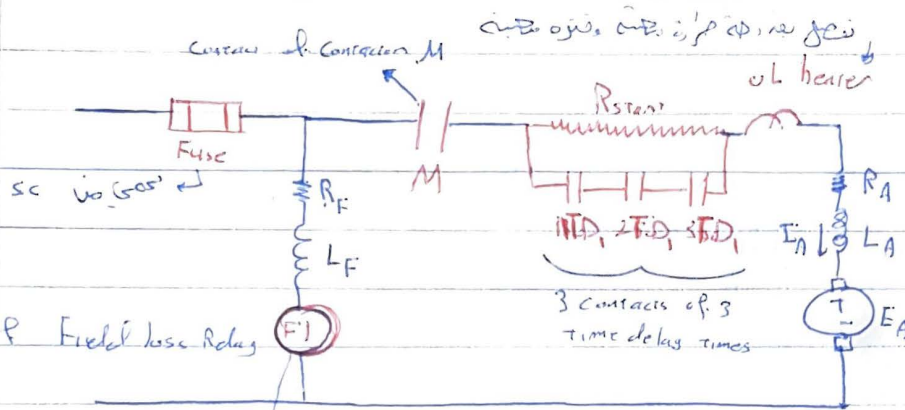


$C_1, C_2, C_3 \rightarrow$ CONTACTS of relay C_1, C_2 & C_3 (Normally opened contacts)

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

C_1, C_2 & C_3 are 3 contacts of time delay relays on armature Voltage sensing relays. (1)

Video



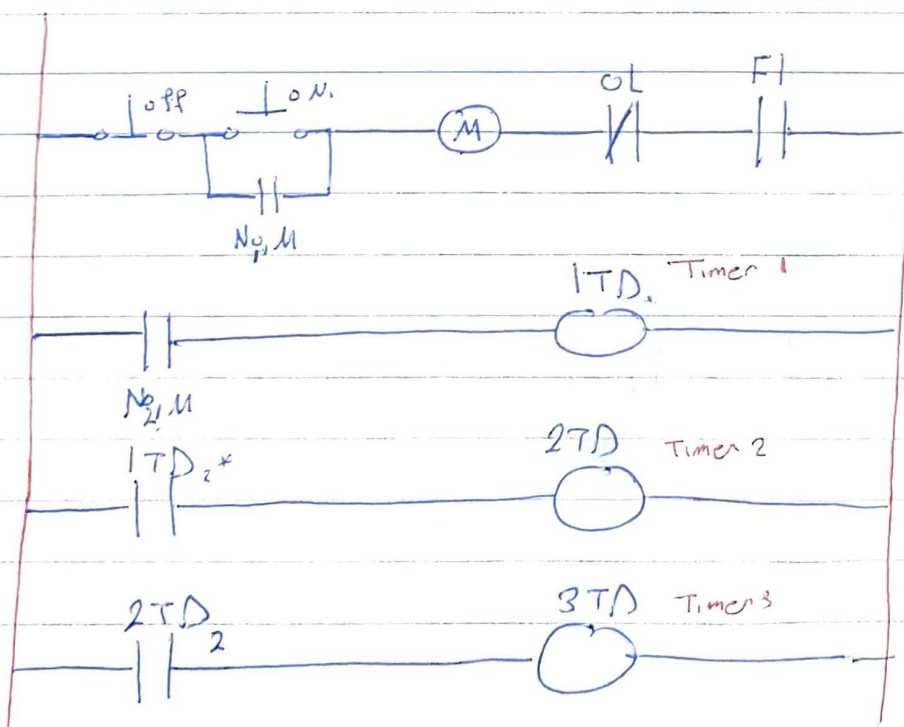
shunt

Coil of Field Loss Relay

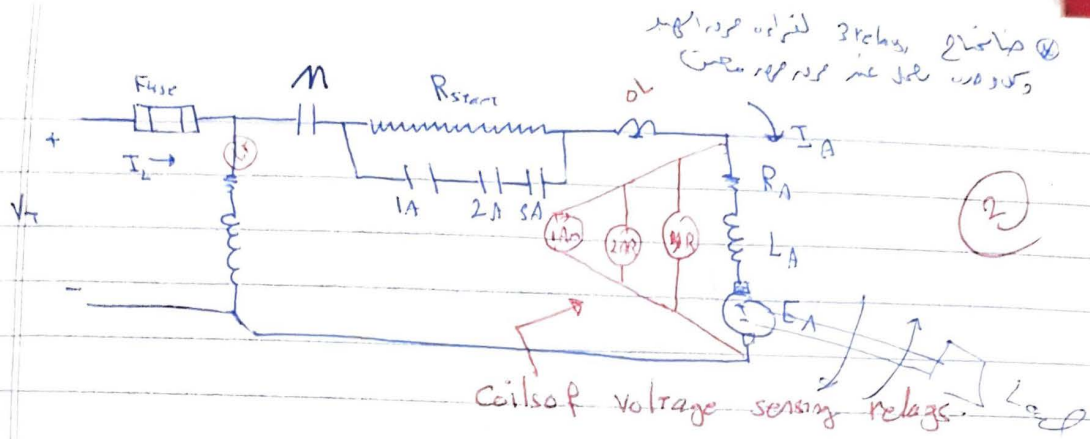
التيار الجهد في الحقل

التيار الجهد في الحقل
هو
(في الحقل)

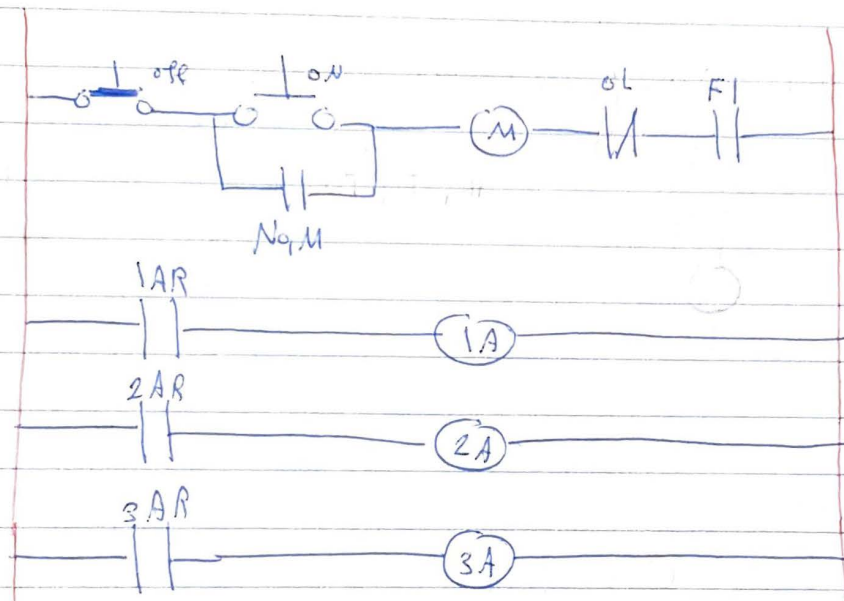
Control Circuit



2



Control circuit



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

OL ϕ Cut off the current when the Temp increased too much than Normal's Temp (for long time) $\times$

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

RP