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Process Dynamics & Control

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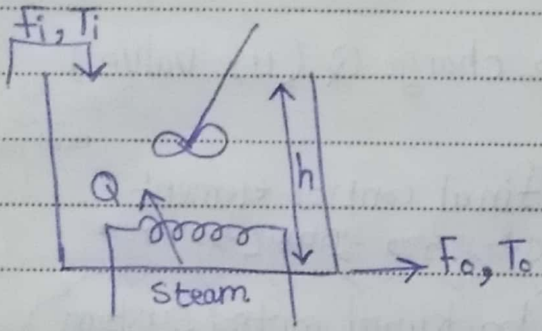
▸ Subject : .... / /

* Process :- Series of operation to utilize the resources to Produce usful Product in an economic way.

* why need Process control :-

- Safty - Quality - Quantity - economically - Optimization



Process variables :-

T_i, T_o, F_i, F_o, Q, h

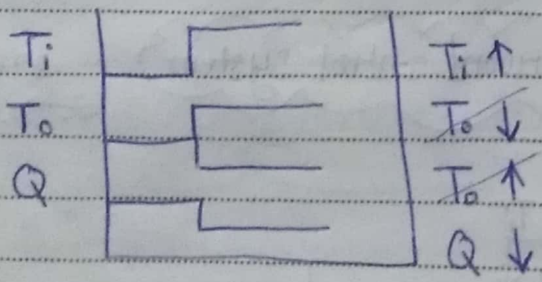
input (T_i, F_i, Q) — output (T_o, F_o, h)

*input and output :- any variables effect the system (no physical direction)

*if no change Process (st.st) no need control, if we have variables we need control.

* control objective :-

$T_o, h, f_o \Rightarrow$ ~~control of~~ we would like to control (output) variables (control variables)



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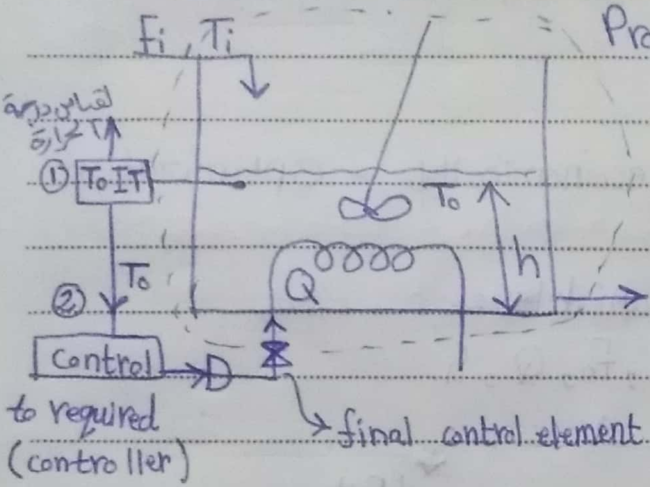
* to control To :-



Process system

① temp indicator transmeter (TIT)

③ to change Q (use valve) عبارة عن controller

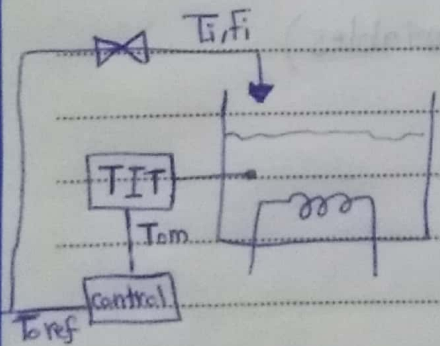
final control element

* جزء مربوط ع system وجزء مربوط ع controller

Feed backward control system

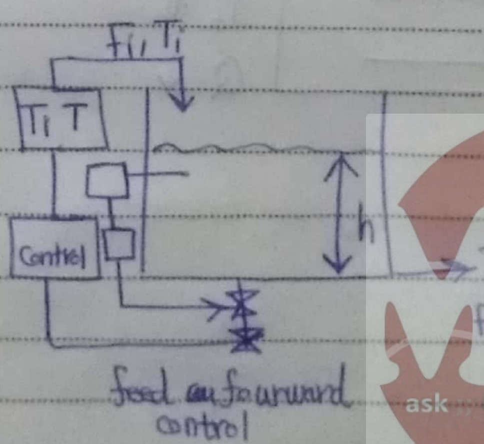
① Select the control variables
② mesuring device
③ controller
④ Final control element
⑤ manipulated variables (I change it to acheive my control). valve الـ

* the other control way ⇒ Prevention and maintanance



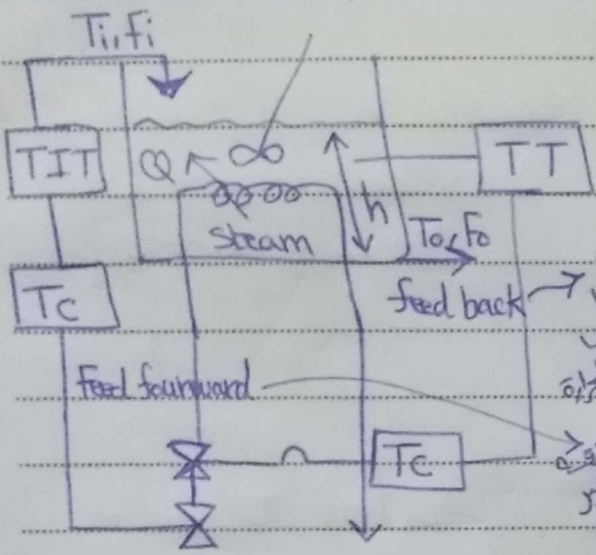
feed fourward control system

التنوع تحذير مسبق



Subject :

* We can combound feed back and fourward



يصلح بدون ما يعرف السبب تغير درجة الحرارة

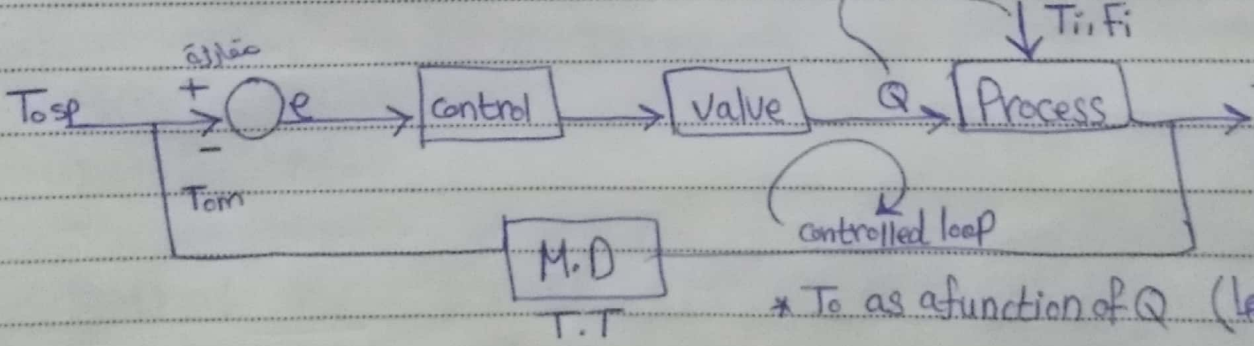
ما إله علاقة بأي متغير غير درجة الحرارة

* To effective by Ti, fi

* P&ID بنحوله → Block diagram

Disturbances (ما بقدر اتحكم فيهم)

manipulated variable (أنا بغيرها فقط وبتحكم عنها)



it is our control variable

* To as a function of Q (بيلش من عندها)

* لازم نيسكر الـ block diagram

* The dynamic modeling (unsteady state)

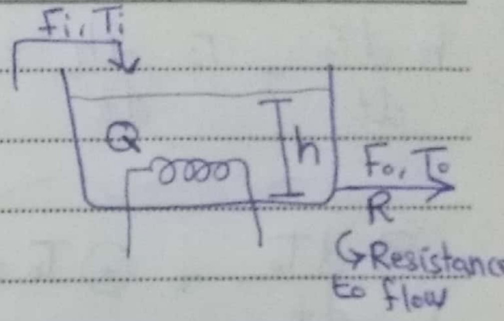
theoretical
(Analytical Analysis)

Experimental
(Just is valid at this Process or condision) (not general)

* mass balance, energy balance, momentum + rate equation + thermodynamic
→ D.E or P.D.E

* mass balance

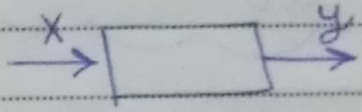
$$\frac{d[\rho A h]}{dt} = \rho_i f_i - \rho_o f_o$$



$\rho A h = \rho V = m$

f:- volumetric flowrate

assume ρ constant $\Rightarrow$ A constant



$y = ax^2 + bx + c$

$$A\frac{dh}{dt} = f_i - f_o$$

$F_o = \frac{h}{R}$, R:- resistance to flow (constant)

$$AR\frac{dh}{dt} + h = Rf_i \rightarrow \boxed{1}$$

* h only dependent on f_i
* input function in output

* Energy balance

$$\frac{d[\rho A h [T_o - T_{ref}] c_p]}{dt} = \rho_i c_p f_i (T_i - T_{ref}) - \rho_o c_{p_o} f_o (T_o - T_{ref}) + Q$$

assume $T_{ref} = 0$, (ρ, c_p, A) constant

$$\frac{A \rho c_p d[hT_o]}{dt} =$$

$$\frac{d[hT_o]}{dt} = \frac{1}{A} f_i T_i - \frac{1}{A} f_o T_o + \frac{Q}{A\rho c_p}$$

Subject: .... / /

$$h\frac{dT_o}{dt} + T_o\frac{dh}{dt} = \frac{1}{A} f_i T_i - \frac{f_o T_o}{A} + \frac{Q}{\rho A c_p}$$

$$\circledast\frac{dT_o}{dt} + \circledast T_o = \circledast T_i + \circledast f_i + \circledast Q \rightarrow \boxed{2}$$

* لازم كل input يظهروا بالمعادلة

* $\boxed{1}$ and $\boxed{2}$ equation dynamic model

• the first step

* deviation form (deviation from steady state)

• the second step

$$x \rightarrow \boxed{\text{Transfer function}} \rightarrow y$$

* حتى أوصل لـ deviation form نطرح معادلتي من steady state

$$AR\frac{dh}{dt} + h = Rf_i$$

$$-\quad 0 + h_{ss} = Rf_{iss}$$

$$AR\frac{d(h-h_{ss})}{dt} + (h-h_{ss}) = R(f_i - f_{iss})$$

Let :- $h - h_{ss} = h'$

$f_i - f_{iss} = f_i'$

$$AR\frac{dh'}{dt} + h' = Rf_i'$$ deviation form

Laplace transfer :- it transfer L.D.E to Algebric equation

* initial conditions are zero

$$\rightarrow \boxed{TF} \rightarrow$$

$L\ y(t) = y(s)$

$L\ y(t-\theta) = e^{-\theta s}\, y(s)$

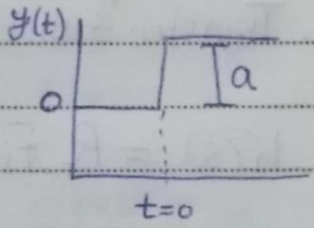
$L \dfrac{dy}{dt} = s\, y(s) - y(0)$

$L \int y(t)\, dt = \dfrac{1}{s}\, y(s)$

1. Step function

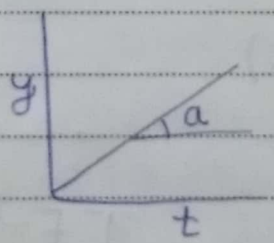
$y(t) = 0 \quad t \leq 0$

$y(t) = a \quad t > 0$



$L\ \text{step} = \dfrac{a}{s}$

2. Ramp function



$L[y = at] = \dfrac{a}{s^2}$

* Final value Theorm

$y(s) = \ldots$

$y(s) = L\ y(t)$

$y(s) = \ldots$,

$y(t) = L^{-1}\ y(s)$

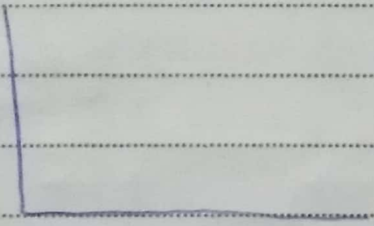
$y(t)_{\infty} = \lim_{s \to 0} s\, y(s)$

↳ final value (steady state value)

Subject: .... / /

* Initial value Theorem

$y(t_0) = \lim_{s \to \infty}$



$L\left[AR\frac{dh'}{dt} + h' = Rf_i'\right]_L \rightarrow$ Transfer function

$AR[s\,h'(s) - h'(0)] + h'(s) = R\,F_i'(s)$

$AR\,s h'(s) + h'(s) = Rf_i'(s)$

$h'(s)[ARS+1] = R\,f_i'(s)$

$\frac{h'(s)}{f_i'(s)} = \frac{R}{ARS+1}$ T.F $\rightarrow$ Relation ~~an~~ between Laplace transfer input with Laplance change transform in the output

$f_i'(s) \rightarrow \boxed{\frac{R}{ARS+1}} \rightarrow h'(s)$

$\frac{h'(s)}{f_i'(s)} \neq \frac{h'(t)}{f_i'(t)}$

$G(s) = \frac{h'(s)}{f_i'(s)} = \frac{R}{ARS+1}$

▶ Subject : .... / /

$$\frac{h}{F_i} = \frac{R}{ARS+1}$$

$$\boxed{h(s) = \frac{R}{ARS+1} * f_i(s)}$$

* first order system.

- what is first order system? system described by a 1st order D.E

$$a_0 \frac{dy(t)}{dt} + a_1 y(t) = b X(t)$$

* لما ما اكتب (-) بعرف انها deviation form

وبعدين بوخذ L

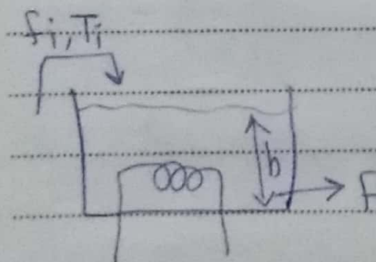
$$\frac{a_0}{a_1}\left[s\, y(s) - \cancel{y(0)}\right] + y(s) = \frac{b}{a_1} X(s)$$

$$y(s)\left[\frac{a_0}{a_1} S + 1\right] = \frac{b}{a_1} X(s)$$

$$\boxed{G(s) = \frac{y(s)}{X(s)} = \frac{b/a_1}{\frac{a_0}{a_1} S + 1}}$$

* standered form of the T.F of 1st order system.

* Polynomial (S) first degree
* two constant



$$L\left[AR \frac{dh}{dt} \pm h = R f_i\right]$$

$$[ARS+1]\, h(s) = R f_i \Rightarrow \boxed{G(s) = \frac{h(s)}{F_i(s)} = \frac{R}{ARS+1}}$$

constant

1st order

K :- steady state gain

T :- time constant

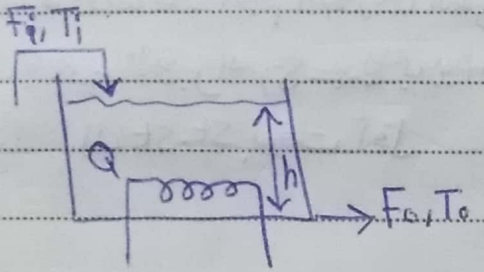
$$= \frac{K}{\tau S + 1}$$

S T A R S N O T E B O O K

Subject : .... / /

* first order system

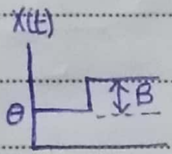
$$G(S) = \frac{K}{\tau S+1} \qquad AR\frac{dh}{dt} + h = RF_i$$

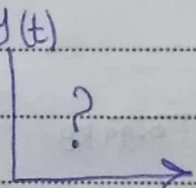


$$G(s) = \frac{h(s)}{f_i(s)} = \frac{R}{ARS+1} = \frac{K}{\tau S+1}$$

$$X(s) \rightarrow \boxed{\frac{K}{\tau S+1}} \rightarrow y(s)$$

X (t) step change



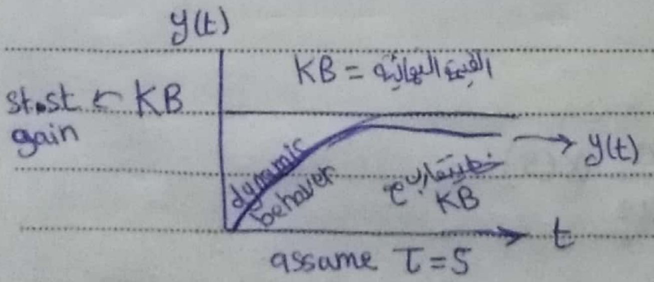


$$y(S) = \frac{K}{\tau S+1} * X(S) = \frac{K}{\tau S+1} * \frac{B}{S}$$

$$\frac{y(S)}{X(S)} = \frac{K}{\tau S+1}$$

$$y(t) = L^{-1}\, y(s) = L^{-1}\left[BK / S(\tau S+1)\right]$$

$$y(t) = KB\left[1 - e^{-t/\tau}\right]$$ its the response of 1st order system.



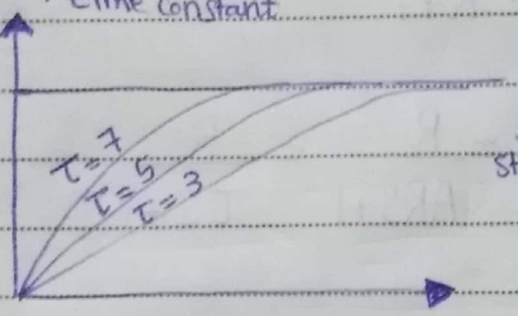
at t=0, y=0

at t=∞, y=KB

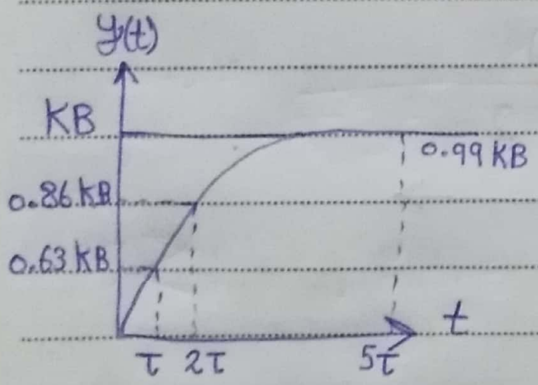
Subject :

if $\tau = 3, 5, 7$

↳ time constant



* كل ما كان القيم أصغر من المفروض
يبتدي التغير أسرع ← يعني يوصل
الـ st.st بوقت أقل



* بغير (KB and τ)
لما أغير ← R and A
∴ بغير Physics
of system.

* Second order system :-

$$a_0 \frac{d^2y}{dt^2} + a_1 \frac{dy}{dt} + a_2 y = b X(t)$$

$$L\left[\frac{a_0}{a_2}\frac{d^2y}{dt^2} + \frac{a_1}{a_2}\frac{dy}{dt} + y = \frac{b}{a^2} x(t)\right]$$

$$\frac{a_0}{a_2}\left[s^2 y(s) - \cancel{\dot{y}(0)}^{\,0} - \cancel{y(0)}^{\,0}\right] + \frac{a_1}{a_2}\left(s\, y(s) - \cancel{y(0)}^{\,0}\right)$$

$$+ y(s) = \frac{b}{a_2} X(s)$$

$$\frac{a_0}{a_2} s^2 y(s) + \frac{a_1}{a_2} s\, y(s) + y(s) = \frac{b}{a_2} X(s)$$

$$y(s)\left[\frac{a_0}{a_2} s^2 + \frac{a_1}{a_2} s + 1\right] = \frac{b}{a_2} X(s)$$

Subject : .... / /

$$G(S) = \frac{y(S)}{X(S)} = \frac{b/a_2}{\frac{a_0}{a_2}S^2 + \frac{a_1}{a_2}S + 1}$$

* standered form of 2nd order system
* 3 constant

مقام من الدرجة الثانية
* في حال كان ٣ بدل ١ نقسم كل الحدود على ٣ عشان يصير ١

$$G(S) = \frac{y(S)}{X(S)} = \frac{K \rightarrow \text{st.st gain}}{S^2\underbrace{\tau^2}_{\text{time constant}} + 2\underbrace{\xi}_{\text{damping factor}}\tau S + 1}$$

$$y(t) = L^{-1}\, y(S) = L^{-1}\left(\left[\frac{K}{\underbrace{S^2\tau^2 + 2\xi\tau S + 1}_{\text{عبارة تربيعية}}}\right] * X(S)\right)$$

$$Ay^2 + By + C = 0$$

$$y_{1,2} = \frac{-B \pm \sqrt{B^2 - 4ac}}{2A}$$

$$\tau^2 S^2 + 2\xi\tau S + 1 = 0$$

$$S_{1,2} = \frac{-2\xi\tau \pm \sqrt{(2\xi\tau)^2 - 4\tau^2}}{2\tau^2}$$

$$S_{1,2} = \frac{-2\xi\tau \pm 2\tau\sqrt{\xi^2 - 1}}{2\tau^2}$$

$$S_{1,2} = \frac{-\xi}{\tau} \pm \frac{\sqrt{\xi^2 - 1}}{\tau}$$

$\xi > 1 \rightarrow$ 2 Real Different Roots

$\xi = 1 \rightarrow$ " " equal "

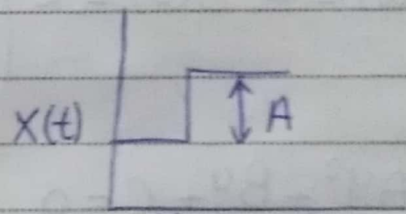
$\xi < 1 \rightarrow$ 2 complex Roots $\rightarrow L^{-1}y(t) = \ldots$ Sin – cos

$$y(s) = \frac{K}{(\quad)(\quad)} \, x(s)$$

$$X(s) \longrightarrow \boxed{\frac{K}{\tau^2 s^2 + 2\xi\tau s + 1}} \longrightarrow y(s)$$

$$y(s) = \frac{K}{\tau^2 s^2 + 2\xi\tau s + 1} * \frac{A}{s}$$

$\xi < 1$, $y(t) = \text{-- } \sin \text{ --- } \cos \text{ -}$

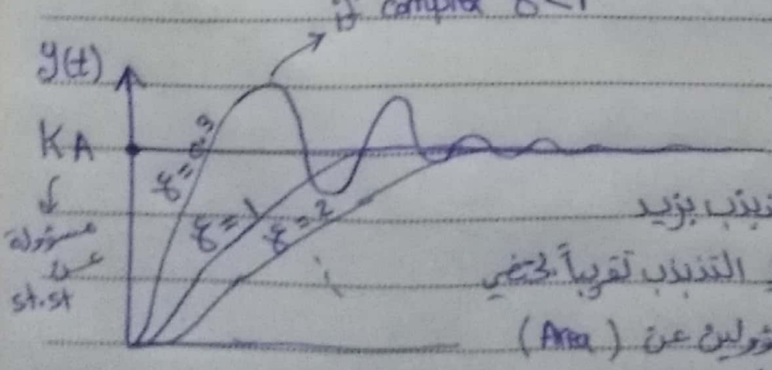


$$X(s) = \frac{A}{s}$$

$$y(t)_\infty = \lim_{s \to 0} s\, y(s)$$

$$y(t) = \lim \cancel{s}\left[\frac{K}{\tau^2 s^2 + 2\xi\tau s + 1} * \frac{A}{\cancel{s}}\right] = KA$$

$$y(t)_0 = 0$$

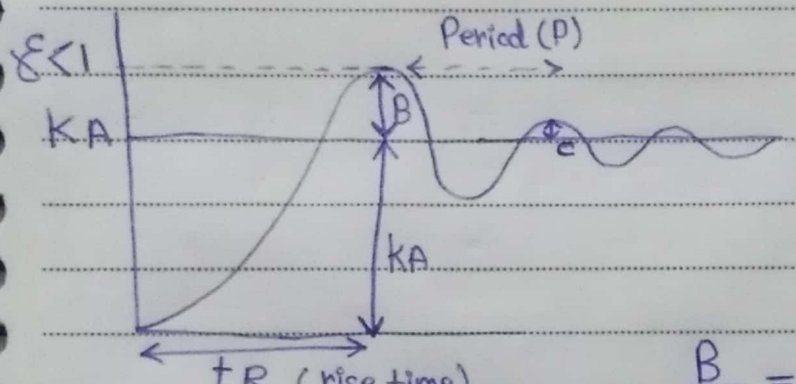


* كل ما قلت ξ التذبذب يزيد
* لما تقترب ξ من 1 التذبذب تقريباً يختفي
* τ و ξ ⇐ مسؤولين عن (Area)
لحد KA
* أما ξ هي اللي ممكن توجلي ال Area
يلي بعد KA

$\xi < 1$ underdamped

$\xi = 1$ critically damped

$\xi > 1$ overdamping



$y(t) = \ldots$

$\frac{dy}{dt} = 0$

$\frac{B}{K_A}$ = overshoot = $\exp\left(\frac{-\pi\xi}{\sqrt{1-\xi^2}}\right)$

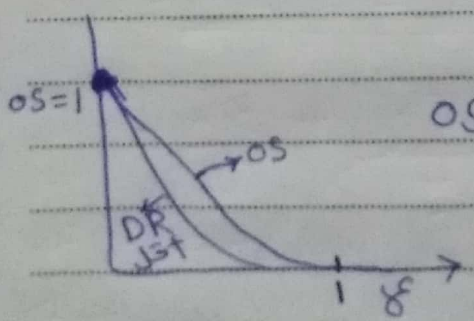
ratio between one ~~peak~~ Peak and two Peak $\Rightarrow$ يدل على سرعة الاختفاء

$$\frac{C}{B} = \text{Decay Ratio} = \exp\left(\frac{-2\pi\xi}{\sqrt{1-\xi^2}}\right)$$

$DR = (OS)^2$

Decay Ratio ↳ overshoot

$$P = \frac{2\pi\tau}{\sqrt{1-\xi^2}}$$



$$OS = \exp\left(\frac{-\pi\xi}{\sqrt{1-\xi^2}}\right)$$

$$DR = (OS)^2$$

* OS ↑, ξ ↓
* min value $\xi = 0$
* at $\xi = 1$, OS = 0

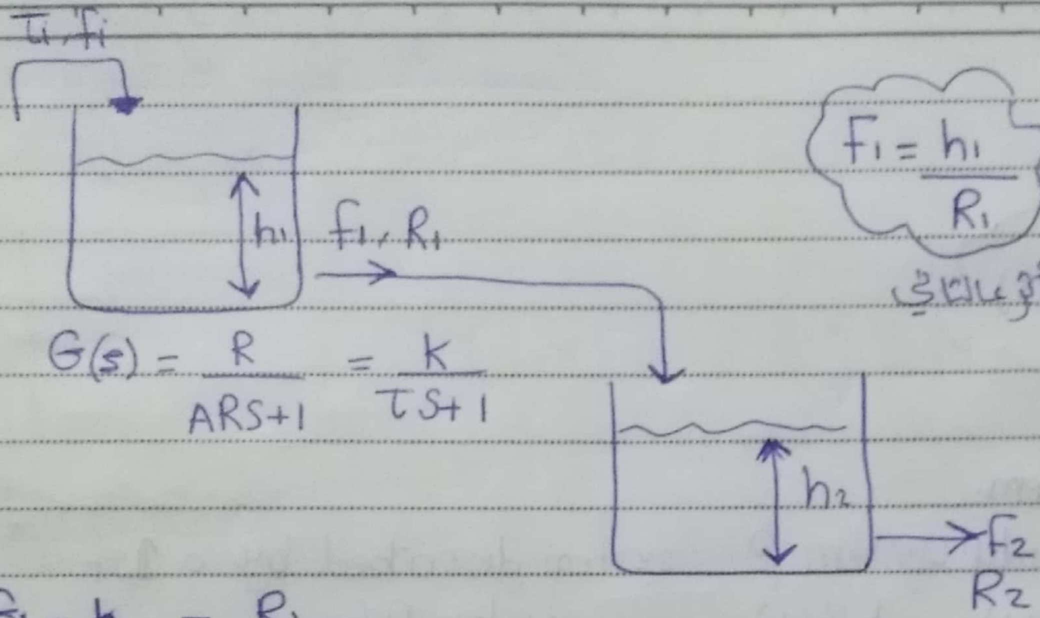
max value OS = 1

min value " = 0

$DR = (OS)^2$

$= (0.5)^2 = 0.25$

▸ Subject : .... / /



$$f_1 = \frac{h_1}{R_1}$$

* هون الـ tank الأول بأثر عالتاني والعكس غير صحيح

non-interacting system

$$G(s) = \frac{R}{ARS+1} = \frac{K}{\tau S+1}$$

$$G_1 = \frac{h_1}{f_i} = \frac{R_1}{A_1R_1S+1}$$

$$G_2 = \frac{h_2}{F_1} = \frac{R_2}{A_2R_2S+1}$$

$$\frac{h_2}{f_i} = \frac{h_1}{f_i} * \frac{h_2}{f_1} \quad , \quad f_1 = \frac{h_1}{R_1} \quad , \quad R \text{ constant}$$

$$\frac{h_2}{f_i} = \frac{\cancel{h_1}}{f_i} * \frac{h_2}{\cancel{h_1}}$$

$$= \frac{R_1}{AR_1S+1} * \frac{R_2}{A_2R_2S+1}$$

$$= \frac{R_1 R_2}{(A_1R_1S+1)(A_2R_2S+1)}$$

$$= \frac{k_1 k_2}{(\tau_1 S+1)(\tau_2 S+1)}$$

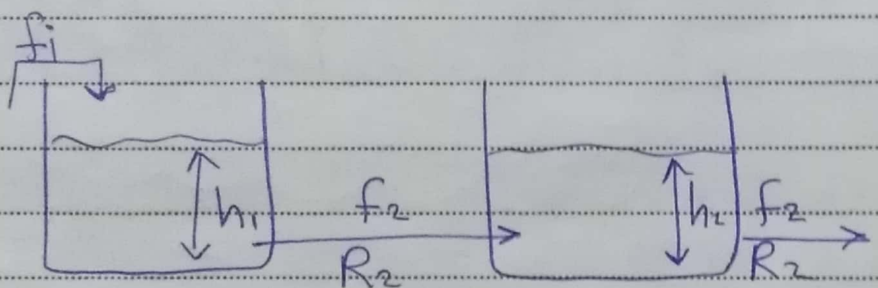
Subject : * 2nd order deravitave
2nd system

$$= \frac{K}{\tau^2 S^2 + 2\zeta\tau S + 1}$$

$$\tau = \sqrt{\tau_1 \tau_2} \qquad \zeta = \frac{\tau_1 + \tau_2}{2\sqrt{\tau_1 \tau_2}}$$

$\tau_1 = A_1 R_1$, $\tau_2 = A_2 R_2$
$K_1 = R_1$, $K_2 = R_2$

* how can I increase zeta



* مستحيل h_2 تكون أكبر من h_1
لانه h_1 هي ال driving force

$$f_1 = \frac{h_1 - h_2}{R_1}$$

* $h_1 - h_2 = 0$
معناته ال tank 2
متساويين
وما عندنا flow

mass balance of tank 1 :-

$$A_1 \frac{dh_1}{dt} + h_1 = f_i - f_1$$

$$* \quad A_1 \frac{dh_1}{dt} + h_1 = f_i - \frac{h_1 - h_2}{R_1}$$

* هدول ال 2 tank
أثروا ببعض
interacting system

mass balance of tank 2 :-

$$A_2 \frac{dh_2}{dt} = \frac{h_1 - h_2}{R_1} - \frac{h_2}{R_2}$$

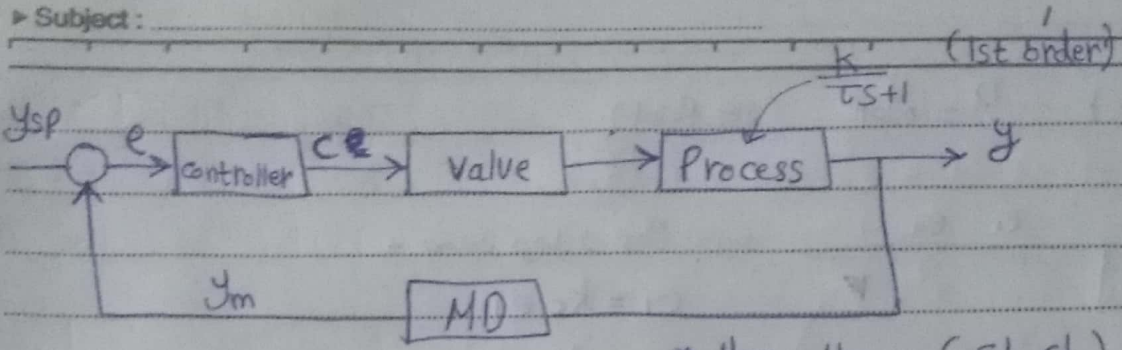
$$\frac{h_2}{f_i} = \frac{K_1 K_2}{\tau_1 \tau_2 S^2 + (\tau_1 + \tau_2) S + 1}$$ for system 1

$$\frac{h_2}{f_i} = \frac{?}{\tau_1 \tau_2 S^2 + \left((\tau_1 + \tau_2) + A_1 R_2\right) S + 1}$$ for system 2

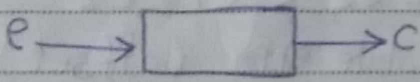
جزء من system الأول
وجزء من system الثاني

interaction coeff

Subject:



* $y_{sp} = y_m$ (st.st) error = 0
* if Process at st.st controller doesn't work. $e(t) = 0$



$C(t) = K_c e(t)$ ⟶ أبسط علاقة * مابتوصف العملية بالبداية

Proportienal controller

$$\boxed{c(t) = K_c\, e(t) + \bar{c}}$$ Simulate the actual Process

change بيشتغل الـProcess لما يكون عندي

diviation from st.st ($\bar{c} = 0$)

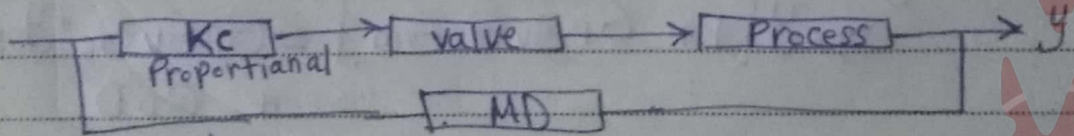
$$\boxed{c(t) = K_c\, e(t)}$$

Laplac transform

$L[\bar{c}(t) = K_c\, \bar{e}(t)]$

$\bar{c}(s) = K_c\, e(s)$

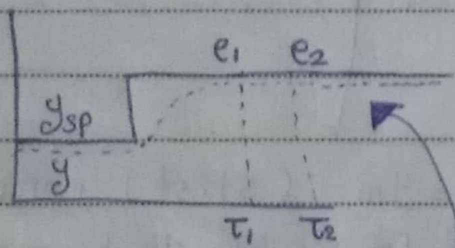
$$\boxed{G_c(s) = \frac{c(s)}{e(s)} = K_c}$$ Proportional controller



- dynamic Part ا-كاباتي
* response similtanouse (very fast controller)
* Simple and cheape

Scanned with CamScanner

at St.st $y = y_{sp}$ (set Point)



- بحاول يوصل لـ y_{sp} الجديدة

$c_1 = K_c e_1$

$c_2 = K_c e_2$

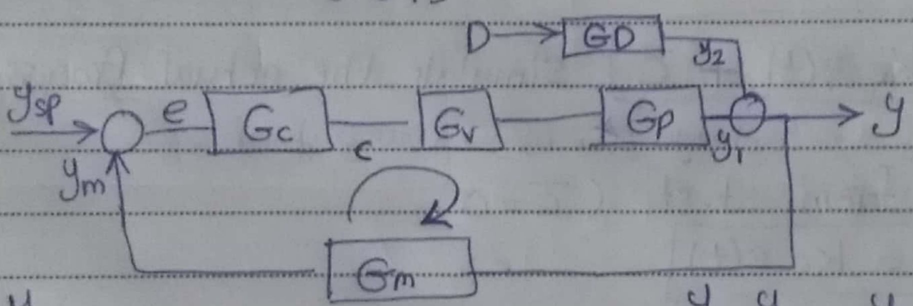
if $e_1 = e_2 \rightarrow c_1 = c_2$

Steady state error (offset)

depend on
* resulution

الدقة قليلة فبالتالي يعطي عندي error (offset)

not detected   0.01
0.015 $\rightarrow$ 0.01



$\frac{y}{y_{sp}}$ - $\frac{y}{D}$

$y = y_1 + y_2$
$= G_p * m + G_D * D$
$= G_p G_v C + G_D D$
$= G_p G_v G_c * e + G_D D$
$= G_p G_v G_c [y_{sp} - y_m] + G_D D$
$= G_p G_v G_c y_{sp} -$
$G_p G_v G_c G_m * y + G_D D$

* Characteristic of the system
* not dependent on change

$\Rightarrow y[1 + G_p G_v G_c G_m] = G_p G_v G_c * y_{sp} + G_D D$

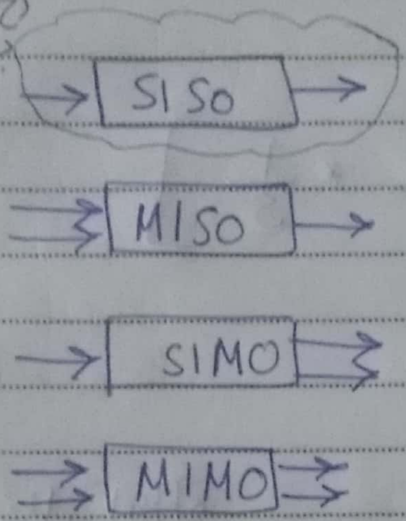
closed loop T.F

$$y = \frac{G_c G_v G_p}{1 + G_c G_v G_p G_m} * y_{sp} + \frac{G_D}{1 + G_c G_v G_p G_m} * D$$

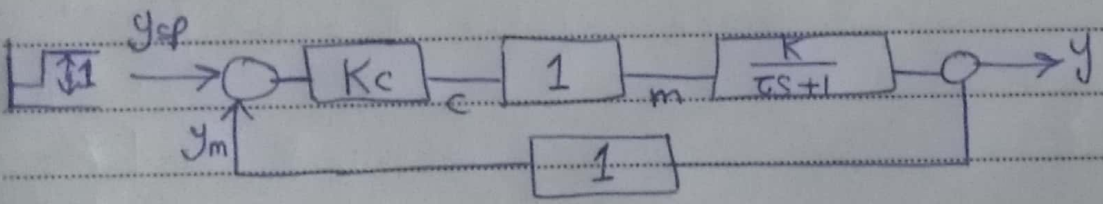
$1 + G_c G_v G_p G_m = 0$ characteristic equation

ومسمناها أبلش الحل

* النظام مكون من T.F يلي داخل loop



(Single input singk outPut)

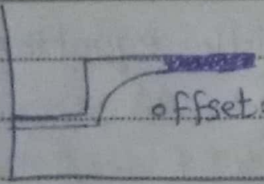


$$y = \frac{K_c * 1 \left(\frac{K}{\tau S+1}\right)}{1 + K_c * 1 * \frac{K}{\tau S+1} * 1} * \frac{1}{S}$$

$$y = \frac{\frac{K_c K}{\tau S+1}}{\frac{\tau S+1 + K_c K}{\tau S+1}} * \frac{1}{S}$$

$$\cancel{y = \frac{K_c K}{\tau S+1}}$$

$$y = \frac{K_c K \,(1+K_c K)}{\frac{\tau}{1+K_c K} S+1} * \frac{1}{S}$$



offset = new set Point − $y(t)_\infty$
1 −

$$y(t)_\infty = \lim_{s\to 0} y(s)$$

$$y(t)_\infty = \lim_{s\to 0} \cancel{s}\left[\frac{K_cK/1+K_cK}{\frac{\tau}{1+K_cK}s+1} * \frac{1}{\cancel{s}}\right]$$

offeset = new y_{sp}

$y_{sp} \propto \frac{1}{K_c}$

$$\boxed{\text{offset} = \frac{1}{1+K_cK}}$$

* زيادة Kc بتقل offset
لكن ما بقدر أزيد Kc كثير
لانو بأدي لل un.st.st