why control?

Control :- operate under known & specified conditions.

① safety :- (environment, process, - - -)

② operability :- certain conditions are required by chemistry & physics for the desired reactions.

③ Economic : → plants are expensive & intended to make money

→ final products must meet market requirment of purity otherwise they will be un-saleable.

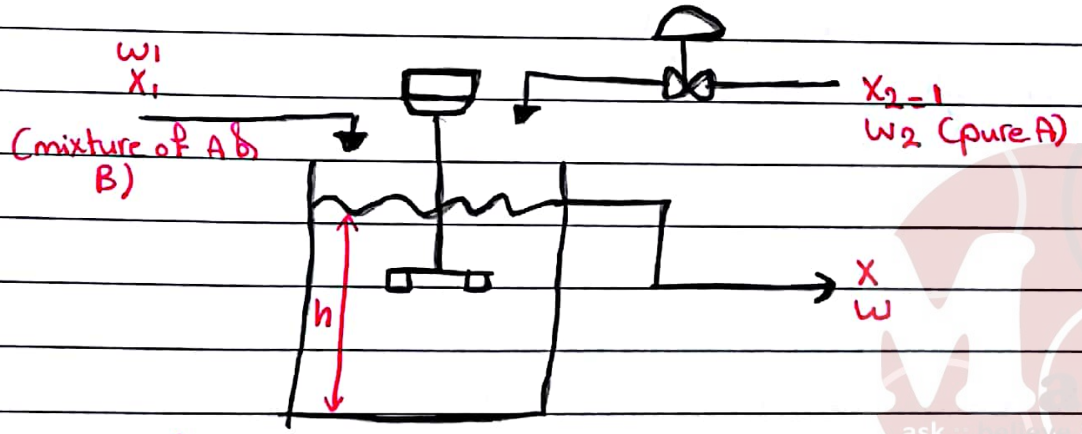
→ Conversely the manufacture of an excessively pure product will inviove un necessary cost.

process :- refers to a physical or chemical change of matter or conversion of energy.

process variables :-

- Inputs
- outputs

* Any thing const. it's not our objective in control, but we can use them in our calculations.



W_1, W_2 & W → mass flow rate

X_1, X_2 & X → mass fraction of component A

Control

*Speed of mixing: could be variable or not

* Hight :- constant   عنده ال Outlet :
as an over flow.

* Cross sectional area :- constant

* mass flow rate :- variable ~~[illegible]~~

* mass fraction :- variable (x_1, x) while x_2 is constant.

* We always concern with variables not with constants!

* we call constants ⇝ "process parameters".

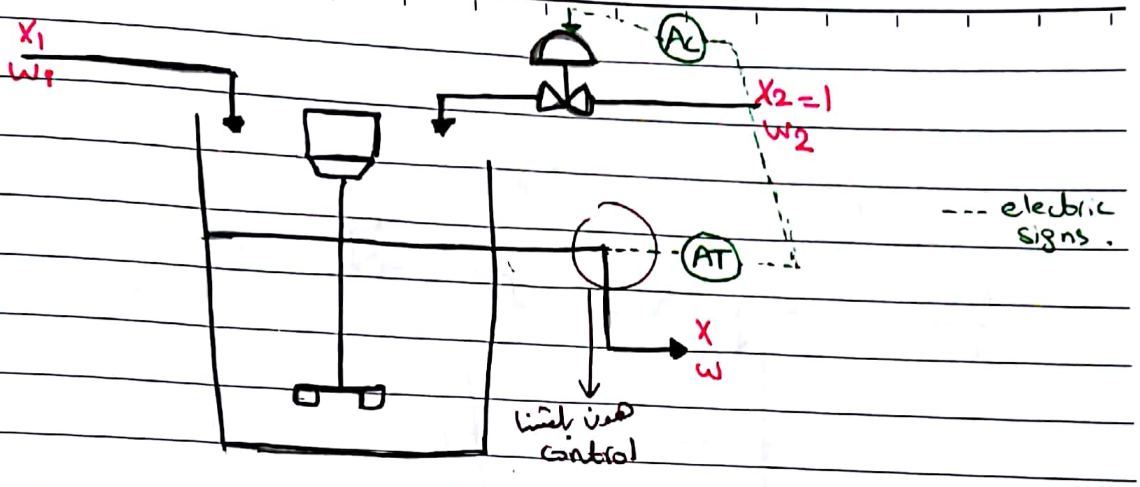
w_1 → هي مُتغيرة
(w_2, w) مشان هيك
بيتغيروا بناءً على ال
overall balance.

Inputs :- x_1 , w_1 , w_2 --→ they are variables.
Outputs :- X , w .

what should we control?
our control objective is X or w
عادةً بيكونوا هم ال (outputs).
وبعد ما احدد ال objective لازم أحدد الكونترول اللي
بتوصلني ال (target) تبعي وهي بتكون
(My control system)

Five Apple

Control



AC: composition controller

AT: Composition anylazer / transmitter.

المفروض يقارن القراءة اللي مسناها مع الـ desired أو الـ required value

it's call (set point) → the value you sit it!

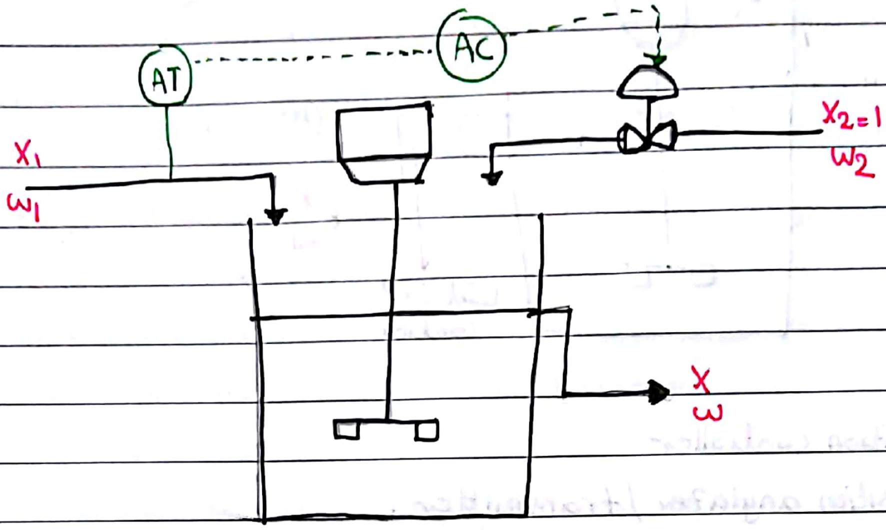
We should :- ① identify our control variables
② our measuring device.
③ ناخذ قراءة لـ element آخر
مشان يعمل control.

*Elements of our control system :-

① control variables w
② measuring devices AT
③ Controller AC
④ final control element. Valve
⑤ manipurated variable W_2 → اللي بنغيره احنا.

دائماً بيكون واحد من الـ inputs

There is a deviation of conc. occured → so I should do correction.



* Elements of control system :-

① Control variable W_1, X_1 — المفروض (x) بس هو indirect.
② measuring device AT
③ controller AC
④ final control element control valve
⑤ manipurated variable. W_2

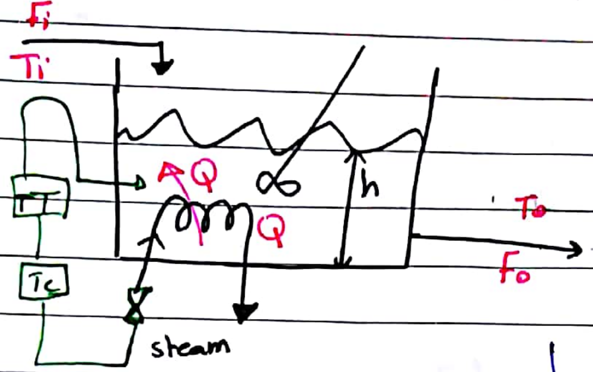
indirect → depends on Calculated value of outputs.

فهون انا بحسب لـ Outputs مالي قبل بقيسها قياس ! .

Here it (A PREVENTION ACTION)

Feed forward :- monitors & correct the changes according its measures !

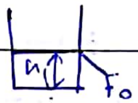
Feed back :- monitors & correct the changes according its sorces .



well stirred tank.

Outlet = Inlet.

مش ثابتة كنترل [h]
flow
تبعي مسحت



بعمل الاشي اللي قبل كانت ال Outlet
ع ال over flow
h → const.

Control variable ⇝ T

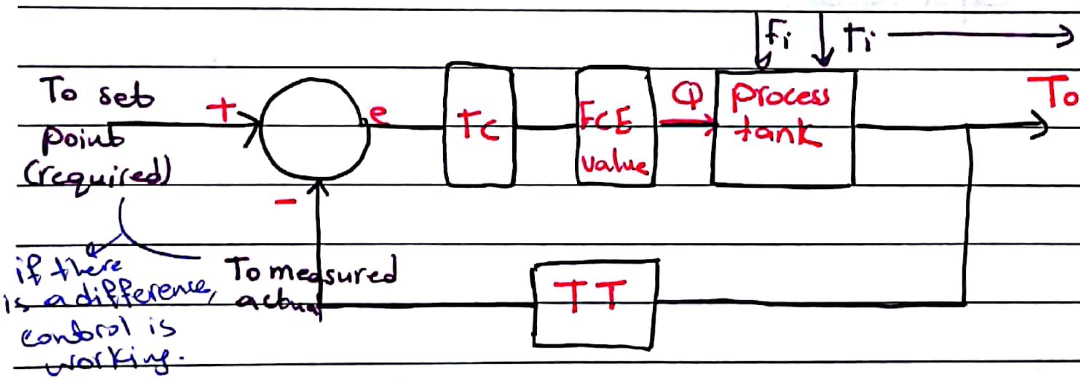
هاد بشكل اسمه Process & Instrument (piping) Design ...... P&ID

ولازم بنحوله ل Block diagram

لعشان اعمل ال Control ← لازم يكون في علاقات بين ال Variables .

اول اشي برسم ال (Block) بعدها بطلع ال Control variable اللي بدي اعمله Control (as output).

Block diagram for temperature control for this system.



ممكن يتغيروا randomly
مش زي ما بدي
To بسميها disturbances

Q: manipulated variable

To: control variable بعمل Control ع To وآثرها بيظهر منه
من ال (Q).

Control

* لازم يكون في علاقة رياضية بين $\boxed{Q \& T}$ لنسميها model of proces

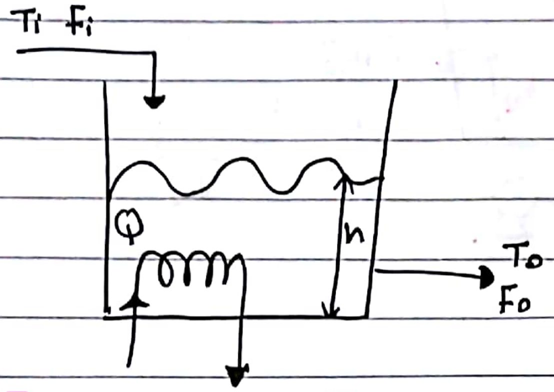
Kinds of models → steady state → (design) لازم يكون عنا
زي لما بدي احسب مثلاً ال (Volume)
→ unsteady state

Ways to get dynamic models → experiment
→ Theoritical.

① Theoritical → (analytical)
based on basic equations (mass, energy & momentum balances).
\- rate equations.
general model. ال (الفروض الي حطينا)

② ~~Theoritical~~ Experimental (Imperical model)
Some of parameters → may not be in basic equation (mass, energy, &
→ Some of lack in information.
Valid Just for this experiment.
* اسمه (disody) ← اله

* un steady state modeling :-



mass

$$\frac{d(\rho v)}{dt} = \rho F_i - \rho F_o$$

$$\frac{kg}{ft^3} \times \frac{ft^3}{time}$$

$$\frac{dv}{dt} = F_i - F_o$$

F_i → volumetric flow rate.

let ρ → const.

$V = Ah \Rightarrow \quad \frac{dAh}{dt} = F_i - F_o$

A → const

$$\boxed{A\frac{dh}{dt} = F_i - F_o}$$

عشان $\textcircled{F_o} = \frac{h \to \text{driving force}}{R \to \text{resistance to flow}}$

معتمدة
على
$\textcircled{h}$ بال.

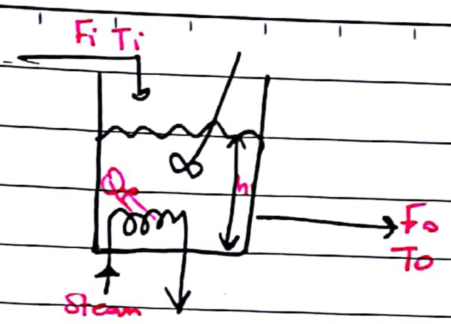
$$\boxed{A\frac{dh}{dt} + h = RF_i}$$

is a function in the ~ $\textcircled{h}$ التغير في

change in F_i

بس (F_i) هي الي بتغير.

control



$$\boxed{AR\frac{dh}{dt}h + h = RF_i}$$

energy Balance (Enthalpy Balance)

$$\frac{d[\rho v c_p(T_o - T_{ref})]}{dt} = \rho c_p f_i (T_i - T_{Ref}) - \rho c_p F_o (T_o - T_{ref}) + Q$$

بفرض ρ, cp ← Const

ويعتبر ال Tref ← Zero

$V = Ah$

$$\rho c_p A \frac{dhT_o}{dt} = \rho c_p f_i T_i - \rho c_p F_o T_o + Q$$

$F_o = \frac{h}{R}$

$$\frac{dhT_o}{dt} = \frac{f_i T_i}{A} - \frac{F_o T_o}{A} + \frac{Q}{\rho c_p A}$$

$f_o = \frac{h}{R}$

$$\frac{dhT_o}{dt} + \frac{h}{AR}T_o = \frac{1}{A}f_i T_i + \frac{Q}{\rho c_p A}$$

$$\frac{hdT_o}{dt} + T_o\boxed{\frac{dh}{dt}} + \frac{1}{AR}hT_o = \frac{1}{A}f_i T_i + \frac{Q}{\rho c_p A}$$

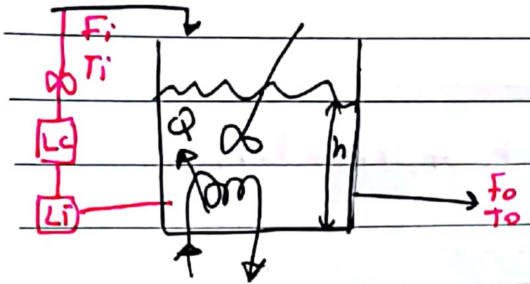
بجيبها منة معادلة ↓

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

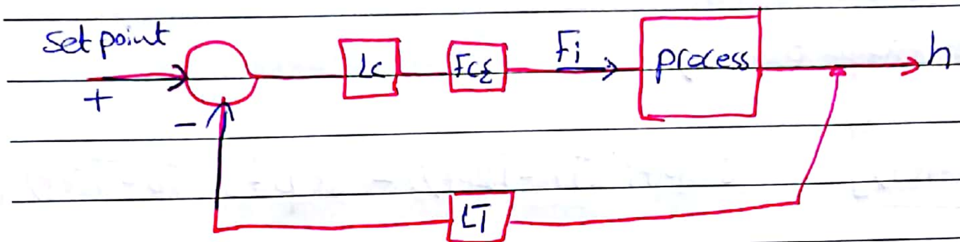
المفروض يطلع

$$\frac{dT_o}{dt} + T_o = ---- f_i T + --- \frac{Q}{\rho c_p A}$$

هاي اللي بستفيد منها ال اللي بيغيرو بـ To هو fi , Ti , Q .



$$AR\frac{dh}{db} + h = RF_i$$



Manipulated → fi

Control variable → h

انو احط المعادلات اللي بتعبر عنه بالتغير
في ال variable مش ال variable
وباخذها عال steady state نفسه

بترتبط بين ال level
ومعدل ال inlet flow rate

$$\boxed{AR\frac{dh}{dt} + h = RF_i}$$

* $\frac{dh}{dt}$ at steady state = 0

* deviation from Steady state. (بطرح منها ال steady state)

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

$$0 + h_{ss} = RF_{iss}$$

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

(h-hss) ← عشان اوحدها.

$$\boxed{h-h_{ss} \longrightarrow h'}$$

$$\boxed{F_i - F_{ss} \longrightarrow F'}$$

$$\boxed{AR\frac{dh'}{dt} + h' = R f_i'}$$

← هاي اللي بتربط التغير في ال level مع التغير في ال flowrate

← controler مصمم ال deviation

↳ transfer function: function which transfers the change in inputs with the transfer in the outputs.

lablace transform :-

(linear بيحول ال differential equation to Aljebric)

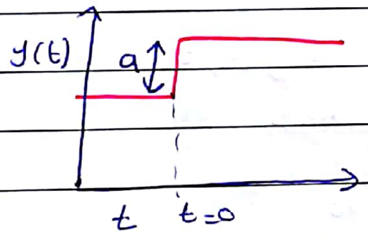
t → t domain   s → imagnary domain

$\mathcal{L}\, y(t) = y(s)$

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

1 * STEP function :-

$$y(t) \begin{cases} 0 & t<0 \\ a & t \geq 0 \end{cases}$$



$\mathcal{L}$ step function $= \dfrac{a}{s}$

2 * Ramp function :-

$y(t) = at$

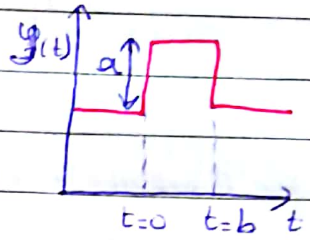
gradually بتغير بزيادة
as temp or pressure

$\mathcal{L}(at) = \dfrac{a}{s^2}$

3* Pulse function.

زيادة ورجوع للقيمة في لحظة ثانية.

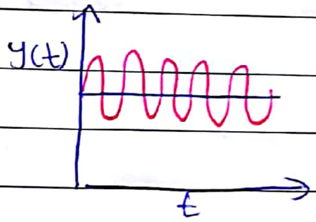
$$y(t)\begin{cases} 0 & t<0 \\ a & 0<t<b \\ 0 & t>b \end{cases}$$



$$\mathcal{L}(\text{pulse}) = \frac{1-e^{-bs}}{s}$$

4* sin function

$$y(t) = a \sin wt$$



$$\mathcal{L}(\sin) =$$

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

Final value Theorem:

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

$$y(s) = \frac{k}{s(as+1)}$$

$$y(t) = \mathcal{L}^{-1} y(s) = \mathcal{L}^{-1} \frac{k}{s(as-1)}$$

$$y(t) = k(1-e^{-at})$$

$$y(t)_{\infty} = k$$

$$y(t) = \lim_{s\to 0} s\, y(s) = \lim_{s\to 0} \cancel{s}\left[\frac{k}{\cancel{s}(as+1)}\right] = k$$

⊛ Initial value theorem

$$y(t)\Big|_{\text{at zero}} = \lim_{s\to\infty} s\,y(s)$$

$$y(t) = k\left[1 - e^{-at}\right]$$

$$y(0) = \text{zero}$$

$$\lim_{s\to\infty} s\,y(s) = \lim_{s\to\infty} \cancel{s}\left[\frac{k}{\cancel{s}(as+1)}\right] \Rightarrow \frac{k}{\infty} = \text{zero}$$

at initial always the initial value of deviation = 0

Control

* first order system :-

what is first order system ?

It is a system discribed by first order differential equation.

differential → linear → deviation → lablace.

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

$$+ a_1 y_{ss} = b X_{ss}$$

→ deviation

$$a_0 \frac{dy}{dt} + a_1 y' = b x'$$

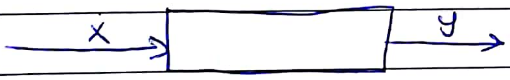
$y' = y - y_{ss}$

$X' = X - X_{ss}$

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

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

because all the initial Values of the deviation is equal zero



$$\frac{a_0}{a_1} s y(s) + y(s) = \frac{b}{a_1} X_s$$

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

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

→ transfer function :- $\dfrac{\text{lablas transform of the change in the output}}{\text{lablas transform of the change in the input}}$

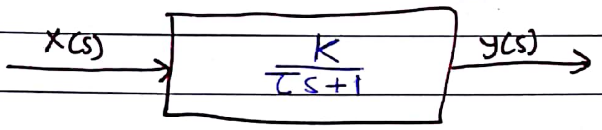
$\dfrac{Y(s)}{X(s)} \longrightarrow \dfrac{\text{lablas transform of output}}{\text{Input}} \neq \dfrac{y(t)}{x(t)}$

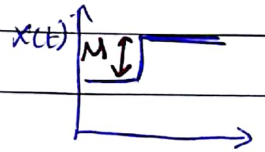
$$\frac{Y(s)}{X(s)} = \frac{K}{\tau s+1}$$

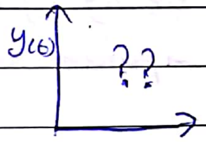
K : Steady state gain = b/a_1

τ : time constant = a_0/a_1

first order system : is a system can be identify by K & τ







لما نرسم هون يعني بكون احكم

بال time domain

$$Y(s) = \frac{K}{\tau s+1} * X(s)$$

$$Y(s) = \frac{K}{\tau s+1} * \frac{M}{s}$$

$$Y(s) = \frac{KM}{(\tau s+1)s}$$

$$y(t) = \mathcal{L}^{-1} Y(s) = \mathcal{L}^{-1} \frac{KM}{s(\tau s+1)}$$

$$\frac{1}{s(s+a)} = \frac{1}{a}\left(1-e^{-at}\right)$$

$$y(t) = KM\left[1-e^{-t/\tau}\right]$$

اهم نقطة الرجعة هي ال final value

$y(t)$ at ∞ = KM

$\left(e^{-t/\tau}\right) = 0$

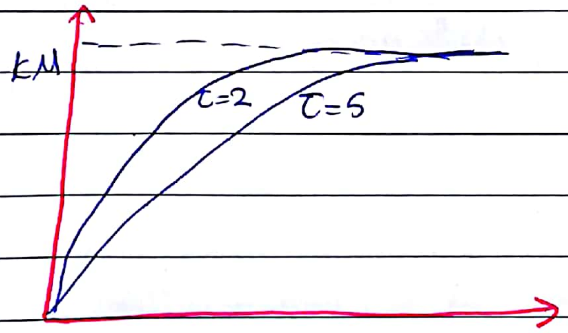
$KM[1-0] = KM$

0 = initial value أول ال

Final is determined by K only.

يعني كان عندي Steadystate صار في تغير ورجع بعدها Steadystate.

K → is aparameter of my system
but M is not aparameter



$\tau = 2$
$\tau = 5$ } → وصلوا نفس ال steady state value

قيمة ال final مابتعتمد على τ

τ → تقريباً هي ال residence time

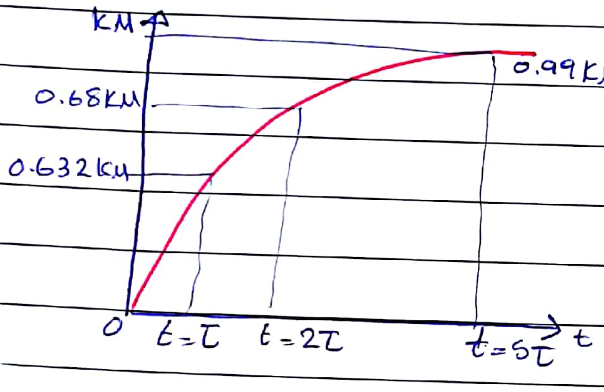
τ ↑ ابطأ responce

Five Apple

τ → بتحدد ال dynamic behavior

K → بتحدد ال steady state value

$$\frac{y(s)}{x(s)} = \frac{K \xrightarrow{\text{موجودة بالبسط}}}{\tau s+1 \xrightarrow{\text{موجودة بالمقام}}}$$



τ is a time

$$y(t) = KM\left[1 - e^{-t/\tau}\right]$$

$t = \tau$

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

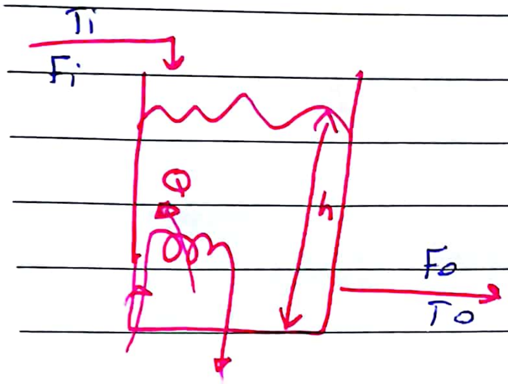
* responce of step change

لما يكون $\boxed{t = 1\tau}$ ← هي أصل النقطة اللي معكسه التحرك في طلعها ال System يعني أرجحية .

وهي إلي بتحددانا ال System هو first order system .

* responce to steady state at time $\boxed{5\tau}$

Control



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

$$G(s) = \frac{h(s)}{F_i(s)} = \frac{R}{ARs+1} = \frac{k}{\tau s+1}$$

Control

Second order system

its afunction described by 2nd order differential equation.

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

lablace transform → transfer function

$$a_0[s^2y(s) + s\,\overset{0}{\cancel{y(0)}} - \overset{0}{\cancel{y'(0)}}] + a_1[s\,y(s) - \overset{0}{\cancel{y(0)}}] + a_2\, y(s) = bXs$$

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

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

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

standard form of second order system.

* صورة عامة لل transfer function هي الي بتوصف order ثاني ل system

$$G(s) = \frac{Y(s)}{X(s)} = \frac{K}{\tau^2 s^2 + 2\xi\tau s + 1}$$

K → steady state gain

τ → time constant

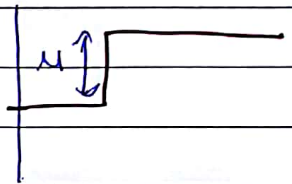
ξ → damping factor

* Second order is Identified by three parameters,

* Final value therm → final value of the system depends on ⓚ Just

* Transiantresponce depends on $\underline{(\tau)}$

$$\frac{y(s)}{x(s)} = \frac{k}{\tau^2 s^2 + 2\xi\tau s + 1}$$



$$y(s) = \frac{k}{\tau^2 s^2 + 2\xi\tau s + 1} * X(s).$$

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

$\boxed{\text{step } \frac{M}{s}}$

$$Ay^2 + by + c = 0$$

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

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

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

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

The roots depends on ξ

$\xi > 1 \rightarrow$ 2 real different roots

$\xi = 1 \rightarrow$ 2 imaginary roots

$\xi < 1 \rightarrow$ 2 real equal roots

بس احول iablace → sin cos, بيطلع معي $y(t) = \text{---} \sin, \cos$

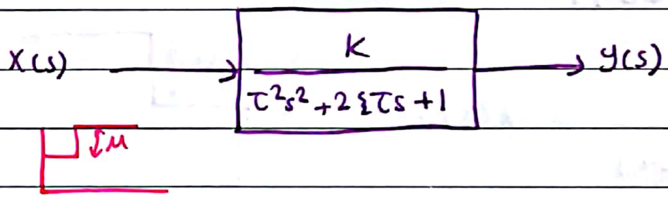
$\xi < 1 \rightarrow$ oscillation responce , $\xi \geq 1 \rightarrow$ no oscillation responce

$$G(s) = \frac{k}{\tau^2 s^2 + 2\xi\tau s + 1}$$

$0 < \xi < 1$ under damped (responce).

$\xi = 1$ Critically damped

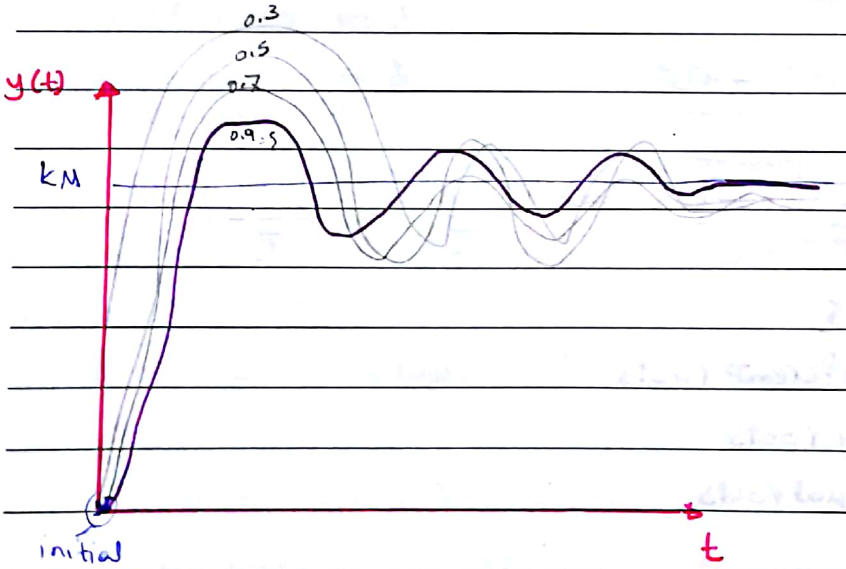
$\xi > 0$ over damped



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

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

$$y(t) = \mathcal{L}^{-1} \frac{kM}{s(\tau^2 s^2 + 2\xi\tau s + 1)}$$



y(t) is the output in the deviation form.

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

$$= \lim_{s\to 0} \frac{\cancel{s}\,kM}{\cancel{s}(\tau^2 s^2 + 2\xi\tau s + 1)}$$

$$= KM$$

responce $\xi < 1$

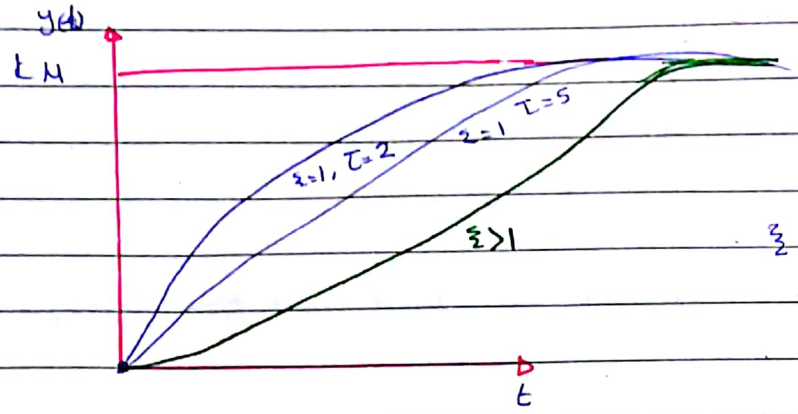
الـ oscillation الـ

بيبلّش بعدها بيصير:

y(t) = - - - - - أو ممكن أرسمه بطريقة

t   y(t)

Secondorder



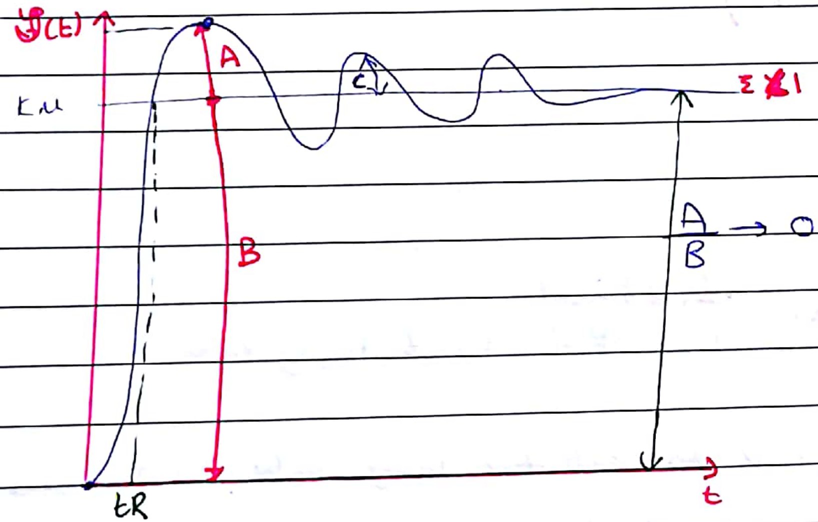
↑ ξ → responce is slower

اللي بيعتبر ξ هو nature of responce

اللي بيعتبر K هو final value

اللي بيعتبر السرعة ξ, τ

* نهتم بأول oscillation لأنه بيعتبر maximum deviation from steady state



$\frac{A}{B}$ → overshoot.

B → steady state

$y(t) =$ - - - - - - - -

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

$\frac{dy}{dt} = 0 =$ - - - - - - - - → بحاول بتطلع منه

maximum (t)s & minimum.

maximum ← أول قيمة هي

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

The only parameter which affects is (ξ)

$K, \tau \rightarrow$ not affect

Overshoot gives the maximum deviation from the steady state.

$\frac{C}{A}$: (decay ratio)

(to the rate at which the ocsillation is disappeared). سرعة اختفاء ال ocsillation

$$D.R = \exp\left(\frac{-2\pi \xi}{\sqrt{1-\xi^2}}\right)$$ → مربع ال over shoot

$D.R = (0.5)^2$

Settling time :- الوقت اللي بيكون فيه steady state.

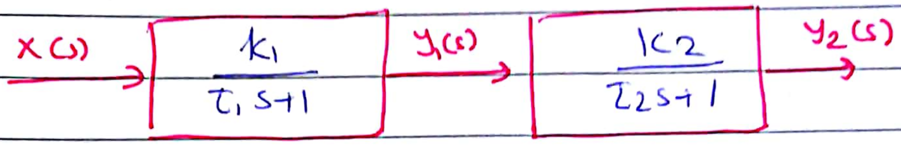
time at ~~w~~ ± 5% of the final steady state

Risetime : time required to reach the steady state first time

بيعبر عن سرعة ال (initial responce)

كيف ممكن نطلع بني second order system ؟؟

2 tank in series .

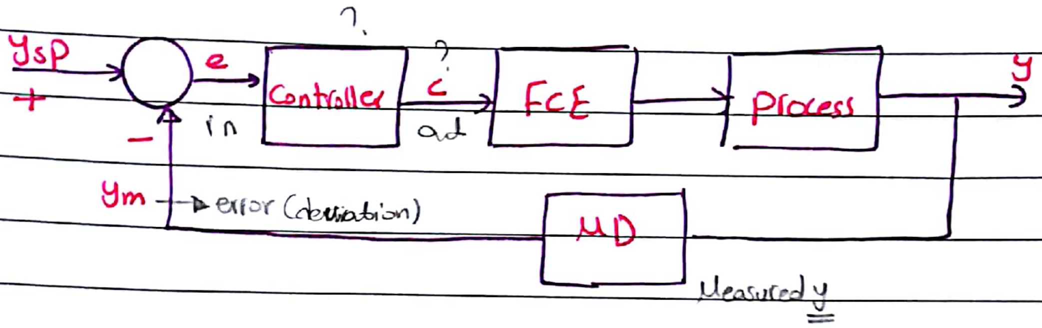


$$\frac{y_1}{X} = \frac{k_1}{\tau_1 s+1}$$

$$\frac{y_2}{y_1} = \frac{k_2}{\tau_2 s+1}$$

$$\frac{y_1}{X} * \frac{y_2}{y_1} \Rightarrow \frac{k_1}{\tau_1 s+1} * \frac{k_2}{\tau_2 s+1}$$

$$\Rightarrow \frac{k_1 \; k_2}{\tau_1 \tau_2 s^2 + (\tau_1 + \tau_2) s+1}$$



Types of controller :-

based on signal :- − Electrical ---- Electrical signal
− Pneumatic ---- pneumatic signal

based on Action − Model of the controller

I Proportion controller

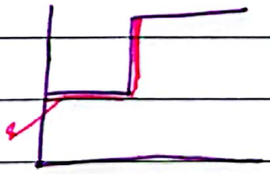
out c: $C = K_c\, e \rightarrow$ in ---- deviation form $C_{ss} = 0$

$C = K_c\, e + C_{ss}$ ---- not deviation form

$$C(s) = K_c\, e(s)$$

$$G_c(s) = \frac{C(s)}{e(s)} = K_c$$ no dynamics, no transient behavior

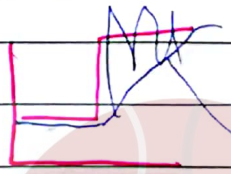
* ما في مقام ← polynomial is zero order



$\boxed{\text{zero order}}$

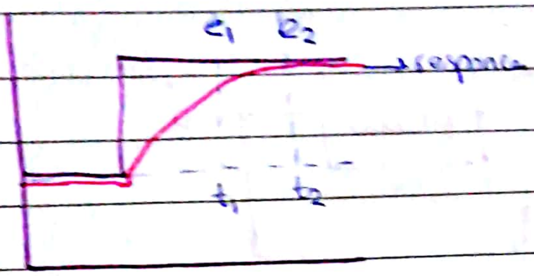
بيروح من steady state للثاني بشكل لحظي .

* بمعادلة كهربائية بسيطة ،



قبل كان حسب ال order

Simple, Fast, cheap



Steady state : deviation between Setpoint & measured = 0

لما يصير عنى تغير ويحاول الكنترولر يوصل التغيير
ما يوصل لل (new s.s) الا بيكون عنا
فرق (deviation, error)
لما يصل يوصل [Final s.s]
حاولنا بيكون عنا deviation
Steady state error = offset

if at time① ⇒ e_1 & $t_2 = e_2$ & $\boxed{e_1 = e_2}$

$$C_1 = K_c \, e_1$$
$$\parallel \qquad \parallel$$
$$C_2 = K_c \, e_2$$

if $e_1 = e_2$ then $C_1 = C_2$ at this moment the Controller is stuck

why ?

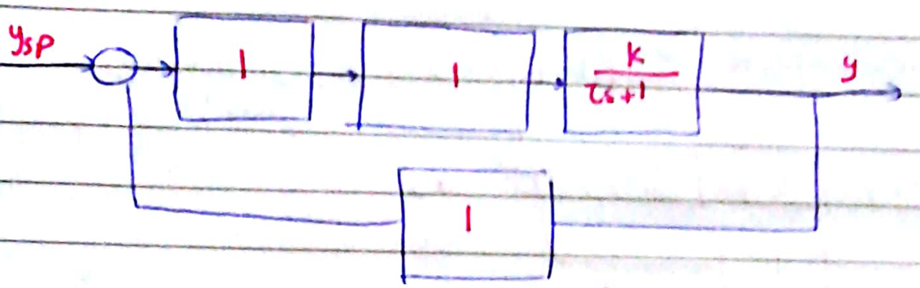
y_m const → قرائتها ما بتتغير .

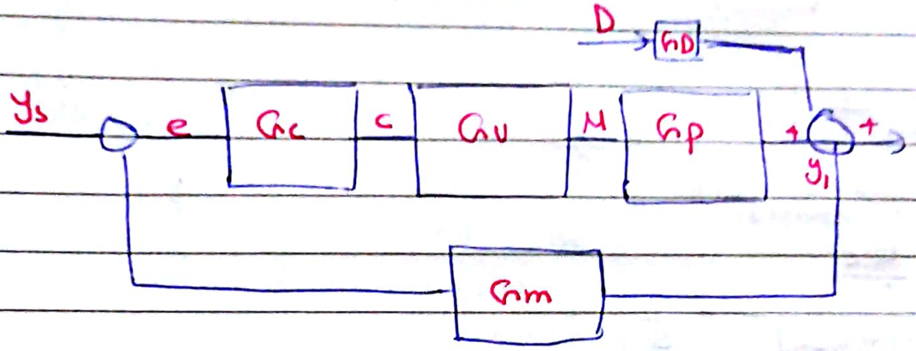
because within resolution of the measured value .
↓
the change is

Ex: $y_{m1} = 0.007$
$y_{m2} = 0.0075$
} → Small value can't measure by device

فممكن ال measured تكون القراءتين متساويات مش صح
فممكن يقبل ال detection الها .

* closed loop transfer function:-





$y = y_1 + y_2$

$\Rightarrow Gp * M + GD * D$

$\Rightarrow Gp(Gv.c) + GD*D$

$\Rightarrow Gp(Gv).Gc.e + GD*D$

$\Rightarrow Gp\ Gv\ Gc\ [ysp - ym] + GD*D$

$\Rightarrow Gp\ Gv\ Gc\ ysp - Gp\ Gv\ Gc\ ym + GD*D$ --> $ym = Gm*y$

$y + Gp Gv Gc\, y_m \Rightarrow Gp\, Gv Gc\, ysp + GD*D$

$y\,[1 + Gp Gv\, Gc Gm] = Gp\, Gv\, Gc\, ysp + GD*D$

$$\boxed{y = \frac{Gc\, Gv\, Gp}{1 + Gv Gc Gp Gm}\, ysp + \frac{GD}{1 + Gc\, Gv\, Gp Gm}\, D}$$ → closed loop transfer function

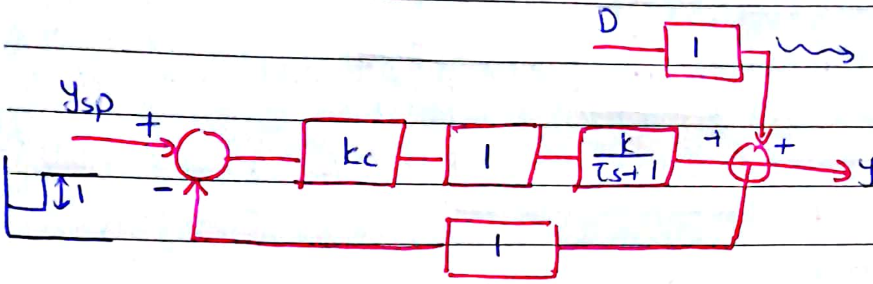
$$\boxed{1 + Gc\, Gv\, Gp Gm = 0}$$ Characteristic equation.

الكلام مبيعتمدش على الـ input
بس بيعتمد على الـ transient response
= البسط هو اللي بيحدد الـ forward path of the system.

(characteristic eq) of the system هو الـ closedloop الـ transient اللي بيحدد الـ

(P) Controller :-

$G(s) = K_c$



D نفترض انه التغيير في
= Zero !

$$y = \frac{K_c[1]\left[\frac{k}{\tau s+1}\right]}{1+K_c[1]\left[\frac{k}{\tau s+1}\right][1]} * \frac{1}{s}$$

وحدنا المقام ←

$$y = \frac{\frac{K_cK}{\cancel{\tau s+1}}}{\frac{\tau s+1\ +K_c[K]}{\cancel{\tau s+1}}} * \frac{1}{s}$$

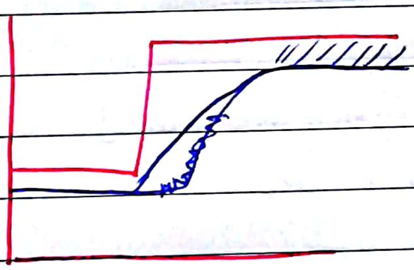
مقسم على $(1+K_cK)$

$$y = \frac{K_c/K/(1+[K_cK])}{\frac{\tau s}{1+K_cK}+1} * \frac{1}{s} \rightarrow$$

first order sys system but with smaller time constant

((Time constant loop)) أقل من

ال ((time constant process))



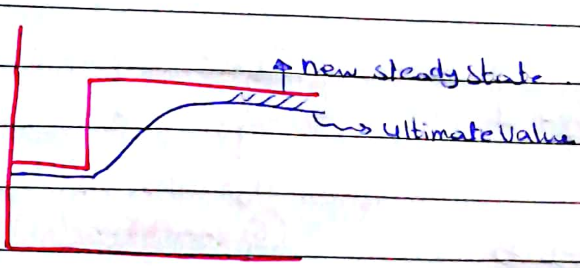
offset = New steady state − $y(t)_{\infty}$

ultimate value of the response.

$$y(t)_{\substack{\infty\\ s\to0}} \rightarrow \lim_{s\to0} s\,y(s). \rightarrow \lim_{s\to0} \cancel{s}\cdot\left(\frac{K_cK/(1+K_cK)}{\frac{\tau}{1+K_cK}s+1} * \frac{1}{\cancel{s}}\right)$$

$$\rightarrow \frac{K_cK/(1+K_cK)}{1} =$$

$$y(t) = \frac{K_cK}{1+K_cK}$$



$$\text{offset} = 1 - \frac{K_cK}{1+K_cK} \Rightarrow \frac{1+K_cK-K_cK}{1+K_cK}$$

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

$$\text{offset} \propto \frac{1}{K_c}$$

كل ما زاد ال (K_c) قلّ ال offset

لحد ما يوصل ال steady state

بس ما بنقدر نزيدها ! لانو البروسيس بصير unstable.

كرمال نصير $K_c=\infty$ مستحيل تكون ال Zero-offset !!

* Proportional ~~cont.~~ Inegral controller (PI):-

هون انا ما بطلع على ال instant error

بس بشوف ال Comulative error

فبحتاج على ال controller → (integral element)

$$c = K_c e + \frac{K_c}{\tau_I}\int_0^\infty e(t)\,dt + \bar{c}$$

$\bar{c}$ → signal at S.S

2 parameters (K, τ_I)

deviation form:-

$$c = K_c e + \frac{K_c}{\tau_I}\int_0^\infty e(t)\,dt$$

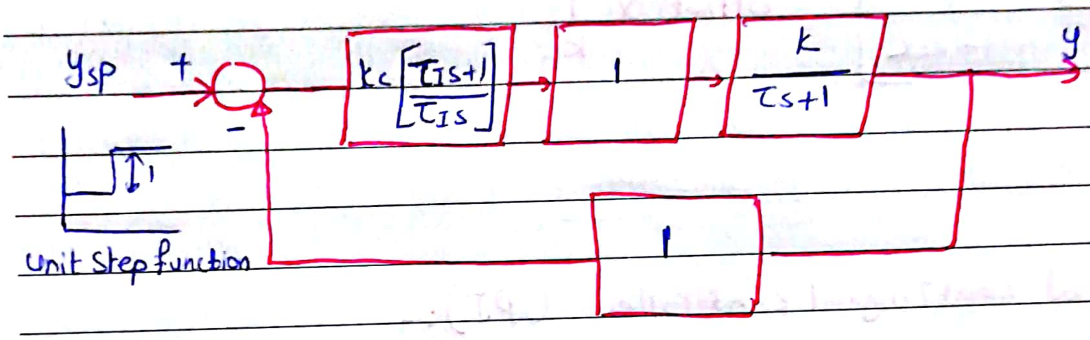
$$C(s) = K_c\, e(s) + \frac{K_c}{\tau_I} * \frac{1}{s}\, e(s) \Rightarrow C(s) = K_c\left[1 + \frac{1}{\tau_I s}\right] e(s)$$

$$G(s) = \frac{C(s)}{e(s)} = K_c\left[1+\frac{1}{\tau_I s}\right] \Rightarrow K_c\left[\frac{\tau_I s+1}{(\tau_I) s}\right]$$

ال dynamics تبعتها
بتعتمد على (S)

④ We use (PI) to eleminate the offset ④

responce
ابطأ من ال P controller



$$y(s) = \frac{K_c\left[\frac{\tau_I s+1}{\tau_I s}\right][1]\left[\frac{K}{\tau s+1}\right]}{1+K_c\left[\frac{\tau_I s+1}{\tau_I s}\right][1]\left[\frac{K}{\tau s+1}\right][1]} * \frac{1}{s}$$

$$y(s) = \frac{\frac{K_c K(\tau_I s+1)}{\cancel{(\tau_I s)}\cancel{(\tau s+1)}}}{\frac{(\tau_I s)(\tau s+1)+K_c K(\tau s+1)}{\cancel{(\tau_I s)}\cancel{(\tau s+1)}}} * \frac{1}{s}$$

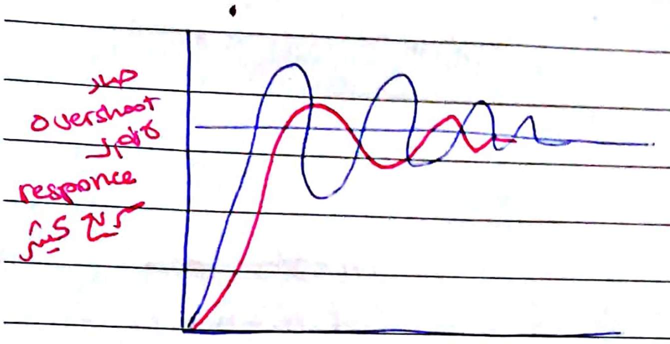
First order ال dynamical زود
second order ✓
يعني عمل oscellation

$$y(t)_{\infty} = \lim_{s\to 0} s(y(s)) \Rightarrow \lim \cancel{s} * \frac{K_c K(\tau_I s+1)}{\tau_I s(\tau s+1)+K_c K(\tau s+1)} * \frac{1}{\cancel{s}}$$

$$\Rightarrow \frac{K_c K}{K_c K} = 1$$

offset = 1 − 1 = 0

↝ we add the integral term to eleminate the offset the problem on PI controller → introduce oscillation



* بطلع على ميل الماس عشانه بيمثل معدل التغير.

(P) → instant error

(PI) → comulative error.

PID :- proportional Integral derevative Controller

$$C = \underbrace{\underbrace{\underbrace{K_c e}_{P} + \frac{K_c}{\tau_I}\int_0^{\infty} e(t)\,dt}_{PI} + K_c \tau_D \frac{de(t)}{dt}}_{PID}$$

to reduce the oscillation caused by Integration term.

its a predective element!

بيتنبأ انه عند نقطة معينة في منحنى عالية فممكن يصير

عنا oscillation فبروح بتصرف ع مدار r, ساكن.

صار الـ term بجزئه
مشان يصير
practical &
↓ Applicable PID

$$\frac{C(s)}{e(s)} = K_c\left[1 + \frac{1}{\tau_I s} + \tau_D s\right]$$

$$G(s) = \frac{C(s)}{e(s)} = \boxed{K_c}\left[\frac{\boxed{\tau_I}\boxed{\tau_D}s^2 + \tau_I s + 1}{\boxed{\tau_I s}}\right] \ast \left[\frac{1}{\alpha s + 1}\right] \rightarrow \text{filter}$$

$(\tau_I s) \rightarrow$ 9 dynamic

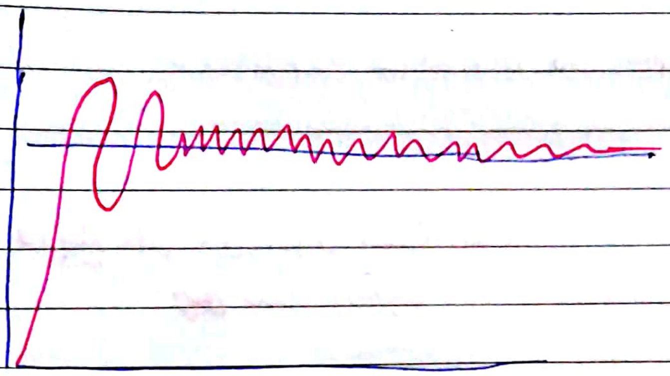
3 parameters

درجة البسط اعلى من درجة المقام عشان هيك صار عنا 0

(predicting capability)

physically realizable

(un-Ideal controller)



noisy signal

PID عمل مشكلة في ←

in the case of high frequency oscillation

$$C = K_c e(t) + \frac{K_c}{\tau_I}\int \text{——} \boxed{\pm} \tau_D \frac{de}{dt}$$

بصير كانه مرة + ومرة -

oscillation driving the contoller not elemint the oscillation }

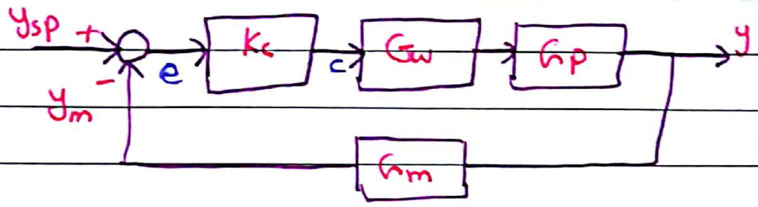
we can't deal of high frequency noise. (oscillation).

اذا كان هيك احسن انه ارجع لل PI

Control Mode :-

how it's acting :-

- Direct mode.
- Reverse mode.



* Direct mode :-

If the measured controled variable increased and the output of the Controller increased, then the controller in direct mode.

$y_m \uparrow ,\ c \uparrow \rightarrow$ direct.

How to set the controller in the direct mode? put Kc less than Zero

$$\overset{\uparrow}{c} = \enclose{circle}{K_c}\left[\underbrace{y_{sp} - \overset{\uparrow}{y_m}}_{\text{بتقل}}\right]$$

لازم يكون سالب .

-ve

$$\text{input} \rightarrow \boxed{\text{Gain}} \rightarrow \text{output}$$

$$\text{Gain} = \frac{\Delta\,\text{output}}{\Delta\,\text{input}} \qquad \boxed{K_c < 0}$$

* Reverse mode :-

If the measured controlled variable increased and the output of the Controller decreased, then the controller in reverse mode.

$y_m \uparrow ,\ c \downarrow \rightarrow$ ~~tardi~~ reversed

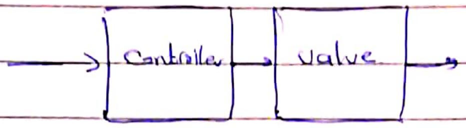
How to set the Controller in the direct mode.

$$\downarrow c = \enclose{circle}{K_c}\left[\underbrace{y_{sp} - \overset{\uparrow}{y_m}}_{\text{بتقل}}\right] \qquad \boxed{K_c > 0}$$

+ve

Control value.

(*) To have synchronization between the controller & the value.



→ Air to open value (Fail close)

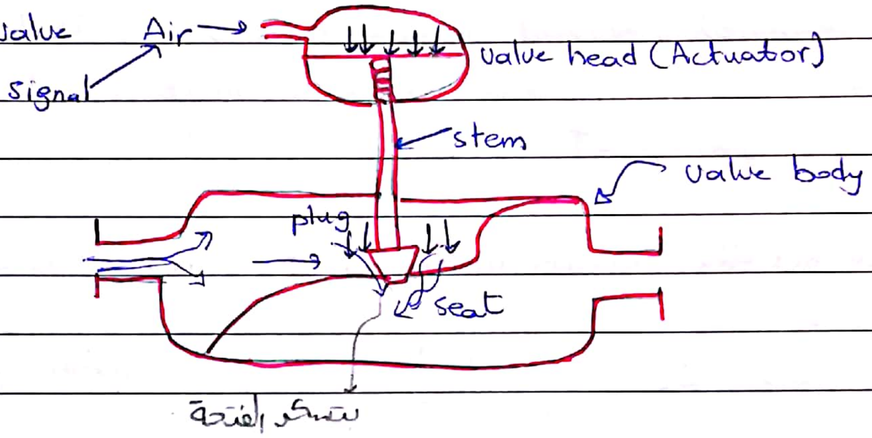
→ Air to close value. (Fail open) } اذا انقطعت ال Signal بيفتح

safety الاختيار بناءً على ال
of the process

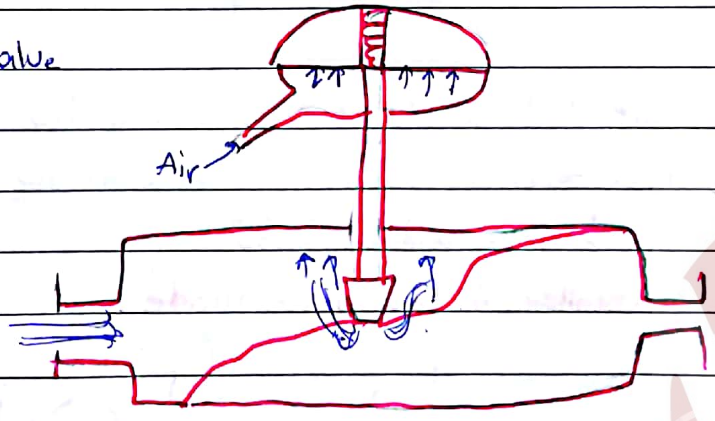
→ Pnematic value. (pnematic signal : compressed Air)

→ Electric value.

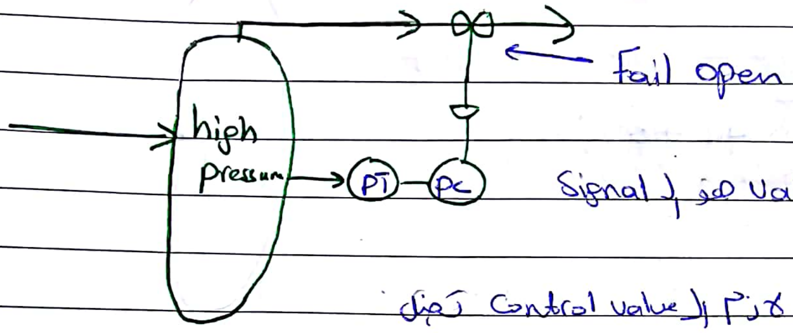
* Air to close value



* Air to open value

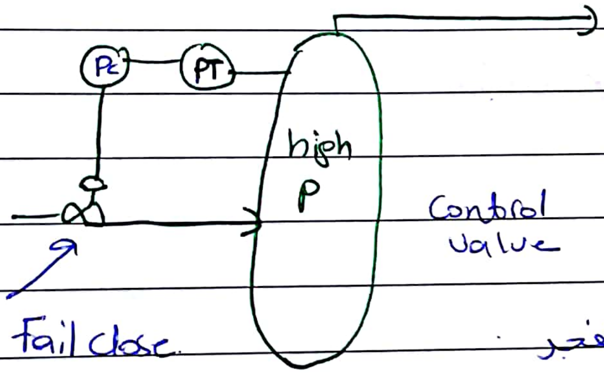


why Fail open ?
Fail close ?
↳ safety



* اللي بيتحكم بفتحة ال value هو ال Signal

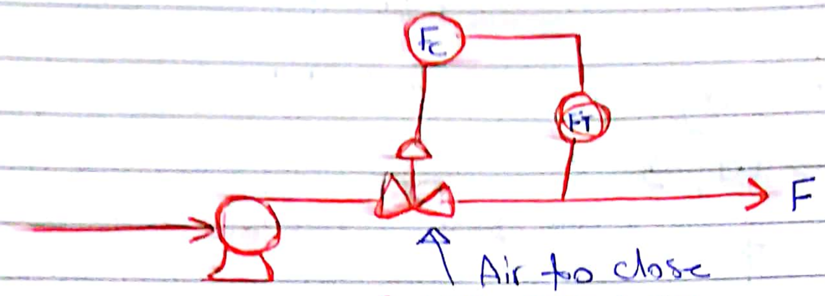
اذا راحت ال Signal ← لازم ال Control value تضل مفتوحة لانه لو كانت مسكر رح يضل ال pressure يزيد لحد ما ينفجر.
مشان ال safety لازم يضل open



اذا راحت ال Signal ← لازم يتسكر ال Control value

لانه لو ضل مفتوح رح يزيد ال (p) لحد ما ينفجر.
مشان ال safety لازم تضل Close.

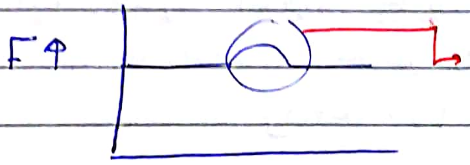
Is it direct or Reverse ?



Air to close

لازم ال ⓒ تزيد عشان يسكر .

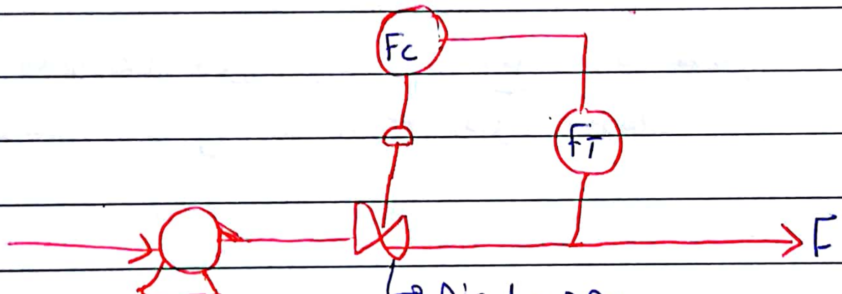
Control variable : Flow



عشان يرجع على قيمته لازم ال signal تزيد

$C\uparrow$ $\uparrow y_m (F\uparrow)$

عشان هيك هاد (Direct)



Air to open

لما يزيد ال flow بدي ارجع للقيمة لازم يسكر .

بصير لازم ⓒ تقل عشان يسكر .

$\downarrow c$ $\uparrow y_m \rightarrow$ Reverse.

* Flow characteristics of the valve :-

تغير الـ flow بالنسبة مع مقدار فتحة الـ valve

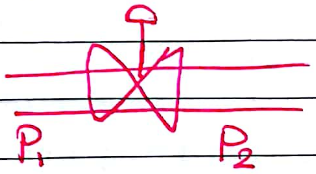
تغير الـ flow مع فتحة الـ valve

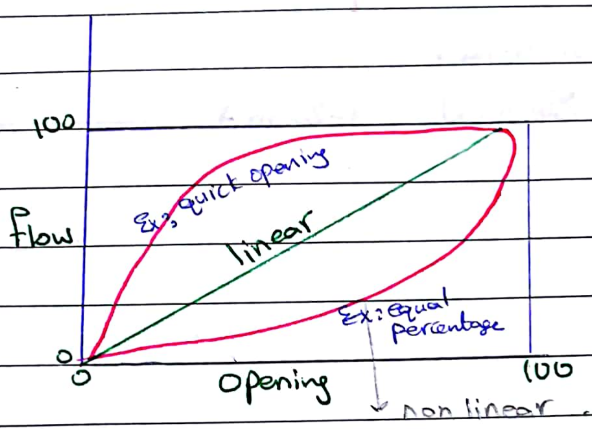
$$F = C_v \, f(x) \sqrt{\frac{\Delta P}{\rho}}$$

C_v → const, represent mechanical design of the valve

ΔP → pressure drop across the valve $(P_1 - P_2)$

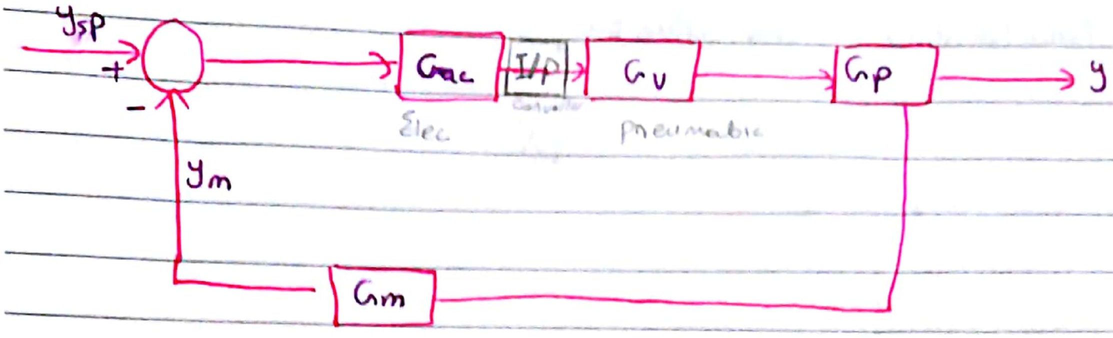
ρ → density of the fluid





When I choose linear, quick openig or equal percentage ?

للامتحان



Control signals.

① Electrical 4-20 mA ——▷ اذا ال Gv كانت Air to open

واحتجنا Signal = 4 ـه حيكون

completly closed

واجتنا Signal = 20 ـه حيكون

completly open.

② pnematic ~~Psi~~ 3-15 psi.

if Gv → Air to open

Signal = 3 → completly closed

Signal = 15 → completly opened

* بقدر احول بين النوعين اذا كانت مثلاً Gc elect. ـه وال Gv pneumatic ـه

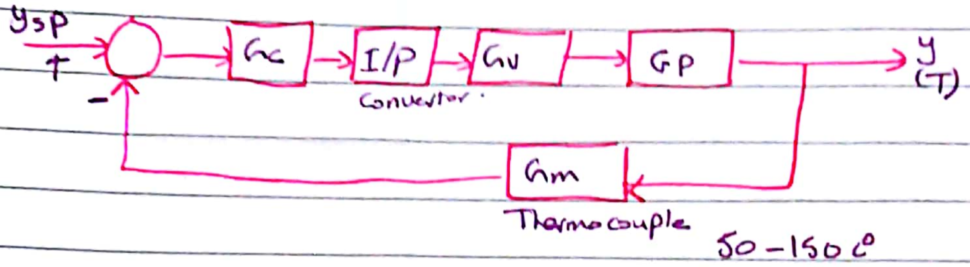
وبحتاج لازم احط Convertor بيكون اسمه I/P $G = \frac{12}{16}$

اذا العكس بحط P/I $G = \frac{16}{12}$

Thermo Guple → لازم تكون ال output electrical

فما بيحكي شو نوعه.

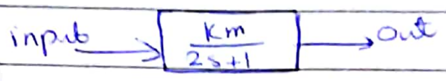
First order system has a time const = 2 & input range of 50-150c°



Output Standard ثابت 20-4

Gain = ??

Gain = $\frac{\Delta \text{output}}{\Delta \text{input}}$



$= \frac{20-4}{150-50} = \frac{16}{100} = 0.16$

* Design of control system.

→ control loop configration.

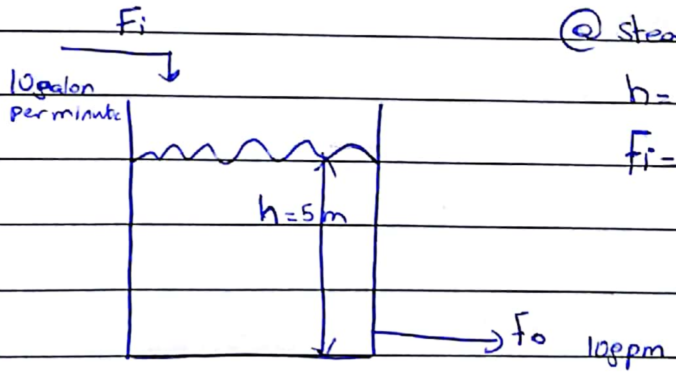
→ Dynamics of the system.

→ Controller type : P, PI, PID. k_c, τ_I, τ_D

→ Control values

* controller mode
* Air to open, Air to close
* linear, quick opening, Equal percentage.

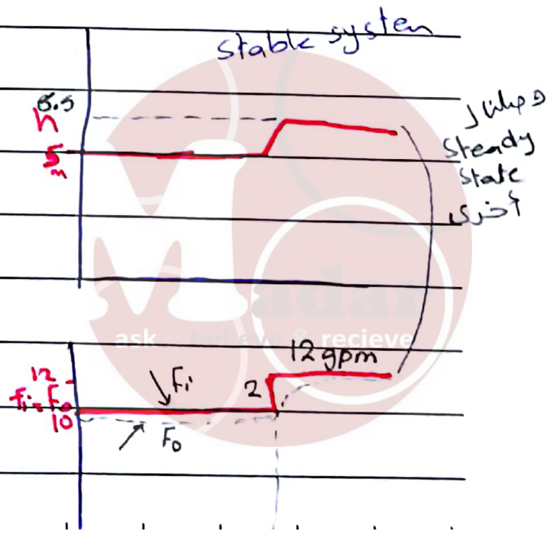
① Stability of control system.



@ steady state.

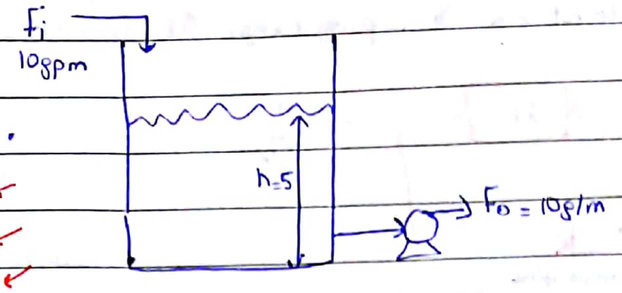
h = const

Fi = 2 Fo



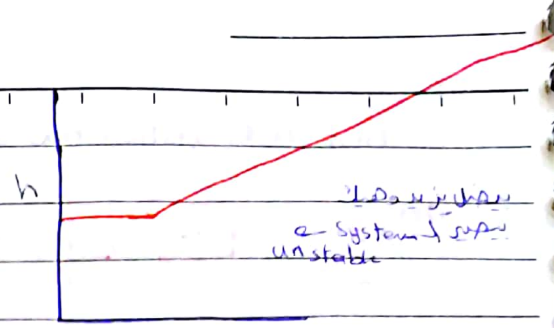
وصلنا ل Steady State أخرى

→ self regulated system

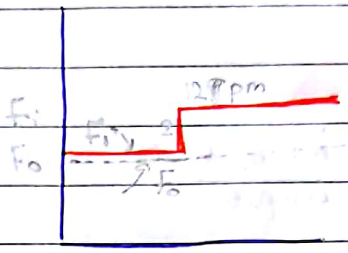


Fi زودت ←
h بيرتفع ←
Fo مابتزيد ← لأنه عند pump = وعند سرعة ثابتة الها
(The outlet of the pump is const)

un regulated system.



بيضل يزيد دوماً
بيصير ال system unstable



* في الحالتين كان ال input bounded
بس في unstable ← كان ال Output غير .

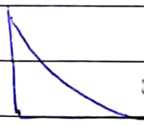
→ If the responce of asystem to bounded Input is bounded, Then the system is stable.

→ If the responce of asystem to bounded Input is unbounded, then the system is unstable.

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

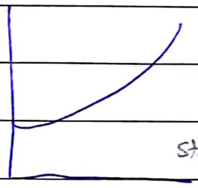
$$\boxed{0 = 1 + G_c G_v G_p G_m}$$ character eq. ← اول اشي بكتبه
بس يطلب ال (Stability)

Ⓐ → $y(s) = \frac{1}{S+a}$, $y(t) = e^{-at}$



→ $S = -a$
بيوصل ال steady state

Ⓑ → $y(s) = \frac{1}{S-a}$, $y(t) = e^{at}$

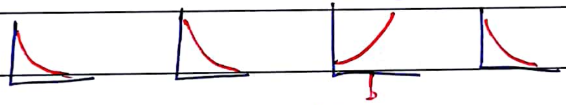


→ $S = +a$
مابيوصل ال steady state

* Example.

$$y(s) = \frac{1}{(s+a_1)(S+a_2)(S+a_3)(S+a_4)}$$

$$\Rightarrow \frac{C_1}{S+a_1} + \frac{C_2}{S+a_2} + \frac{C_3}{S+a_3} + \frac{C_4}{S+a_4}$$



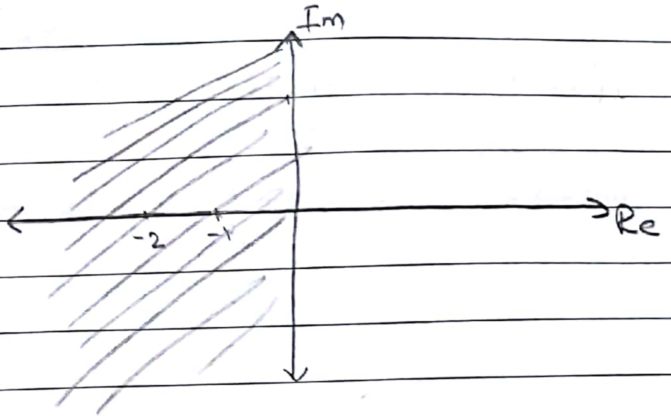
هذا بيروح لل
∞

حتى لو كانوا كلهم Stable ← يعني بيروحوا لل (+)
وواحد منهم كان بيروح لل ∞
∴ كلهم بيروحوا لل ∞ .
system goes to unstability.

عشان يكون ال stable system
Ⓐ أي (-ve) تكون roots لازم كل ال

4 Stability Analysis.

1) Root Locus Method



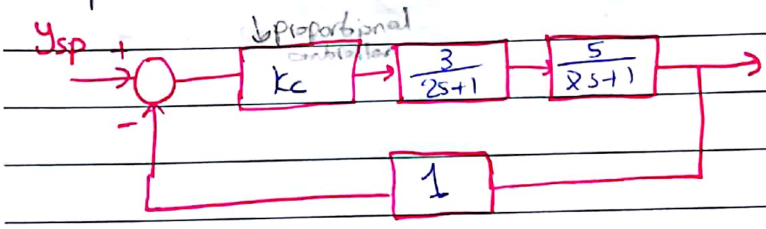
$1 + G_c G_p G_v G_m = 0$

$a_n s^n + a_1 s^{n-1} + \cdots = 0$

If All Roots or the Real part of the root are (-ve), then the process is stable.

examples: → 1) $-3+5j$
2) $-1, -2$

Simple.



characteristic eq.:- $1 + K_c\left[\frac{3}{2S+1}\right]\left[\frac{5}{7S+1}\right][1] = 0$

$(2S+1)(7S+1) + 15\,K_c = 0$

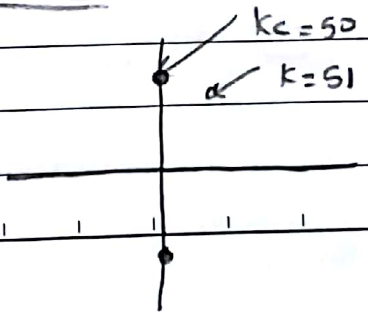
$14\,s^2 + 9s + 1 + 15\,K_c = 0$

اللي بيحدد قيمة الجذور وطبيعتها هو Kc

بنفرضهم

Kc	S_1	S_2
0		
1		
10		
15		
30		

→ برسمهم وبشوف كيف الرسمة بتطلع بدي.
القيم اللي بتطيني موجبة أو أكثر كل (+) معناته صار
القيم هي اللي بتعمل unstability



مثلاً لو كانت Kc = 50 على ال line لو بعدهم منهم هيكون (Critical stable) فأي زيادة صغيرة خالص الـ roots +ve

لو ظهر عندي (PI) ← controller يعني عندي أكثر من parameter مهم (kc) و (τ) هيك بحتاج أكثر من
معادلة مشان ارتبط ما في مخرج لطريقة ثانية.

2- Rowth - Hurwitz Array.

Test I:- ① write the ch. Equation as a polynomial with decreasing power

f.s $a_0 S^n + a_1 S^{n-1} + a_2 S^{n-2} + a_3 S^{n-3} + \cdots + a_n S^{n-n} = 0$

② let a_0 be +ve.

③ if one or more of coeficients is/are -ve ⇒ System unstable.

$a_0, a_1, a_2, \cdots$

④ if all the coeficient are +ve ⇒ Go to test (Two) not enough to Judge.

Test (II)

From the R-H Array

a_0	a_2	a_4	a_6	--- even
a_1	a_3	a_5	a_7	----- odd
A_1	A_2	A_3	--- 0	---- لما يخلص عندي صفر
B_1	B_2	0		

$$A_1 = \frac{a_1 * a_2 - a_0 a_3}{a_1} \qquad A_2 = \frac{a_1 * a_4 - a_0 a_5}{a_1}$$ ⇝ check this from Book

$$B_1 = \frac{A_1 * a_3 - A_2 * a_1}{A_1}$$

* if all elements in coloumn (1) are positive (stable)

* if one or more element is negative, the system is unstable

* Example :

$8s^3 + 12s^2 + 9s + 1 + Kc = 0$

S	9	0
12	1+Kc	
$\frac{12*9 - 8(1+Kc)}{12}$	0	
$\frac{\frac{12*9 - 8(1+Kc)}{12} * (1+Kc) - 12*0}{\frac{12*9 - 8(1+Kc)}{12}}$	0	

$B_1 = 1 + Kc$

* Conditions for stability should be positive.

$\frac{12*9 - 8(1+Kc)}{12} > 0 \rightarrow \frac{12*9}{8} > 1 + Kc \rightarrow 18.5 > Kc$

$1 + Kc > 0 \rightarrow Kc > -1$ $\boxed{-1 < Kc < 18.5}$

لوكانت kc ← 20 صيطلع عندي (+) root
kc ← -2 ، ، ، ، unstable system ←

* لازم احدد + ranges تبعت القيم اللي بدي احطها ، اشتغل عليها.

Design of control system.

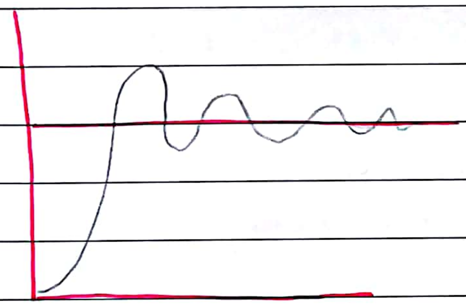
Stability

Design Criteria (Tuning criteria)

① simple Criteria → صار تصاميم بحققلي ال (overall)

- one the desired objectives بكون مصمم بإشي معين بس.

- O.S
- D.R



$$y = \frac{G_c G_v G_p}{(1 + G_c G_v G_p G_m)} y_{sp} + \frac{G_{d}}{- - - -}$$

ممكن يكون عندي هاد
2nd order system :-

$$\tau^2 s + 2\xi\tau s + 1$$

ممكن Gc تحدد قيمة (ξ) وهاي بتحدد قيمة
ال Overshoot

Overshoot ≯ 20%.

whats a controller give me a response of overshoot ?... ?

Decay Ratio = $\frac{1}{4}$ → لما نفحص المعادلة حتكون بدلالة ξ
و ξ بدلالة ال controller
أو T_i, K_c أو ... .

. **D.R** فلازم ξ نختار ال Controller اللي بيعطينا قيمة
وهيك بيكون اختيارنا بناءً على سرعة اختفاء ال(oscillation).

* Design a controller which minimizes the overshoot & the rise time?

this controller is impossiple because there two conditions are opposite to each other.

اذا بدي اقلل ال Overshoot ← rise time
بده يزيد

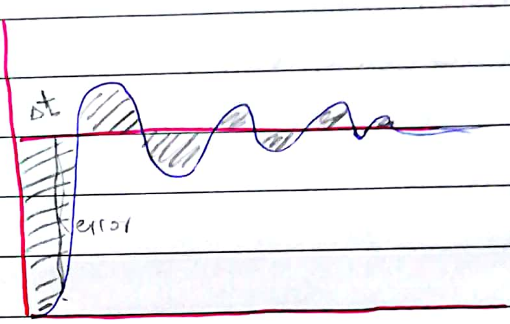
② comprehensive critera :- (overall) هون بيكون شغله

what is the overall objective of the controller?

minimize the deviation from the set point

Comprehensive ال WT

2.1 - Integral methods



Area = $\int_0^\infty e\,dt$

ممكن يلغي البعض من بعضها design

بناءً ع حساب = [illegible]

يواجه error أكبر بحيث مايلغي بعضه

أحد الحلول إنه أعمل Error²)

Integral of square error (ISE) 2.1.1

$\Rightarrow \int_0^\infty e^2\,dt$

مشكلته إنو لما يكون error fraction لما أربعه بصير أقل.

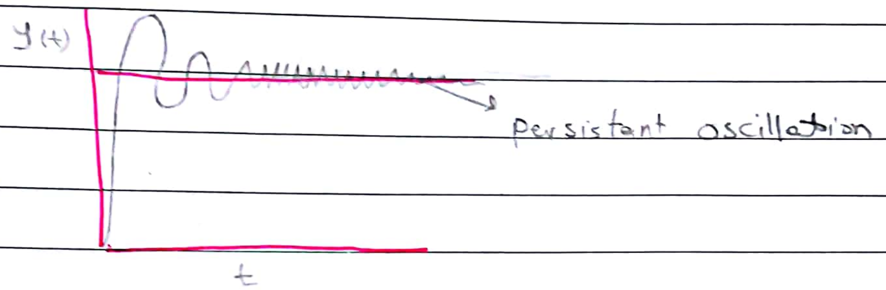
0.5 → 0.25 زي مثلاً

Integral Absolute error (IAE) ... 2.1.2

$\Rightarrow \int_0^\infty |e|\,dt$

if I expect large error its better to use ISE

& if I expect small error its better to use IAE.



❀ Integration of time & Absolute value of the error ~~IAE~~ (ITAE)

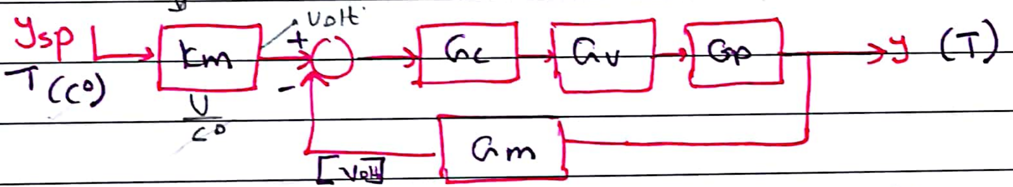
$$\int_0^\infty t|e|dt \quad \ldots \quad 2.1.3$$

2.2) Direct synthesis method.

ratio هون البسط (deviation) على البسط
between setpoint & measured

بس ← as whole process

[illegible] quantitative block diagram



$K_m = \frac{Volt}{C°}$. حطينا الـ (K_m) عشان يصير عندي توافق بالوحدات

$$\frac{y}{y_{sp}} = \frac{K_m G_c G_v G_p}{1 + G_c G_v G_p G_m} \longrightarrow$$

let $G_m = K_m$

let $G_m G_v G_p = G$

$$\frac{y}{y_{sp}} = \frac{G_c G}{1 + G_c G}$$

$$\boxed{G_c = \frac{1}{G}\left[\frac{y/y_{sp}}{1 - y/y_{sp}}\right]}$$

Control system design

→ Simplecriteria

→ Comprehensive Criteria

- Integral Methods
- Direct synthisis methods .

$$G_c = \frac{1}{G}\left[\frac{y/y_{sp}}{1 - y/y_{sp}}\right]$$

y/y_{sp}: performance criteria

هاي اصلا لازم نحددها .

where $G = G_m G_p G_v$,

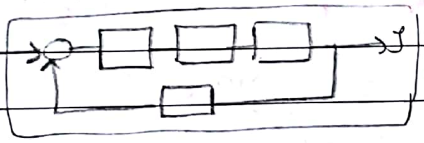
$y/y_{sp} = 1$ → there is no deviation at all (perfectcontrol)

$$G_c = \frac{1}{G}\left[\frac{1}{1-1}\right] = \infty$$

→ ما في controller يحقق ال perfect situation

its not achivable .

overall dynamics of all control system is zero order



ف لازم نزود ال (order)

$$\frac{y}{y_{sp}} = \frac{1}{\tau_c s + 1}$$

بحط ازود واقرب بال (τ_c)

↳ design parameter

enable me to achive or not achive the perfect control

$$G_c = \frac{1}{G}\left[\frac{\frac{1}{\tau_c s+1}}{1 - \frac{1}{\tau_c s+1}}\right]$$

$$G_c = \frac{1}{G}\left[\frac{\cancel{\frac{1}{\tau_c s+1}}}{\frac{\tau_c s + \cancel{1} - \cancel{1}}{\cancel{\tau_c s+1}}}\right] \Rightarrow G_c = \frac{1}{G} * \frac{1}{\tau_c s}$$

Five Apple

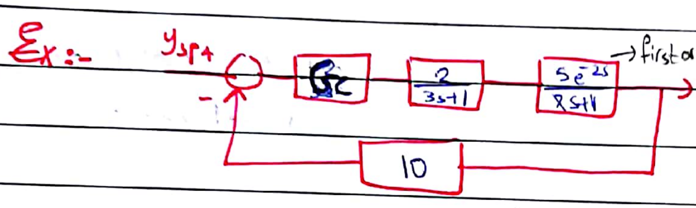
$$G_c = \frac{1}{G} + \frac{1}{\tau_I s}$$

فتح

$$G_c = K_c\left[\frac{\tau_I s+1}{\tau_I s}\right]$$

بالاخر بتطلع عندي
وحدة من معادلات
ال controller
اللي اله اسماء واخذناه
قبل .

Ex :-



→ first order plus time delay

or plus dead time

← سؤال مهم للامتحان : انه

← ليش حطيناه Constant blc .

$$\frac{y}{y_{sp}} = \frac{1}{5s+1}$$ → مش هنا مع ال system اللي فوق . → كانه وحدة مساعداد ال system فيها delay مشان هيك بديا اعتبرها .

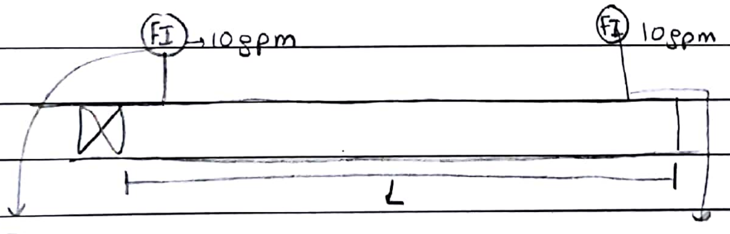
$$\mathcal{L}\, y(t) = y(s)$$

$$\mathcal{L}\, y(t-3) = e^{-3s}\, y(s)$$

$$\frac{y}{y_{sp}} = \frac{e^{-\theta s}}{5s+1}$$

بيعبر عن time delay

يعني → there is a delayed responce for any reason.



V : سرعة ال flow

هون نحس بالتغير فورا

بياخذ وقت عشان يبين التغير .

$$\Rightarrow t = \theta = \frac{L}{V}$$

delay dead time

* Example : $G = \frac{2.7(0.5s - 1)}{2s + 1}$

$\frac{y}{y_{sp}} = \frac{1}{\tau_c s + 1}$ or $\frac{2s}{\tau_c s + 1}$ is it good for this system.

$G_c = \frac{2s+1}{2.7(0.5s-1)} * \frac{1}{\tau_c s}$

درجة المقام لازم تكون اعلى
من البسط أو على الأقل
تساويه

positive root

unstable معناه

لازم يكون
غير

the main characteristic of the G

ف لازم يكون

$\frac{y}{y_{sp}} = \frac{(0.5s-1)}{\tau_c s + 1}$ → عشان يصير يروح
مع يلي قبل

$G_c = \frac{2s+1}{2.7\cancel{(0.5s-1)}} * \frac{\cancel{(0.5s-1)}}{\tau_c s} = \frac{2s+1}{2.7\, \tau_c s}$

→ Controller design

Simple criteria

→ Comprehensive criteria

- Integral
- Dsm

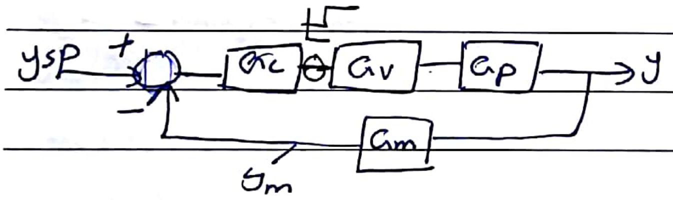
→ Emperical Method

- Cohen coon
- Ziegler-Nicols

Cohen-coon :-

→ open loop Method

وبدي أعمل exp. test



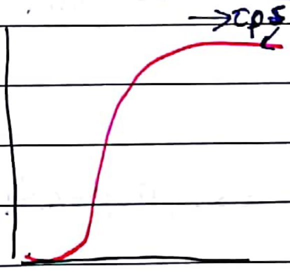
فبدنا نغير ل valve

فتحناها لأنه يمكن الوحيد اللي بقدر

ادخل منه عال process

time　　Input　　output (y)

$$G_p = \frac{K_p e^{-\theta s}}{\tau_p s + 1}$$



fitting for first order + dead time

اللي بدنا ع هو اللي لازم يعطينا ياهم　K_p, θ, τ_p

اذا طلعت (Gp) بهاد الشكل !

في عندي Formulas بتعطيني Gc

$$\text{PID}: K_c = f_1(K_p, \tau_p, \theta)$$

$$\tau_I = f_2(K_p, \tau_p, \theta)$$

$$\tau_D = f_3(K_p, \tau_p, \theta)$$

② Ziglar-Nicols Method.

based on closed-loop test.

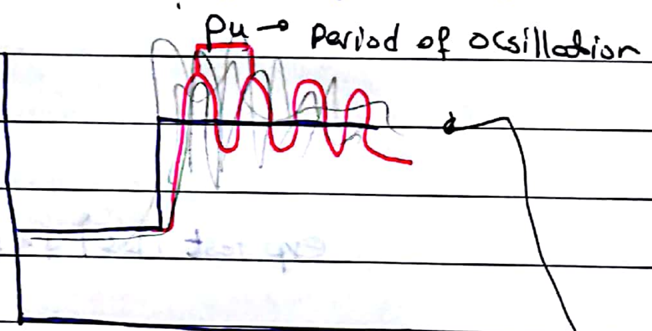
← بعمل دائرة وبحطها في وضع ال automation

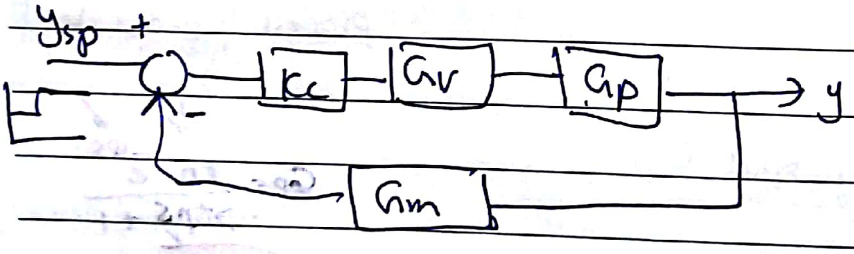
← انو بس احط Kc = Gc as P controller

وبخلي قيمة Kc قليلة .

slow responce ← large offset

وببدأ أزيد في قيمة (Kc) ولما بيطلع على ال responce لما تعطيني (Const) oscillation





→ Continueous Sustained oscillation

قيمة (Kc) هي اللي اعطتنا هاد ال responce بسميها Ku

(the ultimate value)

يعني هاي اعلى قيمة لل (Kc) وبقدر استخدمها عشان بعديها بصير unstable

المطلوب مني استخدم قيمة اقل بكثير من (Ku) عشان ابعد عن ال unstability .

P : $K_c = \frac{K_u}{2}$

PI : $K_c = \frac{K_u}{2.2}$

PID : $K_c = \frac{K_u}{1.2}$

$\left.\begin{matrix} \\ \\ \end{matrix}\right\}$ chek!!

PI = $\tau_I = \frac{P_u}{??}$, PID = $\tau_I = \frac{P_u}{??}$ $\tau_D = \frac{P_u}{??}$

السؤال اللي بيجي عليها هو:
انه بيعطيني حسابات وبيسأل انه

Are these numbers acceptable or not, According to cohen coon or Zigler ؟

* simple single feedback control loop :-

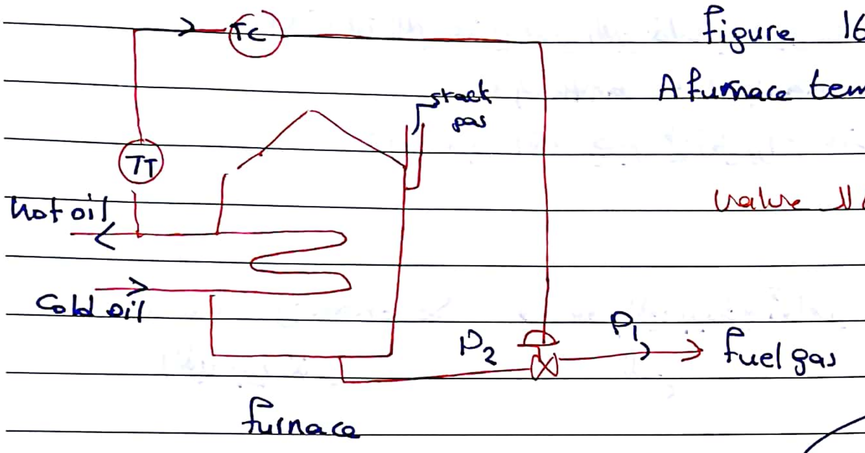


figure 16.1
A furnace temp. control schem.

ال controller ح يودي signal لل valve
انه يفتح بنسبة معينة.

افترضنا انه كل
X% valve opening
بتديني 3gal/min flow rate

بس هاد الحكي ممكن
ما يصير لانه متعلق at constant ΔP
فلما يختلف اي اشي منهم ΔP كل اشي رح يتغير.

→ flow through the value is not function of the value opening only, ... but it's function of ΔP "pressure drop"
600 ! → so, no, there is no garantee!

* fuel gas is a utility stream → فهو مشترك بين وحدات كثيرة
→ cooling water
→ steam
→ fuel ...

ال fuel رح يتغير حسب استهلاك الوحدات اللي بتأثر
فما بقدر افرض انه ΔP يكون ثابت
فحساباتي ممكن تكون غلط.

الحل انه احط controller (ΔP) عشان يصير عندي const. flow ← const. ΔP
ومهمته :-

ال flow controller هو نفس ال P controller

اضافة على ΔP اللي انا حطيت عليه كمان حساباتي
يعني بتحدد temp requirement ← ثبت temp
temp controller

Cascad controller:- manipulated variable subject to changes, Subject to Fluctuation.

المشكلة اللي عندي هي اللي خلتني اروح من ال Simple لل Cascade

انه ال manipulate variable

كان معرض انه يصير في تغييرات عندي خارجية !

to satisfy my original controller

Primary master → وهو اللي بيعطي أوامر لل Secondary Slave اللي بينفذ.

* featurness of cascade:-

① 2 controller

② 2 transmitters

③ one control Value

y_1 → لازم اقرأ المتغيرات

y setpoint قبل ما احل زي عمل

ratio controller → ratio between A & B = → ratio between setpoints = ratio between

أكثر ما بهمني كمية Ⓐ و Ⓑ

Wild flow → outlet flow of reactor

لمن صحح احط ال valve بعد ال reactor

مشان هيك يعني عندي wild flow

انه احافظ واهمت ال Ratio

① manipulation ratio.

بصير اقيسه بس ما بقدر اغيره.

② division ratio

لانه ما بقدر اتحكم فيه
مش وقفة تتكون هي
بس لنفترض انه مصوحلي
كل اشي بس بس مش قادر
اتحكم فيه.

* selective control ① ← انه اختارين الـ sensors مثلاً الأكبرهم حسب معينة

high ط low

لما تكون مش مهم

تزيد بس المهم ماتنقص

② ~~المشكلة~~ انه اختارين controller و controller

Over ride control system

مش transmitter و signal.

level or flow controll

للـ normal control

(activation) مابيعملها

الا اذا صار عنا مشكلة.

For safety or protection.

Boiler or furnace control

← بدي اعمل control له steam pressure

← بدي اعمل ratio control

← لازم اضبط الـ ratio between air & fuel

← بعدين excess air

← ممكن يصير عندي fluctuation

② cascade controller نحطها مشان هيك

ط T يعني ← P ط

بعمل analysis

طويلة عشانهم

فكرانه F ↓

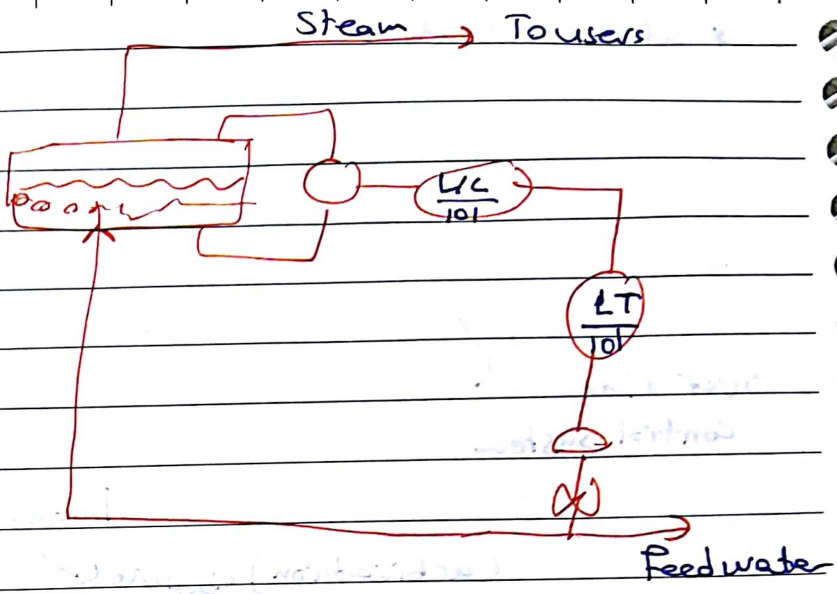
بس طلع يعني الـ

combustion is low

يعني Fuel ↓

أو air ↓

Boiler drum control .



Feed ← ماضيا اضي ←

disturbance →

→ steam P change

P → level → بيزيد
بيقل

→ حجم ال
bubble

level ال بيزيد فبيزيد.

بس هي مطرقة ونوبيجي

انتفاخ (swell)

كمية المي نفسها أو اقل

بس الحجم بيزيد (منتفخ)

فمشان هيك ال controller

بده يقلل ال flow

فكمية المي الحقيقية بيقللها

بيزيد ال evapmator

فبتزيد ال bubbles مع ال

بيزيد level .

- بيتنشف المي بالاضر ←

over مشكلة ←

disturbance من ضروري

Feed forward control

control dev عليه

لو زاد ال P شو بيصير ؟!

ال bubble بيقل

بس كمية المي ما بتقل بتضل زي ما هي

فبصير عنا shrink

بالlevel

ف ال controller رح يزيد المي

واللي بيدخل بال feed رح تكون

باردة فرح تبرده ف ال bubbles

رح تقل أكثر

ف رح تطلع مي مع steam

(droplets water
in steam)

مصايب مشكلة بيعمل Trip

بال turbines