The University Of Jordan

Faculty of Engineering and Technology.

Department of Electrical Engineering.

Experiment #1

Single Phase Power Transformers.

* group (3) * section : Thursday. *

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	3-
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※ Objectives:

1) Determine the parameters of the transformer equivalent circuit by conducting the No-load & Short-circuit Tests.
2) Investigate the performance char. of transformers under resistive loading conditions.

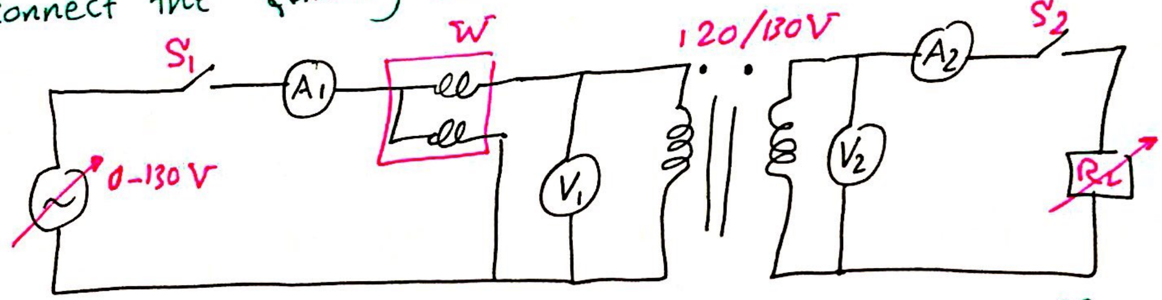
※ Equipment:

Power transformer, Transformer trainer, Variable AC power supply, Resistive Load, Wattmeter.

※ Procedure:

• Procedure (1): No load Test

1) connect the following circuit.



2) set the load resistance to its MAX., & keep S_2 off.

3) Turn S_1 ON.

4) By means of the VARIAC, start to increase the input Voltage (V_1) in steps to match the requirements of table (1), in each step record V_2 & I_1 & P_i.

5) Turn ON VARIAC Knob fully clockwise & turn S_1 OFF.

Table(1): No load Test.

$N = \frac{V_1}{V_2}$

V_1	V_2	I_1	P_i	Turns Ratio
20	20	0.07	0.75	1
40	40	0.11	2.2	0.9523
60	62	0.15	4.8	0.9677
80	84	0.21	8.4	0.94786
100	106	0.3	14	0.94339
110	116	0.39	17	0.94827
120	127	0.56	24	0.94488
125	130	0.73	32	0.9615

• Procedure (2): Short-circuit Test.

1) Connect the previous circuit agin. short-circuit the load resistance & switch ON S_2.
2) Turn S_1 ON & start to increase V_1 to match the requirements in Table (2). record V_{sc}, P_{sc}, I_2.
3) Turn the VARIAC Knob fully CW & turn OFF S_1.
4) Remove the short across the load & switch S_2 OFF.

Table(2): Short Circuit Test.

I_1	I_2	P_i	$V_{sc} = V_1$
0.5	0.466	1.8	4
1.0	0.919	6	8
1.5	1.416	14	11
2.0	1.846	26	13
2.5	2.33	40	16

• Procedure (3): Load Test

1) Connect the circuit (same previous circuit).
2) with S_2 is in the OFF state (the secondary coil is o/c) turn S_1 ON & set V_1 to 120V RMS.
   Record V_2, I_2, P_i & P_o in Table(3).
3) Turn S_2 ON & vary R_L to match the requirements in Table (3). record V_2, I_2, P_i & P_o.
   V_1 should be kept constant at its initial value throughout the test.
4) Turn the VARIAC Knob fully CW & turn S_1 OFF.
5) Add a capacitive load in parallel with the min. resistance Load (R = Max). for three different values of capacitive Load (up to = I = 2A), take the readings of V_2, i_2, P_i, P_o, p.f & calculate the efficiency & voltage regulation.
   Draw the phasor diagram.
6) repeat step (5) above from inductive load take measurements for one reading only & draw the phasor diagram.
7) Disconnect the ckt & measure the DC resistance of the primary & secondary winding using an ohmmeter.

Table (3): load Test.

$pf = \frac{P_{in}}{I_1 V_1}$

$V.R\% = \frac{V_2 - V_1}{V_1} \times 100\%$

I_1	V_1	V_2	I_2	P_i	P_o	P.F	V.R%	η%
0.55	120	125	0	24	0	0.3636	4.16	0
0.7	120	122	0.4	76	46	0.65	1.66	60.53
1	120	120	0.6	100	80	0.83	0	80
1.4	120	119	0.8	124	104	0.738	-0.833	83.87
1.4	120	118	1	152	128	0.905	-1.67	84.21
1.6	120	117	1.25	192	156	1	-2.5	81.25
1.75	120	113	1.5	220	188	0.92	-5.83	85.45
2.2	120	110	1.75	248	216	0.939	-8.3	87.1
2.35	120	108	2	300	260	0.912	-10	86.67

※ Results & Discussion:

(1) Calculate the Turns Ratio? shown in Table (1).

(2) Calculate the parameters R_c & X_m of the exact equivalent cct?

$N \simeq 0.94$, taking 120 volt. ⇒ $N = 0.94488$

$Y_E = \frac{1}{R_c} - j\frac{1}{X_m}$; $V_{oc} = 127$, $I_{oc} = 0.56$, $P_{oc} = 24W$.

$\Rightarrow Y_E = \frac{I_{oc}}{V_{oc}} \angle -\cos^{-1} pf$ ⇒ $Y_E = 1.488 \times 10^{-3} - j\,4.15 \times 10^{-3}\,S$

$pf = \cos\theta = \frac{P_{oc}}{V_{oc} I_{oc}}$

so $R_c = 672.04\,\Omega$, $X_m = 240.9\,\Omega$

(3) Calculate the parameters R_1, R_2, X_1 & X_2?

$R_{eq} = R_1 + a^2 R_2$

$X_{eq} = X_1 + a^2 X_2$

referred to primary.

$pf = \frac{P_{sc}}{V_{sc} I_{sc}}$

$Z_{SE} = \frac{V_{sc}}{I_{sc}} \angle \cos^{-1} pf$

$= R_{eq} + j X_{eq}$.

Taking $I = 1.5A$, $a = 0.94488$

$I_{sc} = 1.416$, $V_{sc} = 11$, $P_{sc} = 14$

⇒ $pf = 0.89882$

⇒ $Z_{SE} = 7.77 \angle 26° = 6.98 + j\,3.41\,\Omega$

so $R_{eq} = 6.98\,\Omega$

$X_{eq} = 3.41\,\Omega$

⇒

Take $R_1 = R_2'$ $\Rightarrow 6.98 = R_1 + a^2 R_1$ $\Rightarrow R_2' = a^2(3.67)$
$X_1 = X_2'$ $\Rightarrow$ $R_1 = 3.67\,\Omega$ so $R_2' = 3.312\,\Omega$

$\Rightarrow 3.41 = X_1 + a^2 X_2$ $\Rightarrow$ $X_1 = 1.789\,\Omega$
$X_2' = 1.615\,\Omega$

(4) Plot V_2 vs. V_1 ? comment on the nature of the curve & its relationship with a ?

(5) Plot I_o vs. V_1 ? comment on the nature of the curve.

(6) Plot P_{in} vs. V_1 ? explain the nature of the curve.

The figures shown in the last pages.

(7) Calculate from Load-test, for each step P_o, η, V.R%, Pf ?

Results shown in Table (3).

(8) Plot η, V.R%, Pf vs. P_o At what load the efficieny is MAX?

the figure in the last pages.

Max $\eta\% = 87.1\%$ @ $I_2 = 1.75\,A$.

(9) Using the results of OC & SC tests. calculate the load at which η is max. Compare the value with your previous result in the load test ?

from the No-load test we have $P_i = 24\,Watt$
& $R_{eq} = 6.98\,\Omega$ so: $I = \sqrt{P_i / R_{eq}} = \sqrt{\frac{24}{6.98}} = 1.85\,A$

we notice that it is almost the same amswer was obtained before.

(10) Draw the P.D of the transformer under:

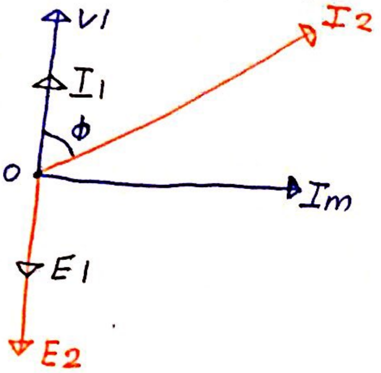
- No load, S/C, resistive load, Inductive load, & capacitive load.

* At what loading condition will the V.R be MAX.

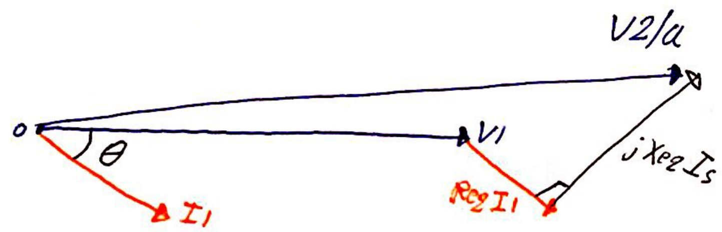
(11) Draw the approximate L-equ. cct of the transformer with all parameters given numerically.

phasor diagrams:

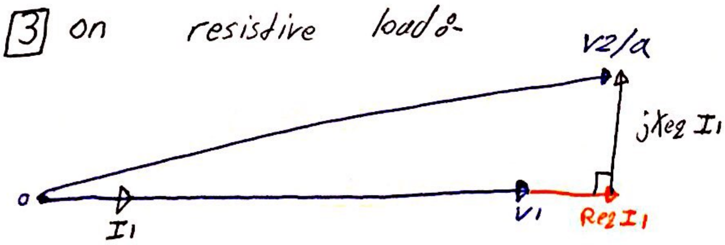
1 on no Load:-



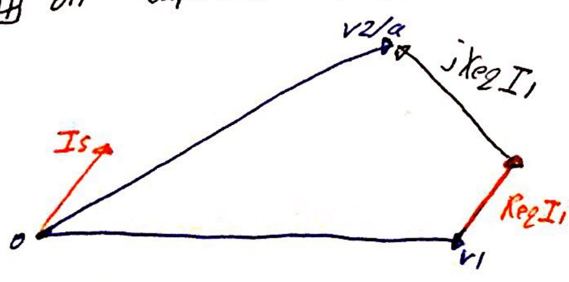
2 on ~~resistive~~ induc load:-



3 on resistive load:-

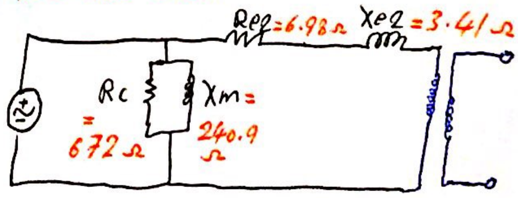


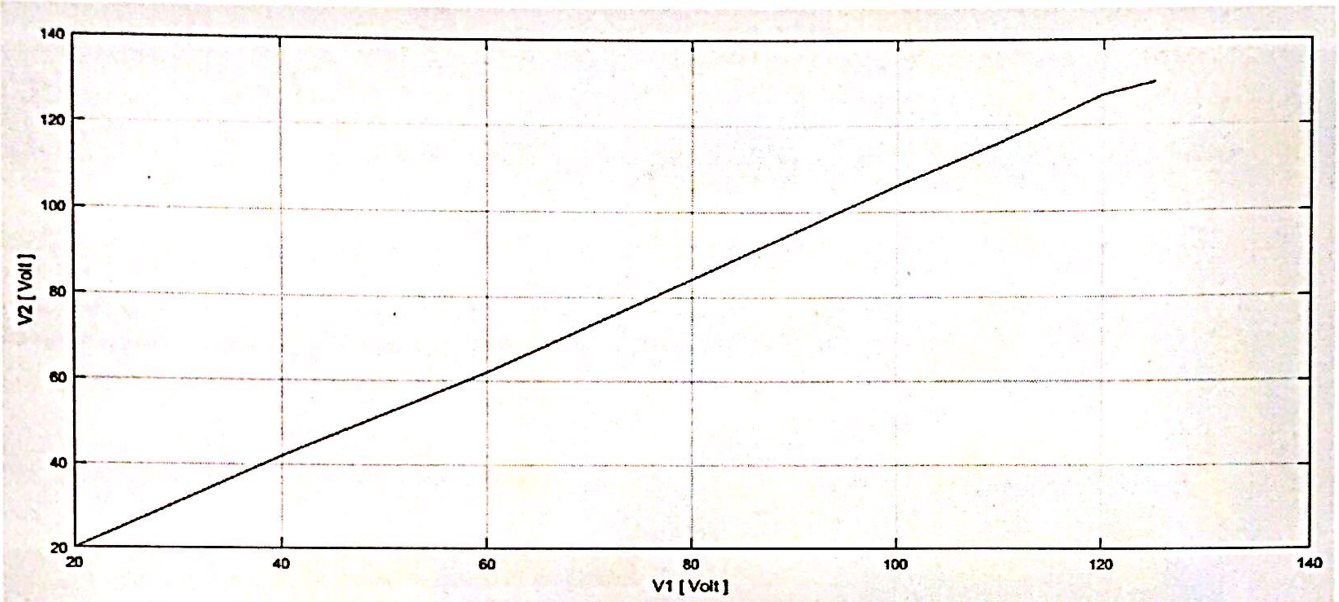
4 on capacitive load:-



conclusion: The max V.R will on the inductive load, but the best Load we can use is the capacitor because it increase the voltage level; but capacitors needs High cost.

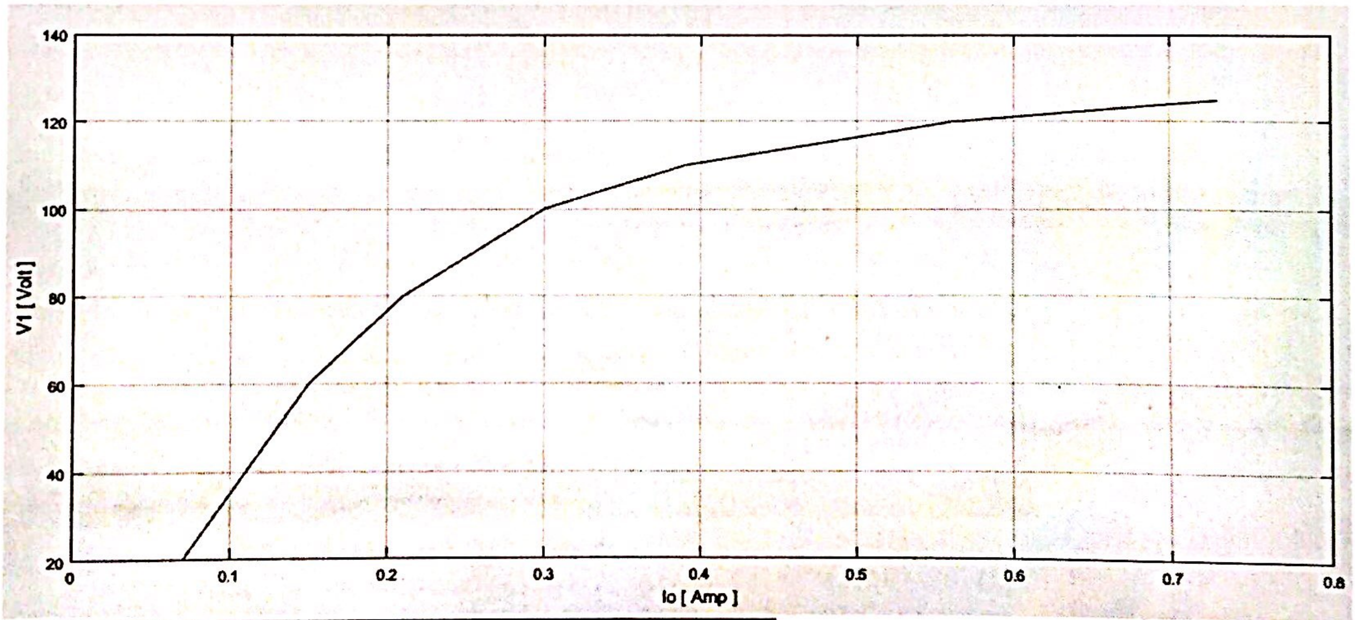
L-equ. CKT.





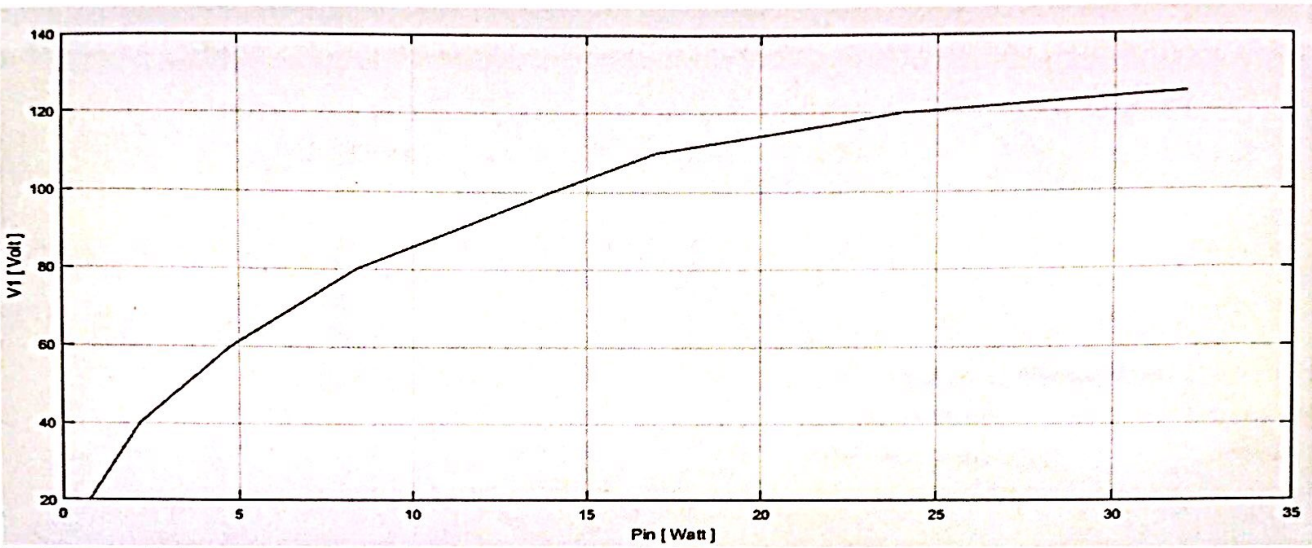
Command Window

```
>> V1=[20 40 60 80 100 110 120 125];
>> V2=[20 42 62 84 106 116 127 130];
>> plot(V1,V2,'-k')
fx >>
```



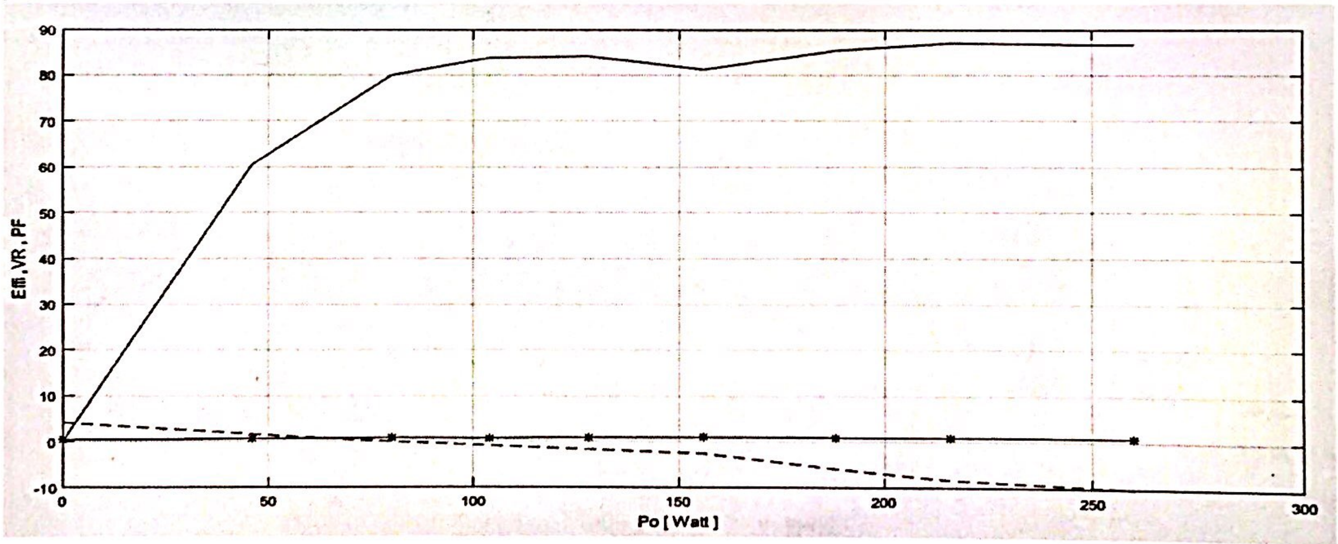
Command Window

```
>> V1=[20 40 60 80 100 110 120 125];
>> Io=[0.07 0.11 0.15 0.21 0.3 0.39 0.56 0.73];
>> plot(Io,V1,'-k')
fx >>
```



Command Window

```
>> V1=[20 40 60 80 100 110 120 125];
>> Pin=[0.75 2.2 4.8 8.4 14 17 24 32];
>> plot(Pin,V1,'-k')
>>
```



Command Window

```
>> Po=[0 46 80 104 128 156 188 216 260];
>> Efficiency=[0 60.53 80 83.87 84.21 81.25 85.45 87.097 86.67];
>> VR=[4.16 1.66 0 -0.833 -1.67 -2.5 -5.83 -8.3 -10];
>> PF=[0.3636 0.65 0.83 0.738 0.905 1 0.92 0.939 0.912];
>> plot(Po,Efficiency,'-k',Po,VR ,'--k',Po,PF,'-*k')
>> % dashed line for Voltage Regulation
>> % Stared line for Power Factor
>>
```

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Experiment #2

Single-phase power transformers Nature of the excitation current & the hysteresis loop.

Group 3 section : Thursday.

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※ Objectives:

- Conduct the polarity Test.
- Examine the nature of the excitation current.
- Construct the Hysteresis loop of a typical magnetic structure & to investigate the effect of having an air gap on this structure.

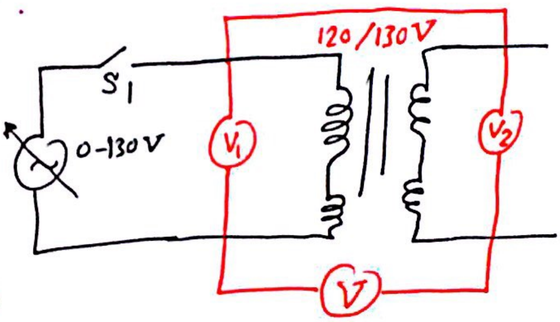
※ Equipment:

Power transformer, transformer trainer unit TT179, variable AC power supply, Resistive load, oscilloscope, connecting wires.

※ Procedure:

- Procedure (1): "polarity Test".

(1) connect the circuit shown:

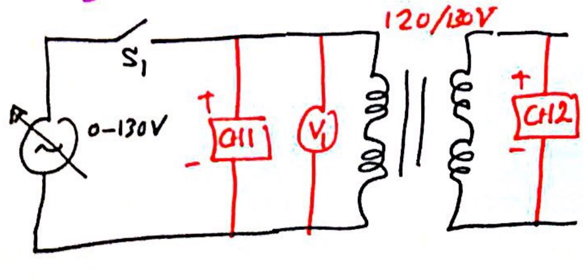


(2) switch ON S_1 & set V_1 @ 120 volt.

(3) record the readings of V_2 & V.

$V_2 = 129$ volt, $V = 10.7$ volt.

(4) switch S_1 off & connect the following circuit.



(5) Oscilloscope settings should be: 5 ms/div, 50 V/div for CH1 & 2 x10 probs are used.

(6) switch ON S_1 & set V_1 @ 120 V.

(7) sketch to scale on graph paper the waveforms on the screen.

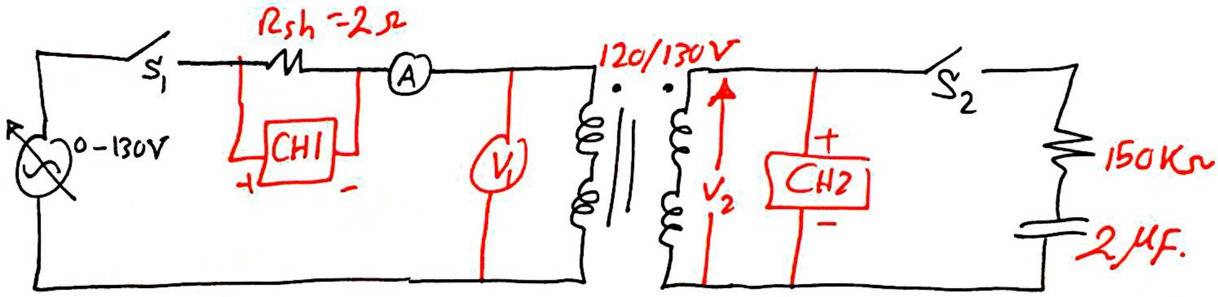
(8) Turn the VARIAC Knob fully CW & turn OFF S_1.

⇒ for 120 volt:

shown in last pages.

• Procedure (2): "The Nature of the Excitation Current".

(1) Connect the following circuit. S_2 is OFF.



(2) Oscilloscope settings should be: 5msec/div, 0.5V/div for CH1.
50 V/div for CH2. x10 probs are used.

(3) switch S_1 ON & set V_1 @ 80V.

(4) sketch the waveform on the screen.

(5) Increase V_1 to 120V & repeat step(4).

(6) Reset the scale of CH1 to 1 V/div.

(7) Turn the VARIAC Knob fully CW & turn S_1 OFF.

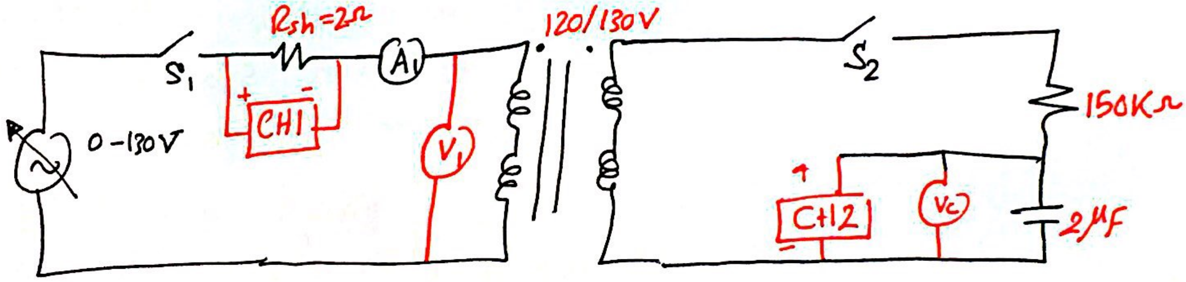
for $V_1 = 80V$:

for $V_1 = 120V$:

shown in last pages.

• Procedure (3) : "The Hysteresis loop".

(1) Connect the following circuit.



(2) Oscilloscope settings:

X-Y mode, X ch. represent voltage across the shunt resistor @ 1V/div, the capacitor voltage V_c is to be shown @ CH1 @ 0.5V/div.

(3) switch S_1 ON & set V_1 @ 80V.

(4) switch S_2 ON.

(5) Record the value of V_c.

(6) sketch the hysteresis loop appears on the screen.

(7) increase V_1 to 120V & repeat (4)-(6).

(8) Turn the Variac Knob fully CW & turn OFF S_1.

* for $V_1 = 80$ volt :
⇒ $V_c =$

* for $V_1 = 120$ volt :
⇒ $V_c =$

shown in last pages.

• Procedure (4) : "EFFECT of introducing an air gap".

release the fasteners on the dissectable transformer frame. remove the E section of the core with its attached coils. Invert the I section such that the vanished face is now facing the E section & thus the varnish Layer is now forming a part of the magnetic circuit. Replace the E-section with coils in position & clamp the transformer frame.

(1) repeat procedure (2) for $V_1 = 120$ volt only.

(2) repeat procedure (3) for $V_1 = 120$ volt only;

(3) Rebuilt the transformer as it was before

Q.1 What is the type of the test transformer (shall or core)?

- core

Q.2 What is the value of the core staking factor?

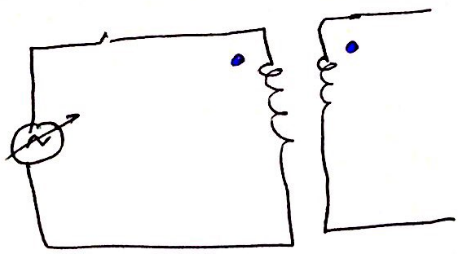
- Less than one maybe 0.9

Q.3 Prove that the two transformers of fig.(1) are identical

Q.4 sketch the schematic diagram of the transformer and use the Dot notation to indicate the relative polarity of the primary and secondary windings. Is the polarity additive or subtractive

- subtractive

⇒



Q.5 Comment on the nature of the excitation current waveform How do the excitation voltage the inclusion of the air gap affect the nature of the ~~core~~ excitation current?

⇒ That increase the reluctance, Linearize magnetic ckt.
The B-H Loop of magnetic ckt is affected by the presence of air gap so, greater ~~B-H loop~~ value of H are required to obtain the same of B as compared with magnetically materials

Q.6 Show that the RMS value of the core flux is given by

$$\phi = \frac{R * C * V_c}{N_s}$$

Use the above relationship to calculat the value of core flux and flux density

⇒ $V_s = N_s A \frac{dB}{dt}$

$B = B_M \sin(\omega t)$

$V_c = \frac{1}{C} \int i_c \, dt = \frac{1}{RC} \int V_s \, dt$

$V_c = \frac{N_s A}{RC} \int \frac{dB}{dt} dt = \frac{N_s A B}{RC}$, $\Phi = BA$

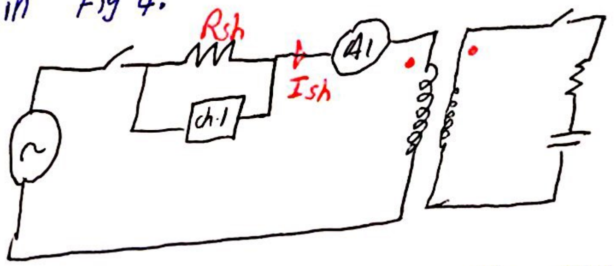
$$\boxed{\phi = \frac{R * C * V_c}{N_s}}$$

$$\phi = \frac{100 * 10^3 * 4 * 10^{-6} * 1.3451}{296} = 1.817 \text{m Wb}$$

$$\boxed{B = \frac{\phi}{A}}$$

7 show that the instantanous Flax intensity of the core is given by $H = (Np/L * Rsh) * Vsh$.

\# $B = \mu H$. , $H = \frac{Ni}{L}$, From the transformer graph in Fig 4.



, Now I have

$i = Rsh * Vsh$.

substitute in H

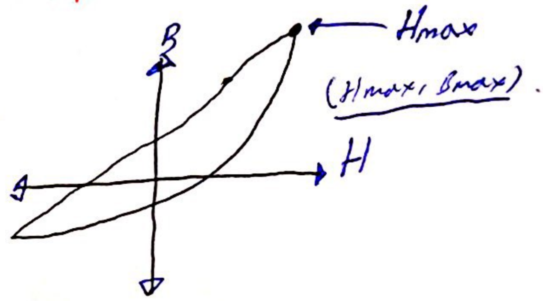
$$H = \frac{N(Rsh * Vsh)}{L}$$

\# the current from the source entering the transformer is Ish which is i , the excitation current.

8 what is the value of the max Flax intensity For the hysterisis Loops of the experiment?

max Flax intensity → Hmax

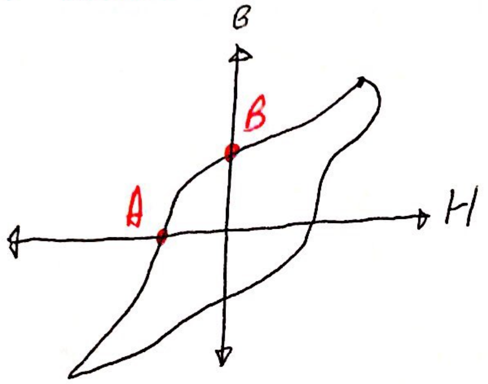
\# Hmax is the point of saturation.



For 80V → 1.3 division

For 120V →

9 Determine the residual Flux Density and coercive Force.



point A :- This point is called the coercive Force. (coercivity)

point B : This point is the residual Flux (Retencivity)

To find the Residual Flux density, we multiply point B (residual Flux) by the voltage division of the oscilloscope.
, same as A.

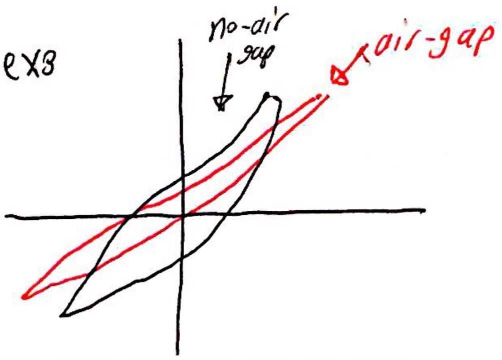
How do the excitation voltage be effected by air-gap.

From the equation $e_{in} = -N \frac{d\phi}{dt}$, when I have air-gap the reluctance will be big and the Flux will be small so the excitation voltage will be small.

10 explain how air-gap effect the hysterisis Loop (height, width, area).

First of all when I add the effect of air-gap, I increase the reluctance of the magnetic CKt, and Fringing effects appear in my CKt.

ex:



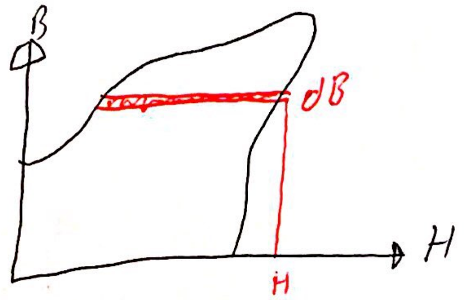
First of all, the width ↑(increase)
Height → same (equal)
area

11 prove that the area of the hysteresis Loop is proportional to the hysteresis Loss of transformer.

Hysteresis Loss = $W_h = k_h F (B_m)^{1.6}$ W

$H = \frac{NI}{L}$, $I = \frac{HL}{N}$

From the hysteresis Loop



$e' = -N \frac{d\phi}{dt}$

$= -Na \frac{dB}{dt}$

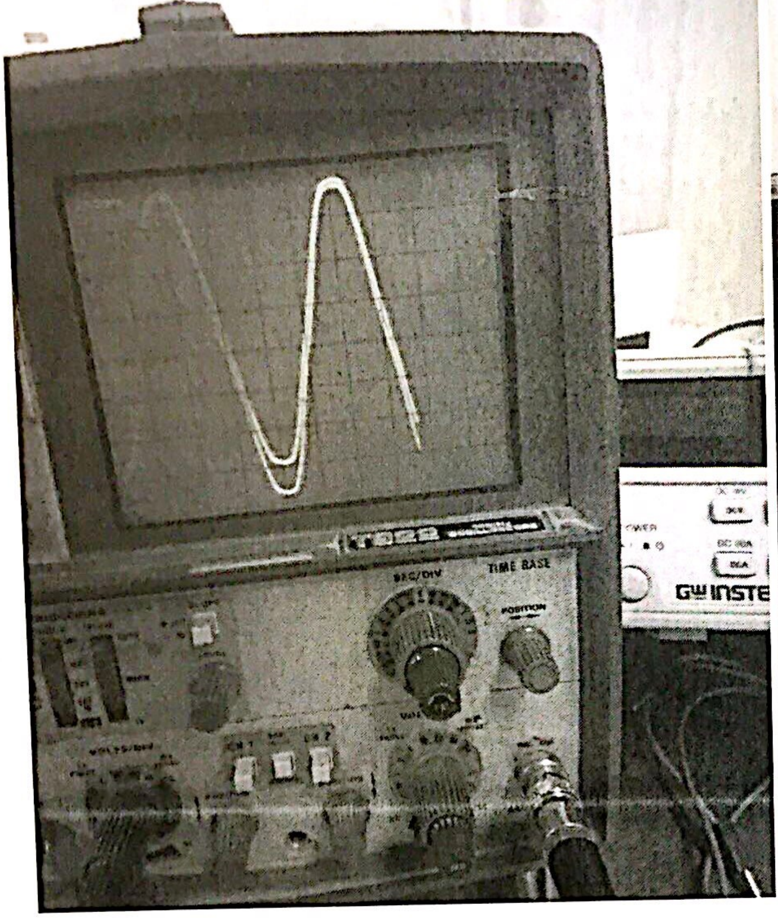
$e = e' \cdot I \cdot dt$

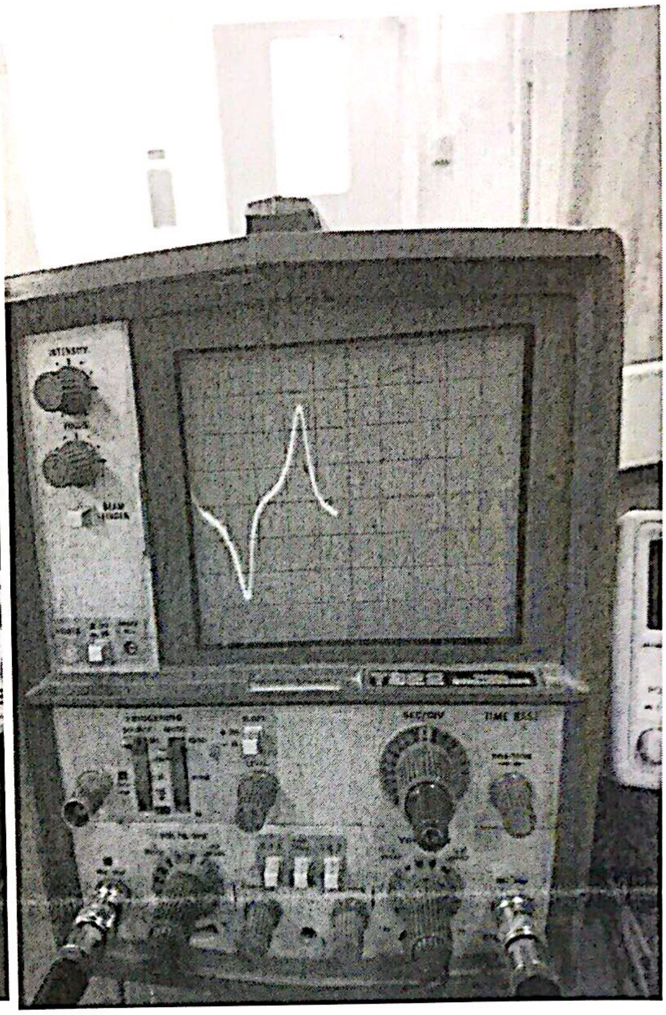
$= Na \frac{dB}{dt} \times I \times dt$

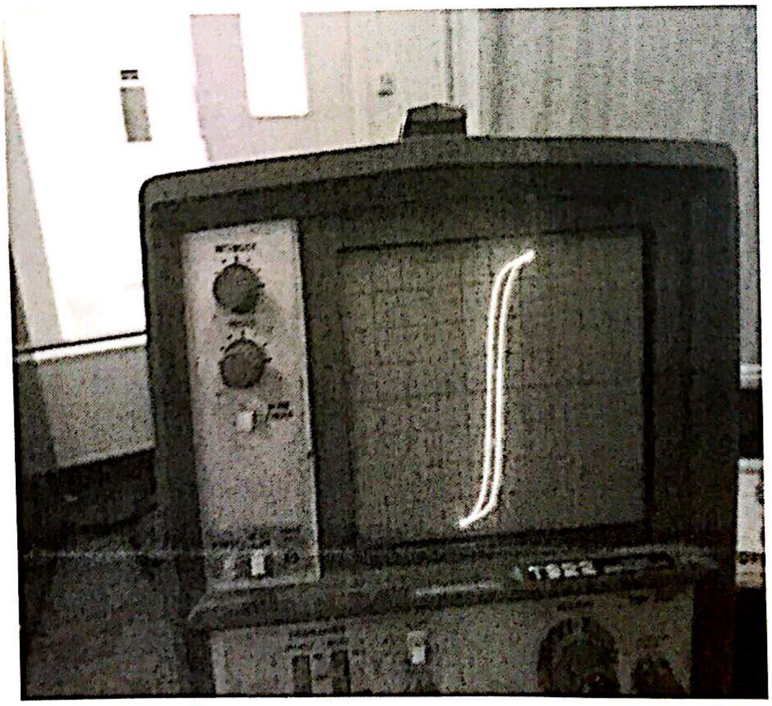
$= Na \frac{dB}{dt} \times \frac{HL}{N} \times dt$

$W = aL \int_0^{B_{max}} H \cdot dB$

so, $\int H \cdot dB$ = total area enclosed by Hysteresis Loop.


SEC/DIV
TIME BASE
POSITION


INTENSITY
SEC/DIV
TIME BASE




GW INSTEK

University Of Jordan

Faculty of Engineering & Technology

Electrical Engineering Department

Electrical Machines Lab

Experiment (3): characteristics of DC separately & shunt Generators.

group (3)
Thursday Section

Reg. Number	Name
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	-2
	-3
	-4
	-5

* Objective:

1) To study No-load characteristics of DC generators.
2) To study External characteristics of the separately-excited & shunt generators.
3) To study Regulation characteristics of the separately-excited & shunt generators.

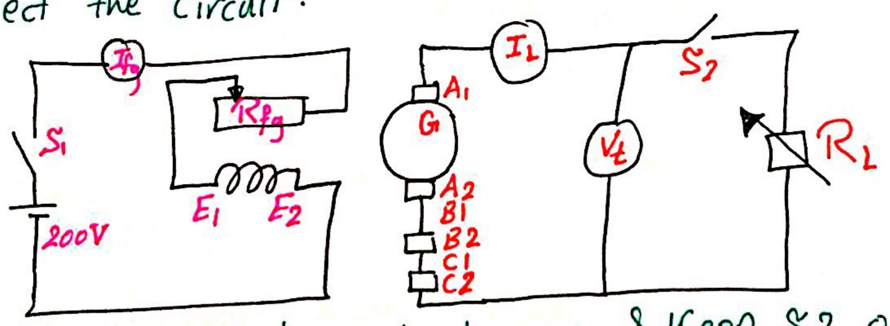
* Equipment:

DC machine, Field regulator, Two Ammeters, one voltmeter, DC power supply, cutoffswitch, control unit, panel mounting frame, connection cables & Plugs, Rubber coupling sleeves & coupling guards.

* Procedure:

Procedure (1):

(1) • Connect the circuit:



(2) • Set the load Resistance to its max., & Keep S_2 OFF.

(3) • Set the field regulator R_{fg} to "g" which implies that the field circuit is open-circuited.

(4) • Turn S_1 ON.

(5) • Run the Prime mover as in the previous section & set its speed to be 2500 rpm. which will be constant through the exp.

- Record the terminal V_t in the table(1):

speed = 2500 RPM = constant.

Table (1a)

I_f (mA)	0	50	75	100	125	150	175	200	225	250
V_t (V)	5.4	50.5	74.6	97.3	123.3	135.6	142.5	152.7	158.2	165.6

- Use the generator field regulator R_{fg} to set the excitation current in steps to match the requirements of the previous table.
- Reset the generator field regulator to the "q" position.
- Reset the prime mover speed to 2000 RPM.

speed = 2000 RPM = constant

Table (1b)

I_f (mA)	0	50	75	100	125	150	175	200	225	250
V_t (V)	7.7	40.4	59.6	74.6	97.4	105.2	113.3	118.9	124.7	127.7

Procedure (2):

- Reset the motor speed to 2000 RPM & Keep this speed fixed throughout the test.
- Set the generator field current to 250 mA.
- Record V_t in table (2).
- Switch S_2 ON.
- Use the Load Resistance R_L to set the values of I_L to match the requirements of table(2). For each value of I_L record V_t in the table.
- Increase R_L gradually to maximum & switch S_2 off.

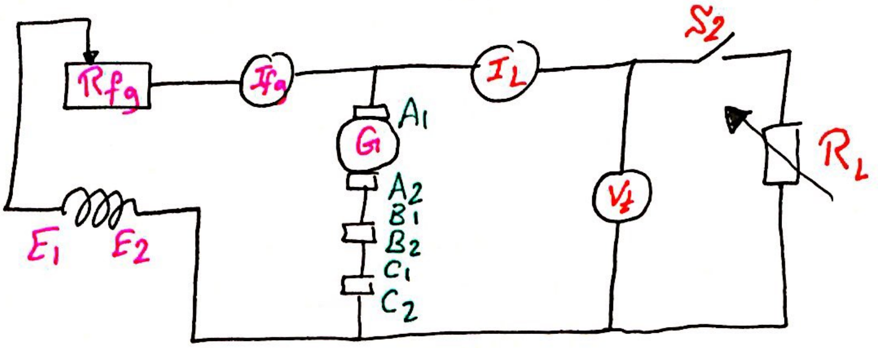
speed = 2000 RPM = constant, I_f = 250 mA = constant.

Table (2)

I_L (mA)	0	0.5	1.0	1.5	2.0	2.5
V_t (V)	124	120.3	113.7	106.7	99.4	93

Procedure (3):

- Connect the circuit:



- Repeat steps (3) - (5) of procedure (1).
- Set the generator field current to 250mA.
- Record V_t in table (3):

speed = 2000 RPM = constant , I_f = 250 mA = constant.

Table (3)

I_f (mA)	0	50	75	100	125	150	175	200	225	250
V_t (V)	6.1	47	61	77	98	102.2	112	118.8	126.5	129

- Switch S_2 ON.
- Use the load Resistance R_L to set the values of I_L that match the requirements of table (4). For each value of V_t, the speed should be Kept constant @ 2000 RPM. For each value of V_t. record I_L.

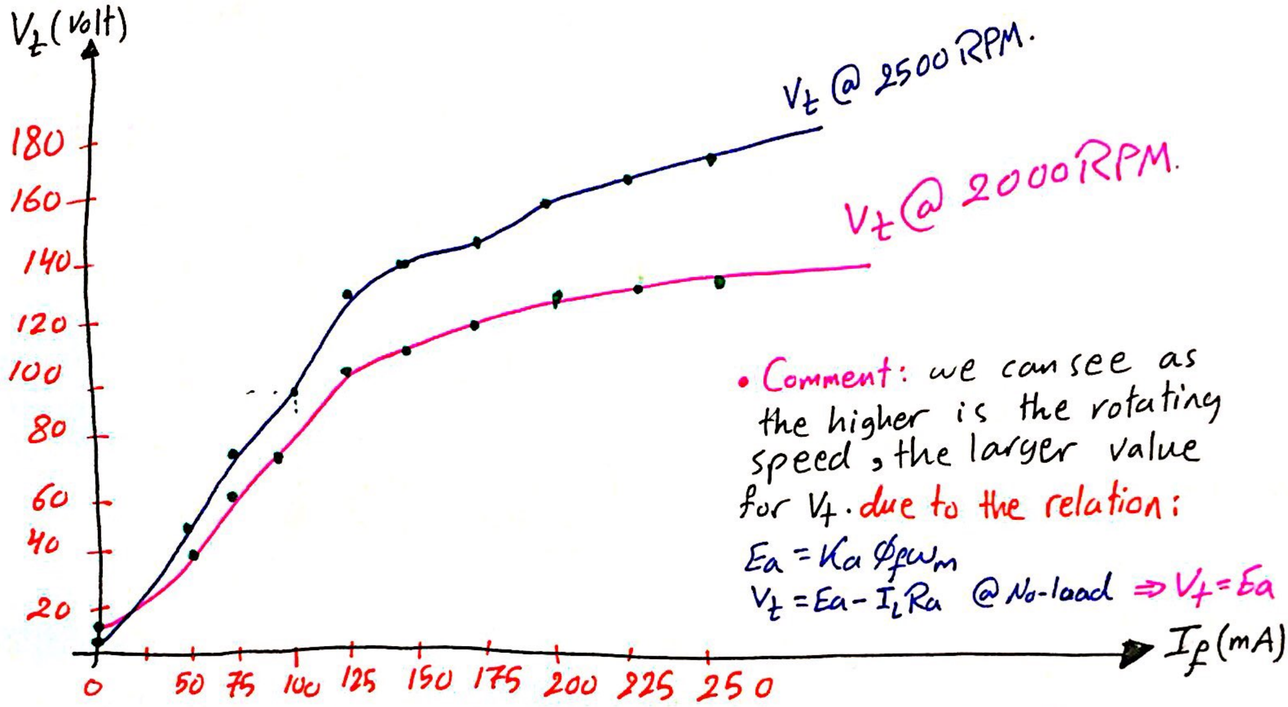
speed = 2000 RPM = constant

Table (4)

I_f (mA)	250	225	210	175	150	125	100	50	37	15	0
I_L (A)	0	0.575	0.84	1.3	1.75	2	2.2	2.4	1.9	1.35	0.9
V_t (V)	127	115	110	100	90	80	60	40	20	10	0

※Results & Comments:

* Plot on the same graph, the No-load char. ($V_t = f(I_f)$) of the DC M/C corresponding to running speeds of 2000 & 2500 rpm.



• Comment: we can see as the higher is the rotating speed, the larger value for V_t. due to the relation:

$E_a = K_a \phi_f \omega_m$

$V_t = E_a - I_L R_a$ @ No-load $\Rightarrow V_t = E_a$

* Show how to determine the critical Field Resistance.

The critical field resistance can be found by the slope:

$$\text{slope} = R_{fc} = \frac{124.7 - 205.2}{(225 - 150)m} = 0.26\,K\Omega$$

* What is the value of the residual voltage. Does this voltage vary with speed.

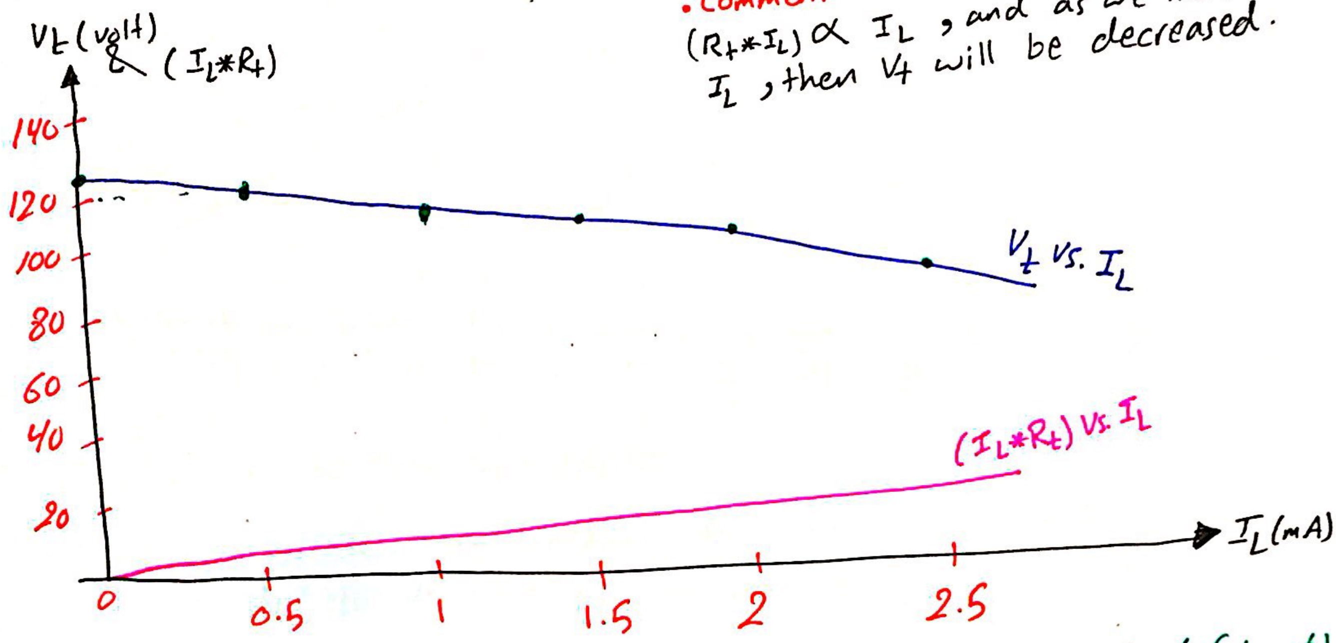
the Residual voltage found @ $I_f = 0$:

@ 2500 RPM $\Rightarrow V_{resid.} = 5.4$ volt.

@ 2000 RPM $\Rightarrow V_{resid.} = 7.7$ volt.

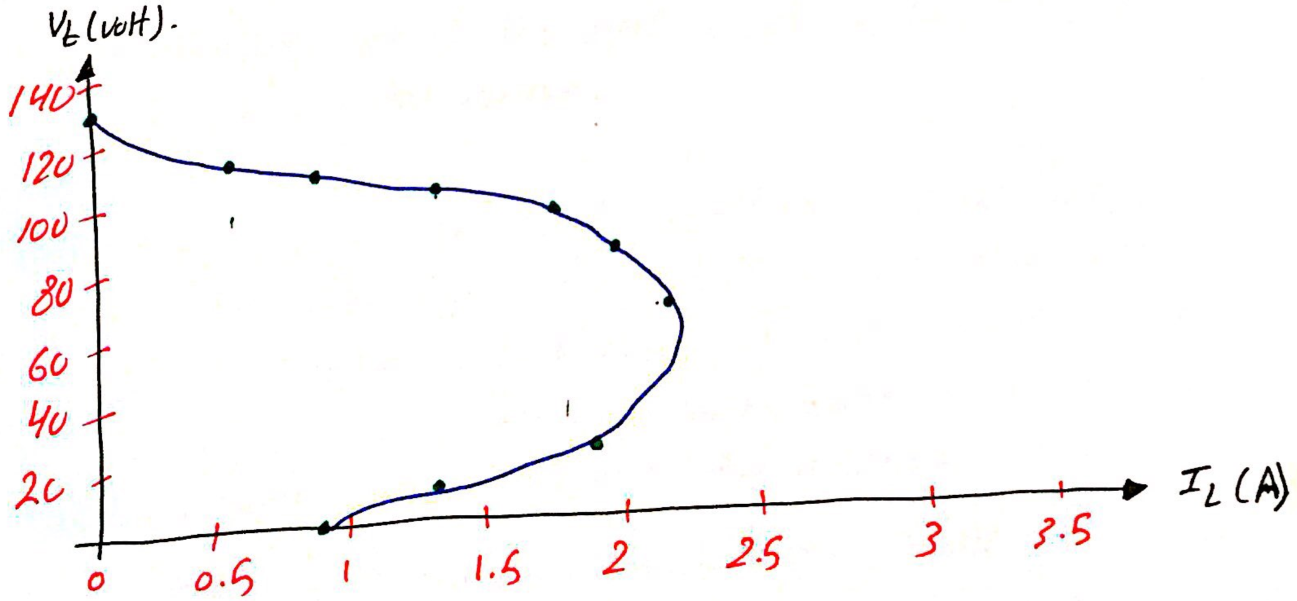
& Yes it does vary with the speed.

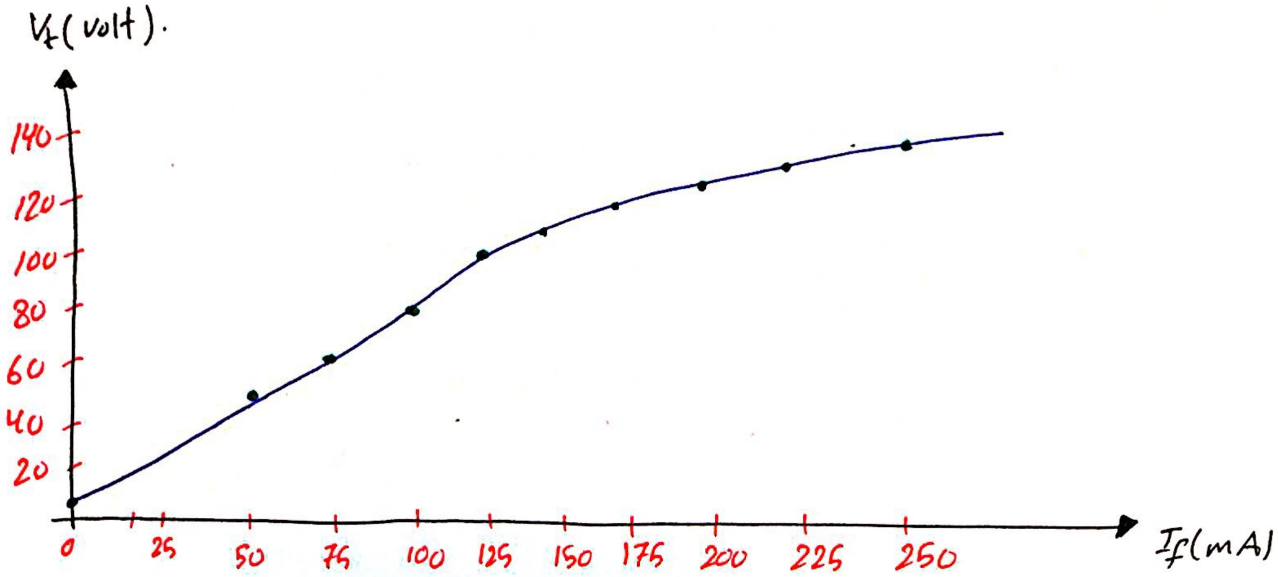
* Plot ($V_t = f(I_L)$) of the DC gen. when it is separately excited. On the same graph, plot ($I_L * R_t$) & the voltage drop due to AR. R_t is the total resistance of the Armature cct.



• Comment: we can see the relation $(R_t * I_L) \propto I_L$, and as we increase I_L, then V_t will be decreased.

* Plot the external char. of the gen. when it is self-excited (shunt). Comment on the nature of the curve.





• Comments on previous two graphs:

→ we can see how the machine start with the high value of V_t the it start to decrease by increasing I_L, until it reach a certain point ($I_L = 2.4A$) the machine start to break-down.

→ The field circuit resistance should be less than the critical field resistance

→ Building up of the EMF needs residual flux to be present in the system.

* How does the short-circuit condition of shunt generators differ from other types of machines. what is the value of the short circuit current & what are the prameters it depends on.

⇒ in the other types: s/c means high current through small path of resistance which damage the machine.

⇒ in the shunt generator: its different because s/c leads to small Load, so V_t approaches zero, which lead I_f to be small (ϕ_f will drop to the residual ϕ_r), so small short circuit current.

... Continue

⇒ the value of the short circuit current can be found as follows:

$$I_{sc} = \frac{E_r}{R_a}$$

→ @ $E_r = 5.4$ volt. (2500 RPM) $I_{sc} = \frac{5.4}{2.5} = 2.16\,A$.

→ @ $E_r = 7.7$ volt. (2000 RPM) $I_{sc} = \frac{7.7}{2.5} = 3.08\,A$.

⇒ The parameters that it depends on:

A_2, B_1, B_2, C_1, C_2.

* Conclusion :

- We learned about the open-circuit test for the DC machine, & we saw the magnetization curve of it @ a different constant speeds (2500 & 2000) RPM.
- We studied the both cases of separately excited generator & shunt generator & we saw the differences for the No-load condition & the load-condition.

* * *

The End.

The University Of Jordan

Faculty of Engineering & Technology

Department of Electrical Engineering

Experiment #4

Characteristics & Speed Control of DC Motors

group: 3
section: Thursday

Reg. No.	Name
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	3-
	4-
	5-

※ Objective :

1) Investigate the load characteristics (torque-speed & torque-current) of DC Motors.
2) Investigate methods of speed control of DC Motors.
3) Evaluation of the motor performance parameters (efficiency, speed regulation).

※ Equipment :

DC Motor (22V), Eddy Current Brake, Variable Resistor (R_B) for eddy current brake control, Variable Resistor (R_{Fext}) for field current control, starting resistance, 3 DC Ammerters & 2 DC voltmeters, speedo-meter & 3 Electromechanical switches.

※ Procedure :

- Procedure (A) : "Rated Voltage, Rated Field."

- connect the Armature circuit terminals $X_1 - X_2$ to the variable (0-400)V DC source (T1 & T2 respectively). Initially, the applied voltage should be zero, & the armature switch S_A should be @ OFF position.
- Connect the terminals of the field circuit Y_1-Y_2 to the fixed 220V DC source (terminals L_1-L_2 respectively). The switch S_F should be OFF.
- Switch ON S_F & adjust the field current to (0.8A) by means of R_{Fext}. Record the value of the field voltage.
- Make sure that the armature starting resistance is Maximum.
- Switch ON S_A & increase the armature voltage terminal gradually up to the rated value of 220 volt. it will be fixed throughout the test.
- Reset the starting resistance to its minimum.
- Record the line current & motor speed in table (A). In this case $T_L = 0$
- switch on Eddy Current Brake source & vary R_E to get a (3Nm) load torque. Record in table (A), the corresponding Line current & motor speed.

- Keep varying T_L, in steps, to match the readings of table(A). In each step, record the corresponding I_L & N_m.
- Reset R_E to its Max. Position & switch it OFF.

* Table(A): $V_T = 220V$, $I_F = 0.8A$.

T_L (N.m)	0	3	6	9	12	15
N_m (RPM)	1600	1575	1550	1525	1505	1495
$I_L = I_A$ (A)	0.9	3.5	6	8	10	12

- **Procedure (B)**: "Reduced Voltage, Rated Field".
  - Keep the field current @ 0.8A. by means of $R_{F(EXT)}$ Reord the value of the Field Voltage.
  - Reduce the Armature Voltage to 160V.
  - Keep the eddy current brake circuit OFF.
  - Record I_L & N_m in Table(B). In this case $T_L = 0$
  - Switch ON the eddy current brake circuit source & vary R_E to get (3 N.m) T_L. Record the corresponding I_L & N_m.
  - Keep varying T_L to match the reading of table(B). In each step record the corresponding I_L & N_m.
  - Reset R_E to its Max. Position & switch it OFF.

* Table (B): $V_T = 160V$, $I_F = 0.8A$.

T_L (N.m)	0	3	6	9	12	15
N_m (RPM)	1150	1125	1115	1100	1075	1050
$I_L = I_A$ (A)	0.8	3.5	5.5	7.9	10	12

- **Procedure (C)**: "Rated Voltage, Reduced Field"
  - Increase V_T to 220V.
  - Keep Eddy current Brake cct off.
  - Reduce I_F to 0.6A by means of $R_{F(ext)}$. Record the value of the field voltage.
  - Record I_L & N_m in Table (C). In this case $T_L=0$
  - Switch ON the Eddy Current Brake source & vary R_E to get (3N.m) T_L. Record the corresponding I_L & N_m.
  - Keep varying T_L to match the reading of table (C). In each step record the corresponding I_L & N_m.
  - Reset R_E to its Max. Position & switch it off.

* Table (C): $V_T = 220V$, $I_F = 0.6A$.

T_L (N.m)	0	3	6	9	12	15
N_m (RPM)	1900	1875	1825	1775	1730	1705
$I_L = I_A$ (A)	1	4.3	6.5	9	12	14

- **Procedure (D)**: "Armature Voltage Control Method"
  - Reset I_F to 0.8A by means of R_{Fext}. Record the value of the field voltage
  - Make sure that R_B is Max. switch on the eddy-current switch.
  - Vary R_E to get $T_L=12$ N.m. Record the corresponding I_L & N_m in Table (D).
  - Reduce the Armature Voltage in steps to match the reading of Table (D). In each step, Keep $I_F = 0.8A$ by means of R_{Fext} & record the corresponding I_L & N_m.

- Reset R_E to its Max position & switch it OFF.
- Increase the Armature voltage back to its rated value of 220 V.

* Table (D): $T_L = 12$ N.m , $I_F = 0.8$ A.

V_T (V)	220	190	160	130	100
N_m (RPM)	1460	1250	1025	840	625
$I_L = I_A$ (A)	10	9.9	10	9.9	9.8

- Procedure (E): "Field Weaking Control Method"

- Make sure that R_B is Max. switch ON the eddy current switch.
- Vary R_E to get the rated Load torque of 12 N.m. Record T_L & the corresponding N_m in Table (E).
- Reduce I_F, in steps, to match the readings of Table (E). In each step Keep the Armature Voltage Constant @ 220 V. Vary R_E to Keep the Armature current @ its rated value 10 A.
- In each step, record the corresponding T_L & N_m in Table (E).
- Reset R_E to its Max. Position & switch it OFF.
- Increase the I_F back to it value of 0.8 A.
- switch off the armature voltage.
- switch off the field voltage.

* Table (E): $I_L = I_A \simeq 10$ A.

I_F (A)	0.8	0.7	0.6	0.5
N_m (RPM)	1495	1600	1790	2010
T_L (N.m)	12	11	10	8.5

*Results & Discussion :

Procedure (A, B & C) :

- In one graph, sketch the Load char. (N_m/T_L) of the three procedures

Drawn in last pages.

- In one graph, sketch th line current-load torque char. (I_L/T_L) of the three procedures.

Drawn in last pages.

- In each case calculate the Developed Torque T_a, & sketch it, in one graph, vs. I_a.

$T_a \omega_m = P_a$, $P_a = I_a * E$, $E = V_t - I_a R_a$

$$\Rightarrow T_a = \frac{I_a (V_t - R_a I_a)}{\omega_m} , \quad \omega_m = \frac{2\pi N_m}{60}$$

results are shown in the following Tables.

- In each procedure, Calculate the speed regulation & sketch it vs. the T_L.

$$SR = \frac{N_{NL} - N_{FL}}{N_{FL}}$$

results are shown in the following tables.

- For each procedure, Calculate the Rotational Losses & sketch it vs. the load speed.

$$P_r = (T_a - T_L)\omega_m$$

results are shown in the following tables.

- For each procedure, calculate the motor efficiency & sketch it vs. T_L.

$$\eta = \frac{\text{developed Torque} - \text{Rotational loss}}{\text{Develoved Torque}} = \frac{T_{output}}{T_{developed}} = \frac{\omega_m * T_L}{\omega_m * T_a}$$

results shown in the following tables.

• For Table (A):

T_L	0	3	6	9	12	15
ω_m	167.5	164.9	162.3	159.7	157.6	156.5
T_a	1.176	4.58	7.88	10.58	13.26	15.86
SR	0	1.58	3.23	4.92	6.31	7.02
P_r	196.98	260.5	305.1	252.3	198.6	133.96
η	0	65.5	76.1	85.1	90.5	94.6

• For Table (B):

T_L	0	3	6	9	12	15
ω_m	120.4	117.8	116.8	115.2	112.5	109.9
T_a	1.06	4.6	7.25	10.4	13.2	16.03
SR	0	2.22	3.14	3.6	6.98	9.52
P_r	127.3	193.2	145.95	157.8	139.5	113.1
η	0	64.7	82.8	86.8	90.6	93.6

• For Table (C):

T_L	0	3	6	9	12	15
ω_m	198.9	196.4	191.1	185.9	181.1	178.5
T_a	1.1	4.7	7.2	10.2	13.7	16.05
SR	0	1.33	4.1	7.04	9.8	11.4
P_r	218.8	336.5	236.8	218	307.9	186.9
η	0	63.64	82.9	885	87.6	93.5

Procedure (D&E):

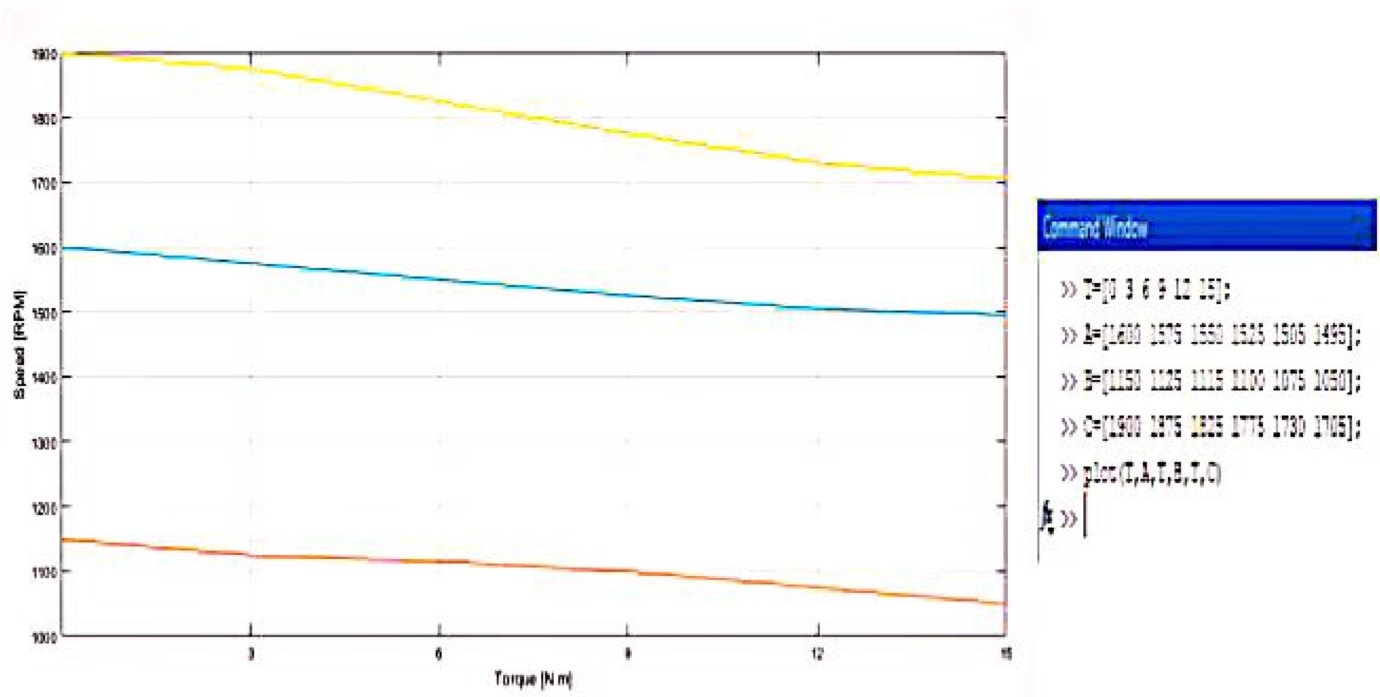
- From Procedure D, sketch the Motor speed vs. the terminal voltage.
  shown in last pages.
- From Procedure E, sketch the Motor speed vs. I_F.
  shown in last pages.
- Compare the features of the two speed control methods.
  * Using the armature voltage control method we can increase the speed of the motor in between the allowed range $(0 \leq \omega_m \leq \omega_{m\,rated})$.
  * Using the field weaking method we can control the speed of the motor in between the limit $\omega_{m\,rated} \leq \omega_m \leq \frac{2}{3}\ \omega_{m\,rated}$

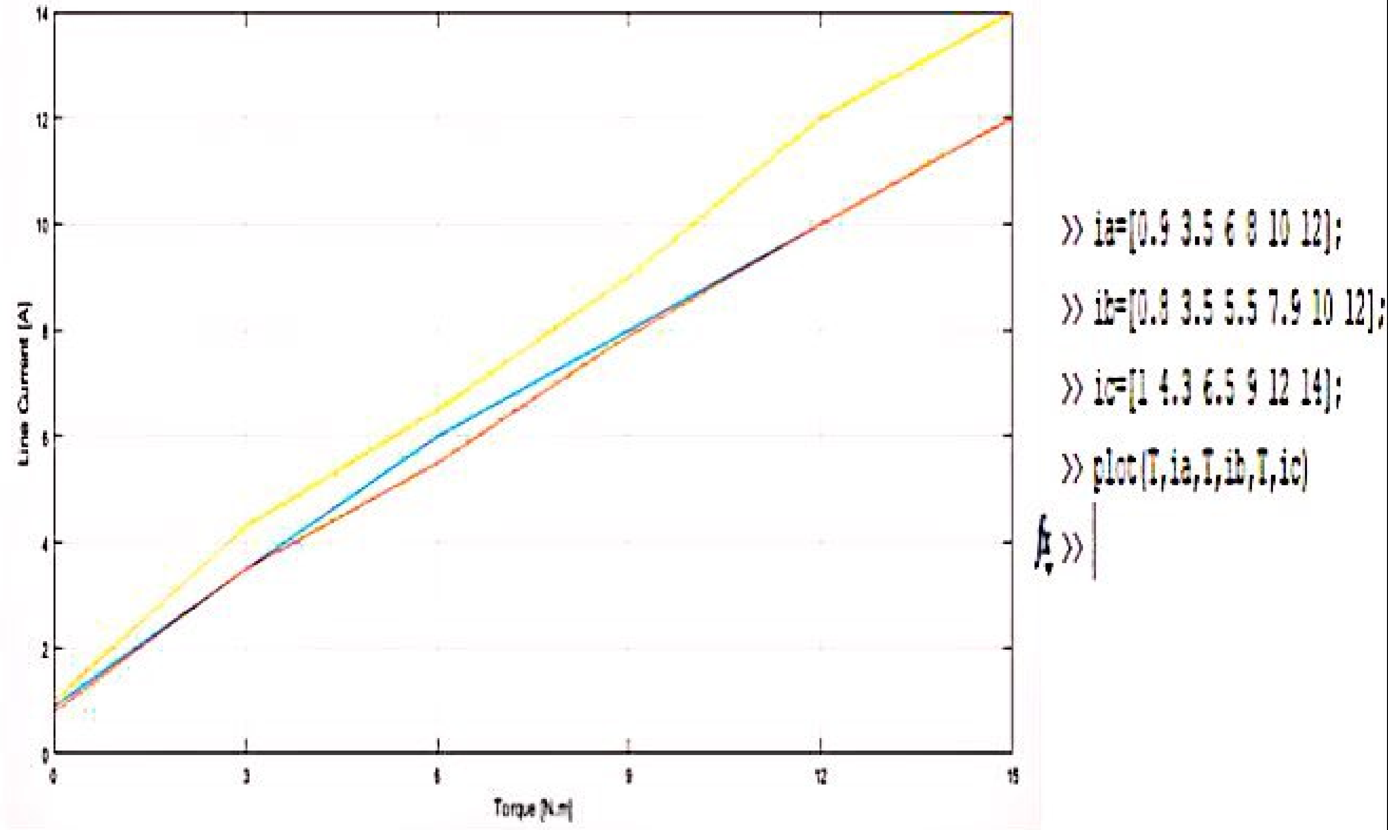
  But we must becarful since speed can reach ∞ due to:
  mechanical strength & sever sparking due to bad communication.
- Plot in one graph, T_L vs. N_m for both procedures.
- Plot in one graph, Output Torque vs. ω_m for both procedures.
  [Drawing is shown in last pages].

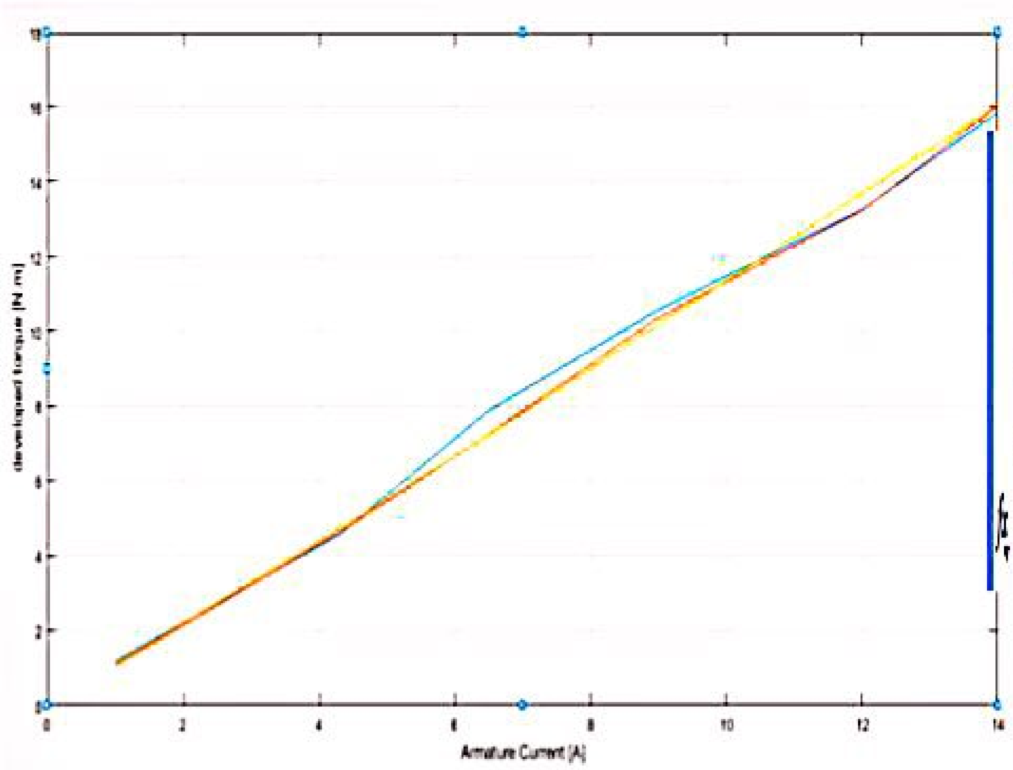
※ Conclusion :

- We learned through this experement how there are more than one method to control the speed of the motor.
- We calculate η, P_r, T_a for each procedure under different conditions

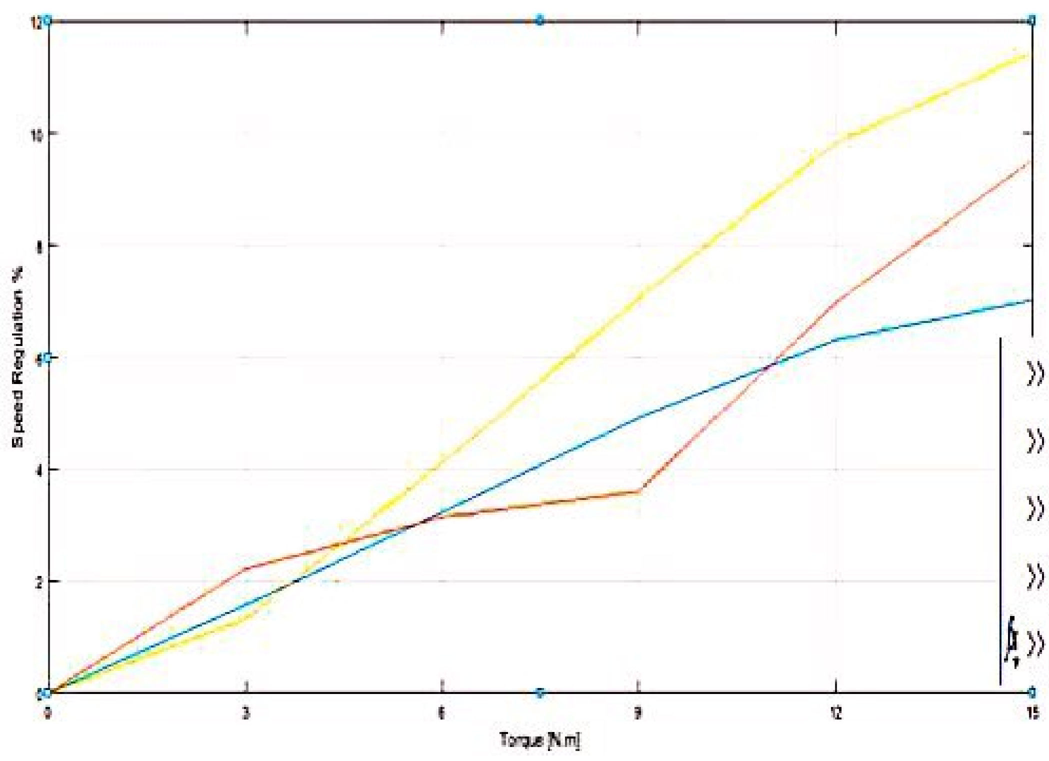
* * *


Speed [RPM]
Torque [N.m]
Command Window
>> T=[0 3 6 9 12 15];
>> A=[1600 1575 1550 1525 1505 1495];
>> B=[1150 1125 1115 1100 1075 1050];
>> C=[1900 1875 1825 1775 1730 1705];
>> plot(T,A,T,B,T,C)
>>

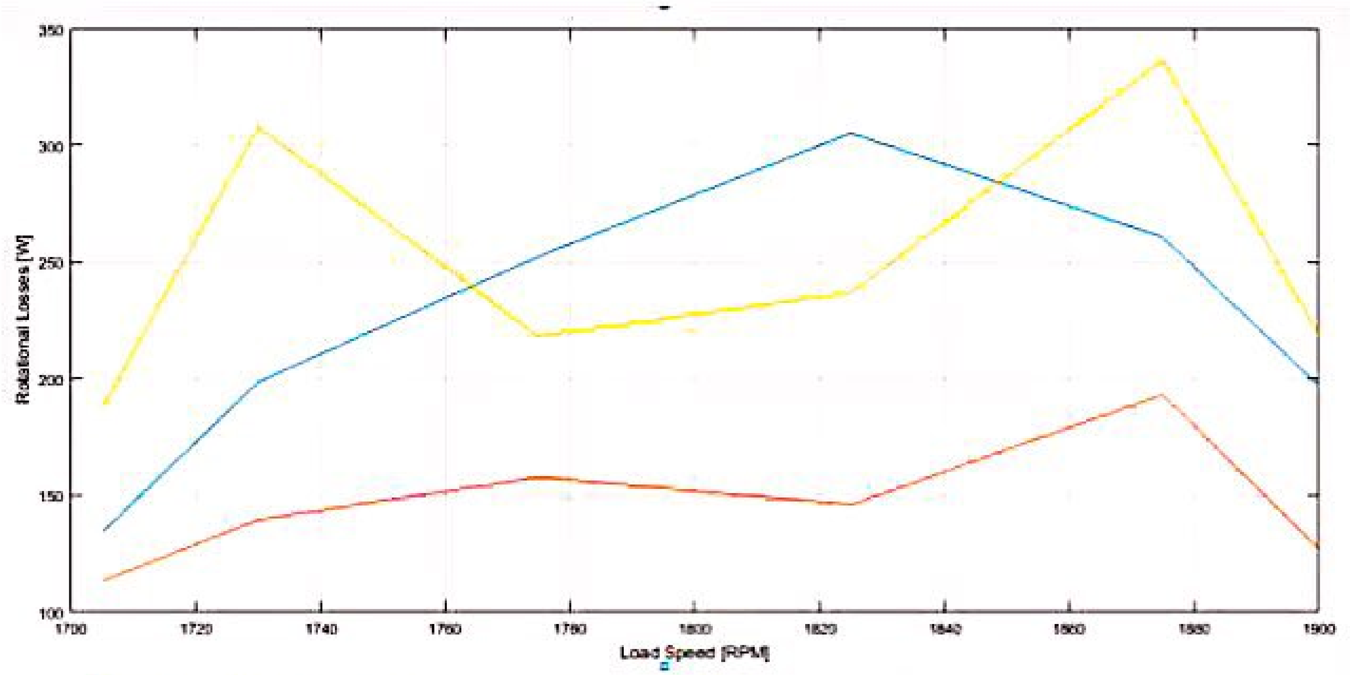

Line Current [A]
Torque [N.m]
>> ia=[0.9 3.5 6 8 10 12];
>> ib=[0.8 3.5 5.5 7.9 10 12];
>> ic=[1 4.3 6.5 9 12 14];
>> plot(T,ia,T,ib,T,ic)
>>



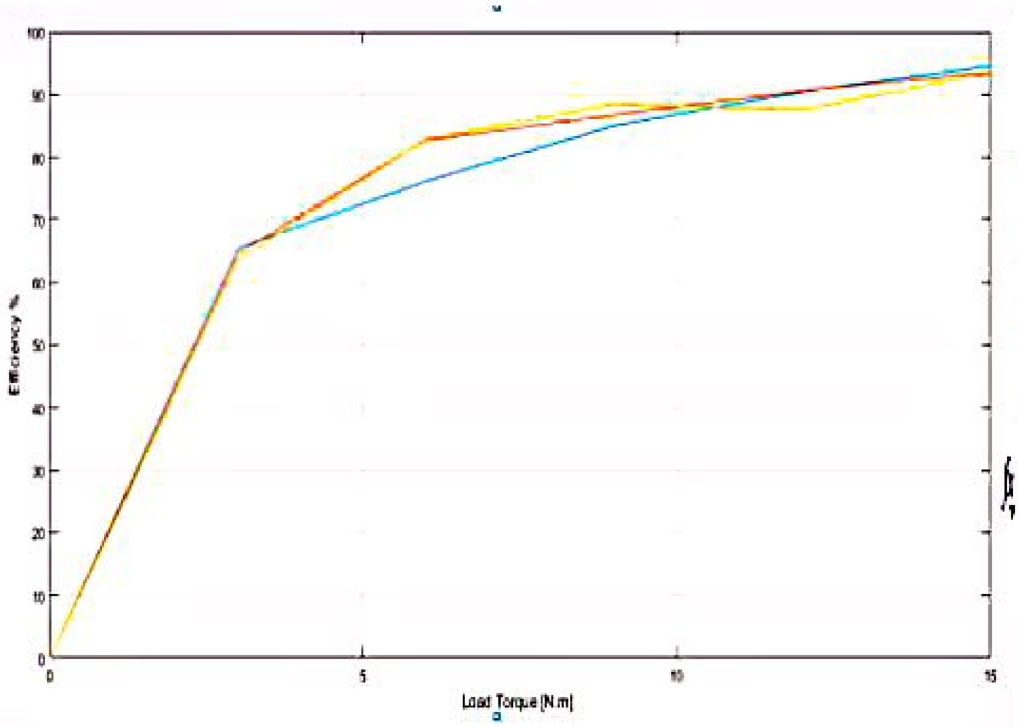

```
>> Tda=[1.176 4.58 7.88 10.58 13.26 15.856];
>> Tdb=[1.067 4.64 7.25 10.37 13.29 16.029];
>> Tdc=[1.1 4.714 7.259 10.173 13.7 16.097];
>> plot(ic,Tda,ic,Tdb,ic,Tdc)
>>
```



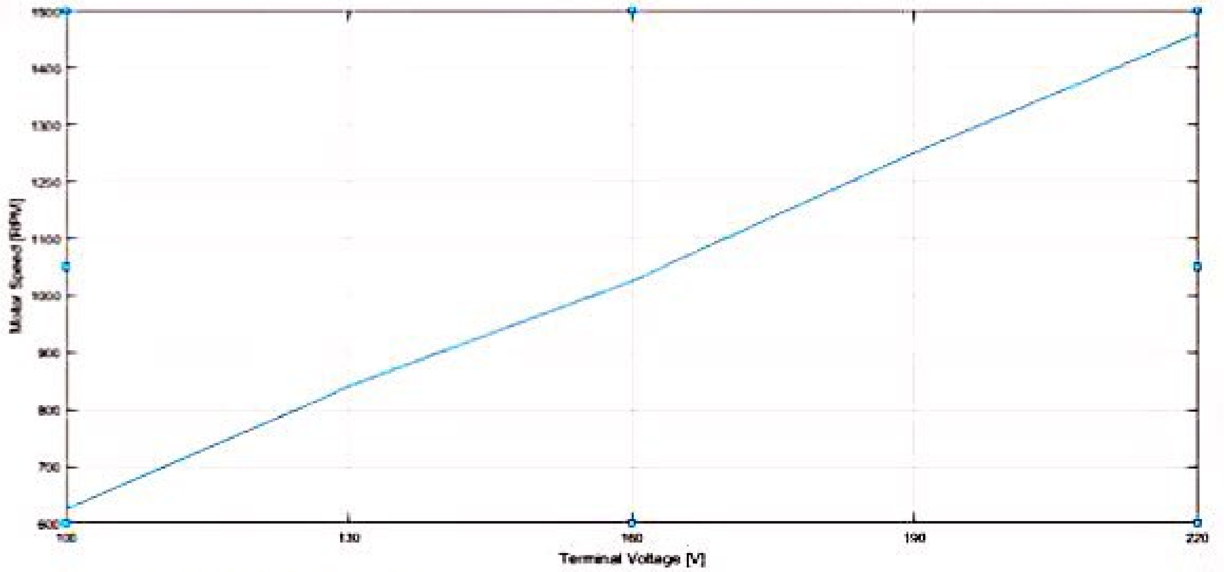

```
>> sra=[0 1.58 3.23 4.92 6.313 7.023];
>> srb=[0 2.22 3.14 3.604 6.977 9.523];
>> src=[0 1.33 4.105 7.04 9.83 11.49];
>> plot(T,sra,T,srb,T,src)
>>
```



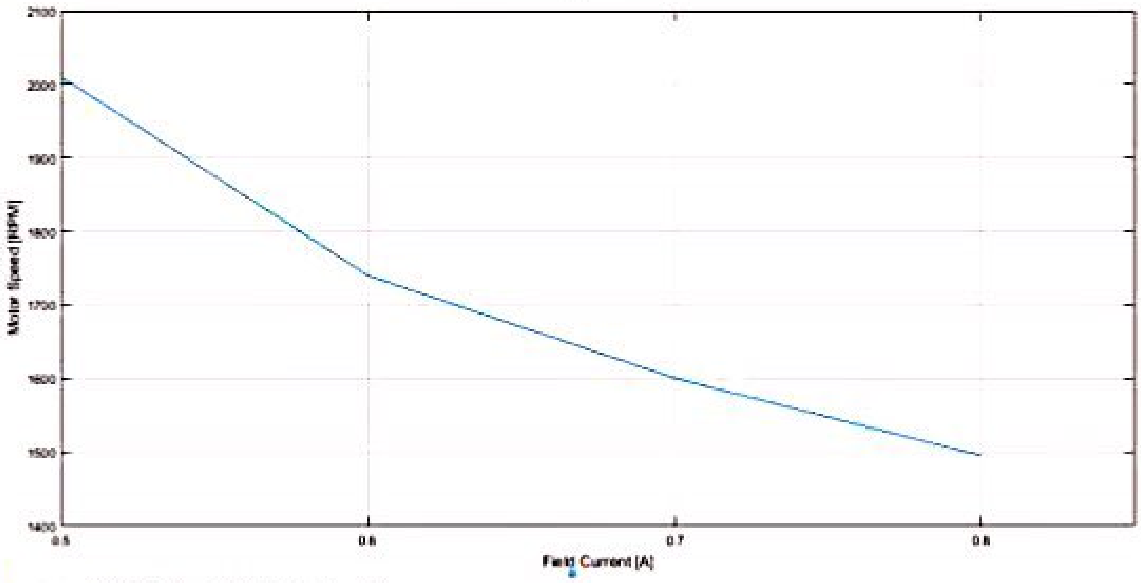

```
>> rla=[196.98 260.54 305.12 252.3 198.57 133.964];
>> rlb=[127.3 193.19 145.95 157.8 139.5 113.08];
>> rlc=[218.79 336.54 236.77 218.0 307.87 186.9];
>> plot(C,rla,C,rlb,C,rlc)
fx >>
```




```
>> efa=[0 65.5 76.1 85.06 90.49 94.6014];
>> efb=[0 64.65 82.75 86.78 90.63 93.58];
>> efc=[0 63.64 82.88 88.46 87.59 93.475];
>> plot(T,efa,T,efb,T,efc)
fx >>
```

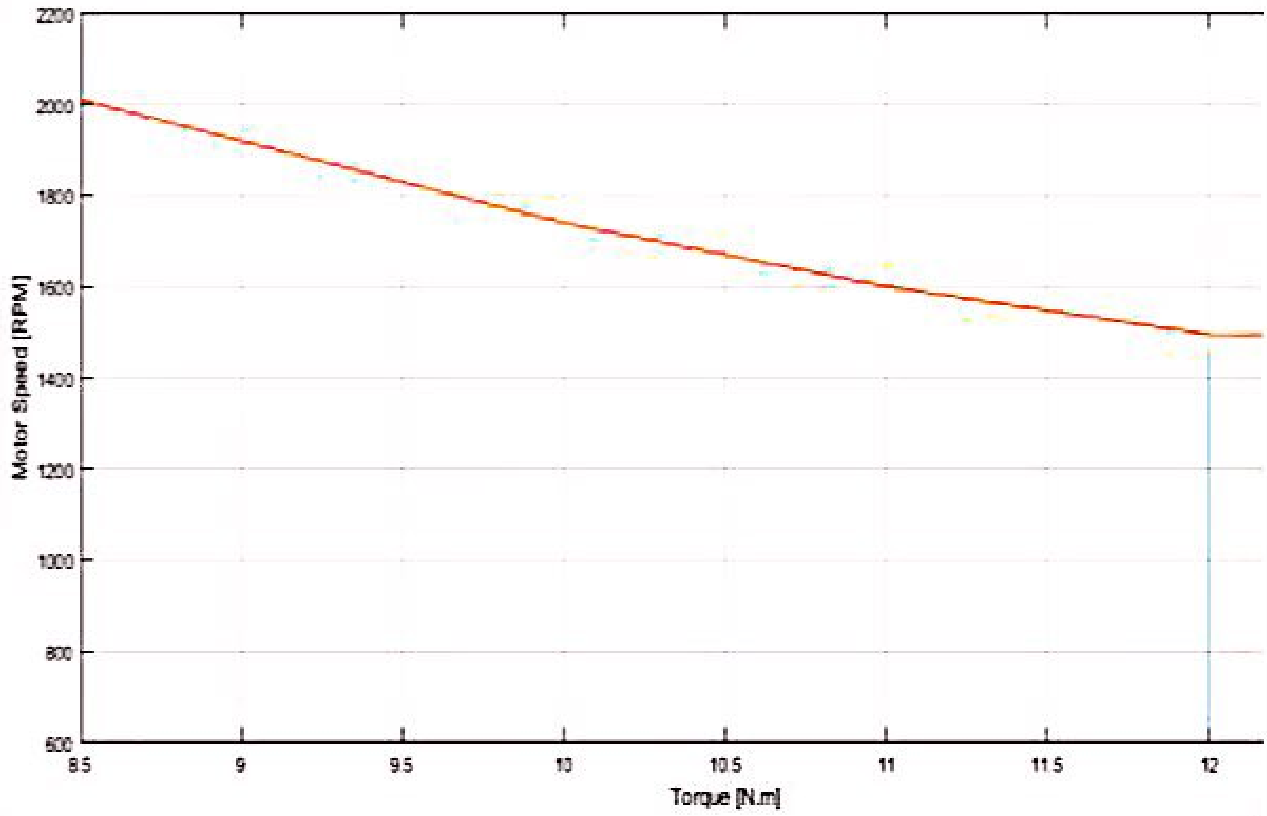



```
>> Vt=[220 190 160 130 100];
>> Nd=[1460 1250 1025 840 625];
>> plot (Vt,Nd)
>>
```

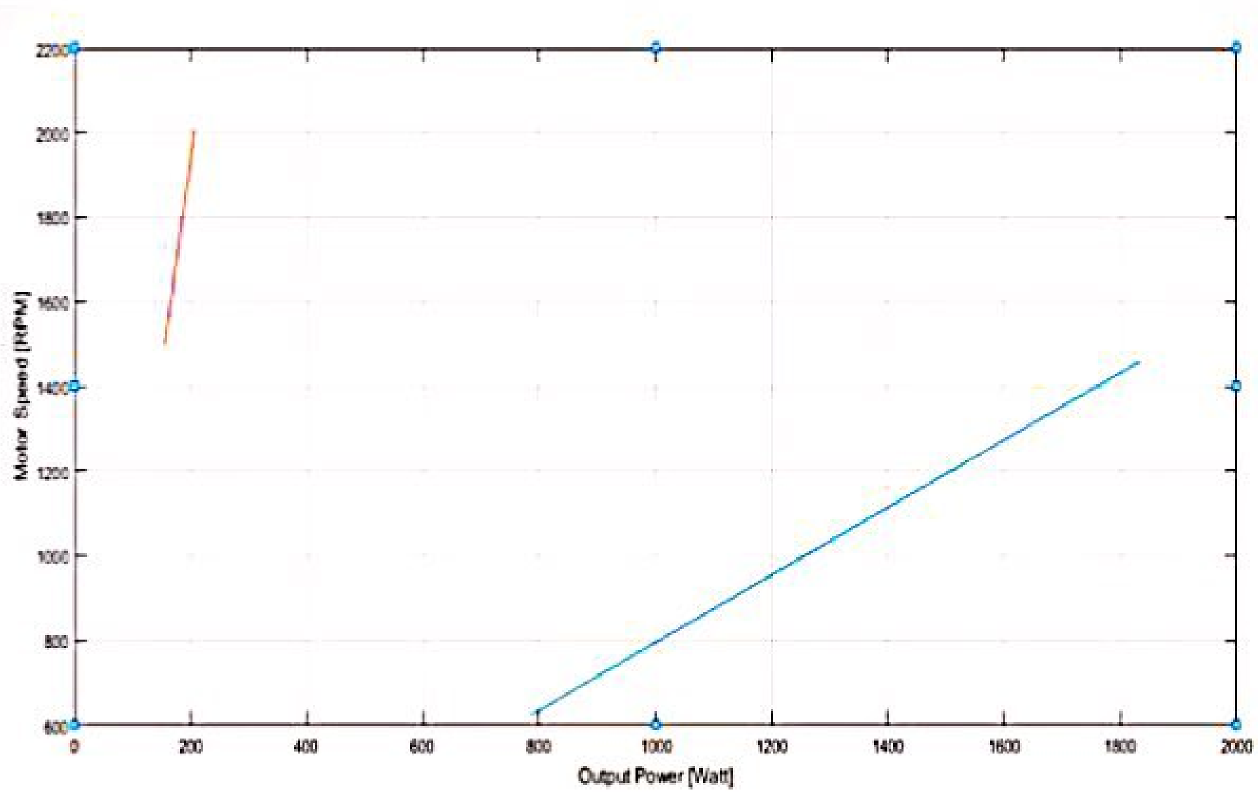



```
>> If=[0.8 0.7 0.6 0.5];
>> speed=[1495 1600 1740 2010];

>> plot (If,speed)
>>
```




```
>> speed=[1495 1600 1740 2010];
>> Nd=[1460 1250 1025 840 625];
>> t=[12 12 12 12 12];
>> tt=[12 11 10 8.5];
>> plot(t,Nd,tt,speed)
```




```
poe =

  153.9895   164.8049   179.2253   207.0361

>> speed=[1495 1600 1740 2010];
>> pod=m.*t

pod =

   1.0e+03 *

    1.8347    1.5708    1.2881    1.0556    0.7854

>> Nd=[1460 1250 1025 840 625];
>> plot(pod,Nd,poe,speed);
fx >>
```

The University Of Jordan.

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Faculty Of Engineering & Technology.

*   *   *

Department of Electrical Engineering.

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Experiment #5

Characteristics Of DC Compound Generators.

group 3
Section: Thursday

Reg. No.	Name
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※Objectives :

- Investigate the No-load char. of DC compound generators.
- Differentiate between the nature & the rules of the shunt & series field windings.
- Investigate & compare the load char. of the DC Cumulatively & Differentially Compound Generator.
- Evaluate the performance parameters (VR, η, ...) of the DC compound generator.

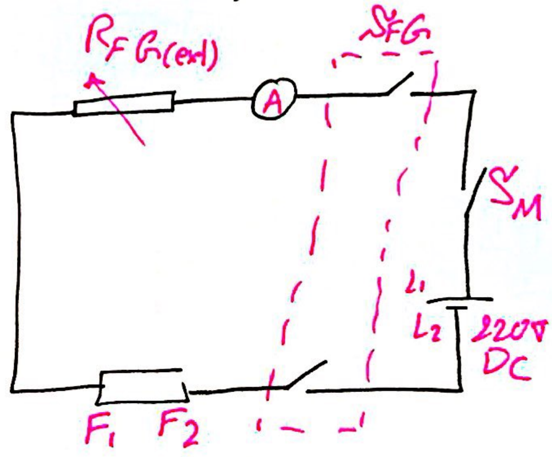
※ Equipment :

DC shunt Motor, Motor starting Resistance, Variable Field Resistor, Variable Resistor (R_L), DC compound generator, 2 DC Ammeters (0-3A), 2 DC Ammeters (0-30A), 1 DC voltmeter, 4 Electromechanical switches, speedometer.

※ Procedure :

- Procedure (A) :

(I) only the Main shunt field winding is Externally Excited:



- while the Generator Shunt (Main) Field current is Zero (S_{FG} OFF) record V_{oc} (volt).
- switch ON S_{FG} & adjust, in steps, the generator field-shunt current by means of $R_{FG(ext)}$, to match the readings in Table (A-I), & record V_{oc}.

- Reset back gen. field current to its Minimum by means of $R_{FG(ext)}$.
- switch OFF the gen. field circuit by means of S_{FG}.

Table (A-I): $I_S = I_L = 0$, $N_m = 1500$ RPM

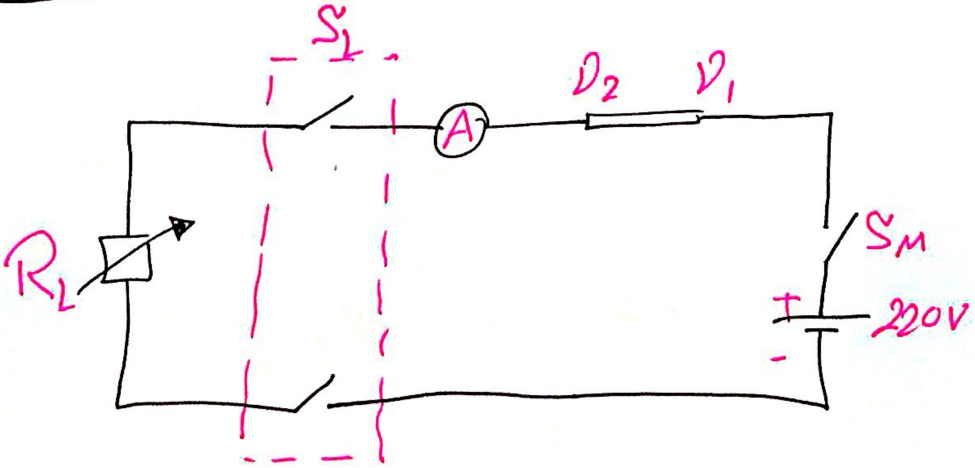
I_F(A)	0	0.3	0.4	0.5	0.6	0.65	0.7
V_{oc}(V)	13.48	204.1	229.7	275.7	311.8	339	346.6

(II) only the Series Field Windings is Externally Excited:

- While the series field windings switch S_L is OFF, ($I_F = 0$) record the V_{oc} in table (A-II).
- switch S_L ON & adjust, in steps, The field-series current I_S which equivalent to the load current I_L, by means of R_L to match the readings in table (A-II), record V_{oc}.
- Reset back I_S to Max. by means of R_L.
- Switch OFF S_L.

Table (A-II): $I_F = 0$, $N_m = 1500$ RPM.

$I_L = I_S$ (A)	0	3	6	9	12	15	18
V_{oc} (V)	12.6	26.2	41.2	57.9	75.5	92.9	109.1



- **Procedure (B):**

(I) Cumulatively Compound:

- switch S_{FG} ON & adjust, in steps, I_f by means of $R_{FG(ext)}$ to 0.65A.
- while the series field winding switch is OFF ($I_s = I_L = 0$) record V_{oc}.
- switch S_L ON & adjust, in steps, I_s by means of R_L to match readings in table (B-I), record V_{oc}.
- Reset back I_s to Min by means of R_L.
- Switch S_L OFF.
- Reset back the shunt-field current to its Min. by means of $R_{FG(ext)}$.
- Switch off the gen. shunt-field (S_{FG}).

Table (B-I): $I_F = 0.65A$, $N_m = 1500$ RPM.

$I_L = I_s$ (A)	0	3	6	9	12	15	18
V_{oc} (V)	346.3	354.7	363	370.8	378	385.5	391

(II) Differentially Compound.

- Reverse (interchange) the connections of the series windings D_1 & D_2.
- Repeat Procedure (B-I) completely as above. Record results in table (B-II).
- Reverse (interchange) back the connections D_1-D_2.
- switch off S_M.

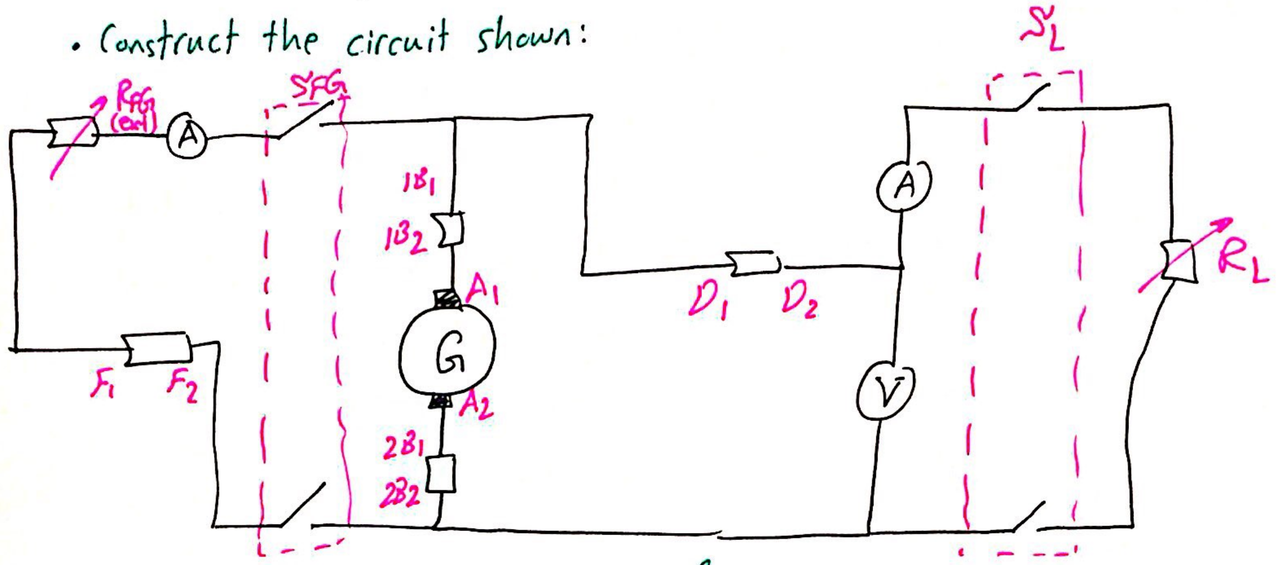
Table (B-II): $I_F = 0.65A$, $N_M = 1500$ RPM.

$I_L = I_s$ (A)	0	3	6	9	12	15	18
V_{oc} (V)	236	228.6	221.4	212.4	202.2	191.6	181

- **Procedure (C):**

(I) Cumulatively Compound:

- Construct the circuit shown:



- Restart the prime mover as before. Adjust $N_m = 1500$ RPM.
- switch S_{FG} ON. & adjust $I_F = 0.65A$ by means of $R_{FG(ext)}$.
- While the S_L OFF, make sure that $V_T = 229V$.
- switch S_L ON & adjust, by steps, I_L by means of R_L to match reading in table (C-I), in each step keep $N_m = 1500$ RPM. Record V_T & I_F.
- Reset back R_L to Max.
- Switch OFF S_L.
- Reset the gen. shunt field current to min. by means of $R_{FG(ext)}$.
- switch OFF S_{FG}.

Table (C-I): $N_m = 1500$ RPM.

$I_L = I_s = 0$	0	3	5	7	9	11	13
V_T (V)	229	227	224	221	219.7	218	216
I_F (A)	0.65	0.65	0.65	0.65	0.65	0.65	0.65

(II) Differentially Compound:

- Reverse the connection of the series field windings $D_1 - D_2$.
- switch S_{FG} ON, & adjust $I_f = 0.65A$ by means of $R_{FG(ext)}$
- while S_L off, make sure $V_T = 240\ V$.
- while S_L off, record V_T in table (C-II).
- switch S_L ON, adjust R_L to match the readings in the table, In each step record I_L & I_F.
- Reset back R_L to Max. & switch off S_L.
- Reset I_F to it Min. by means of $R_{FG}(ext)$.
- Switch off S_{FG}.

Table (C-II): $N_m = 1500 RPM$.

$I_L = I_S$ (A)	0	2.5	3.8	3.5	3	2.5	2
V_T (V)	240	200	150	100	50	25	15
I_F (A)	0.65	0.6	0.4	0.3	0.18	0.1	0

※ Results, Discussions & Comments:

* Procedure A:

- Sketch the No-load (or Magnetization) char. of the gen. (V_{oc} vs. I_f) only shunt field excited.
- sketch (V_{oc} vs. I_s) . only the series fild winding excited.

The graphs shown in last pages.

- Compare the nature of the 2-curves.

⇒ for shunt field, note that $I_f = 0$, the effect that appears on the machine terminals is small & its due to residual flux stored in the core, as $I_f \uparrow$ then $V_T \uparrow$ almost linearly until saturation, V_{oc} is fixed.

⇒ for series field, the same sequance of the EMF building occurrence happen, BUT the generated voltage for series is LOWER than shunt & current in series is LARGER than shunt.
due to the following equation: $\phi = NI\frac{A\mu}{L}$

- Calculate the turns ratio of the shunt & series field winding:

$$E_{a,shunt} = K\phi\omega \quad , \quad \phi = NI\frac{A\mu}{L} \Rightarrow \phi \propto NI$$
$$E_a \propto NI$$

$$\frac{E_{a1}}{E_{a2}} = \frac{N_1 I_1}{N_2 I_2} \Rightarrow$$

$E_{a\,shunt} = 275.7V$ @ $I_f = 0.5A$.
$E_{a\,series} = 57.9V$ @ $I_f = 9A$.

$$\frac{E_{a,shunt}}{E_{a,series}} = \frac{N_{sh}\, I_f}{N_{ser.}\, I_a} = \frac{N_{sh}}{N_{ser}} \times \frac{0.5}{9} = \frac{275.7}{57.9} \Rightarrow N_{sh} = 85.7\, N_{se}$$

* Procedure B:

- sketch on the same graph, the magnetization char. (V_{oc} vs. I_L) of sub procedures (B-I) & (B-II). Notice the degree of saturation in each graph.

the sketch is shown in the last pages.

* since the decrease & increase in both curves is NOT Linear, this indicates that machines have reached the saturation point.

* Procedure C : for Both (C-I) & (C-II), it is required to:

- sketch, in one graph (V_T vs. I_L) of the DC compound Generator.
  since the shunt is separately excited, then $I_a = I_S$
  $E_a = V_T + I_a(R_S + R_a)$; $R_S = 0.2\,\Omega$ & $R_a = 1.2\,\Omega$.
  the sketch shown in last pages.

- For each value of I_L, calculate (VR%). sketch in one graph (VR% vs. I_L).

  $VR\% = \frac{V_{NL} - V_L}{V_L} \times 100\%$, $V_{NL} = E_a$ shown in the coming tables.

- For each I_L. Calculate EMF depeloped Armature, the developed Armature Power P_D, & the shaft (output) power (P_{SH}). sketch in one graph P_D & P_{SH} vs. I_L.

  $P_D = E_a I_a$
  $P_{SH} = V_T I_L$
  shown in the coming tables.

- For each value of I_L, calculate η. sketch in one graph (η vs. load output power).

  $\eta = \frac{P_{SH}}{P_D} \times 100\%$. shown in the coming tables.

Table (C-I), $N_m = 1500$ rpm :

I_L	V_T	VR%	E	P_D	P_{SH}	η%
0	229	0	229	0	0	0
3	227	1.85	231.2	693.6	681	98.18
5	224	3.125	231	1155	1120	96.97
7	221	4.434	230.8	1613.5	1547	95.88
9	219.7	5.735	232.3	2090.7	1977.3	94.57
11	218	7.064	233.4	2567.4	2398	93.4
13	216	8.426	234.2	3044.6	2808	92.23

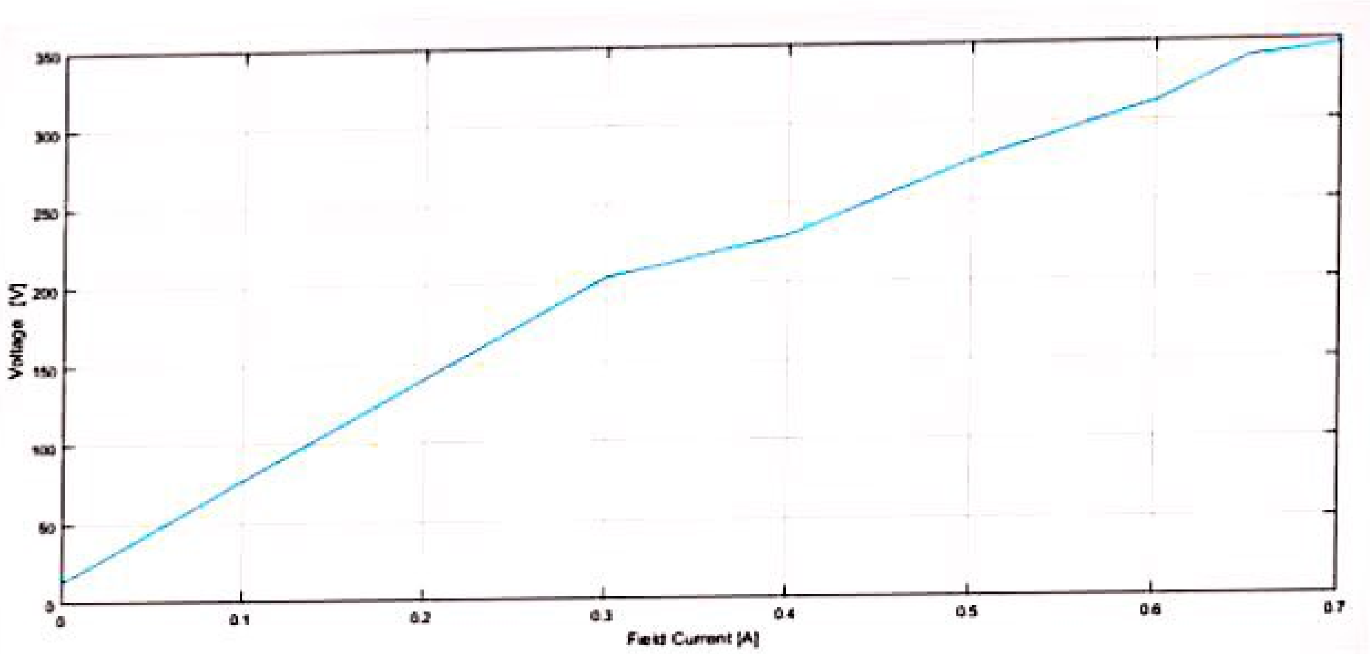
Table (C–II), $N_m = 1500$ rpm :

I_L	V_T	V.R%	E	P_D	P_{SH}	η%
0	240	0	240	0	0	0
2.5	200	1.75	203.5	508.75	500	98.28
3.8	150	3.55	155.32	590.216	570	96.57
3.5	100	4.9	104.9	367.15	350	95.33
3	50	8.4	54.2	162.6	150	92.25
2.5	25	14	28.5	71.25	62.5	87.72
2	15	18.67	17.8	35.6	30	84.27

Conclusion :

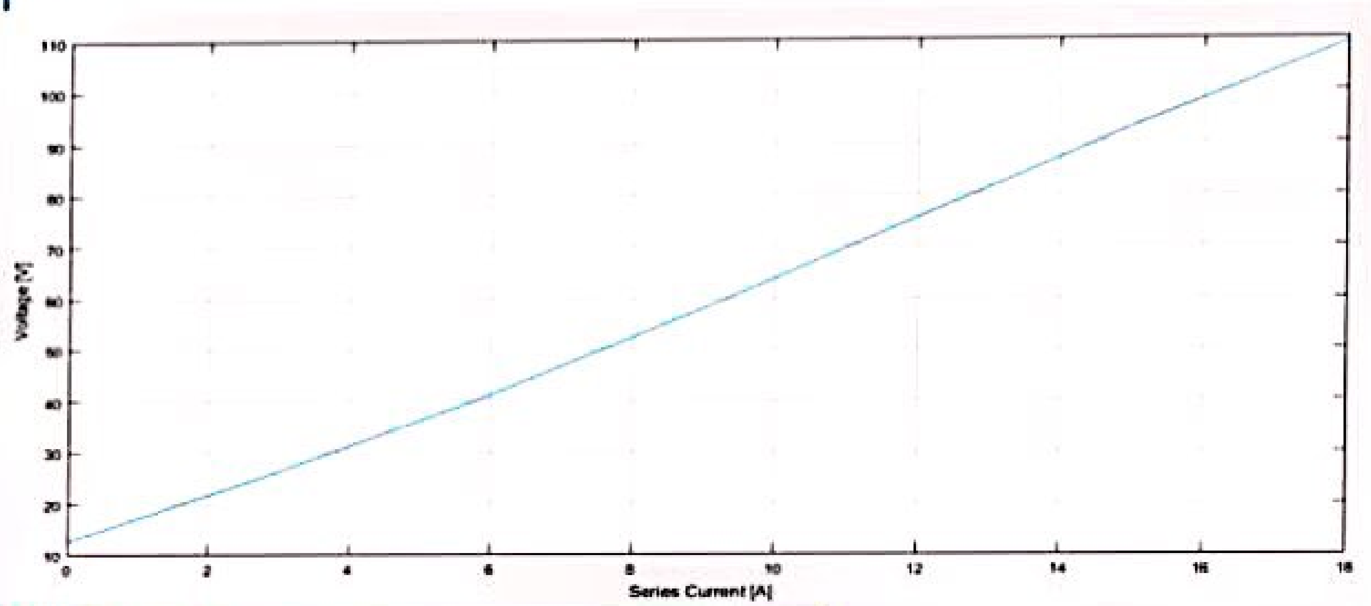
- we saw the effect of both types (cumulatively Compound & Differentially Compound) under the No load condition & Load condition.
- We tested the relationships between I_L, V_T, V.R%, EMF, P_D, P_{SH}, and the efficiency, practically for the load condition.

* * *



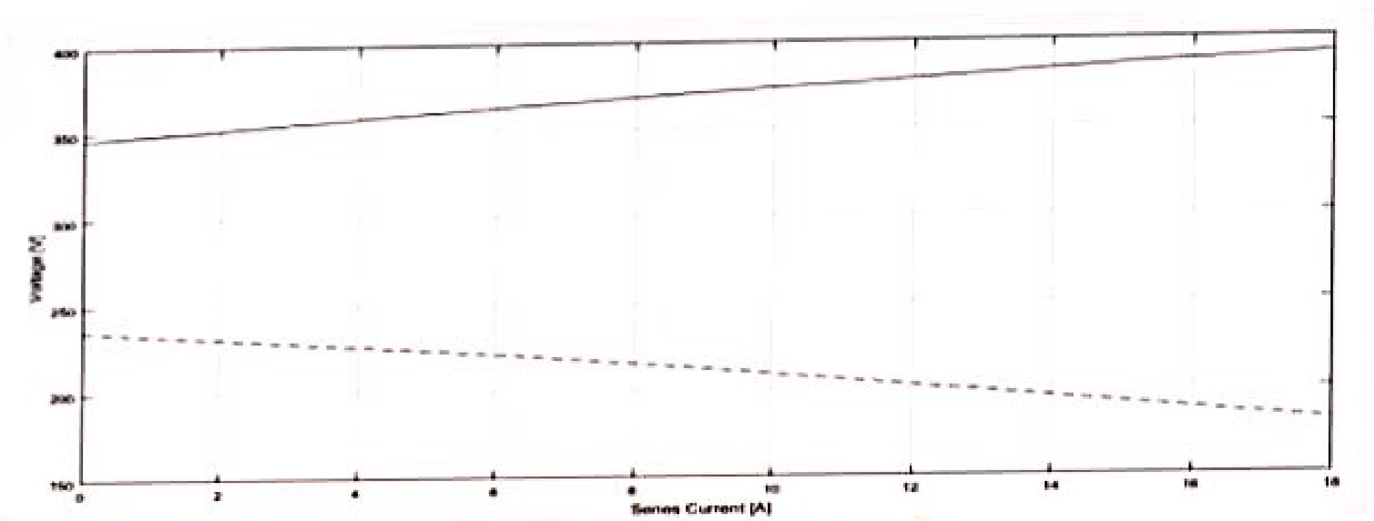
Command Window

```
>> voc=[13.48 204.1 229.7 275.7 311.8 339 346.6];
>> If = [0 0.3 0.4 0.5 0.6 0.65 0.7];
>> plot(If,voc)
>>
```



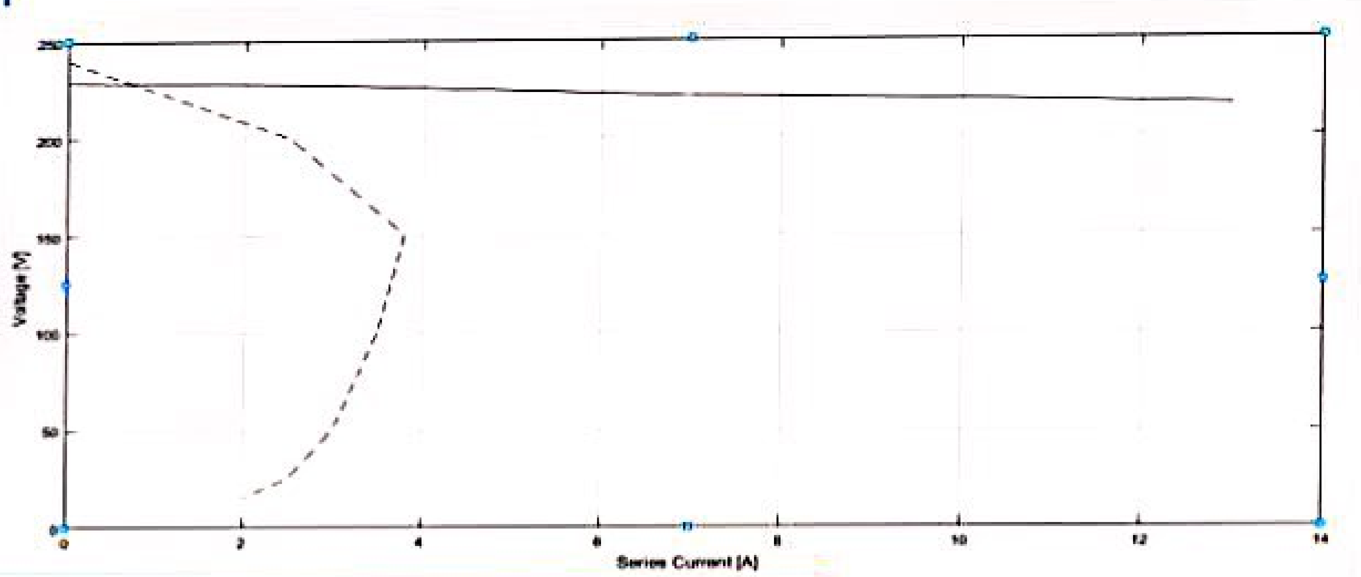
Command Window

```
>> IL=[0 3 6 9 12 15 18];
>> Voc=[12.6 26.2 41.2 57.9 75.5 92.9 109.1];
>> plot(IL,Voc)
>>
```



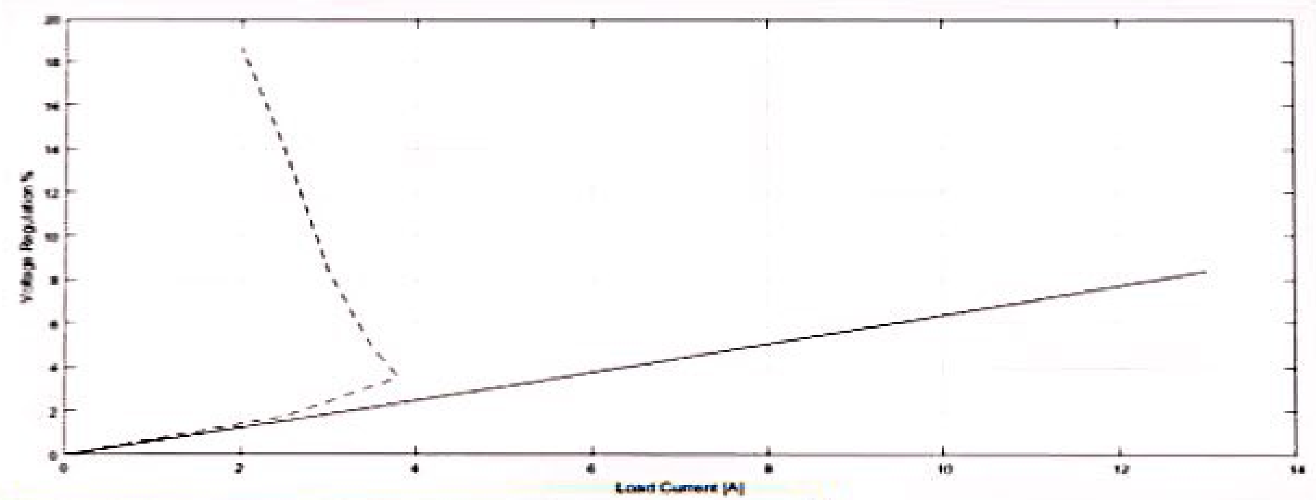
Command Window

```
>> Is=[0 3 6 9 12 15 18];
>> Voc_cumumulative=[346.3 354.7 363 370.8 378 385.5 391];
>> Voc_differential=[236 228.6 221.4 212.4 202.2 191.6 181];
>> plot(Is,Voc_cumumulative,'k',Is,Voc_differential,'--k');
>> %dash line for differential voltage
fx >> |
```



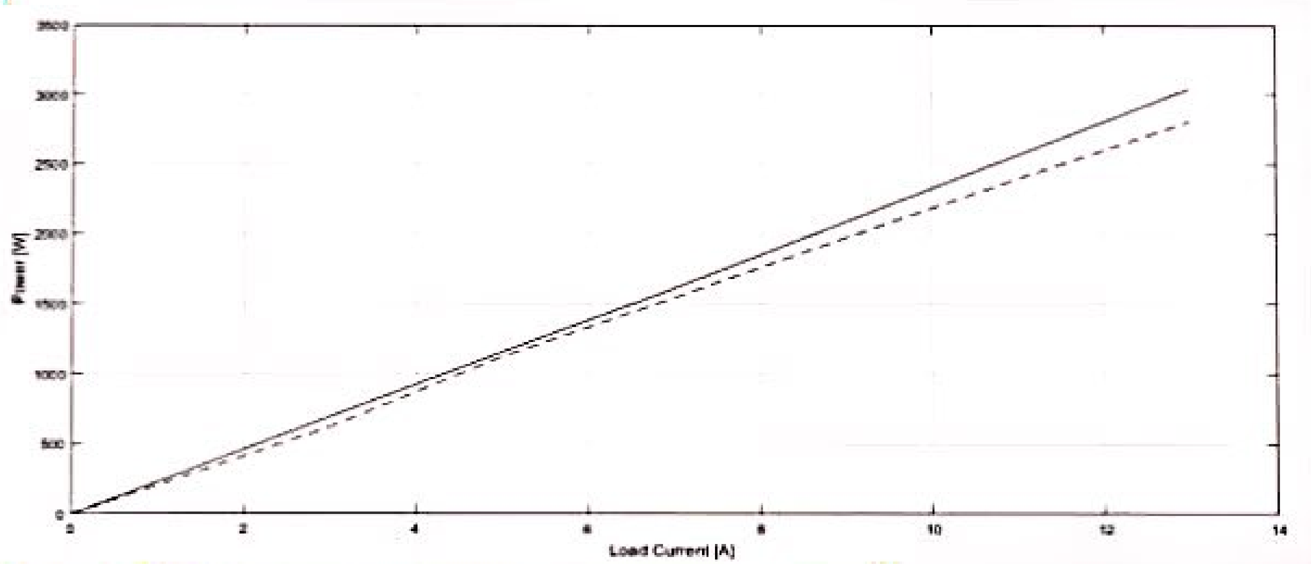
Command Window

```
>> Is_Cumm=[0 3 5 7 9 11 13];
>> Vt_Cumm=[229 227 224 221 219.7 218 216];
>> Is_Diff=[0 2.5 3.8 3.5 3 2.5 2];
>> Vt_Diff=[240 200 150 100 50 25 15];
>> plot(Is_Cumm,Vt_Cumm,'k',Is_Diff,Vt_Diff,'--k')
>> % dashed line for Differential
fx >> |
```



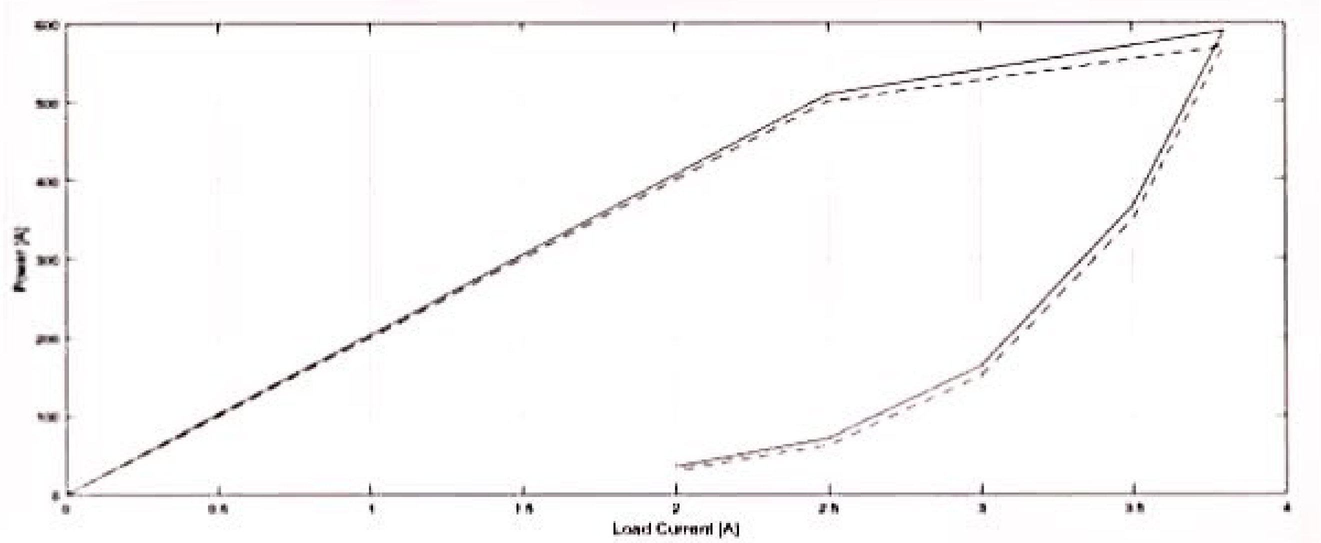
Command Window

```
>> IL_cumm=[0 3 5 7 9 11 13];
>> IL_Diff=[0 2.5 3.8 3.5 3 2.5 2];
>> VR_cumm=[0 1.85 3.125 4.434 5.735 7.064 8.426];
>> VR_diff=[0 1.75 3.55 4.9 8.4 14 18.67];
>> plot(IL_cumm,VR_cumm,'k',IL_Diff,VR_diff,'--k')
>> % dashed line for Differential
>>
```



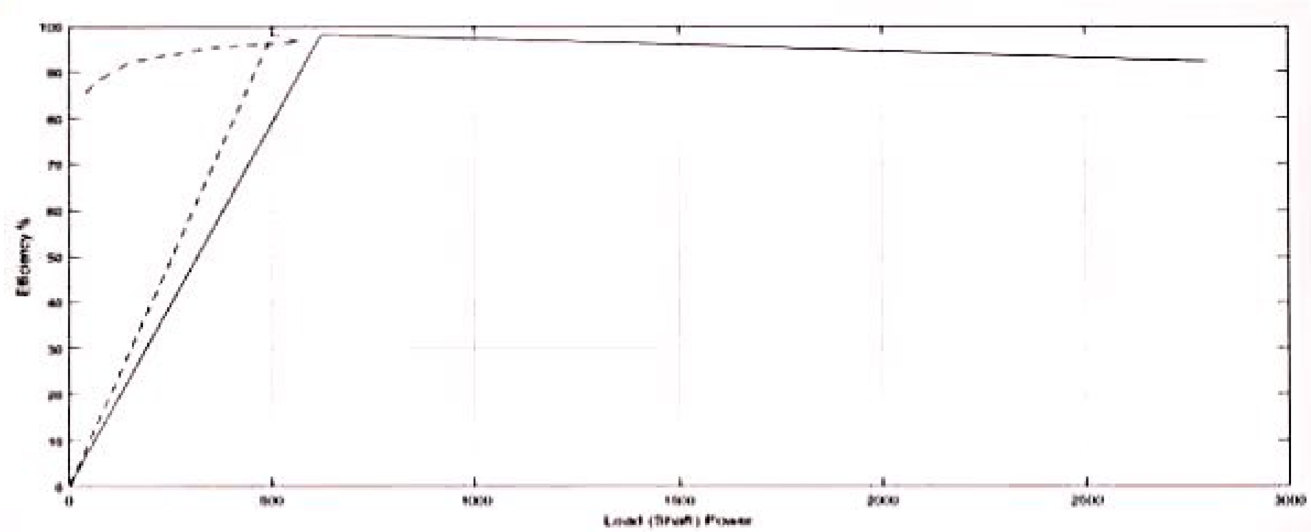
Command Window

```
>> IL_cumm=[0 3 5 7 9 11 13];
>> Pd_cumm=[0 693.6 1155 1613.5 2090.7 2567.4 3044.6];
>> Psh_cumm=[0 621 1120 1547 1977.3 2398 2808];
>> plot(IL_cumm,Pd_cumm,'k',IL_cumm,Psh_cumm,'--k')
>> % dashed line for Shaft Power
>>
```



Command Window

```
>> IL_Diff=[0 2.5 3.8 3.5 3 2.5 2];
>> Pd_diff=[0 508.75 590.216 367.15 162.6 71.25 35.6];
>> Psh_diff=[0 500 570 350 150 62.5 30];
>> plot(IL_Diff,Pd_diff,'k',IL_Diff,Psh_diff,'--k')
>> % dashed line for Shaft Power
fx >>
```



Command Window

```
>> Psh_cumm=[0 621 1120 1547 1977.3 2398 2808];
>> Psh_diff=[0 500 570 350 150 62.5 30];
>> Effi_cumm=[0 98.18 96.97 95.88 94.57 93.4 92.23];
>> Effi_diff=[0 98.28 96.57 95.33 92.25 87.72 84.27];
>> plot(Psh_cumm,Effi_cumm,'k',Psh_diff,Effi_diff,'--k')
>> % dashed line for Differential
fx >>
```

"Experiment 6"

"Three phase Transformer"

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0142629	٢- يوسف محمد يوسف الحاج محمود
0142679	٣- عبد الكريم وائل حميد
0144235	٤- محمد مفيد ابو حماشية
0143994	٥- محمد فهد محمد زكريا جبلية

Experiment 6 Three phase Transformers

OBJECTIVES

1. Determine the parameters of the transformer equivalent circuit by conducting the no Load and the short-circuit tests.
2. Carry out the no Load and Load tests for the various connection of the three phase transformers namely YY, YΔ and ΔΔ

EQUIPMENT

- Power transformer 5KVA 380/110V/110V 4.38A / 7.61A / 7.61A 50Hz
- Variable three phase AC power supply 0-220V Line to Line
- Two Electronic wattmeters
- Measuring instruments (Two voltmeters & Two ammeters)

PROCEDURE 1 STAR-STAR CONNECTION

- Connect the ckt Y-Y (primary Ⓥ, Ⓐ, 2 wattmeter) (secondary Ⓥ)
- Increase the variable voltage (0-190V). The reading shown in this table

V_1	40	70	110	150	190
I_1	0.172	0.221	0.286	0.377	0.526
P_1	7	16	37	60	100
P_2	ϕ	2	6	10	12
V_2	134.5	231.7	364.8	499.3	634.2
P_{tot}	7	18	32	70	102

Now short ckt and connect ammeter. The reading in this table

Note:- primary current does not exceeds the rated current of 7.61 A

V1	1.52	2.47	3.73	4.25	4.756
I1	2	4	6	7	7.6
I2	0.76	1.29	1.83	2.183	2.423
P1	2.54	8	16	22	24
P2	4.2	11	25	35	43
Ptot	6.74	19	41	57	67

- Now keep primary & connect secondary as shown in fig.(1-D)

=> supply voltage = 110V

The reading is:-

V1	I1	V2	I2	P1	P2	Ptot
110	7.79	340.7	2.26	800	800	1600

PROCEDURE 2 STAR - DELTA connection

- Keep primary STAR & connect secondary delta

The reading is:-

V1	I1	V2	I2	P1	P2	Ptot
(o/c test) 110	0.287	136.5	Φ	10	32	42
(Load test) 110	7.64	210.6	3.8	800	800	1600

↳ Here we connect ckt (2B) and set resistance at max.

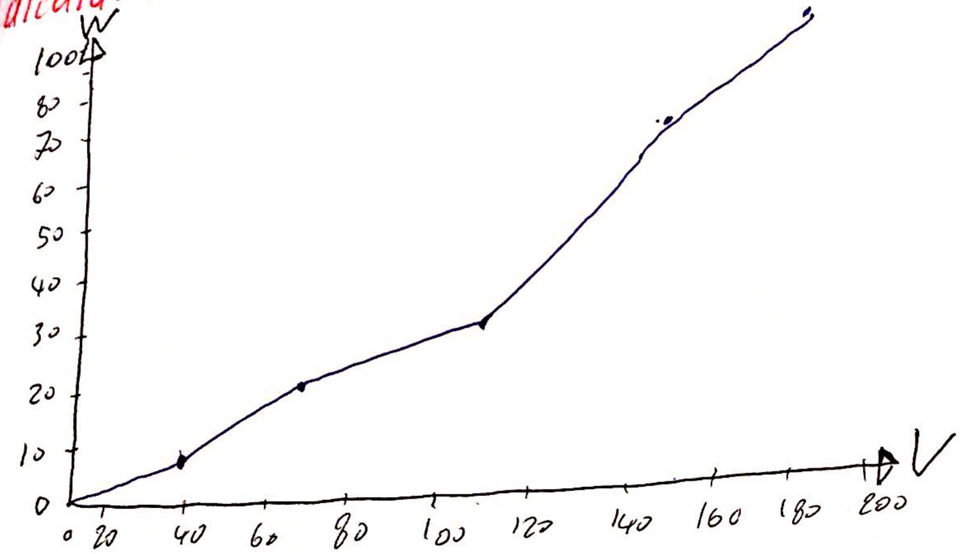
PROCEDURE [3] DELTA - DELTA

- Now connect primary and secondary (Δ-Δ) The reading is :

(o/c test & Load test) same step in Procedure [2]

V_1	I_1	V_2	I_2	P_1	P_2	P_{tot}
110	0.74	361.9	ϕ	160	120	280
110	10	350	2.9	1000	960	1960

Q1 Draw a graph showing the no load power against the primary voltage, Find the values of power to calculate RC and Xm refered to low-voltage?



V=190, reffering to low voltage side.

$$\rightarrow RC = \frac{V_1^2}{P} = \frac{190^2}{100} = 361\,\Omega$$

$$V_{LN} = \frac{190}{\sqrt{3}} = 109.7V$$

$$\rightarrow Xm = \frac{1}{\sqrt{\left(\frac{I_1}{V_1}\right)^2 - \left(\frac{1}{RC}\right)^2}} = \frac{1}{\sqrt{\left(\frac{0.56}{109.7}\right)^2 - \left(\frac{1}{361}\right)^2}} = 255.5\,\Omega$$

RC represents the copper losses

Xm represents the magnitization reactance and represent the eddy current losses.

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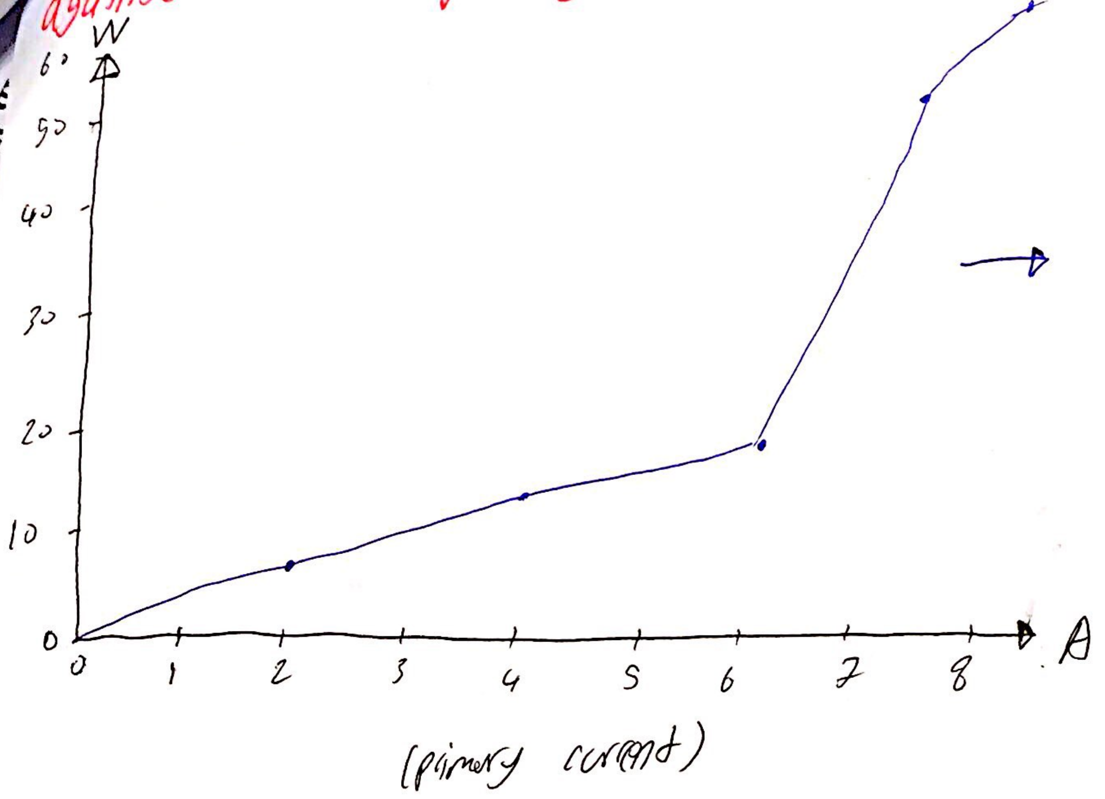
Q.2 Draw a graph showing the short ckt power against the primary current.



$\rightarrow R_{eq} = \frac{P1}{I^2} = \frac{67^2}{7.6^2} = 1.15\ \Omega$

$\rightarrow V_{LN} = \frac{4.756}{\sqrt{3}} = 2.745\ V$

$\rightarrow X_{eq} = \sqrt{\left(\frac{V1}{I1}\right)^2 - R_{eq}^2} = \sqrt{\left(\frac{2.245}{7.6}\right)^2 - (1.15)^2} = 0.045\ \Omega$

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For each of the Four connection calculate the theoritical transformation ratios.

[1] For YY

ratio = $\frac{V2}{V1} = \frac{134.5}{40} = 3.6245$ (OCT)

[2] For YY

ratio = $\frac{340.7}{110} = 3.097$

[3] For YΔ ratio = $\frac{136.5}{110} = 1.24$

[4] For ΔΔ ratio = $\frac{361.9}{110} = 3.29$

[Q4] calculate the voltage regulation for each case:-

→ $V.R = \frac{V_{NL} - V_L}{V_L}$

[1] For YY . 13 %

[2] For YΔ , 5.263 %

[3] For ΔΔ , 5.405 %

...alculate the efficiency of the transformer for ...arious connections.

→ efficiency = η = $\frac{\text{output power}}{\text{input power}}$

[1] For YY = $\frac{\sqrt{3} * 340.7 * 2.26}{1600}$ = 0.835 * 100% = 83.5%

[2] For YΔ = $\frac{\sqrt{3} \cdot 210.6 * 3.8}{1600}$ = 0.866 * 100 = 86.6 %

[3] For ΔΔ = $\frac{\sqrt{3} \cdot 350 * 2.9}{1960}$ = 0.898 * 100% = 89.8%

[6] Explain what is meant by vector group?

→ vector group refers to phase angular displacement of the primary and secondary on a poly-phase (3-6 or n phase).

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ELECTRICAL ENGINEERING DEPARTMENT

ELECTRICAL MACHINES LAB

ELECTRICAL MACHINES LAB.

University of Jordan.

* * *

Experiment #7

* * *

Three Phase Synchronous Generator

* * *

Reg. #	Name
0144235	1 - محمد مفيد أحمد أبوحاشية
0142679	2 - عبد الكريم وائل عيد
0142724	3 - عمران علي محمد المداهنة
0143994	4 - محمد فهد بصيلة.
0142629	5 - يوسف محمد يوسف حاج محمود.

* * *

Section: Thursday. **Group:** 3

ELECTRICAL MACHINES LAB.

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ELECTRICAL ENGINEERING DEPARTMENT

※

※ Objectives:

To obtain O/C C/C , S/C C/C & the Load C/C.

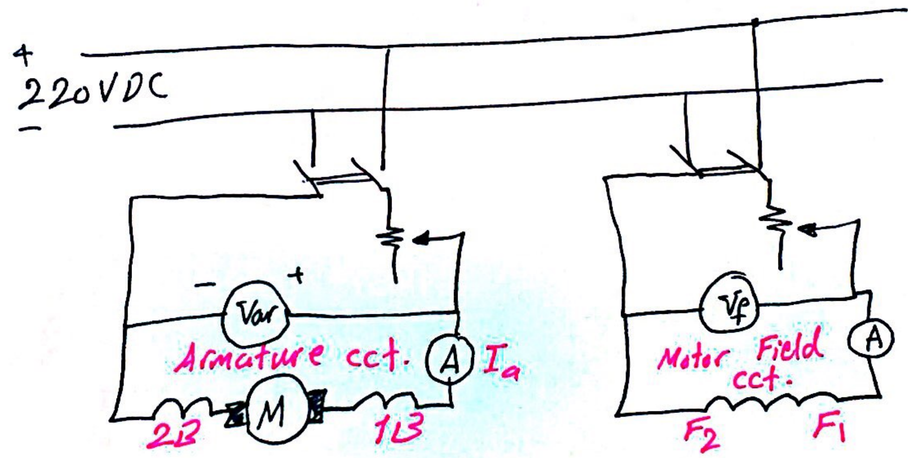
※ Equipment:

DC M/C type siemens 3.6KW (motor), 3ph alternator type siemens 2KVA, Rheostat 1&2 170Ω, 694 Ω respectively, variable resistance & load resistance, Ammeters & voltmeter, stroboscope type movistrob & Double pole switches.

※ Procedure:

- procedure (A): O/C Test.

1) connect the following cct. & Keep S1 OFF.



⟹ Next page the rest of the figure.

2) set the value of the motor Armature variable resistance to MAX.
3) set the Rheostat of motor to min. voltage position.
4) Connect a S/C to Link across the terminals field of the alternator.
5) Set alternator field rheostat to Min. voltage.
6) switch on DC supply to motor field. Make sure that the voltage & currents are within the specified Limits, otherwise switch OFF the supply immediatly.

7) switch ON the dc supply of the motor armature, Make sure also that voltage & currents within the specified limits.

8) Decrease the variable resistance in the motor armature cct & allow the motor to start up.

9) Adjust the speed to 1500 RPM.

10) Remove the s/c link from the Alternator field windings.

11) switch ON dc supply to alternator windings.

12) vary the alternator current in steps of 0.1A until the alternator output voltage not exceed 495V, this voltage 130% of the specified voltage (380V).

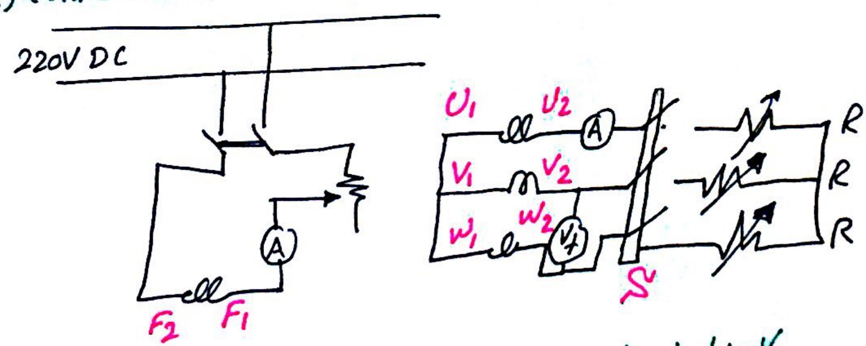
13) Switch OFF the supply for all ccts.

• Table (1): O/C Test.

$I_f(A)$	0	0.3	0.4	0.5	0.6	0.7	0.9	1	1.1
$V_L(V)$	2.6	242	277	342	401	442	512	539	562

• Procedure (B): S/C Test:

1) Connect the cct.



2) Connect terminals U_1, V_1, W_1 by short link.

3) Carry out steps (2) to (10) in procedure (A).

4) Ensure that the field current rheostat in the alternator cct is at the Min. voltage position.

5) Remove the short link.

6) switch ON DC supply to the alternator field.

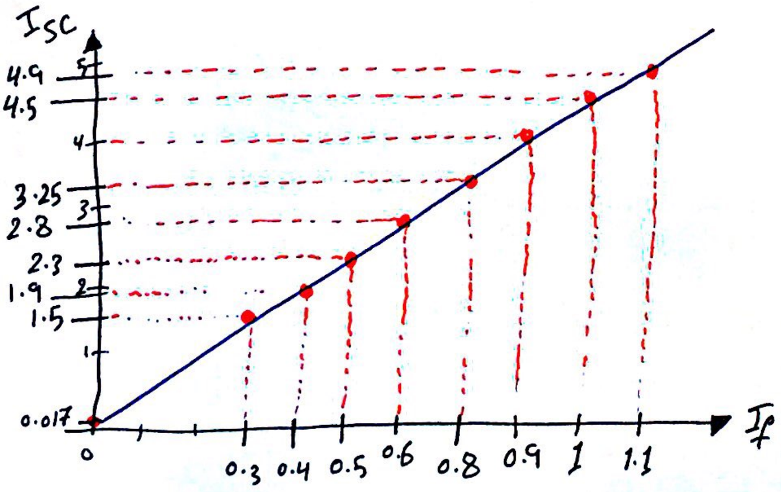
7) Increase I_f in steps of 0.1A & make sure that alternator current does NOT exceed (4.3A). This is 150% * I_{rated} (2.9A)
Keep the speed constant.

8) Vary the speed with I_{sc} = 2.9A & keep the excitation current constant. How Does I_{sc} react. Give an Explanation?
By increasing the field current we note that I_{sc} increasing too, & that due to the almost linear relationship between both of them.

9) switch off all supplies.
10) Plot S/C C/C
11) Find Z_s?

· Table (2): S/C Test.

I_f(A)	0	0.3	0.4	0.5	0.6	0.8	0.9	1	1.1
I_{sc}(A)	0.017	1.5	1.9	2.28	2.77	3.25	4	4.5	4.86



Comment:
· We note that a linear Relationship between I_f & I_{sc}.

$Z_s = R_a + jX_s$; $R_a << X_s$ ⇒ $Z_s = X_s = \frac{V_{oc}}{I_{sc}}$

consider $I_f = 0.3$ → $V_{oc} = 242$ V. → $I_{sc} = 1.5$A ⇒ $Z_s = \frac{242}{1.5} = 161.33\ \Omega$

· Procedure (C): Load Test.

1) connect the cct.
2) Carry out for (2) to (10) in procedure (A).
3) set the load c/c to MAX.
4) Remove the short link.

5) switch ON DC supply of the alt. field.

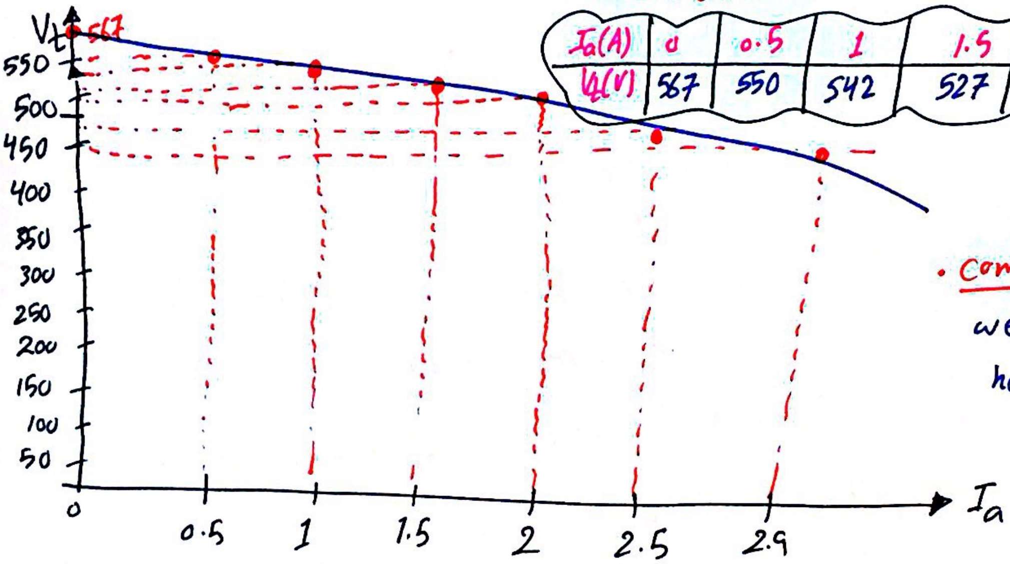
6) Adjust the alternator field current until o/c terminal voltage of the alternator is Max. value obtained in O/C Test (495V) @ speed 1500RPM & keep it Constant.

7) switch ON the load & vary it (0.5A → 2.9A) is step of 0.5A. find V_t & make sure the speed is constant.

8) Plot V-I c/c for the ALternator.

• Table (3): Load Test.

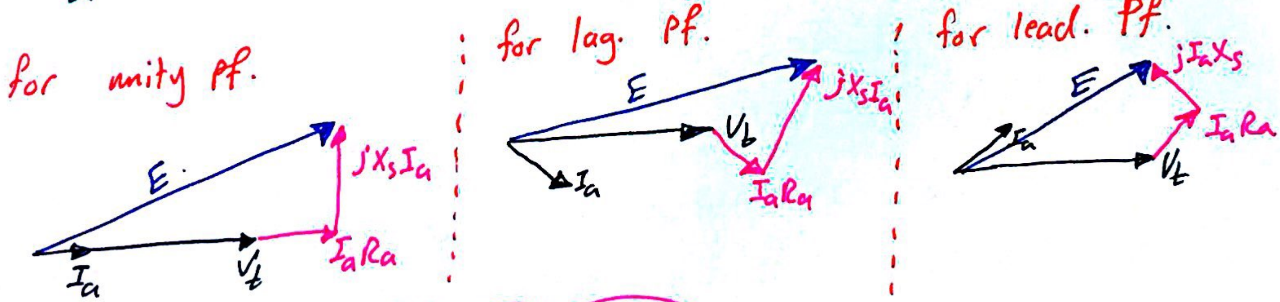
I_a(A)	0	0.5	1	1.5	2	2.5	2.9
V_t(V)	567	550	542	527	510	490	467



• comment:

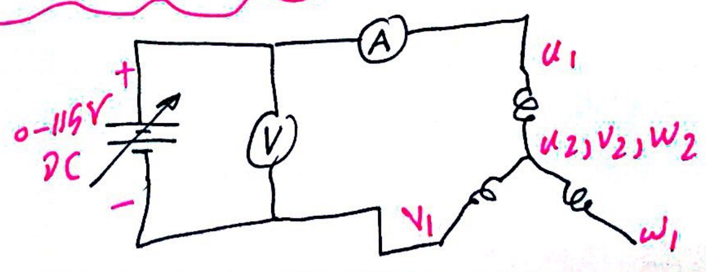
we note that how $V_t \propto \frac{1}{I_a}$.

9) Draw the vector diagrams for each loading condition & correlate the results with those obtained experimentally.



• Procedure (D): Measurement of R_a

1) connect the cct.



2) Make sure that the rheostat is @ zero volt output condition.

3) Increase the current to 2A & record the DC voltage.

4) Determine $R_{a_{DC}}$.

5) Is this Resistance Equal to the AC Resistance & why?

6) Determine the value of X_s?

• Table(4): DC Test.

I(A)	V (V)
2	12.158

The answers as follows:

$$2R_{dc} = \frac{V_{dc}}{I_{dc}} \Rightarrow R_{dc} = \frac{0.5\,V_{dc}}{I_{dc}}$$

$$= \frac{(0.5) \times (12.158)}{2} = \boxed{3.0395}\,\Omega$$

this $R_{dc} \neq R_{ac}$ due to the skin effect

so if we consider a skin factor = 1.6 for example.

$$\Rightarrow R_{ac} = 1.6\,R_{dc} \Rightarrow \boxed{R_{ac} = 4.8632}$$

Now for X_s: $X_s = \sqrt{Z_s^2 - R_a^2}$; $Z_s = \frac{V_{oc}}{I_{sc}} = \frac{380/\sqrt{3}}{2.9} = 75.65\,\Omega$

$$= \sqrt{(75.65)^2 - (4.86)^2} \Rightarrow \boxed{X_s = 75.49\,\Omega}$$

※ Conclusion:

In this experiment we studied a different cases of different characteristics. and we evaluate the parameters of the 3-Ø synh. gen. Using the results of these Tests.

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The University of Jordan.

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Faculty of Engineering & Technology.

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Department of Electrical Engineering.

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Experiment #8

C/C & performance of 3-PH Induction Motors.

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group (3). section (Thursday).

Reg. #	Name
0144235.	1. محمد مفيد أحمد أبوحاشية.
	2.
	3.
	4.
	5.

※ Objective :

1) Evaluation of the motor equivalent cct parameters.
2) Investigate the load c/c (torque-speed & torque-current) of induction motors
3) Evaluation of the motor performance parameters (η, Pf, ...).

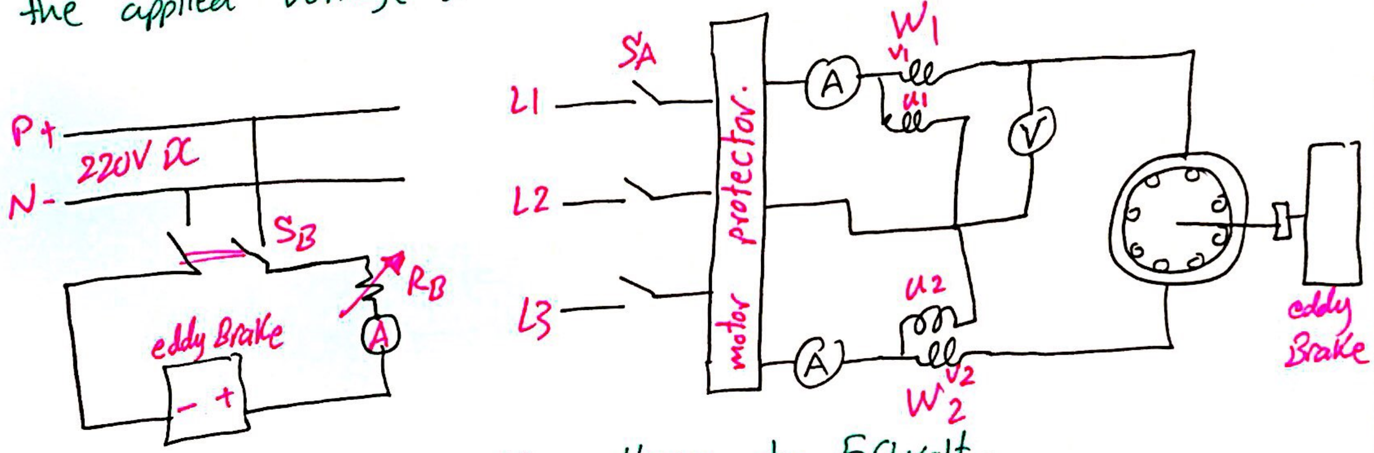
※ Equipment :

Three phase-squirrel cage induction motor, Variable voltage AC source, Eddy-current Brake., variable voltage DC source, variable R_B. , 1 DC Ammeter, 1 DC voltmeter, 2 AC Ammeters, 2 AC Voltmeters, speedo-meter, 3- Electromechanical switches.

※ Procedure :

(A) • No load Test :

• Connect the following cct : the applied voltage should be 0 & the S_A should be off.



. increase the AC variable voltage to 50 volt.

• switch S_A ON & Notice the reading of the Ammeter. Record your Answer in Table(A).

Table(A) : starting condition

V_{BR} (V)	I_L (A)
50	7.8

- Increase the armature terminal voltage gradually up to rated value of 380 volt.
- while being unloaded, record the line currents, the line voltages, the motor speed & the input power in Table (B).
- Reduce the terminal Voltage in steps & record for the same in previous step.

Table (B): No-load Test.

$V_L(V)$	380	350	300	250	200	150	100	50
$I_L(A)$	7	5.2	4	3.5	3	2.5	2	2
$N_m(RPM)$	1475	1500	1500	1475	1475	1475	1475	1475
$P_1+P_2(W)$	700	550	400	300	230	200	190	165

(B) . Blocked Rotor Test:

- Increase the AC variable voltage to 50V.
- Increase the armature terminal voltage gradually up to the point @ which the motor is Blocked (runs at almost zero speed)
- Vary the terminal voltage up to the point @ which the line current reaches its rated value of 11.7A. Record in Table (C).

Table (C): Blocked Rotor Test ($N_m = 0.0$).

$I_L(A)$	$V_{BR}(V)$	$P_1+P_2(W)$
11.7	47	700

- Reset R_B to its Max. position (F-CCW) & switch it OFF.
- Increase the armature terminal voltage gradually up to rated value of 380 volt.

(C) Load Test:

- While being unloaded record the currents, voltages power & speed in table (D).
- Switch ON Eddy-current Brake source.
- Vary R_B in steps to match the torque readings in Table (D) & record for the same requests of step (1).

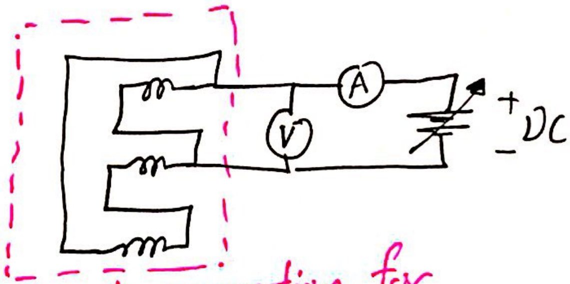
Table (D): Load Test (V_T=380 volt).

T_L (N.m)	0	3	6	9	12	15	18
$I_L = I_A$ (A)	7	7.2	7.3	7.6	7.9	8.3	9.1
N_m (RPM)	1475	1475	1475	1475	1475	1475	1475
P_1+P_2 (W)	600	1250	1500	2200	2300	2400	3100

- Reset R_B to its Max. position & switch it off.
- Switch OFF the terminal Voltage

(D) DC Test:

- Connect the following wiring diagram:
- Increase gradually & carfully, the DC voltage in steps to match the readings of Table (E). In each step, record the DC voltage.



Δ-connection for the stator of the motor.

Table (E): DC Test.

V_{DC} (V)	1.9	4	5.9
I_{DC} (A)	1.0	2.0	3.0

1) Estimate the starting current if the motor is at rated voltage?

@ starting conditions, VBR = 50V, I = 7.8A

* what is the value of slip at no Load, rated?

→ slip at no load equals <u>zero</u>

→ slip at Full load, the slip equals <u>one</u>

From equations $nS = \frac{120F}{P}$, $S = \frac{nS-nr}{nS}$

* Find Po, PF, η ?

using the Following formalas,

1) $Po = T \times wm$, 2) $PF = \frac{Pin}{V I}$, 3) $\eta = \frac{Pout - ph}{Pin - ph}$

$wm = \frac{2\pi nm}{60}$, $Pin = P1 + P2$.

T	0	3	6	9	12	15	18
Wm	154.46	154.46	154.46	154.46	154.46	154.46	154.46
Po	0	463.38	926.76	1390.14	1853.52	2316.9	2780.28
PF	0.225	0.457	0.54	0.7617	0.766	0.761	0.8964
η	0	0.37	0.617	0.632	0.805	0.965	0.8968

* Calculate the Stator Resistance/phase

*1 let $R_1 = R_2 = R_3$

$R_{eq} = (R_1 + R_2) // R_3$

$R_{eq} = \frac{V_{DC}}{I_{DC}}$; $R_{eq} = (2R // R)$

$R_{eq} = \frac{2R * R}{3R} = \frac{2}{3} R$

⇒ a) $R = \frac{3}{2} \cdot \frac{V_{DC}}{I_{DC}} = 2.85\,\Omega$

b) $R = \frac{3}{2} \cdot \frac{V_{DC}}{I_{DC}} = 3\,\Omega$

c) $R = \frac{3}{2} \cdot \frac{V_{DC}}{I_{DC}} = 2.95\,\Omega$

*2 No-load - Table (B)

$P = \sqrt{3}\, V_L I_L \cos\theta = P_1 + P_2$

$\theta = \cos^{-1}\left(\frac{P}{\sqrt{3}\, V_L I_L}\right)$

take $P_1 + P_2 = 300$ @ $V_L = 250\,V$, $I_L = 3.5\,A$, $n = 1475\,rpm$

$\Rightarrow \theta = 78.6^\circ$

$I_{R_{LL}} = I_L \cos\theta = .673\,A$; $I_{X_{LL}} = I_L \sin\theta = 3.43\,A$

$R_c = \frac{V_{ph}}{I_{R_{ph}}} = 643.4\,\Omega$, $X_m = \frac{V_{ph}}{I_{X_{ph}}} = 126.2\,\Omega$

*3 Table (C)

$P_1 + P_2 = P_{tot.} = \sqrt{3}\, V_L I_L \cos\theta = 2200\,W$

$\theta = \cos^{-1}\left(\frac{P}{\sqrt{3}\, V_L I_L}\right) = 63.9^\circ$

$Z_{eq} = \frac{V_L}{I_L} = 50$

$R_{eq} = Z_{eq} \cos\theta = ~~64\,\Omega~~ 21.9\,\Omega$

$X_{eq} = Z_{eq} \sin\theta = 45\,\Omega$

→ let $R_1 = R_2$

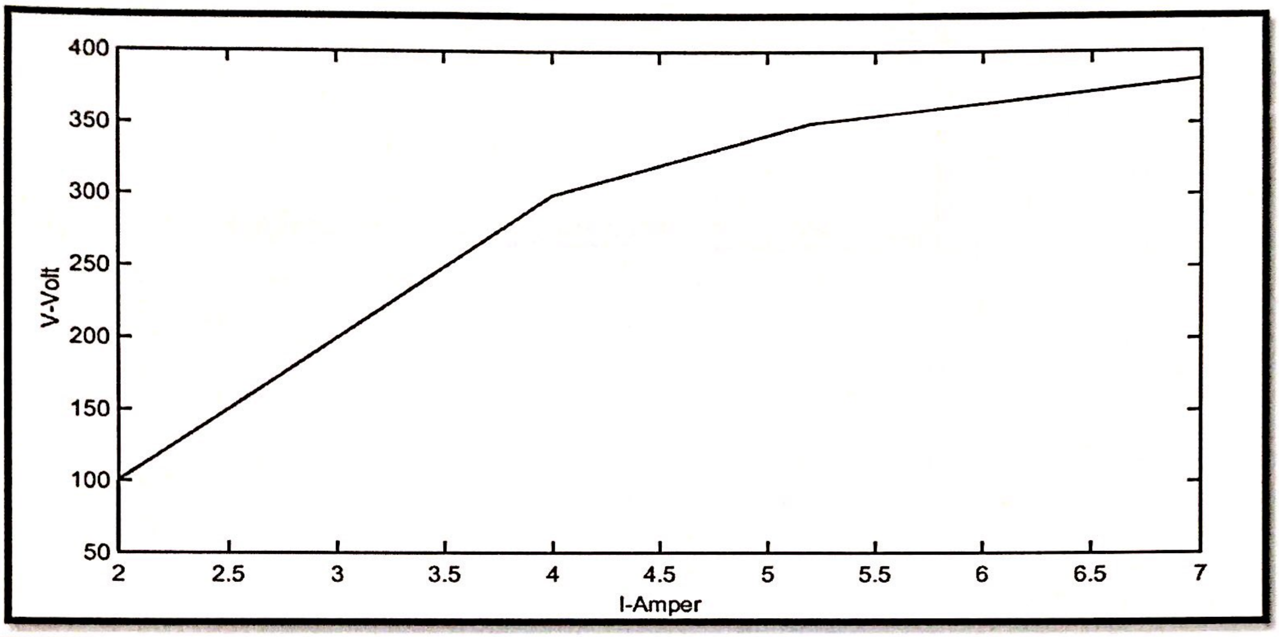
$R_{eq} = 2R_1$, $R_c = \frac{R_{eq}}{2} = \boxed{10.93}$

let. $X_1 = X_2$

$X_{eq} = X_1 + X_2$,

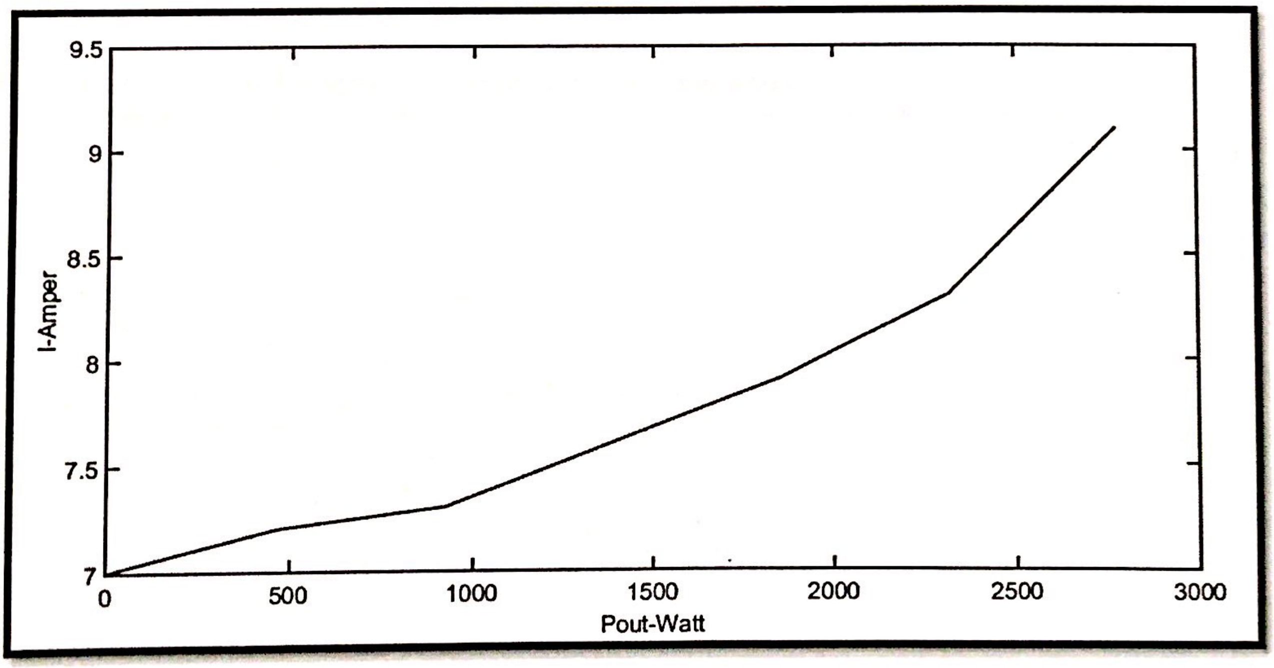
$X_{eq} = 2X =$

$X = \frac{X_{eq}}{2} = \boxed{22.5\,\Omega}$

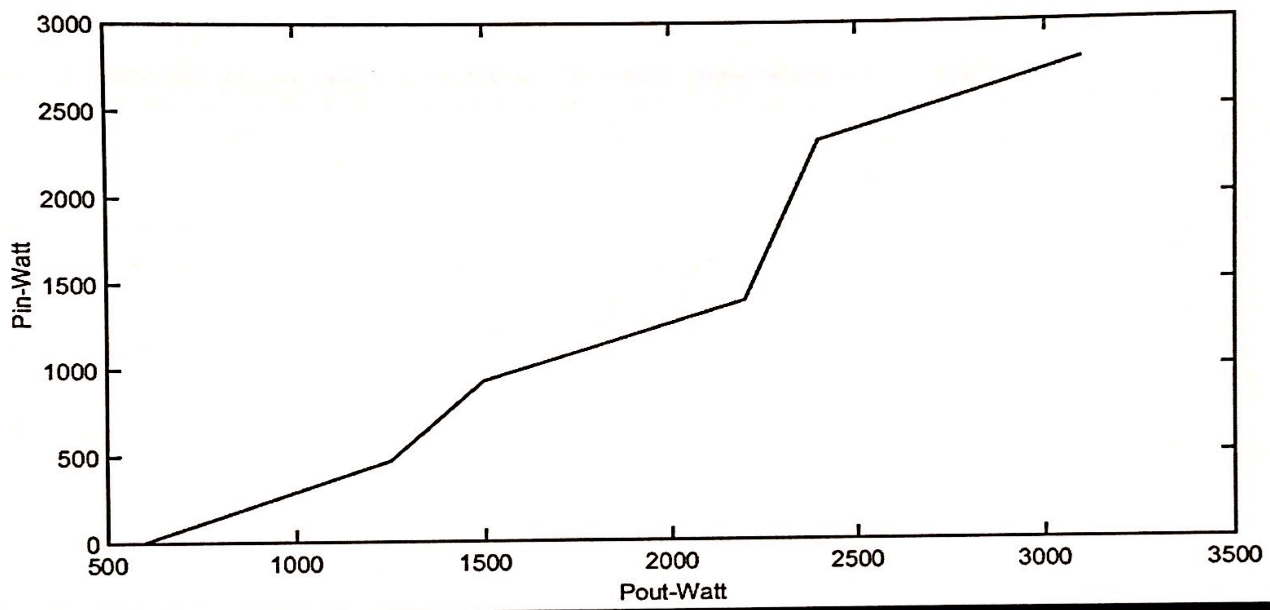


Command Window

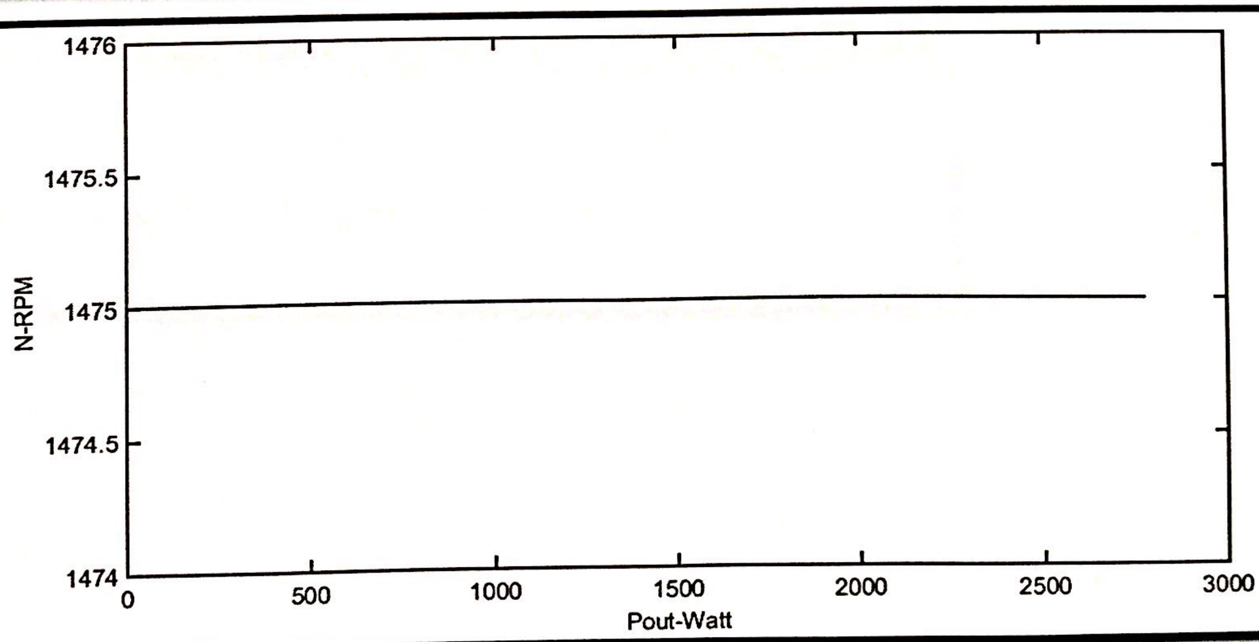
```
>> V=[380 350 300 250 200 150 100 50];
I=[7 5.2 4 3.5 3 2.5 2 2];
plot(I,V,'-k')
xlabel('I-Amper'),ylabel('V-Volt')
>> 
```



```
>> Pout=[0 463.38 926.76 1390.14 1855.52 2316.9 2780.28];
I=[7 7.2 7.3 7.6 7.9 8.3 9.1];
plot(Pout,I,'-k')
xlabel('Pout-Watt'),ylabel('I-Amper')
fx >>
```

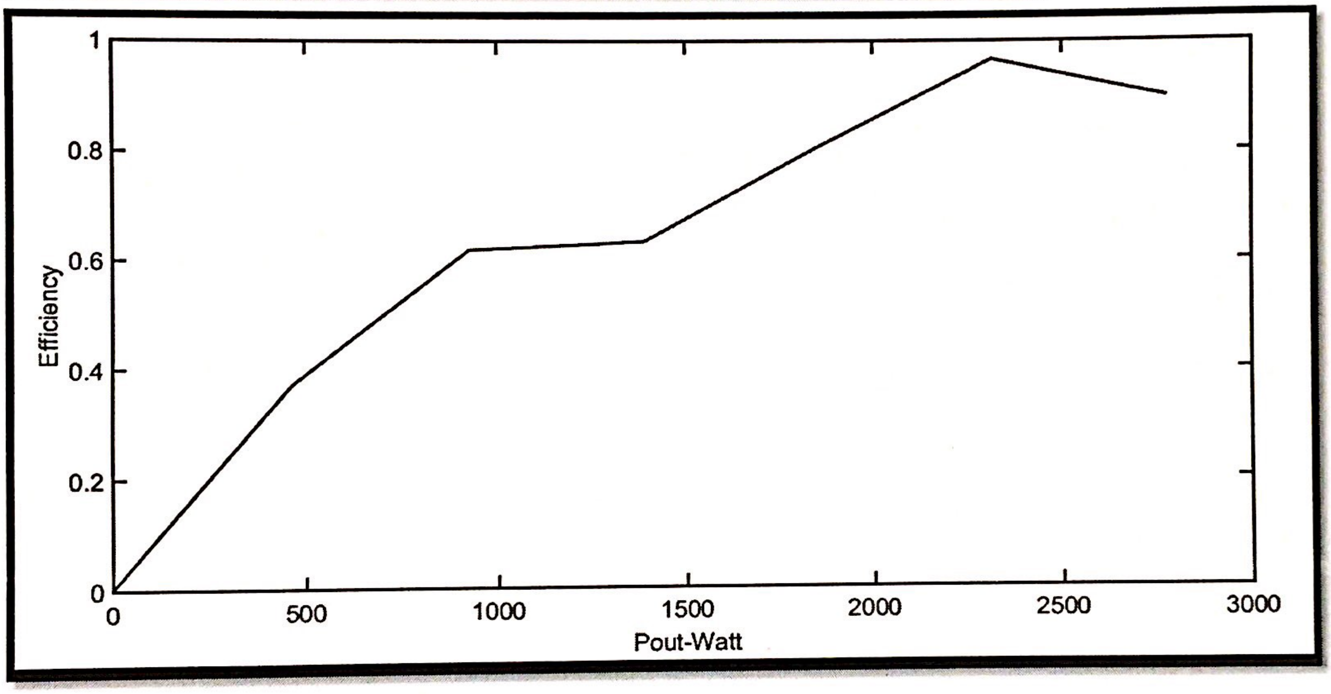



```
>> Pout=[0 463.38 926.76 1390.14 1855.52 2316.9 2780.28];
Pin=[600 1250 1500 2200 2300 2400 3100];
plot(Pin,Pout,'-k')
xlabel('Pout-Watt'),ylabel('Pin-Watt')
fx >>
```



Command Window

```
>> Untitled
>> Pout=[0 463.38 926.76 1390.14 1855.52 2316.9 2780.28];
N=[1475 1475 1475 1475 1475 1475 1475];
plot(Pout,N,'-k')
xlabel('Pout-Watt'),ylabel('N-RPM')
>>
```



Command Window

```
>> Pout=[0 463.38 926.76 1390.14 1855.52 2316.9 2780.28];
Eff=[0 0.37 0.617 0.632 0.805 0.965 0.8968];
plot(Pout,Eff,'-k')
xlabel('Pout-Watt'),ylabel('Efficiency')
>>
```

The University of Jordan

Faculty of Engineering & Technology

Department of Electrical Engineering

Experiment #9

Three-phase Synchronous Motors

Reg. #	Name
0144235	1- محمد مفيد أحمد أبو حاشية.
0142629	2- يوسف محمد يوسف
0142679	3- عبد الكريم وائل عيد.
0142724	4- عمران علي الدهاهنة.
0143994	5- محمد فهد زكريا.

Section: Thursday.

Group: #3.

※ Objective: we want to study the followings:

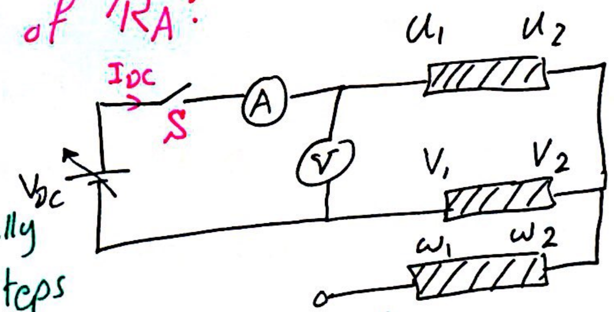
1) Starting procedure.
2) Load characteristics.
3) V-curves.

※ Equipment:

3-ph. sync. M/C (salient pole), Exciter for sync. M/C, 3-ploe cct Breaker, 3ϕ supply, control unit, Load, 2-Ammeters, 1 Voltmeter, 1 wattmeter, 1 Pf meter, Panel mounting frame, connecting cables & Plugs, Rubber coupling sleeves & coupling guards, prime mover set (DC shunt motor).

※ Procedure:

• Procedure (1): Measurement of R_A:



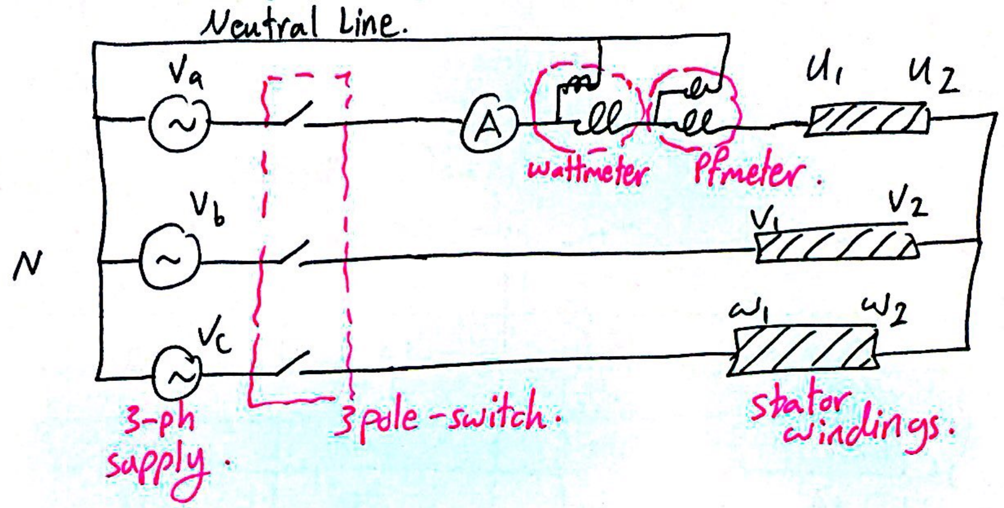
1) connect the following cct:
2) switch S ON. carefully & gradually increase the applied voltage in steps to match the req. in table (1). record V_{DC} in each step.
3) Reduce V_{DC} gradually to min.. switch S OFF.

Table (1): DC R_A.

$I_{DC}(A)$	0.5	1.0
$V_{DC}(V)$	10.8	21.8
$R_{DC}(\Omega)$	21.6	21.8

• **Procedure (3):** Load C/C's :

1) Connect the following cct:



2) switch ON the Control Unit. Adjust its set-start value such that the motor can be started without a load being applied (position 10).

3) set the measuring instruments as follows:
* 1000 V AC for the voltmeter @ the stator terminals.
* 10 A AC for the Ammeter in the stator cct.
* 1 A DC for the Ammeter in the field cct.
* (0.1-30) A RMS, (0.3-1000) V RMS, real power mode for the wattmeter.

4) Adjust the exciter current to 0.6 A.

5) Press the Push-Button switch on the motor ter. board, & while doing this, switch on the CB S. Keep the PB pressed until the motor has reached its highest async. speed. Then release this switch so that the motor continues to run in a sync manner.

6) Set the Torque On the Control Unit in steps as in Table (4). In each step record V_L, N_m, $I_{stat.}$, P_i, Q_i & pf.

7) Reduce the load Torque gradually to min.

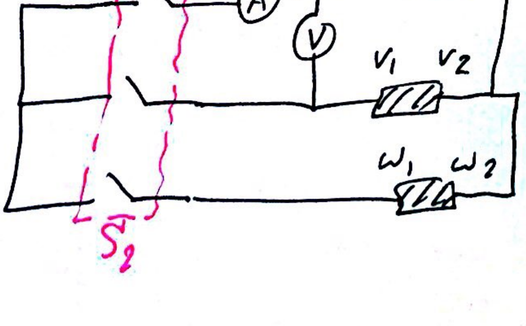
8) switch off S.

Table (4): Load Test.

T (N.m)	2.0	4.0	6.0
I_a (A)	1.4	1.9	2.2
V_t (V)	380	380	380
N (RPM)	1500	1500	1500
P_i (W)	200	310	500
Q_i (VAR)	270	220	120
P.F	0.61	0.85	0.96
leading/lagging	leading	Leading	leading.

• Procedure (4): V – C/C's :

1) Repeat steps (1)-(3) in procedure (3).
2) set the excitation current to 0.6 A.
3) set T_L = 0 N.m. (No-load).
4) Record the $I_{stat.}$ & Q_i & P_i & pf in Table (5).
5) Reduce the excitation current in steps to math the req. of table (5).
6) Repeat steps (3) – (5) But for 2. N.m.



⟹

Table (5): V-C/C's:

T (N.m)	0.0 (N.m)						2.0 (N.m)					
If (mA)	600	500	400	300	200	100	600	500	400	300	200	100
Ist (A)	1.25	0.9	0.45	0.25	0.63	1.2	1.5	1.3	0.95	0.85	1.2	1.7
N (RPM)	All the readings give 1500 RPM.											
P_i (W)	50	50	55	50	60	70	210	200	195	205	210	240
Q_i (VAR)	260	200	100	25	150	220	260	180	100	30	165	320
pf	0.25	0.3	0.7	0.9	0.4	0.3	0.65	0.8	0.92	0.97	0.8	0.65
leading / lagging	lead.	lead	lead	lag	lag	lag	lead	lead	lead	lag	lag	lag

※ Results & Discusions (Comments):

1) Calculate the Average value of R_A. What can you suggest to correct for AC operation.

since the readings taken on 2-phases ⇒ $R_A = 0.5 \times \underset{\text{factor}}{\text{skin}} \times R_{DC}$

consider skin factor = 1.5 @ I_{DC} = 1A:

$R_A = \frac{1}{2} \times 1.5 \times 21.8$

⇒ $R_A = 16.35\ \Omega$ for one phase.

2) Plot, on one graph the o/c & S/C c/c's of the tested machine.

we didn't take it in this exp.

3) Calculate the sync. Reactance of the armature.

Plot synch. Reactance vs. If.

We didn't take it in this exp.

$$Z_S = \frac{V_{oc}}{I_{sc}} = \frac{V_t \text{ (Line to Neutral)}}{I_a \text{ (line current)}}.$$

$X_s = \sqrt{Z_S^2 - R_a^2}$ → it is the Average R_A found in result ①.

4) if the speed of the M/C is NOT fixed during the SCT. Do you expect the S/C current to vary?

No it won't vary.

$I_{sc} = \frac{E_f}{Z_s} = \frac{4.44 N\phi f K}{R_a + jX_s}$

$E_f = 4.44 N \phi_p f K_w$

$X_s >> R_a$

$\Longrightarrow \quad I_{sc} = \frac{4.44 K\phi f N}{j X_s} \equiv$ Constant #.

$\hookrightarrow X_s = 2\pi f L_s$

5) From the load Test, Calculate τ_{dev}, $P_{dev}(HP)$, $P_{out}(HP)$?

* The torque angle found from: $E_a = V_t - I_a(R_a + jX_s)$

using $V_t = 380$ Volt, I_a from the tables, $R_a = 16.35\ \Omega$

& the calculated X_s, BUT we didn't calculate X_s in this exp..

* The following equations will be used:

$P_{dev} = (P_{in})_{3\phi} - 3 I_{a_{NL}}^2 R_a$, $\quad P_{dev}(HP) = P_{dev}/746$

$\tau_{dev} = \frac{P_{dev}}{\omega_m} = \frac{P_{dev}}{2\pi \times \frac{1500}{60}} = \frac{P_{dev}}{157.1}$, $\quad P_{out}^{(HP)} = \frac{\tau \cdot \omega_m}{746}$

⇒ Here is one example for the calculations:

@ $\tau = 2$ N.m, $I_a = 1.4$ A, $V_t = 380$ V, $N = 1500$ RPM, $P_i = 200$ W, $Q_i = 270$ VAR, pf = 0.61 leading.

$P_{dev} = 3 \times 200 - 3 \times (1.4)^2 \times 16.35 = \underline{503.862}$ W.

$P_{dev}(HP) = \frac{503.862}{746} = \underline{0.6754}$ hp. $\quad \tau_{dev} = \frac{503.862}{157.1} = \underline{3.207}$ N.m.

$P_{out} = \frac{2 \times 157.1}{746} = \underline{0.4212}$ hp.

⇒ the rest of the results shown below in the table:

T (N.m)	2.0	4.0	6.0
P_{dev} (W)	503.862	752.9	1262.6
P_{dev} (HP)	0.6754	1.01	1.69
τ_{dev} (N.m)	3.207	4.79	8.04
P_{out} (HP)	0.4212	0.842	1.264

6) Plot, for the load Test the P_{out} (HP), $P_{dev.}$ (HP), τ_{dev}, I_{st}, Pf, P_{in} & Q_{in} & Torque angle vs. load Torque.

shown in the last pages.

7) Plot in one graph paper the V-curves from the results of the procedure.
Plot in one graph paper Pf_{input} vs. I_f. shown in the last pages.

8) What can you deduce from the Plots of (7) above?

In sync. motor the Pf could be controlled by the field current so we can operate the motor under excited to have ind. response or we could operate over excited to have cap. response.
V-curve is representing the variation between I_{st} with I_f @ constant Pf. & Inverted V-curve is representing the variation of the Pf with I_f.

Conclusion:

we learned in this exp to find the Average R_A, & evaluating some requirements like I_a, P_i, Q_i & Pf @ a different Torque & we study about the V-char.'s.

* * *