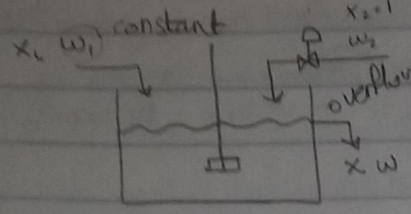
Chapter # 1 : Introduction to process control

1.2 illustrative example - a blending process



inputs $x_1\ w_1\ x_2\ w_2$

outputs $x\ w$

Controlled variable x (from outlets)

manipulated variable w_2 (from inlets)

disturbance variable x_1 since $x_2 = 1$, w_1 is constant

* Design equation assuming steady state operation

(1) $w = w_1 + w_2$

(2) $xw = x_1 w_1 + x_2 w_2$ $\quad x(w_1 + w_2) = x_1 w_1 + x_2 w_2$ $\quad w_1(x_1 - x) + w_2(x_2 - x) = 0$

$\Rightarrow w_2 = w_1 \dfrac{(x - x_1)}{x_2 - x}$ but x must equal the set point x_{sp} & $x_2 = 1$ $\quad \boxed{w_2 = w_1 \dfrac{(x_{sp} - x_1)}{(1 - x_{sp})}}$

we have nominal values to indicate steady state $\boxed{\bar{w}_2 = \bar{w}_1 \dfrac{(x_{sp} - \bar{x}_1)}{(1 - x_{sp})}}$ (*)

* Methods to control x

(1) measure x & adjust w_2

$-(\bar{w}_2 - w_2(t)) = K_c(x_{sp} - x(t))$

K_c must be +ve

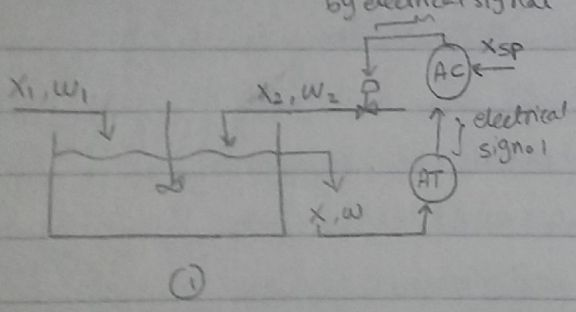
(2) measure x_1 & adjust w_2

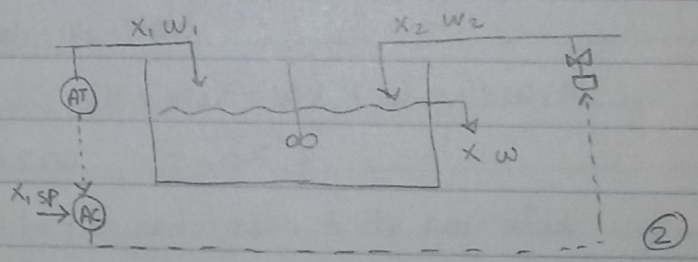
can be derived from (*)

$w_2(t) = \bar{w}_1 \dfrac{(x_{sp} - x_1(t))}{(1 - x_{sp})}$

(3) combine (1) & (2)

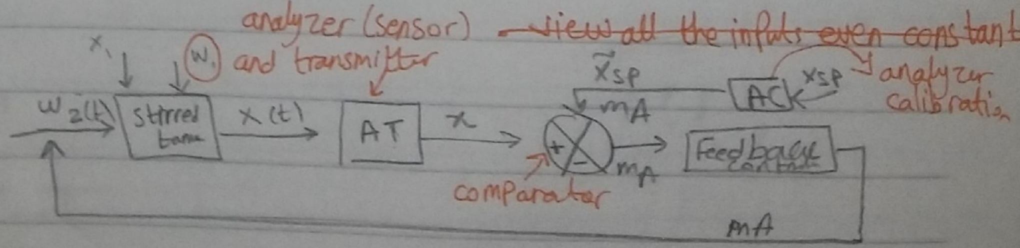
(4) large tank so not to be affected, but high capital cost.





~~1.4 a more complicated example - a distillation column~~

* Making a block diagram



Look

Ch. 2

2.2.1 Conservation Laws

↳ energy conservation law in general

rate of energy accumulated = rate of energy in by convection − rate of energy out by convection + q from surr. to system + work on system by surrounding

- rate of energy accumulated

$U_{total} = U_{internal} + U_{kinetic} + U_{potential}$ neglect $U_{kinetic}$ & $U_{potential}$

$U_{total} = U_{internal}$ rate $\frac{dU_{total}}{dt} = \frac{dU_{internal}}{dt}$

- neglect work done on system
- energy in − energy out $= -\Delta(w\hat{H})$

specific either for molar or mass flow rate

$$\boxed{\frac{dU_{internal}}{dt} = -\Delta(w\hat{H}) + Q}$$

Chapter #2 8 Thioritical models of chemical processes

→ Blending process example

mass $\frac{d(V\rho)}{dt} = w_1 + w_2 - w$ ① overall

$\frac{d(V\rho x)}{dt} = x_1 w_1 + x_2 w_2 - x w$ ② component

- assuming that the density is constant

$\rho \frac{dV}{dt} = w_1 + w_2 - w$ (*)

$\rho \frac{d(Vx)}{dt} = x_1 w_1 + x_2 w_2 - x w$

- expanding the accumulation term

$\rho x \frac{dV}{dt} + V\rho \frac{dx}{dt} = x_1 w_1 + x_2 w_2 - x w$

substitute (*) → $\frac{dV}{dt} = \frac{w_1 + w_2 - w}{\rho}$

$x(w_1 + w_2 - w) + V\rho \frac{dx}{dt} = x_1 w_1 + x_2 w_2 - x w$

$\frac{dx}{dt} = \frac{1}{\rho V}\left(w_1(x_1 - x) + w_2(x_2 - x)\right)$

Now, I have 2 ODE

$dV/dt = (w_1 + w_2 - w)/\rho$

$dx/dt = (w_1(x_1 - x) + w_2(x_2 - x))/\rho V$

Example 2.1 :-

assuming V constant = 2 $\rho = 900$ ⇒ $dV/dt = 0$ $w = w_1 + w_2$

ⓐ steady-state assuming $w_1 = 500$ $w_2 = 200$ $x_1 = 0.4$ $x_2 = 0.75$ x ?

$dx/dt = 0$ $w = w_1 + w_2 = 700$

$0 = w_1(x_1 - x) + w_2(x_2 - x)$ $w_1 x + w_2 x = w x = w_1 x_1 + w_2 x_2$

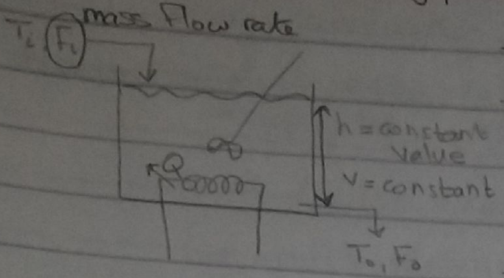
$700x = 0.4 \times 500 + 0.75 \times 200$ $\boxed{x = 0.5}$

ⓑ w_1 changes suddenly from 500 to 400 and remains at the new value determine $x_1(t)$ expression & plot

Look to Back P.19

Ch. 2

2.4.1 Stirred-tank heating process / Constant holdup → no mass balance is needed $F_i = F_o$



→ input : T_i F_i Q — Distirbance F_i

→ output : T_o F_o — Manipulated T_i OR Q

controlled variable T_o — Feedforward control — Feed backward

But here $F_i = F_o = \omega$

→ Process parameters : ρ C_p V

→ energy balance
$$\frac{dU_{internal}}{dt} = -\Delta(\omega\hat{H}) + Q$$

- assuming $U = H = \omega\hat{H} = \rho V c_p (T - T_{ref.})$ & assuming c_p & ρ Temp. independent
- $-(\Delta\omega\hat{H}) = H_{in} - H_{out} = \omega C_p (T_i - T_{ref} - T_{ref} + T_o) = \omega C_p (T_o - T_i)$

$dH = \rho V C_p dT$

$$\Rightarrow \boxed{\rho V C_p \frac{d(T - T_{ref})}{dt} \overset{= dT}{=} \omega C_p (T_o - T_i) + Q}$$

Note

$H_{out} - H_{in}$

$\hat{H}_{out} - \hat{H}_{ref} = C_p (T - T_{ref.})$

$\hat{H}_{ref.}$ assumed = Zero

DoF = 5 − 1 − 1 = 3 The process is under specified.

3 variables must be specified : T_i, F_i, T_o

2.4.2 Stirred tank heated process / Variable hold up

Process variables

Inputs : T_i F_i Q → distirbance variables

manipulated variable Q OR T_i OR F_i

Outputs : T_o F_o h

controlled variable h OR T_o OR F_o — F_o & h ∇ وجهان لعملة واحدة

Process parameters : ρ C_p assumed to be temp. independent

→ mass balance $\frac{dV\rho}{t} = F_i - F_o$ $\boxed{\frac{dV}{dt} = \frac{1}{\rho}(F_i - F_o)}$ (1)

Definition. (it differ in chain rule)

→ energy balance $\rho c_p \frac{dV(T - T_{ref.})}{dt} = F_i C_p (T_i - T_{ref.}) - F_o C_p (T_o - T_{ref.}) + Q$

$$\rho c_p \left(V\frac{dT}{dt} + T\frac{dV}{dt} \right) = \rho c_p \left(V\frac{dT}{dt} + \frac{1}{\rho}(F_i - F_o) \right) + Q$$

$$\rho C_p \left(V\frac{dT}{dt} + \frac{(T-T_{ref.})(F_i - F_o)}{\rho} \right) = F_i C_p (T_i - T_{ref.}) - F_o C_p (T_o - T_{ref.}) + Q$$

$$\rho \cancel{C_p} V \frac{dT}{dt} + \cancel{C_p}(T-T_{ref.})(F_i-F_o) = F_i\cancel{C_p}(T_i - T_{ref.}) - F_o \cancel{C_p}(T_o - T_{ref.}) + \frac{Q}{C_p}$$

$$\rho V \frac{dT}{dt} = \underline{F_iT_i} - \cancel{F_iT_{ref.}} - F_oT_o + \cancel{F_oT_{ref.}} - F_i\underset{T_o}{\underset{=}{T}} + \cancel{F_iT_{ref.}} + F_o \underset{T_o}{\underset{=}{T}} - \cancel{F_oT_{ref.}} + \frac{Q}{C_p}$$ in book

$$\frac{dT}{dt} = \frac{F_i}{\rho V}(T_i - T_o) + \frac{Q}{\rho V C_p} \quad (2)$$

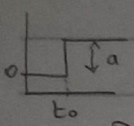
Chapter #3: Laplace Transforms + Ch. #4: Tranfer Function models

- $F(s) = \mathcal{L}\, F(t) = \int_0^{\infty} F(t)\, e^{-st}\, dt$

- constant Function $F(t) = a$

$$\mathcal{L}\, F(t) = \int_0^{\infty} a e^{-ts} dt = \frac{-a}{s} \int_0^{\infty} e^{-st} dt = \boxed{\frac{a}{s}}$$

- Step Function



$$S(t) = \begin{cases} 0 & t<0 \\ a & t \geq 0 \end{cases} \qquad \mathcal{L}\, S(t) = \boxed{\frac{a}{s}}$$

(initial time, time zero, zero time).

- Derivative

$$F(s) = \mathcal{L}\,(dF/dt) = \int_0^{\infty} (dF/dt)\, e^{-ts}\, dt = \boxed{sF(s) - F(0)}$$

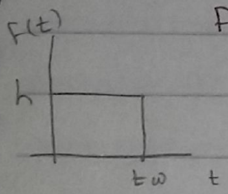
Generally

$$\mathcal{L}\left(\frac{d^n F}{dt^n}\right) = s^n F(s) - s^{n-1} F(0) - s^{n-2} F^{(1)}(0) - \cdots - sF^{(n-2)}(0) - F^{(n-1)}(0).$$

$$\mathcal{L}\left(\frac{d^2 F}{dt^2}\right) = s^2 F(s) - s F(0) - F'(0)$$

$$\mathcal{L}\left(\frac{d^3 F}{dt^2}\right) = s^3 F(0) - s^2 F(0) - s F'(0) - F''(0)$$

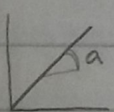
- Rectangular pulse Function



$$F(t) = \begin{cases} 0 & t<0 \\ h & 0 \leq t < t_w \\ 0 & t \geq t_w \end{cases}$$

$$\mathcal{L}\, F(t) = \int_0^{\infty} h e^{-st} dt = \int_0^{t_w} h e^{-st} dt = \boxed{\frac{h}{s}\left(1 - e^{-t_w s}\right)}$$

- Ramp Function

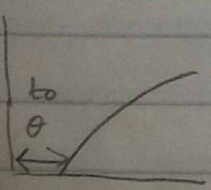


$$f(t) = at \qquad F(t) = \mathcal{L}\, f(t) = \int_0^{\infty} at\, e^{-ts} = \boxed{\frac{a}{s^2}}$$

- Transformation of integral

$$\mathcal{L}\left(\int_0^t F(t^*)\, dt^*\right) = \boxed{\frac{1}{s} F(s)}$$

- Time delay $(\theta \equiv t_0)$ $\quad F_d(t) = F(t-t_0)\, \underline{S(t-t_0)}$ step function change



$$Y(s) = \mathcal{L}\, F_d(t) = \mathcal{L}\, F(t-t_0)\, S(t-t_0) = \boxed{e^{-st_0} F(s)}$$

- Final value theorem

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

- initial value theorem

→ $y(t)_0 = \lim_{t \to 0} y(t) = \lim_{s \to \infty} (sY(s))$

Chapter # 5 : Dynamic behavior of a first order and second order Processes

5.1 2. ramp input

if $Q(t) = 8000 + 2000\, S(t)$

$Q'(t) = 2000\, S(t) \xrightarrow{\text{Transformed}} u_s(s) = \frac{M}{s}$

5.2 Response of First order processes

$G(s) = \frac{Y(s) \leftarrow \text{output}}{X(s) \leftarrow \text{input}} = \frac{K}{\tau s + 1}$ K : process gain, τ : time constant

⇒ Derivation of the above equation.

general formula $a_0 \frac{dy'(t)}{dt} + a_1 y'(t) = b\, x'(t)$ $\div a_1$

$\frac{a_0}{a_1} \frac{dy'(t)}{dt} + y'(t) = \frac{b}{a_1} x'(t)$ Take Laplace Transformation

$\frac{a_0}{a_1}\left(s\,Y(s) + \underbrace{\cancel{y(0)}}_{=\text{zero}}\right) + Y(s) = \frac{b}{a_1} X(s)$ $\frac{a_0}{a_1} sY(s) + Y(s) = \frac{b}{a_1} X(s)$

$Y(s)\left(s\frac{a_0}{a_1} + 1\right) = \frac{b}{a_1} X(s)$ $\frac{Y(s)}{X(s)} = G(s) = \frac{b/a_1}{s\left(\frac{a_0}{a_1}\right) + 1} = \boxed{\frac{K}{\tau s + 1}}$ # K, τ ①

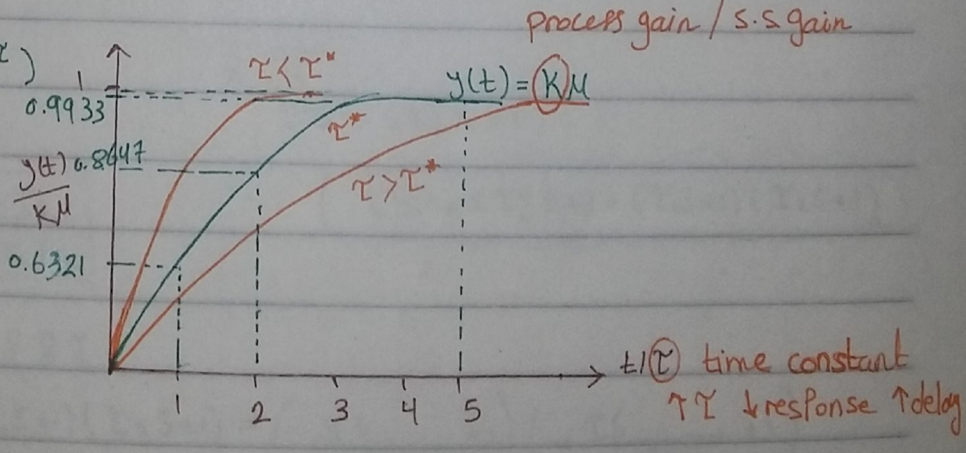
↳ For step function change in input & $X(s) = \frac{M}{s}$

substitute in ① $Y(s) = G(s)X(s)$

$Y(s) = \left(\frac{K}{\tau s + 1}\right) \cdot \frac{M}{s} = \frac{KM}{s(\tau s + 1)}$ in order to see the output response → y(t)

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

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



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5.4 Response of second order processes

From 2^{nd} order differential equation

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

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

$$\frac{a_0}{a_2}\left(s^2y(s) - \cancel{sy'(0)} - \cancel{y(0)}\right) + \frac{a_1}{a_2}\left(sy(s) - \cancel{y'(0)}\right) + y(s) = \frac{b}{a_2}X(s)$$ cancelling zeros

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

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

① Originally, but it can be as a 2 First order systems in series.

→ For input as a step function $X(s) = M/s$

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

- apply final value theorem

$$\lim_{t\to 0} y(t) = \lim_{s\to 0} sy(s) = \lim_{s\to 0}\frac{MK}{\tau^2s^2 + 2\xi s + 1} = MK \text{ (same as } 1^{st} \text{ order).}$$

→ Derivation for 2 first order system in series → It can't be underdamped

$$X(s) \rightarrow \boxed{\frac{K_1}{\tau_1 s + 1}} \xrightarrow{Y_1(s)} \boxed{\frac{K_2}{\tau_2 s + 1}} \rightarrow Y_2(s)$$

relation between Y_2 & X is needed

$$G(s) = G_1(s)G_2(s) = \frac{K_1}{(\tau_1 s + 1)}\cdot\frac{K_2}{(\tau_2 s + 1)} = \frac{K_1K_2}{\tau_1\tau_2 s^2 + s(\tau_1 + \tau_2) + 1}$$ compare with 1

$$= \frac{K}{\tau^2s^2 + 2\tau\xi s + 1}$$

$\boxed{K = K_1K_2}$

$\tau^2 = \tau_1\tau_2 \rightarrow \boxed{\tau = \sqrt{\tau_1\tau_2}}$

$2\xi\tau = \tau_1 + \tau_2 \rightarrow \boxed{\xi = \frac{\tau_1 + \tau_2}{2\sqrt{\tau_1\tau_2}}}$

$\tau^2s^2 + 2\tau\xi s + 1 = (\tau_1 s + 1)(\tau_2 s + 1)$

- OR τ_1 & τ_2 in terms of ξ & τ

$$\tau^2s^2 + 2\tau\xi s + 1 = (\tau_1 s + 1)(\tau_2 s + 1) = \left(\frac{\tau s}{\xi - \sqrt{\xi^2 - 1}} + 1\right)\left(\frac{\tau s}{\xi + \sqrt{\xi^2 - 1}} + 1\right)$$

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$$s = \frac{-2\tau\xi \pm \sqrt{4\tau^2\xi^2 - 4\tau^2}}{2\tau^2}$$

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

$$\frac{-\xi - \sqrt{\xi^2 - 1}}{\tau}, \quad \frac{-\xi + \sqrt{\xi^2 - 1}}{\tau}$$

$$\boxed{\tau_1 = \frac{\tau}{\xi - \sqrt{\xi^2 - 1}} \qquad \tau_2 = \frac{\tau}{\xi + \sqrt{\xi^2 - 1}}}$$

$\xi^2 \geq 1$

→ Cases for ξ 2nd order systems

ξ			
$\xi > 1$	overdamped	2 distinct roots	. if $\xi < 0$ it will be an unstable systems that will, respond to any input. have unbounded
$= 1$	critically damped	2 similar roots	
$0 < \xi < 1$	underdamped	complex roots	

$$y(t) = KM\left(1 - e^{-\xi t/\tau}\left[\cos\left(\frac{\sqrt{1-\xi^2}}{\tau}t\right) + \frac{\xi}{\sqrt{1-\xi^2}}\sin\left(\frac{\sqrt{1-\xi^2}}{\tau}t\right)\right]\right)$$

→ For the case where $0 < \xi < 1$

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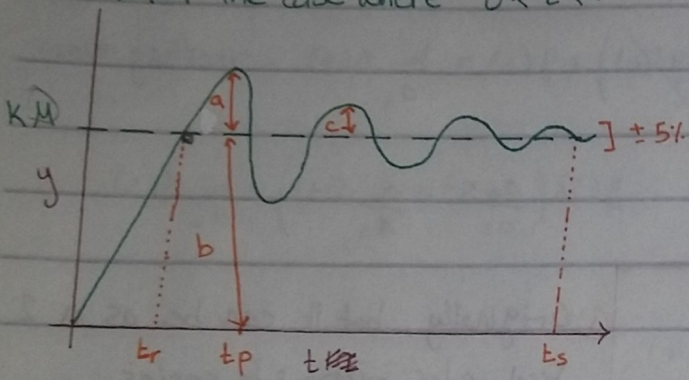

1. Rise Time $y(t) = KM$ First time

2. Time to First peak $\boxed{t_p = \frac{\pi\tau}{\sqrt{1-\xi^2}}}$

Derivative
substitute @ a

3. Settling time t_s

4. overshoot $\boxed{OS = \frac{a}{b} = \exp\left(\frac{-\pi\xi}{\sqrt{1-\xi^2}}\right)}$

5. Decay ratio $\boxed{DR = \frac{c}{a} = OS^2 = \exp\left(\frac{-2\pi\xi}{\sqrt{1-\xi^2}}\right)}$

6. Period of oscillation $\boxed{P = \frac{2\pi\tau}{\sqrt{1-\xi^2}}}$

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Disadvantage: off set appears.
Advantage: fast response

Chapter #8: Feedback controllers + Chapter #11

① Proportional controller

- objective is to reduce the error signal to zero $e(t) = \underline{y_{sp}}(t) - y_m(t)$ mostly constant
- Controller output $P(t) = \bar{P} + e(t)K_c$ constant gain, in order preventing "self destructive"

not $e'(t)$ because $e'(t) = e(t) - 0$

making it in the deviation form $\boxed{P'(t) = e(t)K_c}$ *

$y_m(t) \rightarrow \bigcirc \xrightarrow{e(s)} \boxed{G_c} \xrightarrow{P(s)}$, y_{sp}

Taking Laplace $\boxed{P'(s) = K_c\, e(s)}$

Transfer Function $\boxed{G_c(s) = \frac{P'(s)}{e(s)} = K_c}$ **

- Derivation of $P(s)$: $\mathcal{L}P'(t) = \mathcal{L}e(t)K_c = \int_0^\infty K_c e(t) e^{-st}\,dt$
$= K_c e(s)$

② Proportional integral controller → Proportional form $P'(t) = K_c e(t)$ (I)

→ integral form. $P'(t) = \frac{1}{\tau_I}\int_0^t e(t^*)\,dt^*$ (P)

slower than, but eliminate offset. However, make oscillation

* Combine (I) & (P)

* $\boxed{P'(t) = K_c\left(e(t) + \frac{1}{\tau_I}\int_0^t e(t^*)\,dt^*\right)}$

→ Taking laplace $\mathcal{L}P'(t) = \mathcal{L}K_c\left(e(t) + \frac{1}{\tau_I}\int_0^t e(t^*)\,dt^*\right)$

$\boxed{P'(s) = K\left(e(s) + \frac{e(s)}{s\tau_I}\right)}$

→ Transfer function $G_c = \frac{P'(s)}{e(s)} = K_c\left(1 + \frac{1}{\tau_I s}\right) = \boxed{K_c\left(\frac{\tau_I s + 1}{\tau_I s}\right)}$ **

- Advantage: offset elimination
- Disadvantage: oscillating

reduces the stability of Feedback control system

parallel type

③ Proportional – integral – derivative controller → Proportional $P'(t) = K_c$

→ integral $P'(t) = \frac{1}{\tau_I}\int_0^t e(t^*)\,dt^*$

→ derivative $P'(t) = \tau_D \frac{de(t)}{dt}$

anticipate the future behaviour of error signal by considering its rate of change → stabilize control process (counteract integral mode destabilizing) & improve dynamic response by setting time

However, not good for noisy signals (sensitive), it will contain high frequency, random fluctuation

↓ solution → Filtered term $\frac{1}{\alpha \tau_D s + 1}$ $\alpha \rightarrow 0.05 - 0.2$ (0.1 as common choice)

Combine for PID $\quad p'(t) = k_c\left(e(t) + \frac{1}{\tau_I}\int_0^t e(t^*)\,dt^* + \tau_D \frac{de(t)}{dt}\right)$

Laplace $\quad P'(s) = k_c\left(e(s) + \frac{1}{\tau_D s} e(s) + \tau_D\left(s\,e(s) - \overset{0}{e(0)}\right)\right)$

$$P'(s) = k_c\left(e(s) + \frac{1}{\tau_I s} e(s) + s\,\tau_D\, e(s)\right)$$

Transfer $\quad \boxed{G_c(s) = \frac{P'(s)}{e(s)} = k_c\left(1 + \frac{1}{\tau_I s} + \tau_D s\right)}$ PID without derivative filter

Now, to reduce sensitivity of control calculations to noisy measurement add filter term

$$\boxed{G_c(s) = k_c\left(1 + \frac{1}{\tau_I s} + \frac{\tau_D s}{\alpha \tau_D s + 1}\right)}$$ PID with derivative filter

~~8.3.2 Reverse or direct~~ action

11.2 Closed loop transfer function (To understand ellset meaning) . with out current to pressure transmitter

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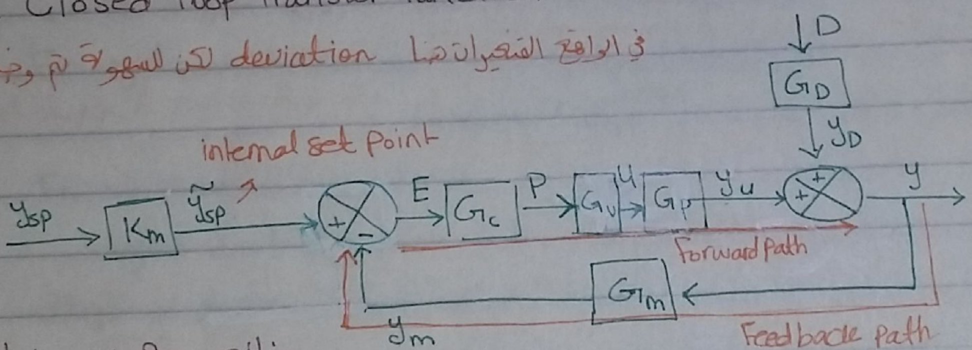


D & y_{sp} independent

* Applying superposition

① Assuming $D = 0$ (no change in D) $\Rightarrow y/y_{sp}$ "set point changes" "servomechanism"

$y = y_D + y_u$ but $D = 0$, $y_D = 0 \rightarrow y = y_u$

$y_u = u G_p = P G_v G_p = E G_c G_v G_p = (\tilde{y}_{sp} - y_m) G_c G_v G_p$

$y = y_u = (y_{sp} k_m - y G_m) G_c G_v G_p$

$y(1 + G_m G_c G_v G_p) = y_{sp} k_m G_c G_v G_p$

①

$$\boxed{\frac{y}{y_{sp}} = \frac{\overbrace{K_m G_c G_v G_p}^{\text{Forward}}}{1 + \underbrace{G_m G_c G_v G_p}_{\text{Forward + Feed back} \equiv G_{OL}}}}$$

OL: open loop

② Assuming $y_{sp} = 0$ (no change in y_{sp}) $\Rightarrow y/D$ "disturbance changes"

$y = y_D + y_u = D G_D + E G_c G_v G_p = D G_D + (\tilde{y}_{sp} - y_m) G_c G_v G_p$

$y = D G_D + y G_m G_c G_v G_p$

②

$$\boxed{\frac{y}{D} = \frac{G_D}{1 + G_m G_c G_v G_p} = \frac{G_D}{1 + G_{OL}}}$$

Now, add ①+② in terms of y

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

11.3.1 Propotional Control and set-point changes

$E = \boxed{\text{offset} = y_{\text{set point}} - y(t)_{m}}$
$\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad \infty$

if it is constant, if not take $\tilde{y}_{sp}(t)$
∞

analog / digital
interface → controlled variable measurement
manipulated variable adjustment
transmition instruments

CHAPTER #9 : Control system instrumentations

9.1 / 9.1.1 → Sensor, transmitter, transducer

between sensor & controller ← Just to controller ; transducer → any conversion between any system component — e.g. between controller and final control element.

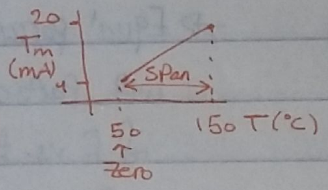
* Standards
  - 3-15 psig
  - 4-20 mA
  - 1-5 V (VDC) direct current

→ 9.1.2 Sensors

* selection criteria

→ 9.1.3 Static and dynamic characteristic

- transmitters are generally designed to be direct ac
- adjustable input range.
- zero & spane of the overall sensor / transmitter are adjustable.
- if sensor power supply fails → 0 mA → controller & actuator to min. or max → if unsafe inverted to give highest value in the operating range.



- For any linear instrument $\boxed{K_m = \dfrac{\text{Output} \cancel{\text{spane}} \text{ range}}{\text{measurement range}}}$ ← span

does not change if zero is changed

- For non linear instrument :
  tangent @ operating point of the characteristic equation
- Maybe dynamics of first order "(results an error between the true and measured value)"

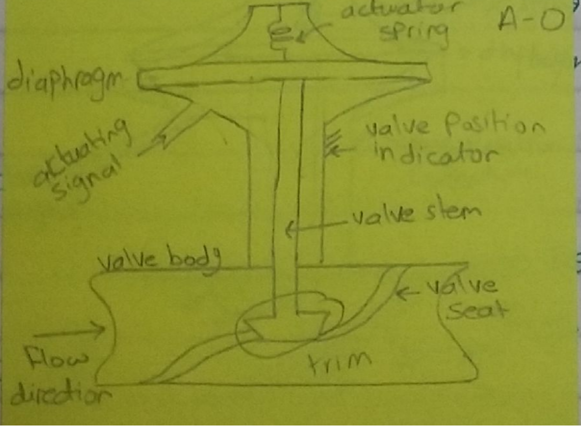
$$\boxed{\frac{Y_m(s)}{Y(s)} = \frac{K_m}{\tau_m s+1}}$$

$[K_m] = mA/°C$ if Temp. "monotonic response"

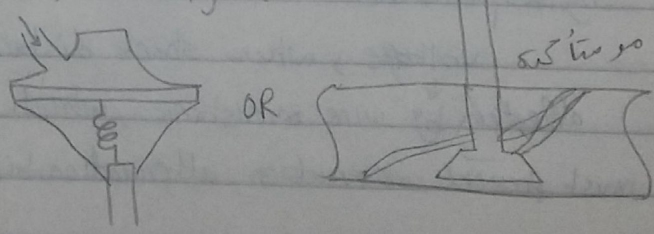
As a result of velocity-distance lag because of → Poor sensor location, long sampling line

→ 9.2 Final Control elements

→ 9.2.1 Control valves



A-O rising stem valve
A-C , reverting



You can find relation function between T_m & T

From the line

$$m = \frac{T_m - T_{m_0}}{T - T_0} \qquad T_m = m(T - T_0) + T_{m_0}$$

$= K_m$

$$T_m = \left(\frac{20-4}{150-50}\right)(T-50) + 4$$

$$\boxed{\begin{aligned} T_m &= 0.16(T-50)+4 \\ &= 0.16T - 4 \end{aligned}}$$

→ 9.2.2 Valve positioners
- Just for pneumatic control valves.
- It eliminate valve dead band and hysteresis, flow rate loading, ---

→ 9.2.3 Specifying and sizing control valves

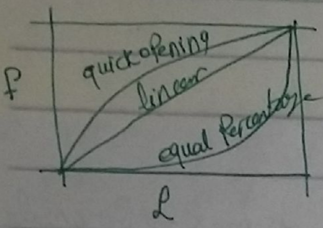
$$\boxed{q = C_v\, f(\ell) \sqrt{\frac{\Delta P_v}{g_s}}}$$

value size depends on f

C_v depends on valve size or capacity

f: valve characterestics, Flow; ℓ: lift (extent of valve opening)

- For constant pressure drop across the valve, f is related to lift (ℓ) by one of the following relations



- linear ($f = \ell$) $\quad 0 \le f \le 1 \quad 0 \le \ell \le 1$
- quick opening ($f = \sqrt{\ell}$) "square root valve"
- Equal percentage ($f = R^{\ell - 1}$) R is a number

R is a valve design parameter 20 → 50

→ Equal percentage valve is named like this because of equal percentage change of f with particular change with ℓ any where in the range. Because of slope of f vs. ℓ ($df/d\ell$) is proportional to f.

- Rangeability of control valve: ratio of max. to min. input signal

Imp. why I have to choose certain value from the chart?
The designer's objective is to obtain an installed valve characterestics that is ~~I~~ as linear as possible that is, to have flow through the valve and all connected process units vary linearly with ℓ.

Choose linear value
if pump characteristics is flat and small friction loss

→ 9.3 Signal transmission and digital communication.

Electronic ~~Digital~~ Signals – current
voltage ; when short distances are involved
allected by wire resistance, which allects the wire length, Temp., aging.

- You must prevent ~~attenution~~ attenuation, biasing, or inducting noise → shielded coaxial cable

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