TurboIEG.com

TURBO
Continuous change

دفتر :

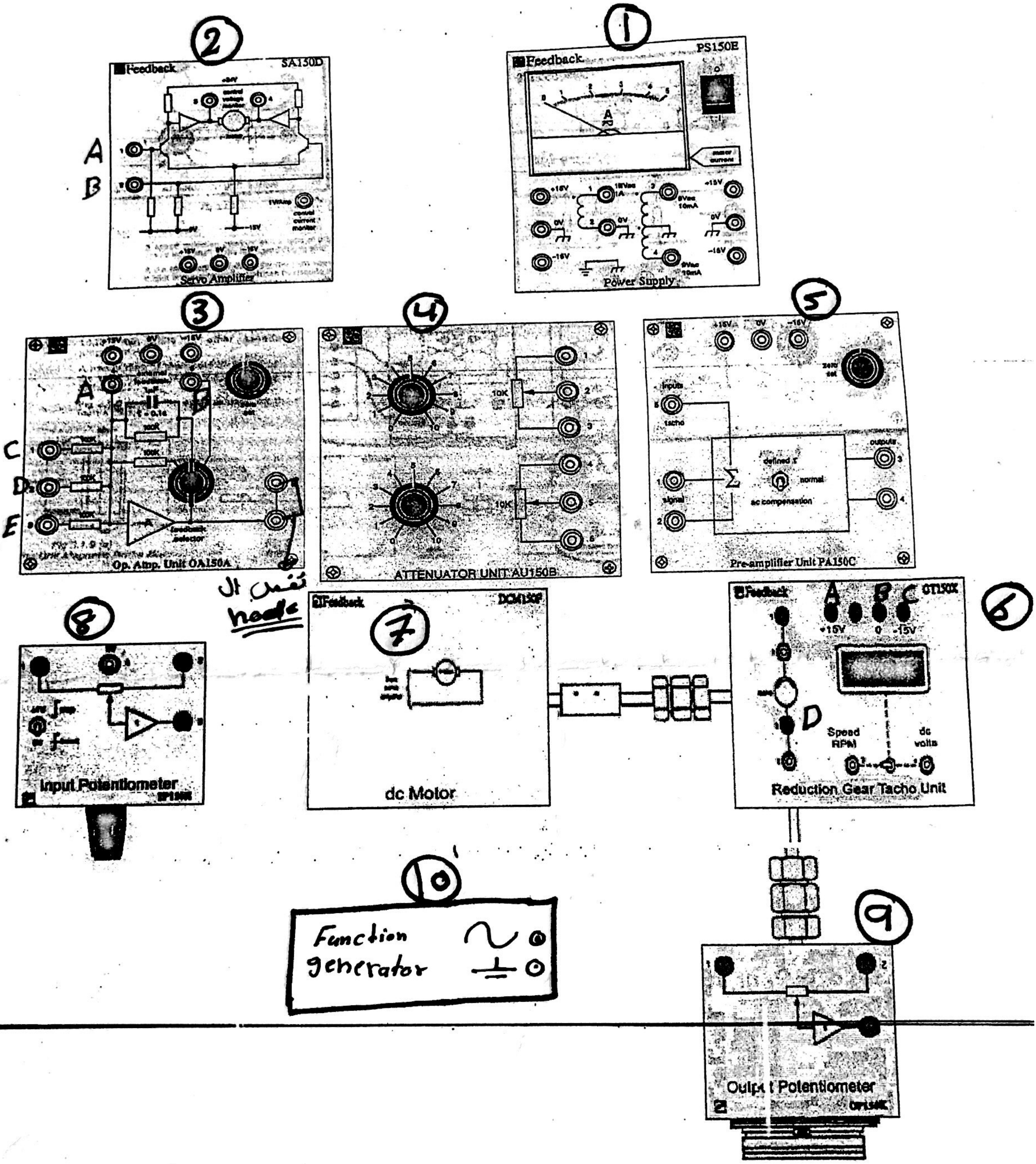
مختبر تحكم آلي

Automatic Control Lab

إعداد : ورد الشلبي

اللجنة الأكاديمية لقسم الهندسة الصناعية

2023


1
Feedback
PS150E
Power Supply
2
Feedback
SA150D
Servo Amplifier
A
B
3
Op. Amp. Unit OA150A
A
C
D
E
4
ATTENUATOR UNIT AU150B
10K
5
Pre-amplifier Unit PA150C
6
Feedback
GT150X
A B C
+15V 0 -15V
Speed RPM
dc volts
D
Reduction Gear Tacho Unit
7
Feedback
DCM150F
dc Motor
8
Input Potentiometer
9
Output Potentiometer
10
Function generator

Servo kit components:

1] Power supply [step Input]

* generates constant voltage [-15, 15] V
* common ground (zero voltage)
* Internally connected to the servo (لاحاجة لتوصيلها خارجياً)
* max current = 2A

2] Servo Amplifier

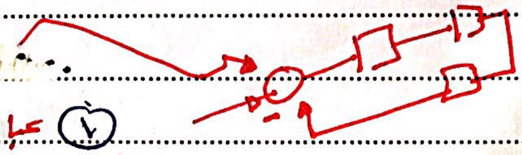
Used as a Drive In Both first (speed) and Second (position) order system ((servo + pre-amp))

شوف ادا الحركة

* Termials A and B chang the Direction of motor Rotation from C.W to C.C.W او العكس
* Changing The Direction of motor Rotation ممكن أنه يحول النظام من stable الى unstable او العكس

3] Operational amplifier

→ operablall amplifier



1) * summing Point عبارة عن
* يحتاج أوصله [15, 0, -15] V من ينفع
* more than one Input and only one out Put
* gain = 1

2) يقدر أزيد ال gain او اقلله من خلال وضع مقاومة بين A, B] → هنا يعمل Controller

* Ex gain = 3 → R = 300 Ω نسبة على 100

3) * Error detector
يقيس الفرق بين Demand and Response

4 Attenuator unit.

Knop

gain [0, 1] → depends on the position of the Knop

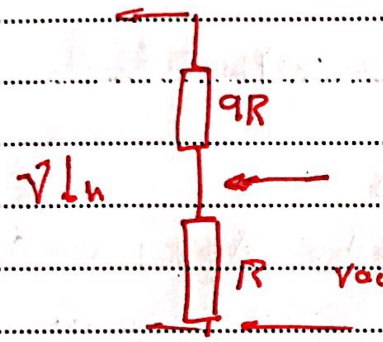
* Controller

summing Point — ادراجاد بعد

* Voltage divider summing Point — ادراجاد قبل

⇒ Vout في تحتوي على مقاومات للتحكم

$V_{out} = V_{in} \left(\frac{R}{R_{total}} \right)$



$V_{out} = V_{in} \left(\frac{R}{10R} \right) = 0.1\, V_{in}$

gain = 0.1

$= \frac{R_{out}}{R_{in}} = \frac{R}{10R} = 0.1$

Input	out put
1, 3	2
4, 6	5

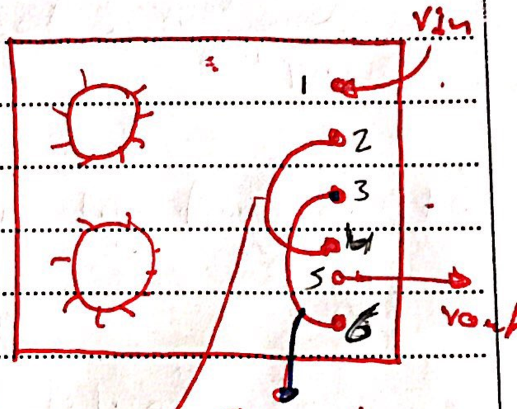
Nodes name

على الرسمة موضحة

Inputs nodes ground — واحد منهم دايما يكون موصول

2 controllers — ممكن استخدم

ممكن اوصل القيمة بدقة وبعدين تانية



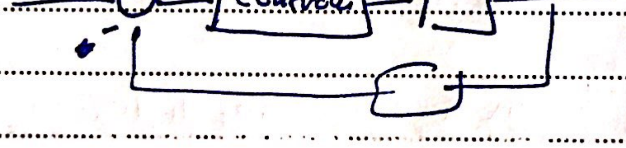
ground

يكون موصول مع ال Zero Power supply تاع — Zero voltage

مثلا ادراج ال ground في الkit

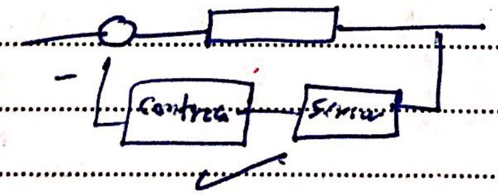
out put from the First controller

يروح → Input للcontroller التاني



summing point بعد

ويمكن ادراج



Sensor بعد controller

5) Pre-amplifier

only used in the second order system (Position Control system)

as a Drive, Drive → [servo + Pre-amp]
In The second order system

* one Input → two outputs Directly connect them to the servo.

* (servo بوصله بال pre-amp ع V output الى عرفها .)

6] Tachometer (Reduction tacho unit)

sensor → عبارة عن
closed بتستخدم فقط في
loop systems

الرموز شو خصها (A,B,C) في الأشكال أول صفحة

(A, B, C) → [-15, 0, 15] بوصلهم حتى تشتغل الشاشة

D → output
Dc-motor متصل مع
Coupling ب

* حتى أحصل على negative feed Back بوصل الفولتية الكبيرة بال ground
و الأخرى تصبح سالبة تلقائيا .

→ In the first order The output of the Tachometer Is Voltage proportional to Input angular speed /

بقدر أعرف إنه النظام position او speed من خلال اذا

✓ موصّل Pre-amp
✓ * two Inputs to the servo
من خلالهم بقدر أعرف الإجابة

ما بوصل Pre-amp
* بوجد two Inputs to the servo
→ Positions

7] DC Motor [servo motor]

Input [electrical] → output [mechanical]

$$T.F = \frac{\Omega(s)}{V(s)} = \frac{K_m}{\tau s+1}$$

$\Omega(s)$ → output speed; $V(s)$ → Input V

K_m → torque constant

τ → time constant

$$\omega(t) = K_m\left(1-e^{-\frac{t}{\tau_m}}\right)$$

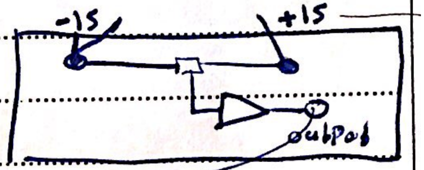
8] Input angular potentiometer

9] output angular potentiometer.

(connected with the Tachometer)

has an output voltage proportional to Input angular position (Theta).

→ feedBack signal

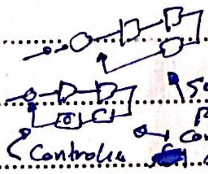


يرجع على summing point

-15, 15

متى يشتغل

10] Function generator



ادخل على controller

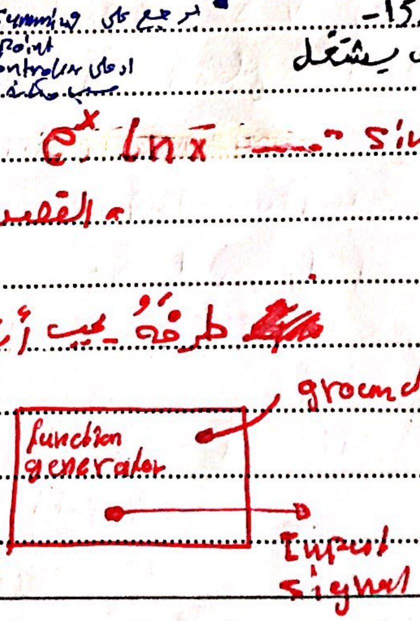
Provides an Input signal such as e^x, $\ln x$, $\sin x$, co

a constant Input — القصد إنه ما يعطي

ال constant من power supply

طرفه يجب إنه يتوصل بال ground

عند بدء التوصيل



Summing Point ال

* [-15, 0, 15] لازم ادخله ب Servo kit على amplifier ال *

Power supply حتى يشتغل ، عدا الى موصول تلقائياً مع

مثل Servo

{ Drive → Servo → first order (speed)
{ Drive → servo + Pre-amp → Second order. (position) }

* Oscilloscope → Draw the output/Input signal *

Stable system → Bounded Input → Bounded output

unstable system → Bounded Input → unBounded output.

اذا غيرت مكانه السلك اللي جاي من tachometer

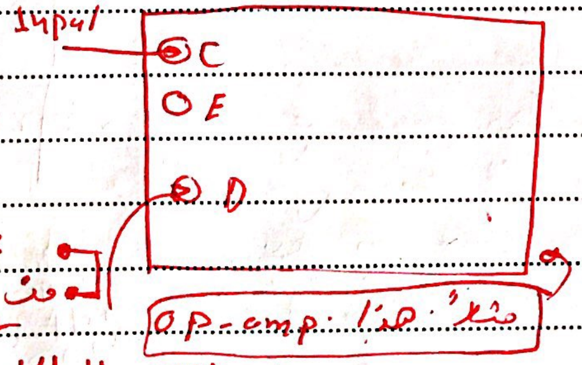
د الداخل ع الـ Summing point او output angular potentiometer

من نقطة D الى E مثلاً

فإنه ذلك لا يؤثر على النظام ؟

sensor (من تاكوميتر) (سلك الفيدباك)

(has no effect)



لو نقلت السلك الداخل في D

الى نقطة E فإنه ذلك لن يؤثر على

النظام.

Closing the loop of the system (add the connection Between the sensor and The summing point)

Reduce the error, make the system faster, stable. Ex number 3

بالتفصيل

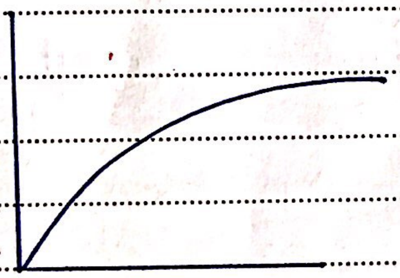
Units 5, 8, 9

Position control system موجودين فقط في

لو جاب نظام موتور جاهز وما فيه الأجزاء دي

يكون speed system أما إذا موجودين دي موجودين

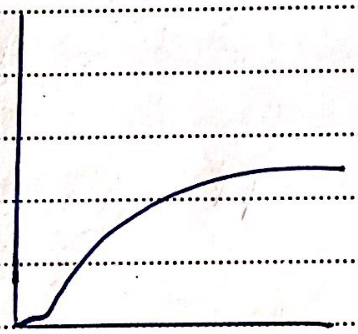
يكون Position.



First order system,

slope ≠ Zero

slope = $\frac{1}{\tau}$



Second order system

slope = Zero.

System order = number of poles (عدد أصفار المقام)

system type = number of poles at (0, 0)

عدد أصفار المقام الواقعة على نقطة الأصل

$$\frac{1}{s^3(s-1)}$$

- 4th order

- 3rd type.

* Speed control system (first order system)

$\frac{\text{output}}{\text{Input}} = T.F = \frac{k}{\tau s+1}$

- stable ممكن تكون
- ① open loop بدال ...
- ② closed loop بدال ...

$\Rightarrow \frac{1}{b}\dot{y} + \frac{a}{b}y = r(t)$ $\mathcal{L}$

$\frac{s}{b}y(s) + \frac{a}{b}y(s) = r(s)$

$\frac{y(s)}{R(s)} = \frac{\frac{b}{a}}{\frac{1}{a}s+1} \Longrightarrow \frac{k}{\tau s+1}$

لازم تكون واحد

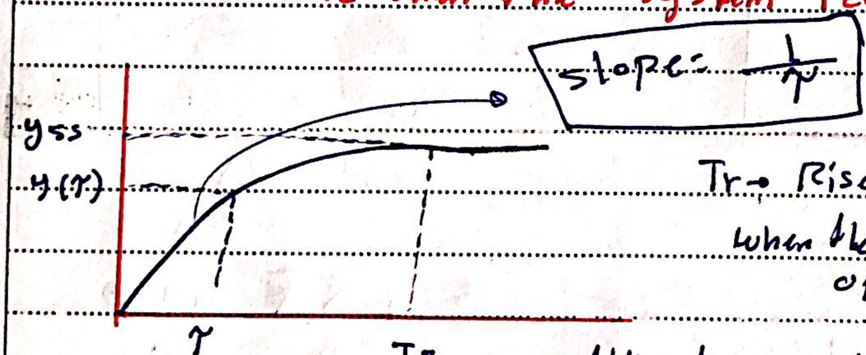
So..

$k = \frac{b}{a}$, $\tau = \frac{1}{a}$ ↳ time constant

DC gain

K defined as $\frac{y_{ss}}{R_{ss}}$ → y_{ss} → find value of the output; R_{ss} → find value of the Input

τ → The time when the system reaches 0.63 of it's final value



T_r → Rise time

when the system change from (10% - 90%) of the final value.

T_s → settling time → when the system reaches (steady state value الزمن اللازم للوصول الى) → 98% of it's final value

$T.F = \frac{k}{\tau s+1}$ → ①

$T_s = 4\tau$ → ②

$y(t) = k(1 - e^{-\frac{t}{\tau}})$ → ③

$k = \frac{y_{ss}}{R_{ss}}$ → ④

$T_r = 2.2\tau$ → ⑤

(Rise time) → when the system change from (10% - 90%) of the final value

$T.F = \frac{9}{s+10}$ for a unit step

find k, τ, $y(t)$

$\Rightarrow \frac{\frac{9}{10}}{0.1s+1}$

$\tau = 0.1$

$k = 0.9$

$y(t) = 0.9(1 - e^{-\frac{t}{0.1}})$

EX) 1) $\frac{3}{S+2}$ 2) $\frac{2}{S+1}$ 3) $\frac{1}{S+4}$ 4) $\frac{1}{S+3}$

a) Find τ for motor number 4.

$T.F = \frac{1}{S+3} \Rightarrow \frac{1/3}{\frac{1}{3}S+1}$ $\tau = \frac{1}{3}$

{ $\tau \propto \frac{1}{\text{السرعة}}$
اذا كانت τ اقل
يكون النظام اسرع }

b) which motor has the fastest (steady state) Responce.?

fastest steady state Responce $\Rightarrow$ أقل τ

يعني يكون أقل Ts من يكون السريع واصل الوصول الى steady state وبالتالي أقل Ts

$\Rightarrow$ for motor 3 $\tau = \frac{1}{4} \rightarrow$ السريع دائما لانه τ اقل

c) which one has the maximum steady state output? (step input)

$k = \frac{y_{ss}}{R_{ss}} \Rightarrow$ مطلوب أبحث عنه أكبر k

$R_{ss} = 1$ $\Rightarrow$ motor 2

$k = 2 = \frac{y_{ss}}{1}$ $y_{ss} = 2$

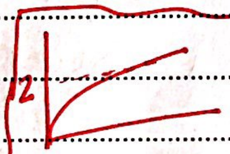
d) If the input = 2V, which motor will have 3 rad/sec steady state output??

$k = \frac{y_{ss}}{R_{ss}} \Rightarrow y_{ss} = k \times R_{ss}$

$3 = k \times 2$

$k = \frac{3}{2}$

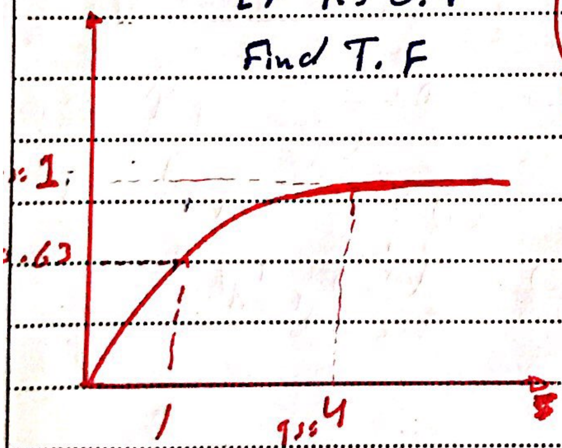
$\Rightarrow$ motor 1



Input = step input
find k

$k = \frac{y_{ss}}{R_{ss}} = \frac{2}{1} = 2$

IF $k = 0.7$
Find T.F



sol

$T.F = \frac{k}{\tau s+1}$ $* T_s = 4\tau$

$4 = 4\tau$

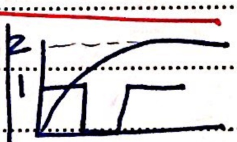
$\tau = 1$

$= \frac{0.7}{1s+1}$

or $y(\tau) = 0.63\, y_{ss} = 0.63$

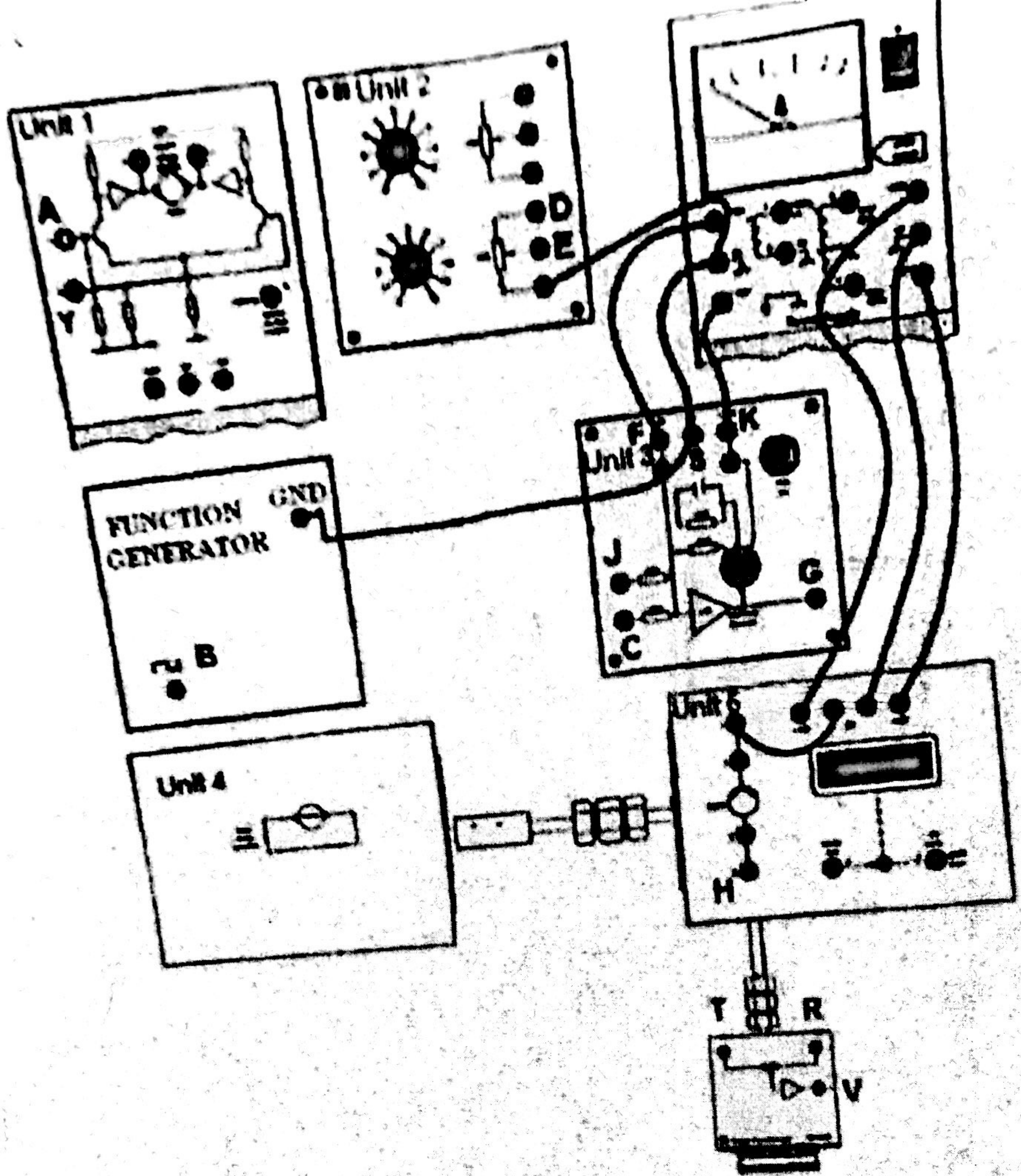
τ at $0.63 = 1$ s

$y(t) = 0.7(1 - e^{-\frac{t}{1}})$



Find k

$k = \frac{y_{ss}}{R_{ss}} = \frac{2}{1} = 2$



Node	Case 1 Closed loop speed control with constant Kp and step input	Case 2 Open loop speed control with step input	Case 3 Open loop speed control with variable input
J			
G			
C			
D			

Second order system (position system)

مستقر بالنسبة → stable ←→ الـ open loop
(stable → نقطة ع
(closed loop ال

$T.F = \dfrac{k\,\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$

معامل $s^2 = 1$

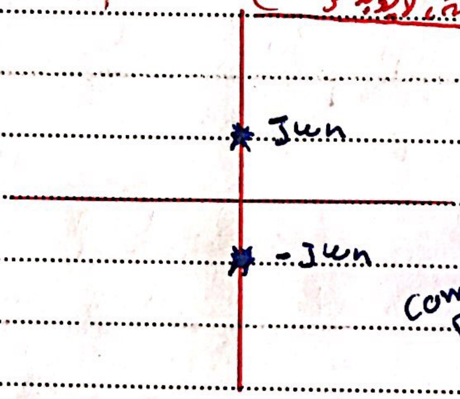
ω_n = natural freq

ζ = damping Ratio

k = DC gain

* note → $\omega_n^2 = 4$
$\omega_n = 2$
(لما القيمة اعويض لايوجد ترددات)

1) undamped system ($\zeta = 0$)

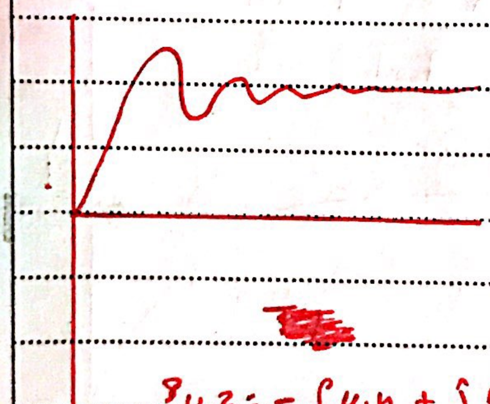


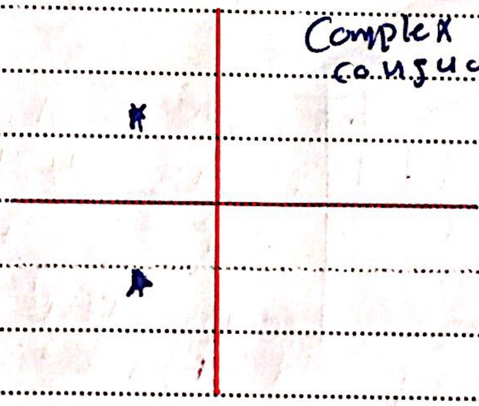
$T.F = \dfrac{\omega_n^2}{s^2 + \omega_n^2}$

$s_{1,2} = \pm j\omega_n$

$y(t) = 1 - \cos\omega_n t$

2) under damped ($0 < \zeta < 1$)



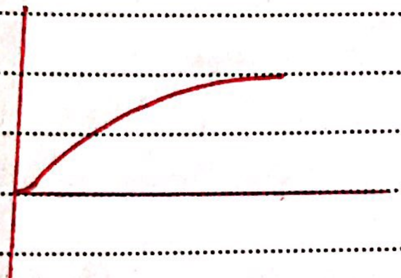


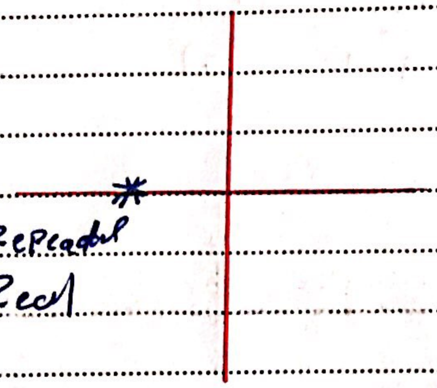
$s_{1,2} = -\zeta\omega_n \pm j\omega_n\sqrt{1-\zeta^2}$ → * حطهم على الحاسبة *

$y(t) = 1 - \dfrac{e^{-\zeta\omega_n t}}{\sqrt{1-\zeta^2}} \sin\left(\omega_n\sqrt{1-\zeta^2} + \cos^{-1}\zeta\right)$

$\omega_d = \omega_n\sqrt{1-\zeta^2}$
↓
damping freq

3) Critically damped ($\zeta = 1$)

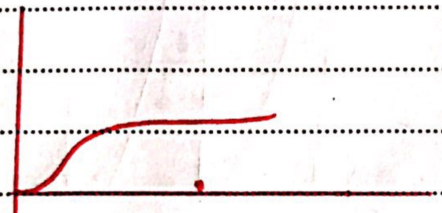


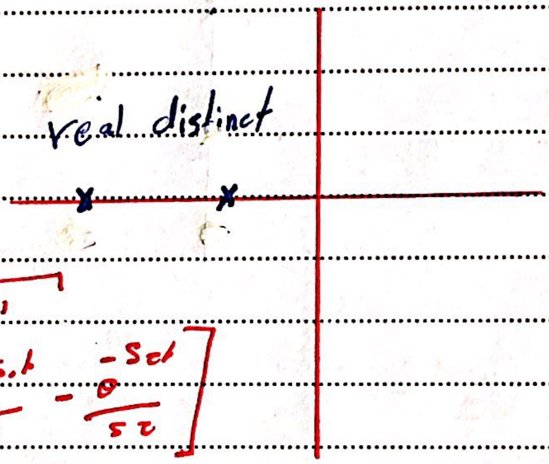


$S_{1,2} = -\omega_n$

$y(t) = 1 - e^{-\omega_n t}(1 + \omega_n t)$

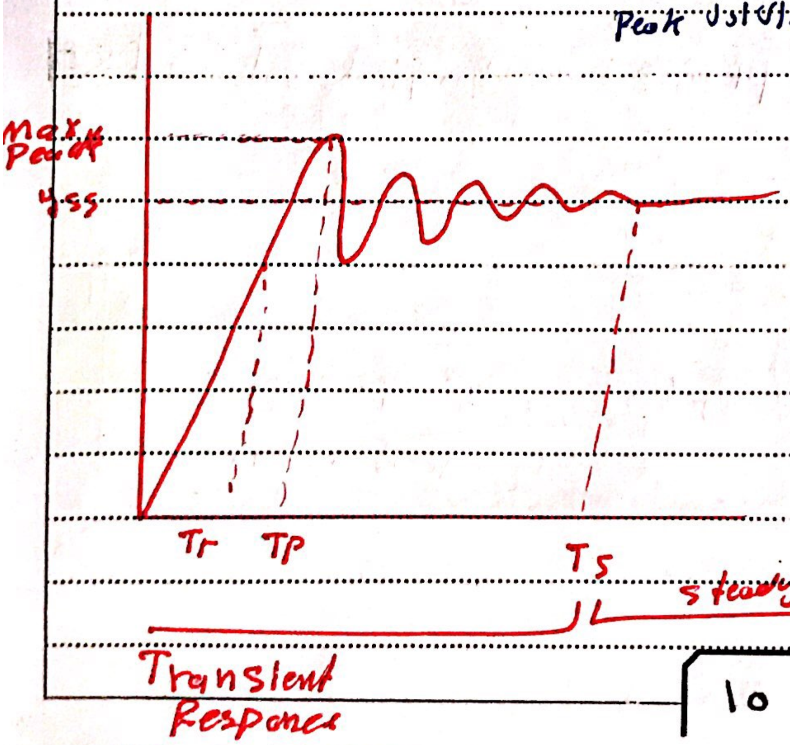
4] overdamped ($\zeta > 1$)





$S_{1,2} = -\zeta\omega_n \pm \omega_n\sqrt{\zeta^2 - 1}$

$y(t) = 1 + \frac{\omega_n}{2\sqrt{\zeta^2-1}}\left[\frac{e^{-S_1 t}}{S_1} - \frac{e^{-S_2 t}}{S_2}\right]$



الوقت اللازم للوصول الى Peak

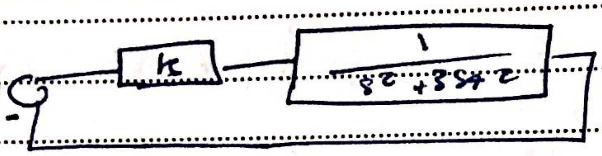
$T_p = \frac{\pi}{\omega_n\sqrt{1-\zeta^2}}$

$T_s = \frac{4}{\zeta\omega_n}$

O.S% / MP% $= \frac{y_{peak} - y_{ss}}{y_{ss}} = e^{-\pi\zeta/\sqrt{1-\zeta^2}}$

$T_r = \frac{2.16\zeta + 0.64}{\omega_n}$

Ex



Find the value of k to achieve $\zeta = 0.707$

Closed loop T.F $= \dfrac{k}{s^2+3s+2+k}$

$\omega_n^2 = 2+k$

$\omega_n = \sqrt{2+k}$

$3 = 2\zeta\omega_n$

$\omega_n = 2.12$

$\omega_n^2 = 4.5 \Rightarrow$

$\omega_n^2 = 2+k$

$k = 2.5$

Ex Find the settling time for T.F $= \dfrac{1}{s^2+2s+2}$

$T_s = \dfrac{4}{\zeta\omega_n}$

$\omega_n = \sqrt{2}$

$2\zeta\sqrt{2}\,s = 2s$

$\zeta = \dfrac{1}{\sqrt{2}} = 0.707 \Rightarrow T_s = \dfrac{4}{0.707 \times \sqrt{2}} = 4\ \text{sec}$

---

1) $\dfrac{1}{s^2+3s+2}$ 2) $\dfrac{1}{s^2+4s+4}$ 3) $\dfrac{1}{s^2-s-6}$ 4) $\dfrac{1}{-s^2-4s-3}$

ζ for The first system.

$\omega_n = \sqrt{2}$

$3s = 2\zeta\sqrt{2}\,s$

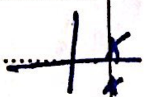
$\zeta = \dfrac{3}{2\sqrt{2}} = 1.06$

- system 2 is Critically damped $\zeta = 1$

stable or unstable — حتى اعرف انه النظام

⇒ اذا تغيرت الاشارة في اعلام
ربو مدد كثر من اشارة + - + ومكه
unstable مثل معادلة ③

⇒ Poles on the RHS — unstable



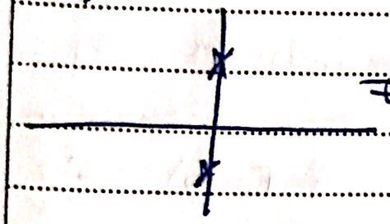
⇒ missing term في اعلام
unstable يكون

مثل $\dfrac{1}{s^2+s}$ / $\dfrac{1}{s^3+s+1}$

11

لازم أكون بعرف أوجد قيمة ζ من مكان البولز

مثلاً



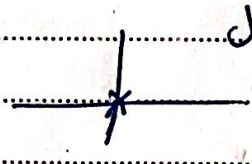
⇒ undamped

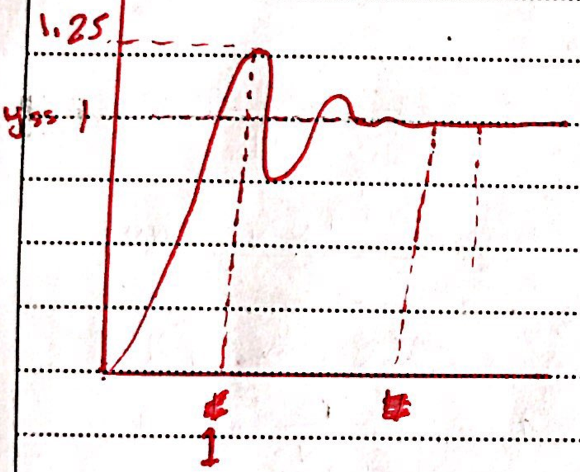
$\zeta = 0$

⇒ يسمى هذا /

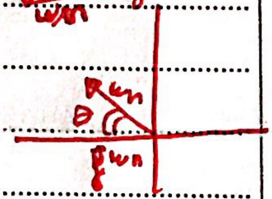
Marginally stable ⟶ البولز على j axis

او نقطة الأصل





$\cos\theta = \frac{\zeta\omega_n}{\omega_n} = \zeta$



$\zeta = \cos(\theta)$

$\theta = 0$ → critically

$\theta = 90$ → undamped

$\theta = (0, 90)$

under

يعرف باستخدام الآلة الحاسبة

Find ζ

$\frac{1.25 - 1}{1} = e^{(-\zeta \times \pi)/\sqrt{1-\zeta^2}}$

Ex

$\theta = 45$

$\zeta = 0.707$ → underdamped

$\zeta = 0.4$

$T_P = \frac{\pi}{\omega_n \sqrt{1-\zeta^2}}$

$1 = \frac{\pi}{\omega_n \sqrt{1-0.4^2}}$

$\omega_n = 3.42$

$T_s = \frac{4}{\zeta\omega_n} = 2.9$

For Input = 2 V

Find The steady state error

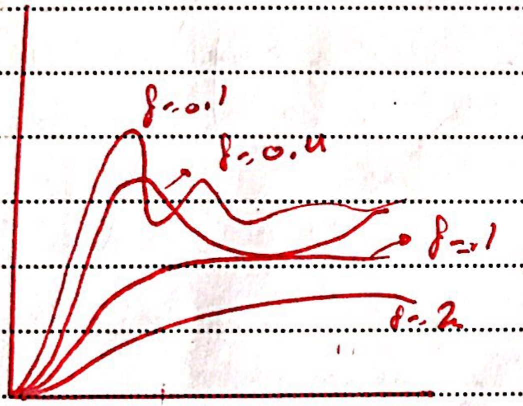
$E_{ss} = \text{Input} - \text{output} \ (y_{ss})$

$= 2 - 1 = 1$

* لما يكون في عندي Imaginary في ال Poles يكون عندي
Part
oscillation
مثل underdamped
undamped

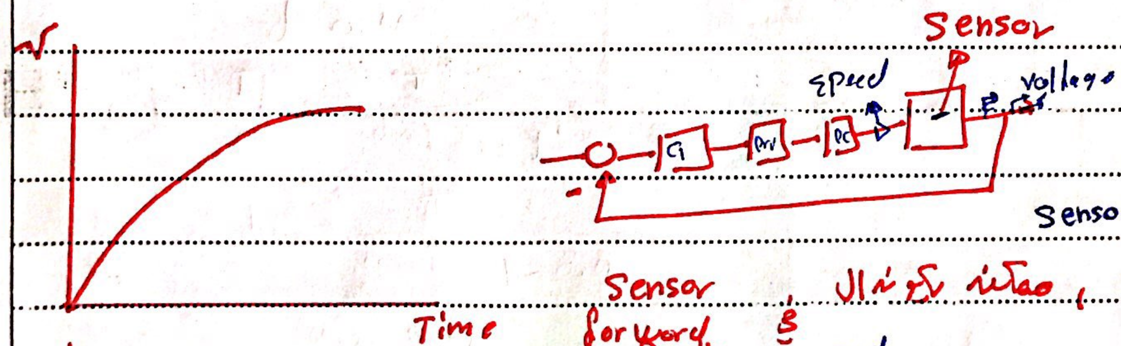
اما في overdamped
: Critically damped
لا يوجد Imaginary لذلك لا يوجد oscillation
Part

* هنالك علاقة عكسية بين قيمة (ζ) و ال overshoot
و عكسية بين ζ و oscillation

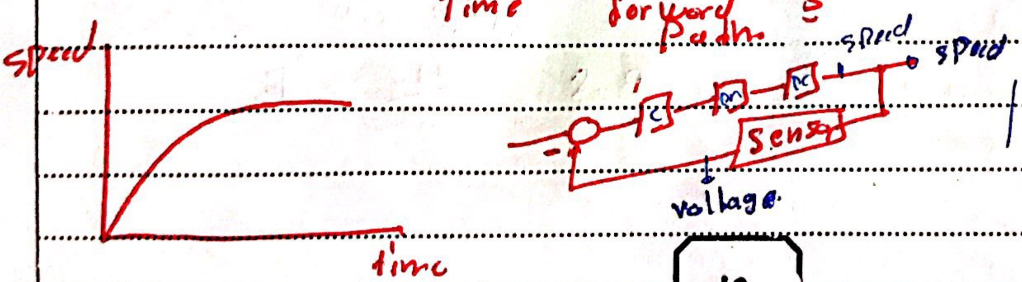


Critically damped faster than over damped في الوصول ال steady state.

* لما أغير controller gain بتغير عندي قيمة ζ و بالتالي تتغير نوع ال Response.



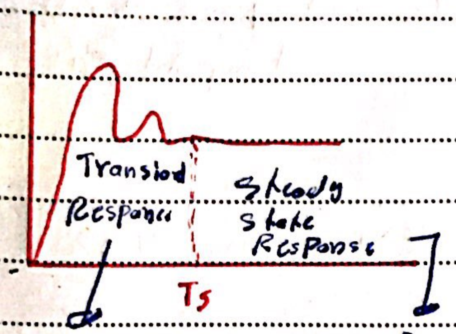
output → voltage
السبب هو مكان ال sensor
اثبت ال y axis، ممكن يكون ال sensor في forward Path.



output ⇒ speed

Characteristics of open and closed loop systems.

Steady state Error, Sensitivity, disturbance rejection.

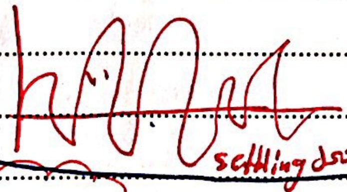


τ, f, ω_n...

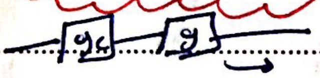
Dc gain
Disturbance
Sensitivity.

في هذه التجربة استخدمنا
speed system
لأنه position system
unstable at open loop

ما بعد settling
حتى أفهم مثلاً
لوحها بالرسمة



Open loop

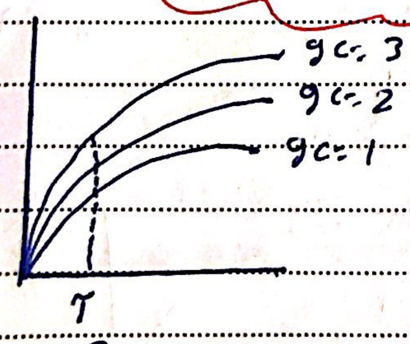


$\frac{1}{\tau s+1}$

$$T.F = g_c g = \frac{g_c}{\tau s+1}$$

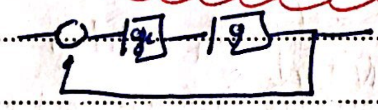
$g_c \rightarrow$ controller gain

لما أزيد او أنقص قيمة g_c
ذلك لن يؤثر على (τ) وبالتالي
لن يؤثر على سرعة النظام



open loop

Closed loop



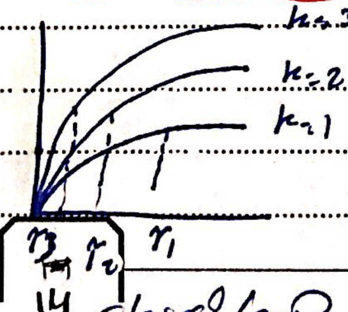
$$TF = \frac{g_c g}{1+g_c g} = \frac{\frac{g_c}{\tau_0 s+1}}{1+\frac{g_c}{\tau_0 s+1}}$$

$$\Rightarrow \frac{\frac{g_c}{\tau_0 s+1}}{\frac{\tau_0 s+1+g_c}{\tau_0 s+1}} \Rightarrow \frac{g_c}{\tau_0 s+1+g_c}$$

$$\Rightarrow \frac{g_c}{\frac{\tau_0 s}{1+g_c}+1}$$

$$\tau_{closed} = \frac{\tau_0}{1+g_c}$$

* لما أزيد g_c تقل τ وتزداد سرعة النظام



14 closed loop

If $k=2$, $\tau_{open}=0.3$

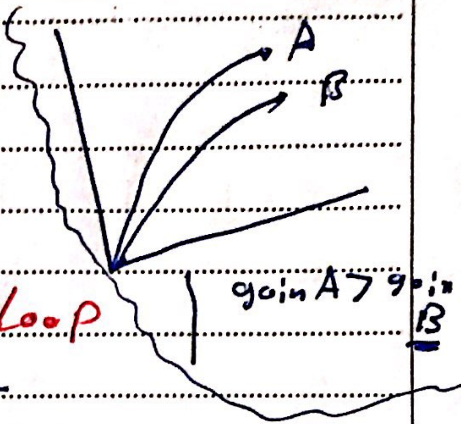
Find τ_{closed}

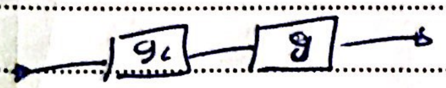
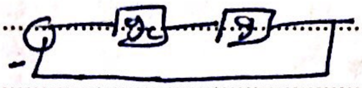
$$\tau_{closed} = \frac{0.3}{1+2} = \frac{0.3}{3} = 0.1$$

* Steady state errors   Input: 3
output: 2
Ex → $E_{ss} = 3 - 2 = 1$

E_{ss} = Input − output

[Unit step Input]



Open loop	Closed Loop
	
	$T.F = \frac{g_c g}{1 + g_c g}$
$E_{ss} = 1 - g_c g$	$E_{ss} = 1 - \frac{g_c g}{1 + g_c g}$
(controller gain) g_c كلما زاد Error يزداد	$E_{ss} = \frac{1}{1 + g_c g}$
g_c ↑ E_{ss} ↑	علاقة عكسية ، كلما زاد g_c يقل Error
(طردية ، سالبة)	

Ex: IF $g = 0.5$ find g_c such that $E_{ss} = 0.5$

$0.5 = 1 - (0.5)\, g_c$

$g_c = 1$

عند قيمة محددة لل gain لما أحول النظام إلى closed Loop رح يقل ال Error ح تزيد ال accuracy

العلاقة بين ال accuracy وال Error عكسية   Error ↑ accuracy ↓

يعني مثلاً بدي أزيد ال accuracy في closed loop بزيد K

اما في open loop بقلل K

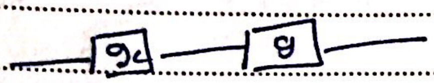
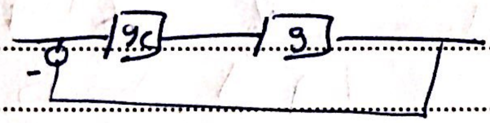
* Sensitivity

⇒ The ratio of the changes in the system T.F due to the change in process or parameter ... %

T.F

$$S_g^T = \left(\frac{\Delta T}{T}\right) \Big/ \frac{\Delta g}{g} \quad \text{or} \quad \frac{\partial T}{\partial g} * \frac{G}{T}$$

Plant

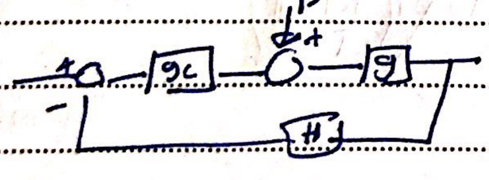
Openloop	closed loop
	
$T.F. = g_c\, g$	$T.F. = \dfrac{g_c g}{1 + g_c g}$
$S^{T}_{g_c} = \dfrac{\partial T}{\partial g_c} \times \dfrac{g_c}{T}$	$S^{T}_{G} = \dfrac{1}{\underbrace{1 + g_c g}_{\text{loop gain}}}$
$= g \times \dfrac{g_c}{g_c g} = 1$	S لما أزيد gc بتقل (علاقة عكسية)
100 %	"وأقل من 1 دائماً"
"عالية جدا"	Sensitivity for closed loop < 1

$$S^{G}_{\gamma} = \frac{\partial G}{\partial \gamma} \times \frac{\gamma}{G} = \frac{\partial G}{\partial \gamma} \times \frac{\gamma}{G}$$

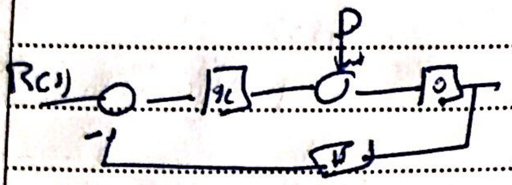
$$S^{T}_{\gamma} = S^{T}_{G} \times S^{G}_{\gamma}$$ → مثل قاعدة السلسلة

$$S^{T}_{R} = S^{T}_{G} \times S^{G}_{\gamma} \times S^{\gamma}_{R}$$

Disturbance rejection.



- لا يؤثر على controller
- دائماً موجود (added to the system)
- يؤثر على Plant



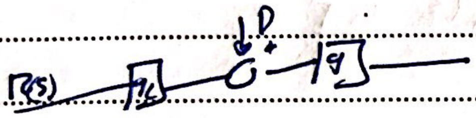
total output = output due to R(s) + output due to D

(Using Super Position)

Closed Loop

$$\frac{y}{R(s)} = \frac{g_c g R}{1+g_c g}$$

$$y_D = \frac{g \cdot D}{1+g_c g}$$ → * كلما زاد gc بتقلل ال output الي جاي من D



Open Loop

$y_{R(s)} = g_c g R$

$y_D = g \cdot D$ → * لا يتأثر ال output الي جاي من D مهما أغير gc

تأثيره رح يقل شوط عملت بـ gc

بتحسب

$$D\% = \frac{\text{output due to D}}{\text{total output}}$$

نسبة ال output الي من D

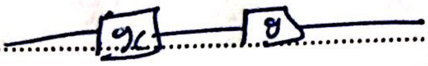
Closed Loop → بعمل Disturbance Rejection

Ex

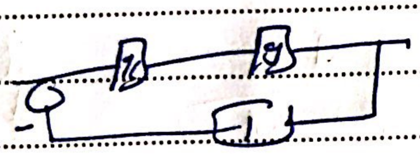
جد العلاقة بين $\omega_{n_{open}}$ و $\omega_{n_{closed}}$

For the second order system

الحل



$$T.F = \frac{g_c\,\omega_{n_o}^2}{s^2 + 2\zeta\omega_{n_o}s + \omega_{n_o}^2}$$



$$T.F = \frac{g_c g}{1 + g_c g} \Rightarrow \frac{\dfrac{g_c\,\omega_{n_o}^2}{s^2 + 2\zeta\omega_{n_o}s + \omega_{n_o}^2}}{1 + \dfrac{g_c\,\omega_{n_o}^2}{s^2 + 2\zeta\omega_{n_o}s + \omega_{n_o}^2}}$$

$$\Rightarrow \frac{g_c\,\omega_{n_o}^2}{s^2 + 2\zeta\omega_{n_o}s + \underbrace{\omega_{n_o}^2 + g_c\,\omega_{n_o}^2}_{\omega^2_{n\,closed}}}$$

$$\omega^2_{n_{closed}} = \omega_{n_o}^2 + g_c\,\omega_{n_o}^2$$

$$\omega_{n_{closed}} = \omega_{n_o}\sqrt{1 + g_c} \leftarrow \quad g_c \uparrow \quad \omega_{n_c} \uparrow$$

جيب ع ζ_{open} ζ_{closed} ؟؟

$$2\zeta_c\,\omega_{n_c} = 2\zeta_o\,\omega_{n_o}$$

$$\zeta_c = \frac{\omega_{n_o}\,\zeta_o}{\omega_{n_o}\sqrt{1 + g_c}} \Rightarrow \zeta_c = \frac{\zeta_o}{\sqrt{1 + g_c}}$$

$g_c \uparrow \quad \zeta_c \downarrow$

√ Input = 2 V

	G	w (rpm)	Vo (exp)	Ess (exp)
open loop system without Disturbance	0.2	690	1.88	0.12
	0.6	1560	4.2	-2.2
	1	2800	7.5	-5.5
closed loop system without Disturbance	0.2	370	1	1
	0.6	520	1.4	0.6
	1	690	1.87	0.13

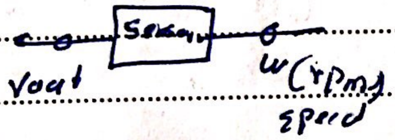
Find Ess,
Find the sensor gain
, which system (open or closed) benefits from the increasing of G?

Sol:
1) Ess = Input - output
= 2 - 1.88 = 0.12

→ closed loop بيوفر قراءات في "طبعا"

أنا فاهم

2) Sensor gain = $\frac{output}{Input}$



$= \frac{V_{out}}{w (rpm)} = \frac{1}{370} = \frac{1.4}{520} = \frac{1.87}{690}$

$= 2.7 \times 10^{-3}$

3) G الي بستفيد من زيادة هو Closed loop

لأنه ال Error صار أقل
زادت ال accuracy.

---

n	V_I	G	$\Delta G/G_0$	Experimentally: Vo	Tn	$\Delta T/T_n$	S_G^T
1	2	0.2	//////	1	1/2	//////	//////
2	2	0.6	0.667	1.4	0.7	0.285	0.427
3	2	0.8	0.25	1.55	1.55/2	0.096	0.384
4	2	1	+0.2	1.87	0.935	0.171	0.855

$\Delta G = G_n - G_{n-1}$

$T_n = V_o / V_I$

$\Delta T_n = T_n - T_{n-1}$

$S_G^T \rightarrow (\Delta T_n / T_n) / \frac{\Delta G_n}{G}$

$\frac{0.7 - 0.5}{0.7}$, $\frac{0.285}{0.667}$

T_n: $\frac{1.87}{2} = 0.935$

$\Delta G/G_0 = \frac{0.6 - 0.2}{0.6} = 0.667$

MatlaB Tutorial

هم تركز مع شرح المهندسة جهاي التجربة

الأوامر المطلوبة

- T.F ( )
- Pole ( ) → يجد قيم Poles
- Zero ( ) يجد قيم Zeros
- step ( ) معلومات عنه step Responce
- Pzmap ( ) يوضح مكانه البولز و الزيروز
- damp ( ) يجد ω_n , ζ

مثله Ts, Tp, Tr

لما بدي أضيف Pole — $\frac{1}{s}$ — بستخدم KD

بدي أضيف Zero — s — بستخدم KI

أما KP ← constant

بدي أحول من underdamped to over or critical we use KI or KP

كلما حا زدت ال gain بتزيد ω_n وبتقل ζ زيتا

Ex

a = [1 , 2]
b = [1 2 4]

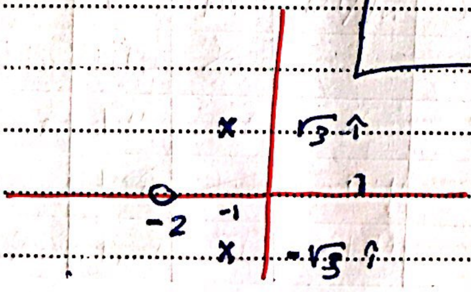
→ T = a/b

1) $T.F(a/b) = \frac{s+2}{s^2+2s+4}$

2) Zero(T) = −2

3) Pole(T) = $-1 \pm i\sqrt{3}$

4) Pzmap (T)



→ stable system (all poles at the LHS)

5) damp(T)

$\zeta = 0.5$

$\omega_n = \sqrt{4} = 2$

$2\zeta\omega_n s = 2s$

$2\zeta 2 = 2$

$\zeta = \frac{1}{2}$

6) step(T)

$T_s = \frac{4}{\zeta\omega_n} = 1$ (?)

$T_p = (\ )$

$T_r = (\ )$

at K=0 البولز هم open loop Poles

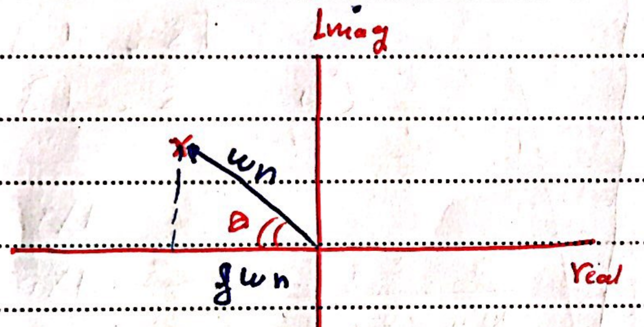
Modeling and simulation

من شرح المهندسة

Root locus Tutorial

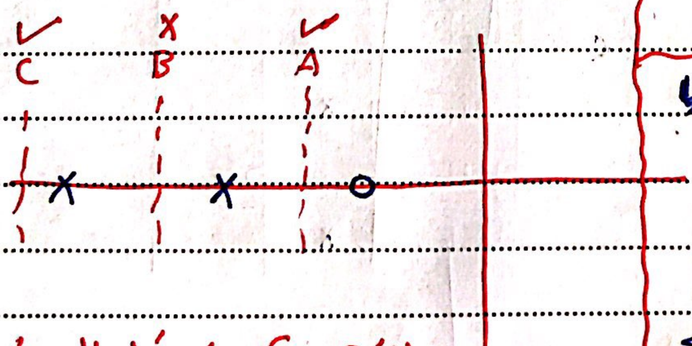
Root Locus:- the Plot of the Paths of all Possible closed loop Poles as the design Parameter takes on the Range of Possible values

closed loop response depends on The location of closed loop poles.



$\cos\theta = \frac{\zeta w_n}{w_n} = \zeta$

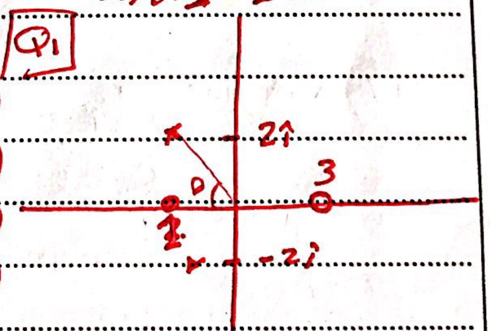
اذا بدي اكبر قيمة wn بزيد K (controller gain)



لازم تكون قبل ال Segment odd number of Poles and Zeros حتى تكون جزء من Root locus

Q1

$s_{1,2} = -1 \pm 2i$



Find w_n, T_s, TF, ζ

$w_n = \sqrt{(2)^2 + (1)^2} = \sqrt{5}$

$T_s = \frac{4}{\zeta w_n} = \frac{4}{1} = 4$

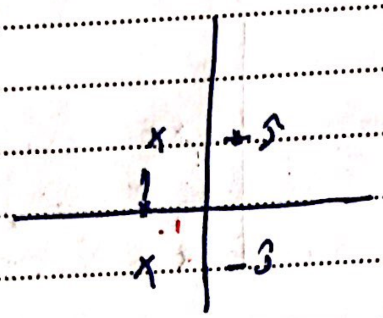
$4 = \frac{4}{\sqrt{5} \cdot \zeta} \Rightarrow$

$\zeta = 0.447$

$T.F = \frac{s+3}{s^2 + 2s + 5}$

$\theta = \cos^{-1}(\zeta) = 63.43^\circ$

for the following sketch Find w_n, ζ, T.F and draw the root locus



$$w_n = \sqrt{(1)^2 + (1)^2} = \sqrt{2}$$

$$1 = \zeta w_n$$

$$\zeta = \frac{1}{\sqrt{2}} = 0.707 \text{ (under damped)}$$

$$T.F = \frac{1}{s^2 + 2s + 2}$$

$$\sigma_A = \frac{\Sigma \text{ Poles} - \Sigma \text{ Zeros}}{\# \text{ Poles} - \# \text{ Zeros}}$$

$$= \frac{2 - 0}{2} = 1$$

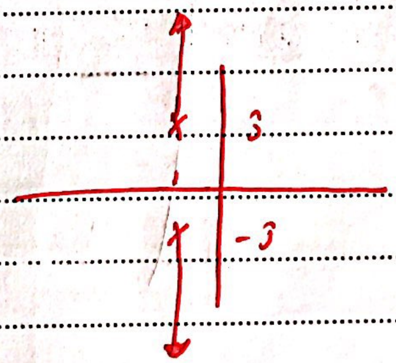
$$\phi = \frac{(180)(2k+1)}{n-m}$$

$k = 0, 1, \ldots n-m-1$

$k = 0, 1$ $\quad n-m-1 = 2-1 = 1$

$$\theta_1 = \frac{180}{2} = 90$$

$$\theta_2 = \frac{(180)(3)}{2} = 270$$



If the system changed to undamped = ??

$$\frac{1}{s^2 + 2}$$

$\zeta = 0$

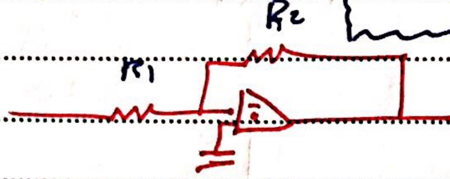
$w_n = \sqrt{2}$

~~overdamped to~~

Capasitor = $\frac{1}{Cs}$
Inductor = Ls

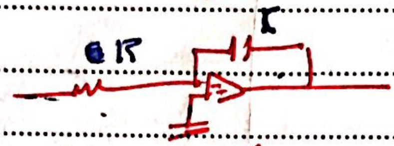
PID controller

- Proprotional → k_P



$TF = \frac{-R_2}{R_1}$

- Integral → $\frac{k_I}{s}$



$T.F. = \frac{-1}{RCs}$

- Derivative → sk_D

$T.F. = -RCs$

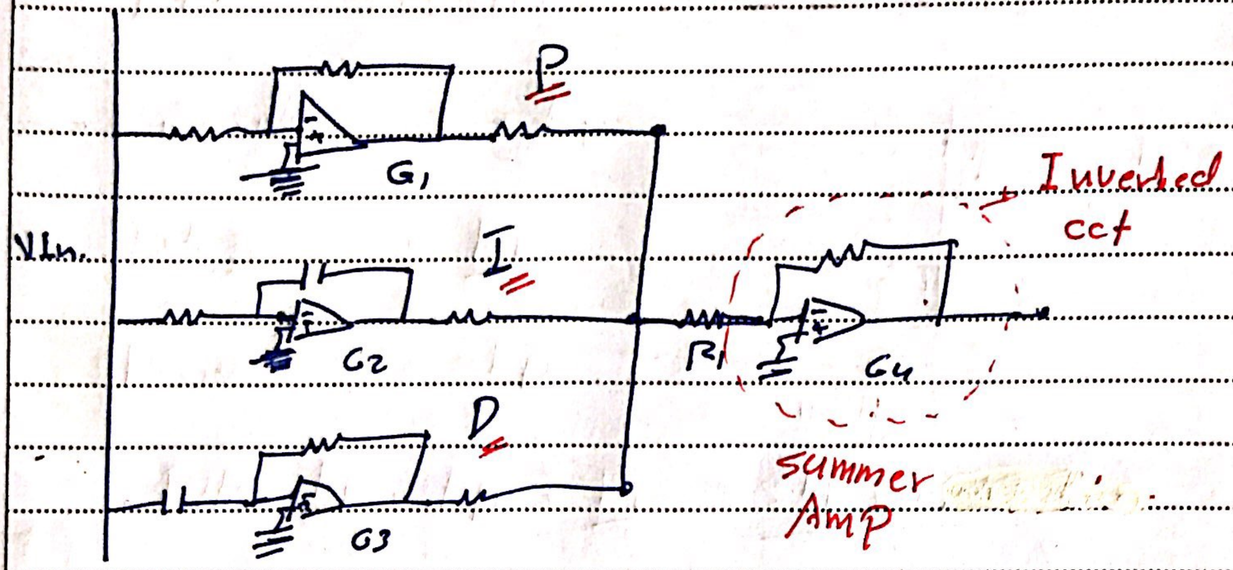
- $PID = k_P + sk_D + \frac{k_I}{s} = \frac{s^2 k_D + sk_P + k_I}{s}$

Controller	Effect
P ($k_P \times V_{error}$)	The main drive, reduce the "overall" error
I ($k_I \times \int V\,dt$)	reduce the final error, (move the system to smaller error.
D ($k_D \times \frac{dV}{dt}$)	reduce The overshot and rining, and Has no effect on the final error

	rise time	overshoot	settling time	steady state error
kP	↓	↑	small change	↓
kI	↓	↑	↑	Eliminate
kD	small change	↓	↓	small change

kP, kI, kD → depends on each other
يعني التأثير مش مستقل

بوحالي شوا ستقر حتى ال overshoot
المطلوب → kD اقل



$$output = G_1G_4 + \frac{G_2}{s}G_4 + G_3G_4s$$

لاحظ انه G4 بيتحكم في مقدار ال output الصادر من كل Amp

لذلك هو يعتبر

<u>Controller - Controller</u>

* التوصيل *

1) حط أعلى مشتقة على طرف لوحدها

2) summing point = المساواة

Ex

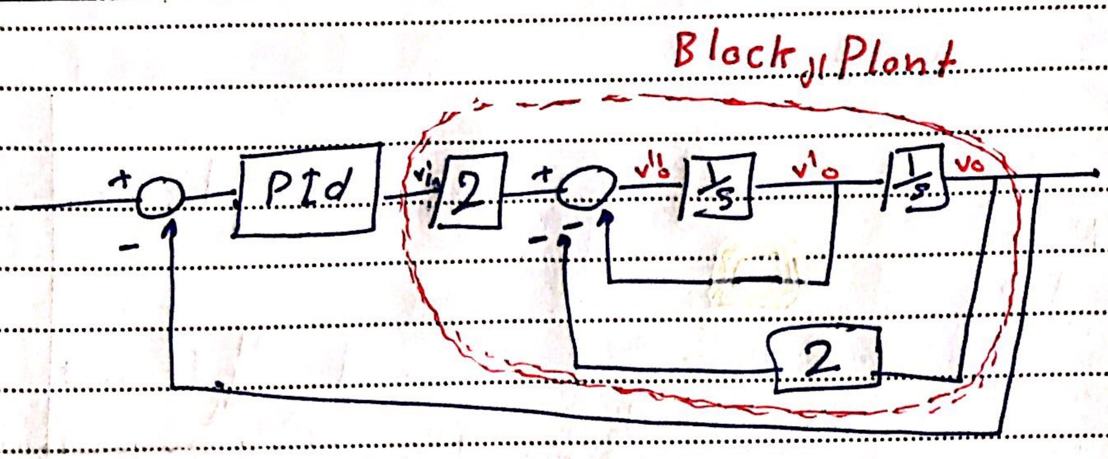
$$\frac{1}{2}V_o'' + \frac{1}{2}V_o' + V_o = V_{in}$$

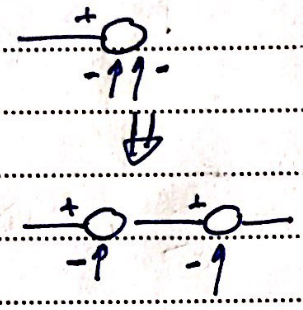
$$\Rightarrow \left[\frac{1}{2}V_o'' = V_{in} - \frac{1}{2}V_o' - V_o\right] \times 2$$

(بحيث انه يكون اعلى مشتقة لوحدها تماماً)

$$V_o'' = 2V_{in} - V_o' - 2V_o$$

تابع





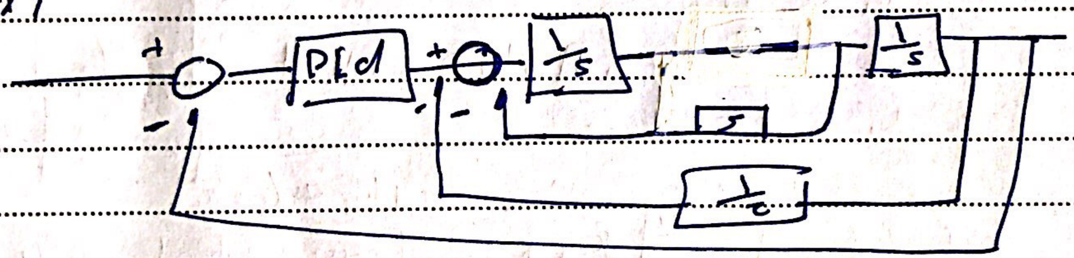
في التوصيل

لو نه ال summing Point

تعامل كل واحد سالب

لذلك بعمل تجزئ

Ex1



وحل

الحل في الصفحة التالية

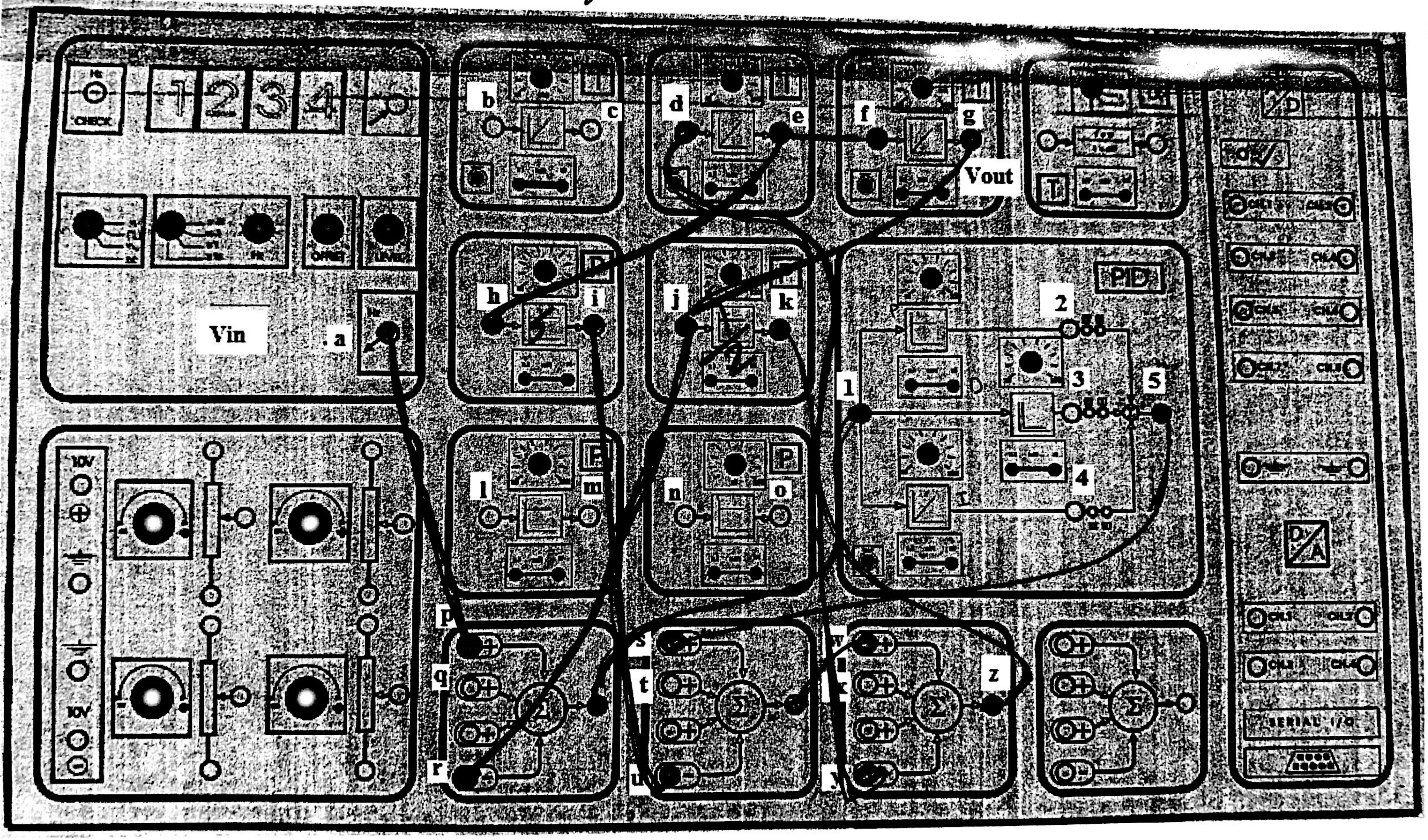
Ex2 $T_s = \dfrac{3}{2s^2+s+1}$ draw the Block diagram

وحل

$$\frac{V_{out}}{V_{in}} = \frac{3}{2s^2+s+1}$$

$\Rightarrow 2s^2 V_{out} + s V_{out} + V_{out} = 3 V_{in}$

Ex 1

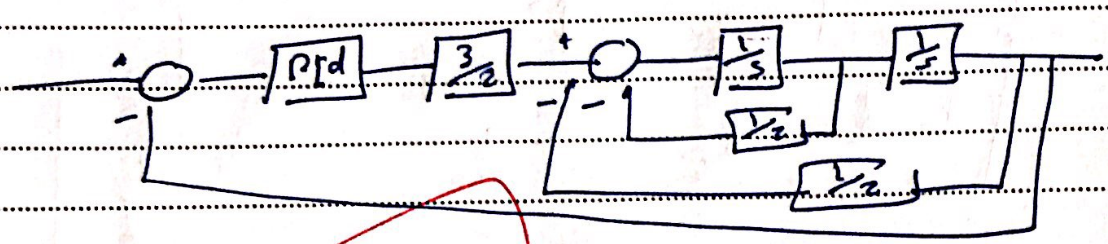


CHECK
1
2
3
4
Vin
a
b
c
d
e
f
g
Vout
h
i
j
k
l
m
n
o
p
q
r
s
t
u
w
x
y
z
1
2
3
4
5
PID
10V
SERIAL I/O

25-A

$2 v_o'' + v_o' + v_o = 3 v_{in}$

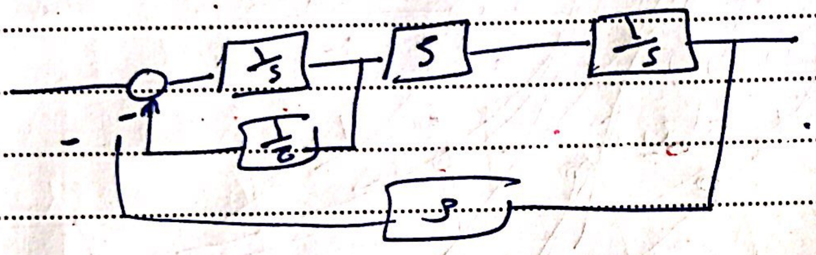
$v_o'' = \frac{3}{2} v_{in} - \frac{1}{2} v_o' - \frac{1}{2} v_o$



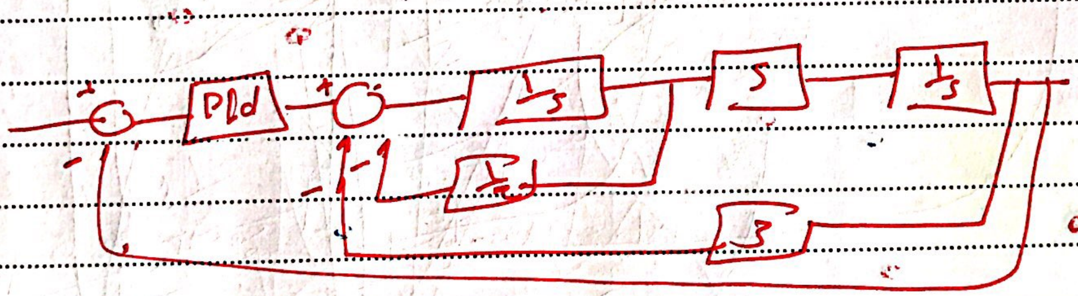
26-A التوصيل في

ملاحظة
دايماً الى داخل
Plant summing point على
vIn لا
دالخارج منها
أعلى v
مشتقة

Ex 3



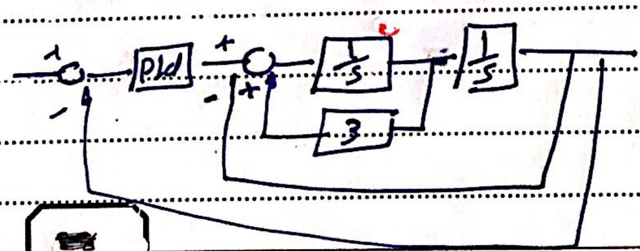
add PID controller
ثم وصل



26-B توصيل في

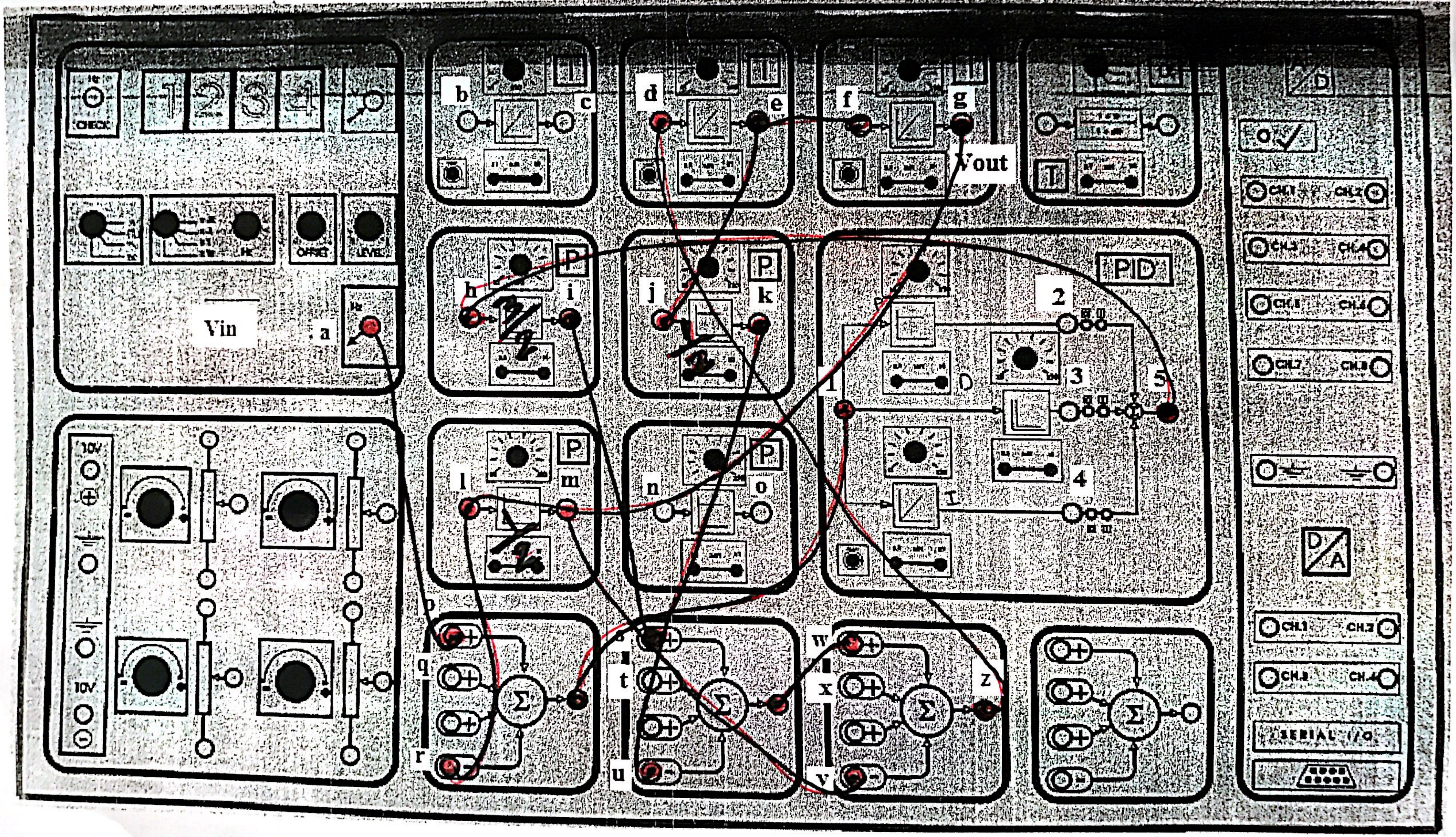
Ex 3 $y'' - 3y' + y = x$

$y'' = 3y' - y + x$

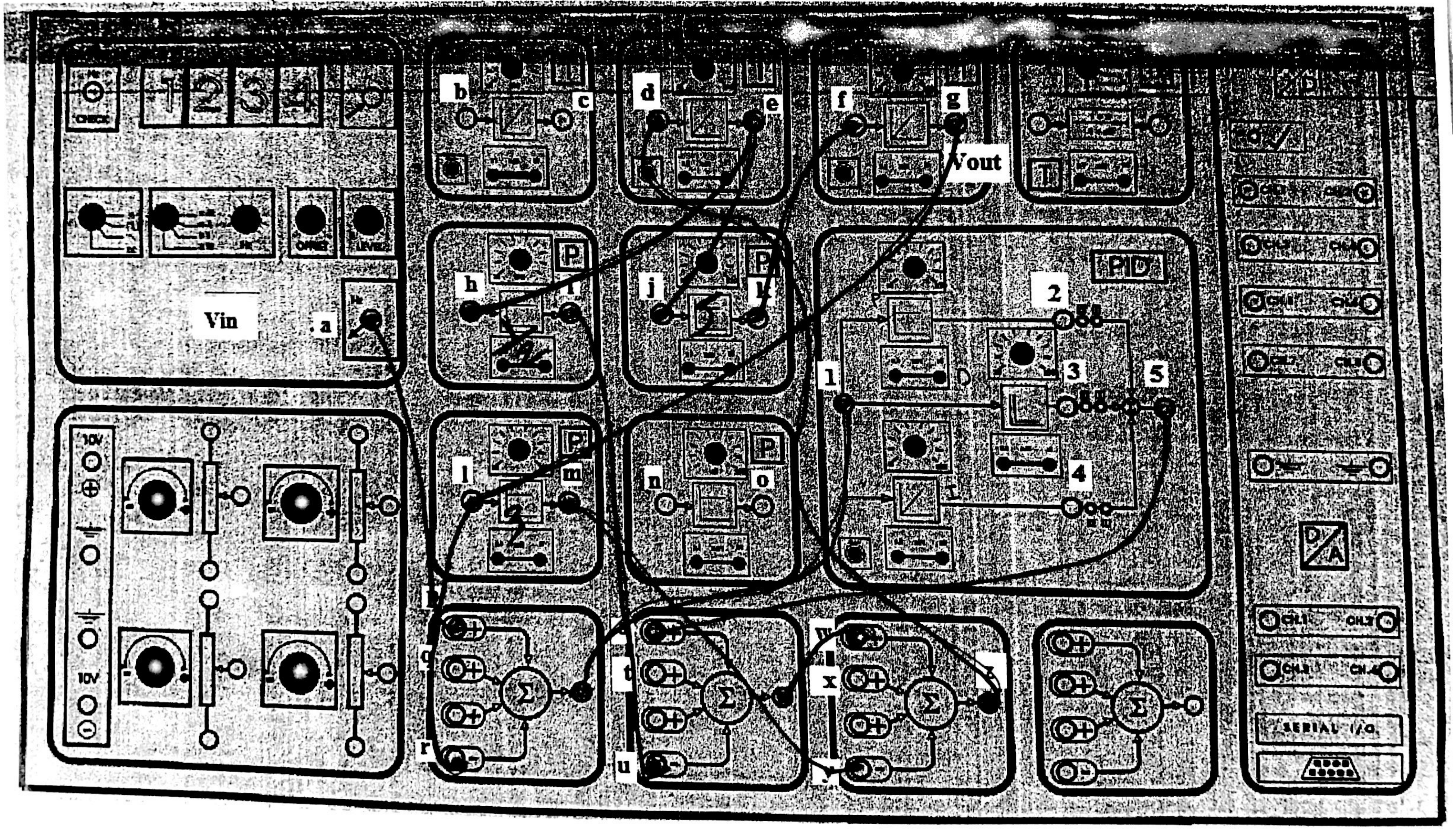


26-C توصيل في

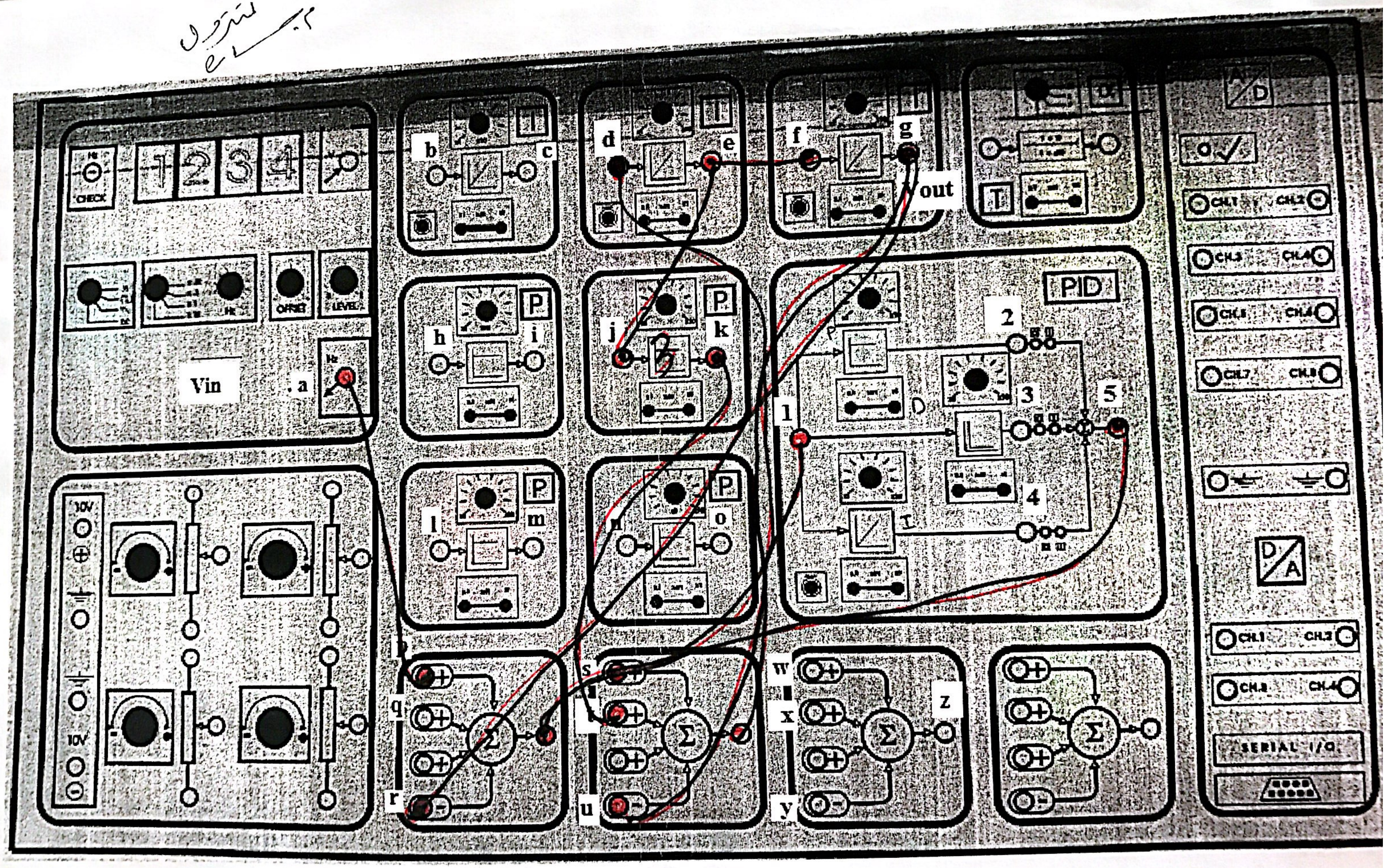
Ex 2


CHECK
1 2 3 4
OFFSET
LEVEL
Vin
a
10V
10V
b
c
d
e
f
g
Vout
h
i
j
k
PID
2
3
4
5
D
l
m
n
o
p
q
r
s
t
u
w
x
v
z
D/A
CH.1
CH.2
CH.3
CH.4
SERIAL I/O

26-A



26-B

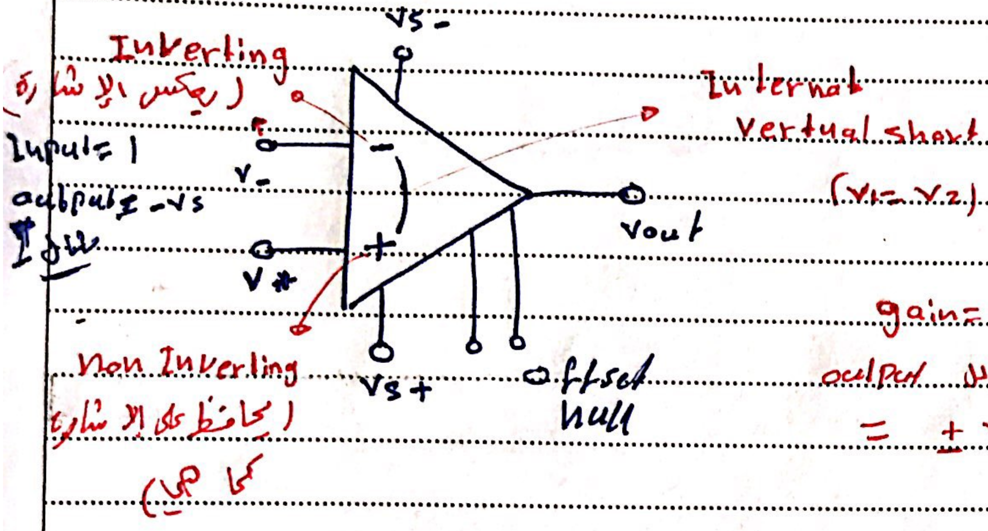


26-C

* Plant

Summing Point

Operational Amplifier.



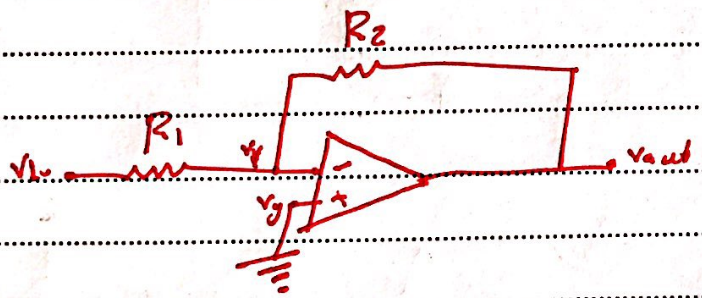
gain = ∞

يكون أكبر قيمة لل output

$= \pm V_s$

★ Ideal operational Amp has the following specifications

1) Infinite Input R
2) Zero output R
3) Infinite common mode-rejection ratio
4) Zero Input current and input voltage offset



1) $I_1, I_2 = 0$

2) $V_x = V_y = \text{Zero}$

3) KCL at each node (using nodal)

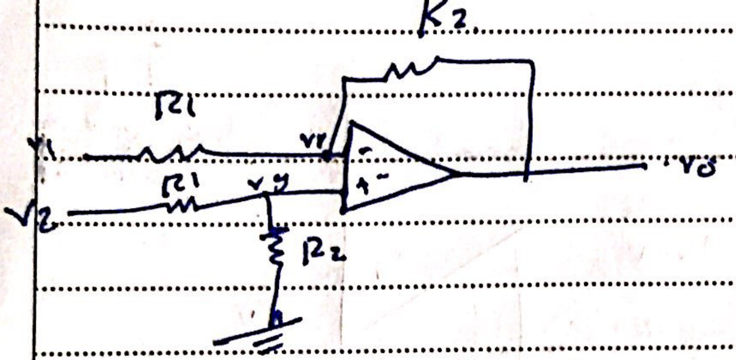
$$\frac{V_x - V_{in}}{R_1} + \frac{V_y - V_o}{R_2} = 0$$

$V_x = V_y = 0 \Rightarrow \frac{V_o}{V_{in}} = \frac{-R_2}{R_1}$

Proportional Amp

$K_p = \frac{-R_2}{R_1}$

$$\frac{v_o}{v_{in}} = \frac{-Z_{out}}{Z_{in}}$$ شكل عام



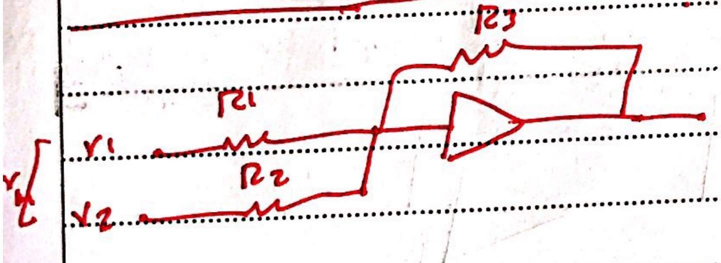
Sol

$$\frac{V_x - V_1}{R_1} + \frac{V_x - V_o}{R_2} = 0 \longrightarrow (1)$$

$$V_y = V_2 \left(\frac{R_2}{R_1 + R_2}\right) \quad * \text{ voltage division}$$

$$V_x = V_y = V_2 \left(\frac{R_2}{R_1 + R_2}\right) \longrightarrow$$ عوض في (1)

$$V_{out} = (V_2 - V_1)\frac{R_2}{R_1} \longrightarrow$$ Diffrence Amp

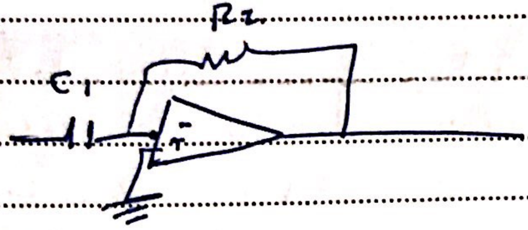


Using super Position

$$\Rightarrow \frac{V_{out}}{V_1} = \frac{-R_3}{R_1}$$

$$\frac{V_{out}}{V_2} = \frac{-R_3}{R_2}$$

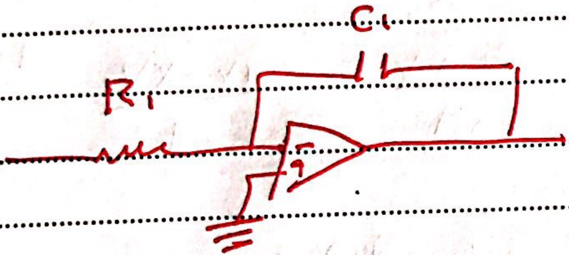
$$\Rightarrow \frac{V_{out}}{V_{in}} = -\frac{R_3}{R_1} - \frac{R_3}{R_2}$$



$$\frac{V_{out}}{V_{in}} = -R_2 C S \rightarrow \text{Drivative Amp}$$

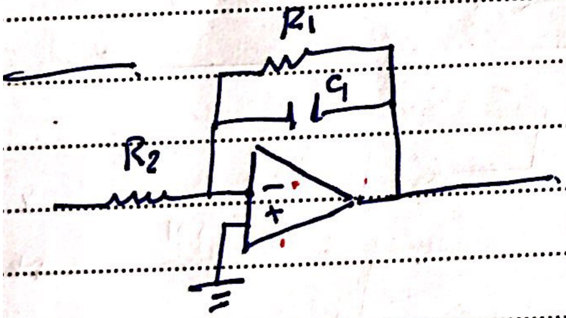
$$K_D = -R_2 C$$

(S معامل)



$$\frac{V_{out}}{V_{in}} = \frac{-1}{R_1 C_1 S} \rightarrow \text{Integral Amp}$$

$$K_I = \frac{-1}{R_1 C_1}$$



Find $\frac{V_{out}}{V_{in}} \Rightarrow \frac{V_{out}}{V_{in}} = \frac{-Z_{out}}{Z_{in}}$

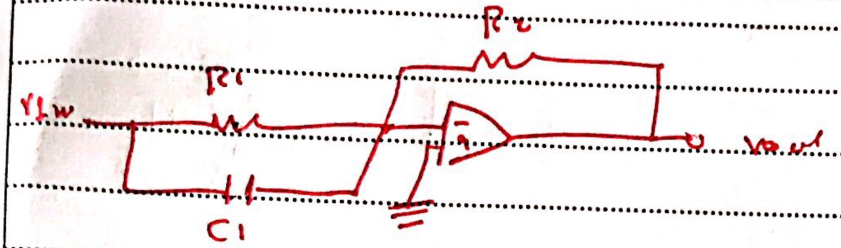
$$Z_{out} = \frac{R_1 \times \frac{1}{CS}}{R_1 + \frac{1}{CS}} = \frac{R_1}{R_1 C S + 1}$$

The genral Rorm Ror the Rirst order systom

$\tau = R_1 C \rightarrow$ كلما قلت تزيد سرعة النظام

$K = \frac{-R_1}{R_2}$

$$\frac{V_{out}}{V_{in}} = \frac{-\left(\frac{R_1}{R_1 C_1 S + 1}\right)}{R_2} \Rightarrow \frac{-R_1}{R_1 R_2 C S + R_2} \Rightarrow \frac{\frac{-R_1}{R_2}}{R_1 C S + 1}$$



$$\frac{V_{out}}{V_{in}} = \frac{-Z_{out}}{Z_{in}}$$

$$Z_{in} = \frac{R_1 \times \frac{1}{Cs}}{R_1 + \frac{1}{Cs}} = \frac{R_1}{R_1 C_1 S + 1}$$

$$\frac{V_{out}}{V_{in}} = \frac{-R_2}{\frac{R_1}{R_1 CS + 1}} = \frac{-R_2(R_1 CS + 1)}{R_1}$$

$$= \frac{-R_2 R_1 CS - R_2}{R_1}$$

$$kP = -\frac{R_2}{R_1}$$

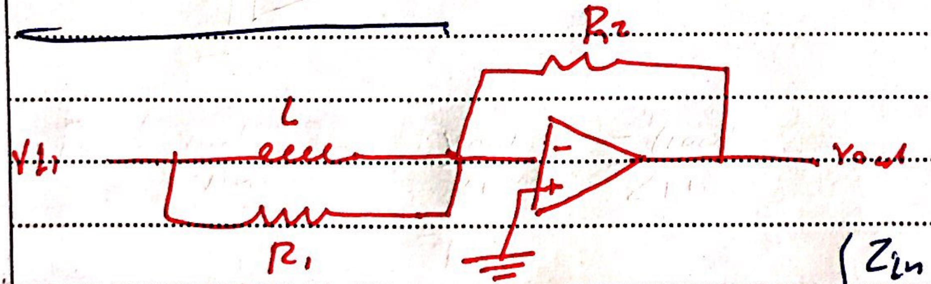
$$kD = -R_2 C_1$$

$$kI = \text{zero}$$

$Z_C = \frac{1}{Cs}$

$Z_L = Ls$

$Z_R = R$



$$\frac{V_{out}}{V_{in}} = \frac{-Z_{out}}{Z_{in}} = \frac{-R_2}{\frac{R_1 Ls}{R_1 + Ls}}$$

$$Z_{in} = \frac{R_1 Ls}{R_1 + Ls}$$

$$= \frac{-R_2(R_1 + Ls)}{R_1 L s} = \frac{-R_2 R_1 - R_2 Ls}{R_1 Ls}$$

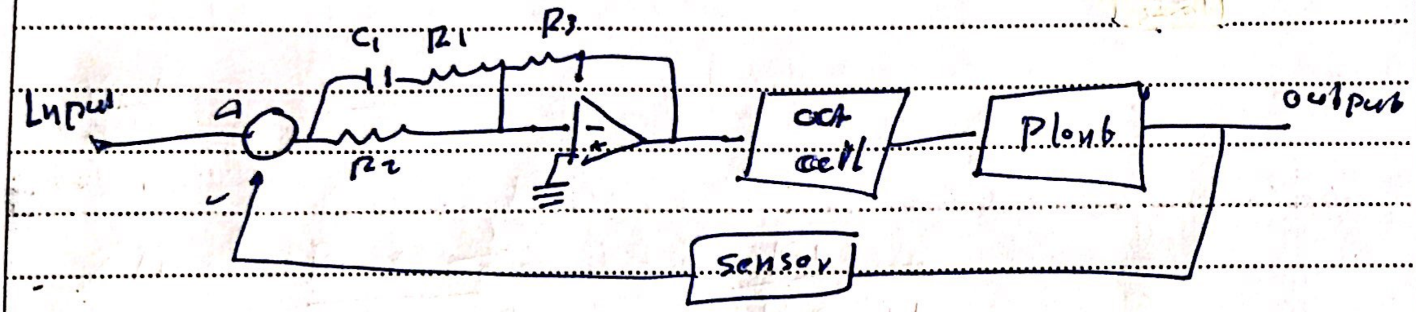
$$kP = \frac{-R_2}{R_1}$$

$$kD = 0$$

$$kI = \frac{-R_2}{L}$$

Magnetic levitation

المبدأ [voltage converted to current]



type of controller → SISO (single Input single output)

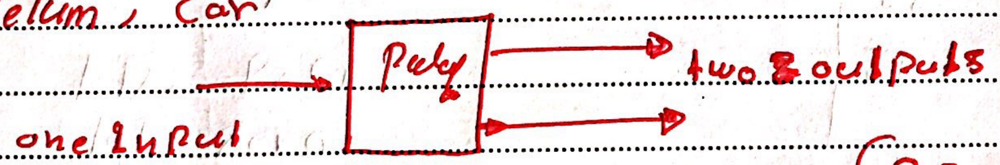
Input → magnetic force   output → Position

number of control signal = number of actuators number of Input = 1

Force
- attraction of upper pole
- repulsive at the lower pole.

---

* Pendelum, car



(SIMO)