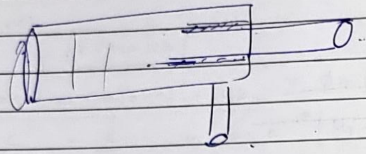
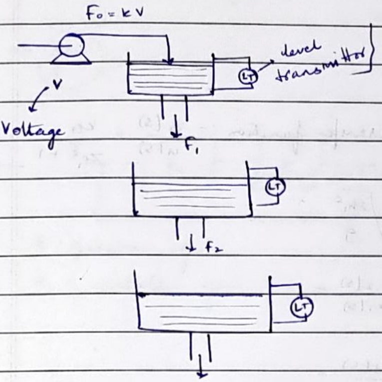


Madhuri

PDC



$$\frac{dh_1}{dt} = \frac{F_0}{A_1} - \frac{a_1}{A_1}\sqrt{2gh_1}$$

$$\frac{dh_2}{dt} = \frac{a_1}{A_1}\sqrt{2gh_1} - \frac{a_2}{A_2}\sqrt{2gh_2}$$

$$\frac{dh_3}{dt} = \frac{a_2}{A_2}\sqrt{2gh_2} - \frac{a_3}{A_3}\sqrt{2gh_3}$$

input = V

Output = level of tank 3.

$a_1, a_2, a_3 \rightarrow$ area of outflow pipe

$A_1, A_2, A_3 \rightarrow$ area of tank

→ PID controller $\quad c = c_b + k_c e + \frac{k_c}{\tau_I}\int e\,dt + k_c \tau_D \frac{de}{dt}$

$e = 0 \rightarrow$ at ss
↳ can be used to ~~cal~~ obtain c_b
$(c = c_b)$
↳ controller bias

$e = SP - PV$
SP → set point
PV → process variable

→ Tuning of PID controller → obtain k_c, τ_I, τ_D → using transfer function model find k_c, τ_I, τ_D

$$\boxed{\text{Dynamic model}} \rightarrow \boxed{\text{Transfer function model}} \rightarrow \boxed{\text{find } k_c, \tau_I, \tau_D}$$

→ current to voltage → use resistor

→ laplace transform of non-linear equation is not possible

Transfer function model

Define: $x_1 = h_1 - h_1^s$; $x_2 = h_2 - h_2^s$, $x_3 = h_3 - h_3^s$, $u = V - V^s$
(deviation variable)

⇒ ss values are desired operating conditions

→ linearize using taylor series approx. about ss value :-

$$\frac{dh_1}{dt} = \frac{k}{A_1}V - \frac{a_1}{A_1}\sqrt{2g}\left[\sqrt{h_1^s} + \frac{1}{2\sqrt{h_1^s}}(h_1 - h_1^s)\right] \quad -①$$

SS :- $\frac{k}{A_1} v^s - \frac{a_1\sqrt{2gh_1^s}}{A_1} = 0 \to (2)$

$= \frac{dh_1^s}{dt}$

(1) − (2)

$\frac{dx_1}{dt} = \frac{k}{A_1} u - \frac{a_1\sqrt{g}}{A_1\sqrt{2h_1^s}} x_1$ ⇒ transfer function :- $\frac{x_1(s)}{u(s)} = \frac{k_{p_1}}{\tau_{p_1} s + 1}$

$k_{p_1} = \frac{k}{a_1}\sqrt{\frac{2h_1^s}{g}}$ $\tau_{p_1} = \frac{A_1}{a_1}\sqrt{\frac{2h_1^s}{g}}$

$\frac{dx_2}{dt} = ---$ $\frac{x_2(s)}{x_1(s)} =$

$\frac{dx_3}{dt} = ---$ $\frac{x_3(s)}{x_2(s)} =$

Process transfer function $= G(s) = \frac{x_3(s)}{u(s)} = \frac{k_{p_1} k_{p_2} k_{p_3}}{(\tau_{p_1}s+1)(\tau_{p_2}s+1)(\tau_{p_3}s+1)}$

Servo, regulatory → ≡

DOF ⇒ ✓

→ Quadruple tank system

$\frac{dh_1}{dt}$

$\frac{dh_2}{dt}$

$\frac{dh_3}{dt}$

$\frac{dh_4}{dt}$

No: of inputs = No: of outputs
↳ DOF = 0

Jacketed CSTR

output → T

MV = F_j

CSTR

A → B → C Van-de-Vusse reaction

A → 2D

desiredproduct = B

Input = $\frac{F}{V}$ = τ → residence time (this will change the conc)

{Donot require c_C, c_D}

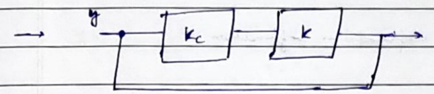
c_B = output, F = Input → plot to know what is the desired value c_B v/s F

eqn (3) & (4) are not required (can be neglected)

Depending on the control objective, we can reduce the no: of equations

Input multiplicity system → same output can be achieved for multiple different inputs

⇒ gain



If k = +ve, k_c = ?

If k changes from +ve to −ve, k_c should change accordingly

k = process gain

k_c = controller gain

→ MATLAB

sfunctions [S-function takes the differential equation in the form of state space model]

>>[edit sfuntmpl]

$\dot{x} = f(x, u)$ → state equation

$y = h(x, u)$ → output map

→ 3 tank system

$\frac{d}{dt}\begin{bmatrix} h_1 \\ h_2 \\ h_3 \end{bmatrix} =$

$u = F_0$, $\dot{x}$ | $x = \begin{bmatrix} h_1 \\ h_2 \\ h_3 \end{bmatrix}$

→ Control relevant state-space model

$\dot{x} = f(x) + g(x)\cdot u$ → non-linear S-S model

$\dot{x} = Ax + Bu$ → linear S-S model

$Y = Cx + Du$

→ No: of continuous states = 3 (h_1, h_2, h_3) → no: of continuous equations.

No: of discrete states = 0 No: of inputs = 1

No: of outputs = 1 (h_3)
↳ we want to measure the level of 3rd tank only.
or 3 (h_1, h_2, h_3) → to get the info about all 3.

Dirfeedthrough → while calculating the output whether input is involved or not. If input is involved → then enter 1 else 0

⇒ x_0 = [ ]; → initial conditions for the states

→ Code

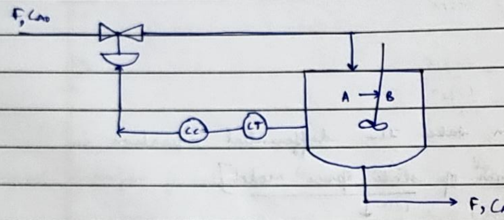
sys = [der1; der2]; → ⓧ

→ Simulink

↓

library browser → simulink → user defined → s-function

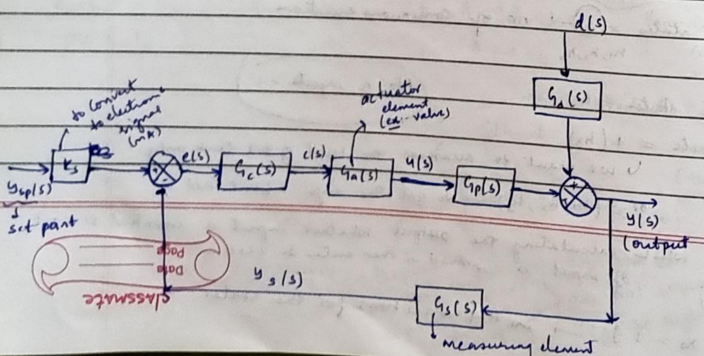
Reactor control



Designing control system

1. select control architecture
   - feedback (initial)
2. find transfer function model of process
   - (a) using model equation
   - (b) Using process data
3. select controller algorithm
   - (A) PID controller
   - (b) Other types.

Feedback control loop



Reactor: $\frac{dC_A}{dt} = \frac{F}{V}(C_{A0} - C_A) - kC_A^2$

V → const F → manipulative variable (u(s))

linearize and take laplace. left over input → disturbance (d(s))

$$y(s) = \frac{(C_{A0}^s - C_A^s)^1/_V}{s + \frac{F^s}{V} + 2kC_A^s}\, u(s) + \frac{F^s/V}{s + \frac{F^s}{V} + 2kC_A^s}\, d(s)$$

$y = C_A - C_A^s \qquad u = f - F^s \qquad d = C_{A0} - C_{A0}^s$

Control valve :- (actuator) $u(s) = \frac{K_a}{\tau_a s + 1}\, c(s)$ [Generally pneumatic control valve]

- Normally first order (specified by vendor)
- Time const specified by vendor
- Gain (calculated from installed characteristics)

→ air to close control valve

→ air to open

Types of Globe valves

Quick opening

Equal percentage

linear

⇒ valve eqn :- $Q = C_v\, f(x) \sqrt{\frac{\Delta P}{s.g.}}$

this will decide which type of valve it is

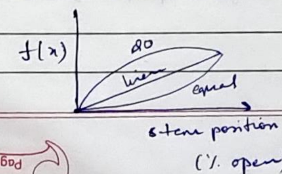
$f(x) = x$ — linear

$f(x) = \sqrt{x}$ → Quick opening

$f(x) = R^{x-1}$ → equal %.

R → rangibility of valve

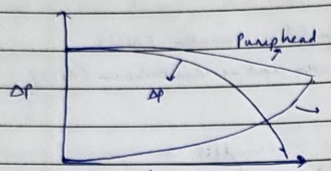
⇒ Inherent control valve.



(pressure drop across the valve is const)

But if flow changes ΔP changes.

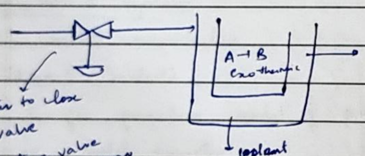
ΔP v/s Q



if ΔP changes, valve characteristics change.

→ Installed flow characteristics

→ When to use air to open valve or air to close valve?
- depends on the safety of the process



∴ If the valve fails, the flow will still continue

But if we use air to open valve, No flow will occur & explosion might take place (exothermic)

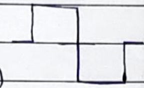
Sensor :- $y_s(s) = \dfrac{K_s e^{-\alpha s}}{\tau_s s + 1}$

→ Gain is calculated from range setting

→ Time const & measurement delay is specified by vendor.

→ Obtain process data using specified signal
- step function
- Pulse function
- Sinusoidal function (rarely used)
- Pseudo random Binary sequence (PRBS)

Doublet (2 pulses opp)



→ Process data includes the actuator and sensor response

→ Evaluate transfer function model from process.

$y_s(s) = g_p(s)\, c(s) + g_d(s)\, d(s)$

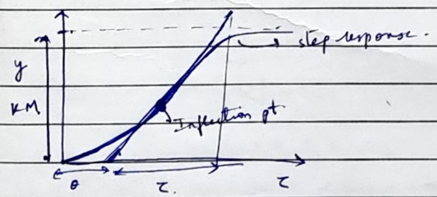
→ 1st order ~~process~~ with dead time (FOPDT)

$$g(s) = \frac{K e^{-\theta s}}{\tau s + 1}$$

→ 4 classical methods (using step response data)

1. Zeigler Nichols method
2. Smith's
3. Sundaresan & Krishnaswamy
4. Nishikawa's

→ Z - N method



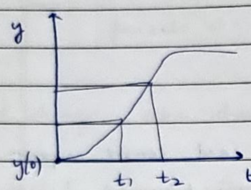
Draw a tangent at the inflection pt.

→ Difficult to find inflection point & to draw tangent

Smith's method

$K = \frac{\Delta output}{\Delta input}$ $\qquad \tau = \frac{3}{2}(t_2 - t_1)$

$\theta = t_2 - \tau$



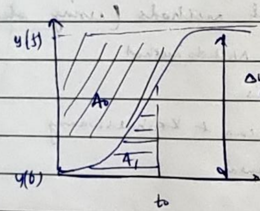
Sundaresan & krishnaswamy

$k = \frac{\Delta output}{\Delta input}$ $\qquad \tau = \frac{2}{3}(t_2 - t_1)$ $\qquad \theta = 1.3t_1 - 0.29t_2$

Nishikawa's

$A_0 = \int_0^\infty (\Delta y(\infty) - \Delta y(t))dt$

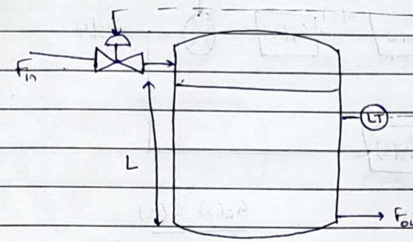
$A_1 = \int_0^{t_0} \Delta y(t)dt$, $t_0 = \frac{A_0}{\Delta y(\infty)}$



$\tau = \frac{A_1}{0.368\,\Delta y(\infty)}$ $\qquad \theta = t_0 - \tau$ $\qquad K = \frac{\Delta y(\infty)}{\Delta C(\infty)}$

PID Controller

Direct / Reverse acting controller



Input ↑, output ↑ → sign of gain = +ve

~~sig~~ sign of gain of level

air to open valve = +ve

product of these 2 = +ve

∴ use reverse control element

Process variable ↑, controller output ↑ → direct acting controller → controller gain = K_c = −ve

PV ↓, controller output ↓ → reverse acting → sign of controller gain = +ve.

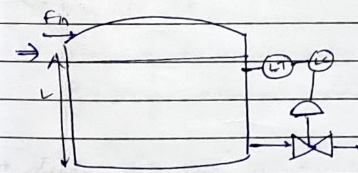
$e = \underset{\text{set point}}{SP} - PV$

$$\left[\frac{dC_{out}}{dt} = K_c \frac{de}{dt}\right]$$

for direct acting PV ↑, e = −ve.

but $\frac{dC_{out}}{dt}$ = +ve ∴ K_c = −ve.

Guidelines of selecting a controller



Process gain = −ve → fout ↑ h ↓.

If we use air to open valve → gain = +ve

product = −ve

∴ use direct acting controller

→ fail open / fail close valve

→ air to open / air to close

Cout ↑ valve will open more

direct acting final control element

(~~reverse~~ / ~~acting~~)

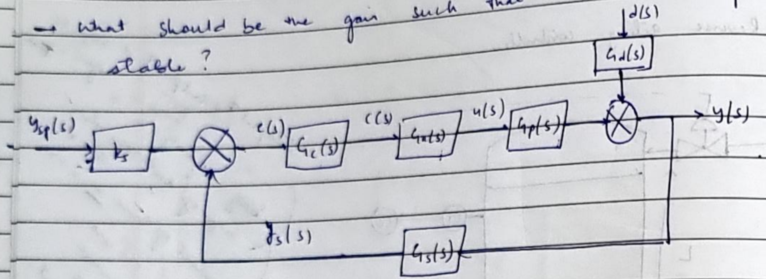
So whatever action controller is taking, valve will be in same direction.

(if the level ↑ the Cout ↓ (close the valve)

(gain = +ve)

(controller → reverse acting controller

→ What should be the gain such that the closed loop system is stable?



$$\frac{y(s)}{y_{sp}(s)} = \frac{k_s G_p(s) G_a(s) G_c(s)}{1 + G_p(s) G_a(s) * G_c(s) G_s(s)} = \frac{G_c(s) G(s)}{1 + G_c(s) G(s)}$$

→ characteristic equation

$$1 + \underbrace{G_c(s) G(s)}_{G_{OL}} = 0 \quad \text{find the poles.}$$

controller gain = K_c (proportional controller)

Proportional control

Integral control

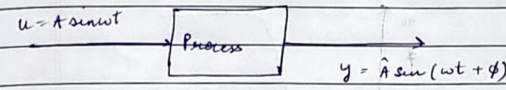
PI control

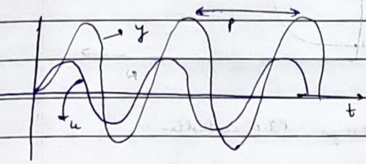
closed loop stability

BIBO → bounded input bounded output

– Stability analysis

Frequency Response





(AR) Amplitude ratio = $\hat{A}/A$

phase lag = $-\Delta t/P \times 360$

$s = j\omega$

$G(s) \rightarrow s = j\omega$

$$G(j\omega) = Re(\omega) + j(Im(\omega)) = e(\omega)\, e^{j\phi(\omega)}$$

$$e(\omega) = \sqrt{(Re(\omega))^2 + Im^2(\omega)} = |G(\omega)| = AR$$

$$\phi = \text{phase difference} = \arctan\left(\frac{Im(\omega)}{Re(\omega)}\right) = \angle G(j\omega)$$

→ Two ways of representing the frequency response.

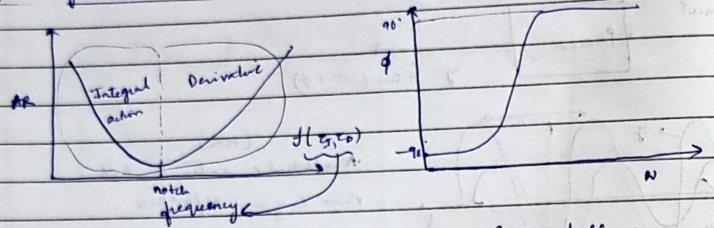
- Bode plot
  Log Log AR v/s ω, semi-log φ v/s ω
- Nyquist plot
  Plot of Re(ω) v/s Im(ω) for various values of ω.
  Frequency response does not appear explicitly in this plot

→ steady state gain ⇒ $k = e(0)\, e^{j\phi(0)}$ → Bode plot.
WRT stabilization of process & is faster

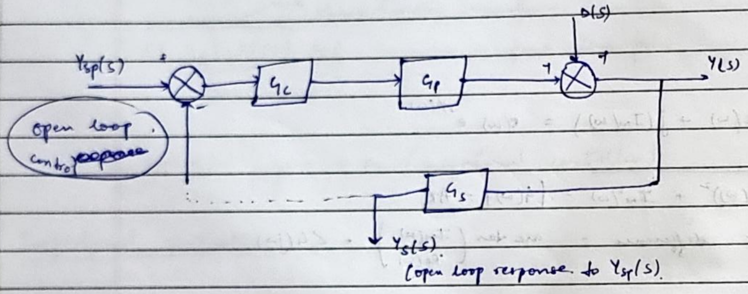
→ Nyquist Diagram

Bode stability

Bode plot of PID controller



By placing the notch frequency we can design PID controller.



→ $AR < 1$ → at some K_c value

→ If $Y_{sp}(s) = 0$ and complete the loop.

Input = $A \sin wt$ $\quad$ $AR = 1 \leftarrow K_c \uparrow$

Output = $A \sin(wt + \phi)$ $\quad$ Signal will not decay.

($\phi = -180$ → Signal will remain same in the loop) ✓ $A \sin wt$

→ $\uparrow K_c$ further, $AR > 1$ → amplitude will go on increasing
↳ the system will become unstable.

→ $\downarrow K_c$ → $AR < 1$ → amplitude $\downarrow$ → oscillations will die. → System is stable

→ ~~Example~~: System is on the verge of instability when $\phi = -180°$, $AR = 1$

Bode stability criteria

K_{cu} = ultimate gain → ~~proportional controller~~

Nyquist stability.

PID controller tuning

$\tau_I \downarrow$ → high Integral action → means more oscillations.

What value of K_c & τ_I should be selected for good performance?

→ Optimization methods use Integral errors.

Direct synthesis method

$G_c = ?$, $Y/Y_{sp} = ?$ → unknown

$\frac{Y}{Y_{sp}} = 1$ → ideally → $G_c \to \infty$.

$\Rightarrow G_c = \frac{Y/Y_{sp}}{G(1 - Y/Y_{sp})}$ $\quad \therefore \frac{Y}{Y_{sp}} \neq 1$ → never

(1) ⇒ $\frac{Y}{Y_{sp}}$ can be considered a 1st order process → $\left(\frac{Y}{Y_{sp}}\right)_d = \frac{1}{\tau_c s + 1}$
→ valid for any process without time delay.

$\tilde{G}$ → process transfer function

$\tilde{G} = K$ $\quad \left(\frac{Y}{Y_{sp}}\right)_d = \frac{1}{\tau_c s + 1}$

$G_c = \frac{\frac{1}{\tau_c s + 1}}{K\left(1 - \frac{1}{\tau_c s + 1}\right)}$ $\quad G_c = \frac{1}{K \tau_c s}$

$G_c = \frac{K_I}{s}$ → Integral controller

$$\tilde{g} = \frac{k}{(\tau_1 s+1)(\tau_2 s+1)} \rightarrow G_c = \frac{\tau_1+\tau_2}{k\tau_c}\left(\frac{\tau_1\tau_2 s^2 + (\tau_1+\tau_2)s + 1}{(\tau_1+\tau_2)s}\right) \rightarrow \text{PID}$$

τ_c = tuning parameter

$$\Rightarrow \tilde{G}(s) = \frac{k_p e^{-\theta_p s}}{\tau_p s+1}$$

$$\left(1 + \frac{1}{\tau_I s} + \tau_D s\right) \rightarrow \text{PID}$$

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

$$G_c = \frac{1/\tau_c s+1}{\frac{k_p e^{-\theta_p s}}{\tau_p s+1} \times \frac{\tau_c s}{\tau_c s+1}} = \frac{\tau_p s+1}{k_p e^{-\theta_p s}\tau_c s}$$

$$\frac{c(s)}{e(s)} = G_c = \frac{\tau_p s+1}{k_p \tau_c s} e^{\theta_p s}$$

⊗ cannot use this

Not physically realisable

$e = y_{sp} - y$

$\rightarrow$ use $e^{-\theta s} = 1 - \theta s$ $\quad G_c = k_c\left(1 + \frac{1}{\tau_I s}\right)$

Q) $g = \frac{2e^{-s}}{(10s+1)(5s+1)}$ $\quad e^{-s} = 1-s$

$$\frac{Y}{Y_{sp}} = \frac{e^{-s}}{\tau_c s+1}$$

$$1 - \frac{e^{-s}}{\tau_c s+}$$

$$g = \frac{2(1-s)}{(10s+1)(5s+1)}$$

$$G_c = \frac{(10s+1)(5s+1)}{2(1-s)\tau_c s}$$

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

$$G_c(s) = \frac{1}{\tilde{g}} \frac{e^{-s}}{(\tau_c + 1)s} = \frac{(10s+1)(5s+1)}{2(\tau_c+1)s} \rightarrow \text{PID}$$

$\rightarrow$ $K_c = ?$, $\tau_I = ?$, $\tau_D = ?$

Open loop control

$y_{sp} \rightarrow \boxed{q} \rightarrow \boxed{g} \rightarrow y$

for $y = y_{sp}$, ideally $q(s) = \frac{1}{g(s)}$ $\quad y = q(s)\,g(s)\,y_{sp}$.

Generally, $y \neq y_{sp}$

$\therefore$ we consider $\frac{y(s)}{y_{sp}(s)} = \frac{1}{(\lambda s+1)^n}$

$$\therefore q(s) = \frac{1}{g(s)}\frac{1}{(\lambda s+1)^n} = \frac{f(s)}{\underbrace{g(s)}_{\text{actual transfer function of the process}}}$$

$\rightarrow$ $g(s)$ is estimated as $g_m(s)$

$$q(s) = \frac{f(s)}{g_m(s)}$$

$f(s) \rightarrow$ filter. It should be chosen in such a way that

- $q(s)$ should not becomes improper (no: of zeros > no: of poles)
- process dynamic characteristics are not violated

Non-invertible $\rightarrow$ TF containing right hand plane ~~poles~~ zeros & dead time

$$g_m(s) = \frac{k e^{-\theta s}}{\tau s+1}$$

$$\frac{1}{g_m(s)} = \frac{(\tau s+1)e^{\theta s}}{k} \rightarrow \text{non-invertable being of dead time.}$$

$$\frac{1}{g_m(s)} = \frac{(\tau_1 s+1)(\tau_2 s+1)}{-\eta s+1}$$

$s = 1/n$

$g_m(s) = g_m^-(s)\; g_m^+(s)$

$\frac{k}{\tau s+1}\, e \rightarrow g_m^+(s)$, $\rightarrow g_m^-(s)$

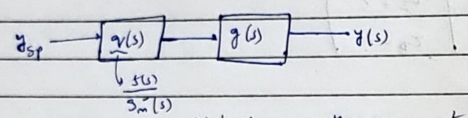
$g_m^-(s)$ is invertible part

$g_m^+(s)$ is non-invertible

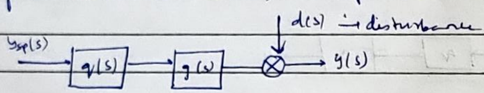
$$q(s) = \frac{f(s)}{g_m^-(s)}$$

open loop control law → only for servo control (no disturbance)

Open loop control is always stable if the process is stable.

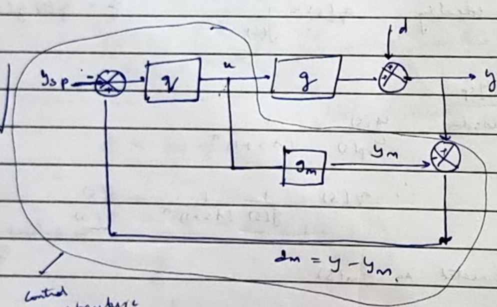


if we have disturbance, the open control law fails



Internal model control ✓

| solves both regulatory problem & servo problem |



internal model control architecture

control structure

$$y(s) = \frac{g(s)\,q(s)}{1+q(s)(g(s)-g_m(s))}\, y_{sp}(s) + \frac{1-g_m(s)\,q(s)}{1+q(s)(g(s)-g_m(s))}\, d(s)$$

ideal: $q(s) = \frac{1}{g_m(s)}$ → $y = y_{sp}$ → It can take care of servo control

→ if $d(s)$ changes also there is no change in the process variable → takes care of regulatory control

→ $g_m(s) = g_m^-(s)\; g_m^+(s)$

$$q_I(s) = \frac{1}{g_m^-(s)}$$

$$f(s) = \frac{1}{(\lambda s+1)^n}$$

$$q(s) = q_I(s)\, f(s) = \frac{f(s)}{g_m^-(s)}$$

(λ, n are the parameters)

Q) $g(s) = \frac{1}{10s+1} e^{-3s}$

No process/model mismatch → $g_m(s) = g(s)$

$g_m^-(s) = \frac{1}{10s+1}$ $\quad g_m^+(s) = e^{-3s}$

$q_I(s) = 10s+1$

$q(s) = q_I(s)\, f(s) = \frac{10s+1}{\lambda s+1}$ → lead-lag TF. lead lag element is available.

$y(s) = g_m^+(s)\, f(s)\, y_{sp}(s) = \frac{e^{-3s}}{\lambda s+1} y_{sp}(s)$

$\frac{10s+1}{(\lambda s+1)^n}$, $n \geq 1$

($n=1$ has advantages.)

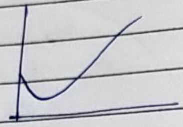
Q) $g(s) = \frac{-9s+1}{(15s+1)(3s+1)}$

$g_m^-(s) = \frac{9s+1}{(15s+1)(3s+1)}$ $\quad g_m^+(s) = \frac{-9s+1}{9s+1}$

$q_I(s) = q_I(s)\, f(s) = \frac{(15s+1)(3s+1)}{9s+1} \frac{1}{\lambda s+1}$

$y(s) = g_m^+(s)\, f(s)\, y_{sp}(s) = \frac{-9s+1}{(9s+1)(\lambda s+1)} y_{sp}(s)$

→ If we have Right hand plane zero, we will have inverse response



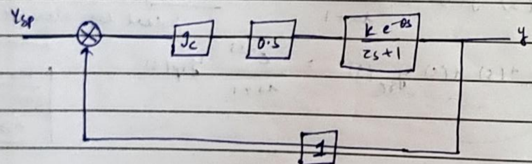
PID controller

$$g_c(s) = \frac{q(s)}{1 - g_m(s)\,q(s)}$$

Q) FODT system using PI controller
Control valve gain = 0.5
measurement device gain = 1

Method	K_c	τ_I
Z-N	0.3426	14.2546
IMC-PI	0.2	10.0

Z-N PI relation :- $k_c = 0.45\,k_u$, $\tau_I = P_u/1.2$



Find k, τ, θ $\quad g_c^{(Z-N)}$ = known
g_c^{IMC} = known.

$$\frac{Y}{Y_{sp}} = \frac{g_c(0.5)\frac{k e^{-\theta s}}{\tau s+1}}{1 + g_c(0.5)\frac{k e^{-\theta s}}{\tau s+1}}$$

$$G_c = k_c\left(1 + \frac{1}{\tau_I s}\right) =$$

$$K_c = \frac{1}{k}\left(\frac{\tau}{\theta + \tau_c}\right) \qquad \tau_I = \tau$$

Z-N method

→ $k_c = 0.3426$ $\quad k_u = \frac{0.3426}{0.45}$ $\quad P_u = 1.2 \times 14.2546$

$P_u = \frac{2\pi}{\omega_{co}}$ → find ω_{co}. $\quad \omega_{co}$ → cross over frequency. ($\phi = -180°$) $\phi = -\pi$

$\boxed{\omega_{co} = 0.3673}$ $\quad \phi = \tan^{-1}(-\omega_{co}\tau) - \omega_{co}\theta$.

get θ

$K_u = \frac{1}{AR_c}$ $\qquad AR_c = \frac{k\,0.5}{\sqrt{1+\tau^2\omega_{co}^2}}$

for IMC PI :- $\boxed{\tau_I = \tau}$

$k_c = \frac{\tau}{k(\lambda+\theta)}$

find τ from here. $\quad \tau = 10 = \tau_I$ $\qquad -74.77\times\pi$

$\boxed{\tau = 10}$

$-\pi = \tan^{-1}(-3.673) - \omega_{co} \times \theta$.

$+\pi = +1.304 + 0.3673 \times \theta$.

$\theta = \underbrace{5.006}_{rad} \times \frac{180}{\pi} = 286.83°$

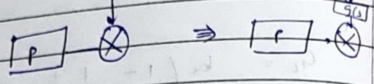
$k = 10$,

→ PID for servo → $f(s) = \frac{1}{(\lambda s+1)^n}$.

→ $f(s) = \frac{\gamma s+1}{(\lambda s+1)^n}$ →

IMC eqn :- $y(s) = \frac{(1 - q(s)\,g(s))\,d(s)}{1 + q(s)(g(s) - g_m(s))}$

$= \frac{1 - q(s)\,g(s)}{1 + q(s)(g(s) - g_m(s))}$ $\quad g(s)\,L(s)$ for disturbance.



$$y(s) = \frac{1 - q(s)\, g(s)}{1 + q(s)\,(g(s) - g_m(s))}\, g(s)\, l(s)$$

$$\underline{y(s) = (1 - q(s)\, g(s))\, g(s)\, l(s)}$$

$\gamma = f(\tau)$

should be calculated using this

Q2) $g(s) = \dfrac{2}{(5s+1)(2s-1)}$

$$q(s) = \frac{(5s+1)(2s-1)}{2} \times \frac{\gamma s+1}{(\lambda s+1)^2}$$

$P_u = 1/2$

$$f(s) = \frac{\gamma s+1}{(\lambda s+1)^2}$$

$$1 = \frac{\gamma(1/2)+1}{(\lambda(1/2)+1)^2}$$

$$\gamma = \left[\left(\lambda\left(\tfrac{1}{2}\right)+1\right)^2 - 1\right]2$$

$$\gamma = \left(\frac{\lambda^2}{4} + \lambda\right)2$$

$$\gamma = \frac{\lambda^2}{2} + 2\lambda$$

$$g_c(s) = \frac{1}{2}\left[\frac{(5s+1)(2s-1)(\gamma s+1)}{\lambda^2 s^2 + (2\lambda - \gamma)s}\right]$$

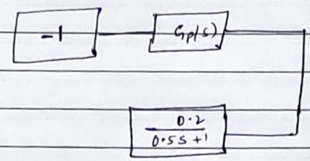
$$g_c(s) = \frac{1}{2}\left[\frac{(5s+1)(\gamma s+1)}{\frac{\lambda^2}{2} s}\right]$$ PID

~~(5s+1)~~

Q3) $g_p(s) = \dfrac{-0.7}{(s+1)(1.5s+1)}$

30sec lag

control valve

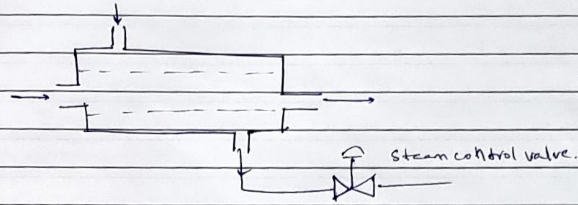


for temp measurement device gain

$= \dfrac{100-20}{20-4}$

$\dfrac{\Delta \text{output}}{\Delta \text{input}}$

Q4)



gain $= \dfrac{4^\circ C}{1\ kg/min}$