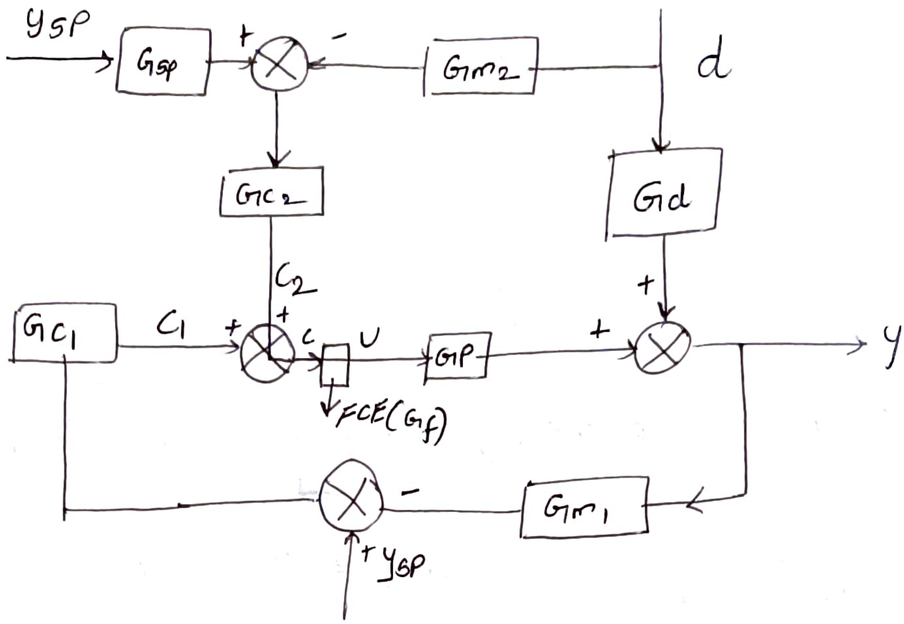
FBC & FFC,



$$y = G_p U + G_d d$$

$$U = c G_f = G_f (C_1 + C_2) = G_f [G_{c_1} (y_{sp} - G_{m_1} y) + C_2]$$

$$C_2 = G_{c_2} [y_{sp} G_{sp} - d G_{m_2}]$$

$$U = G_f [G_{c_1} (y_{sp} - G_{m_1} y) + G_{c_2} [G_{sp} y_{sp} - d G_{m_2}]]$$

$$y = G_d d + G_f G_p [G_{c_1} (y_{sp} - G_{m_1} y) + G_{c_2} (G_{sp} y_{sp} - d G_{m_2})]$$

$$y = \frac{y_{sp} [G_f G_p G_{c_1} + G_{c_2} G_{sp} G_f G_p] + d [G_d - G_{m_2} G_{c_2} G_f G_p]}{1 + G_f G_p G_{m_1} G_{c_1}}$$

$$y = \left[\frac{G_f G_p G_{c_1} + G_{c_2} G_{sp} G_f G_p}{1 + G_f G_p G_{m_1} G_{c_1}} \right] y_{sp} + \frac{[G_d - G_{m_2} G_{c_2} G_f G_p]}{1 + G_f G_p G_{m_1} G_{c_1}} d.$$

CE for FF+FB: $1+G_pG_fG_{c_1}G_{m_1}=0$
CE for FB: $1+G_pG_fG_{c_1}G_{m_1}=0$ } same characteristic eqⁿ

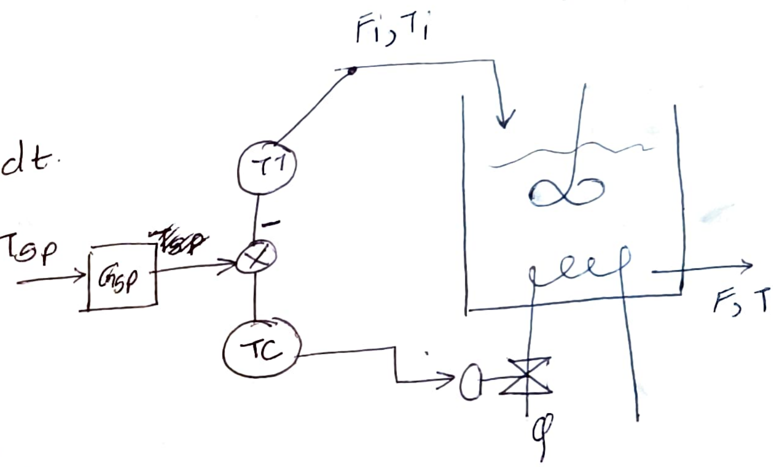
- FFC doesn't provide any additional instability.
- FFC depends on process model $G_c = \frac{G_d}{G_p}$ unlike conventional PID, PI, P ~~controller~~ controller, where $u = K_c(y_{sp} - y)$

∴ perfect control can never be achieved by FFC because of imperfect modelling.

Why combine FBC & FFC?

7/02/2025

FFC



FFC vs FBC

$G_c = \frac{G_d}{G_p}$ | $u = K_c e + \frac{K_c}{\tau_i}\int e\,dt$

$= F_i \rho C_p$

$$\frac{V}{F_i}\frac{dT}{dt} + T = T_i + \frac{q}{F_i \rho C_p}$$

$$\frac{V}{F_i}\left(s\bar{T}(s)\right) + \bar{T} = \bar{T}_i + \frac{\bar{q}(s)}{F_i \rho C_p}$$

$$\tau = V/F_i$$

$$\bar{T}(s) = \frac{1}{(\tau s+1)F_i \rho C_p}\bar{q}(s) + \frac{1}{\tau s+1}\bar{T}_i(s)$$

$$\bar{y}(s) = G_p\bar{q}(s) + G_d\bar{d}(s)$$

$$G_c = \frac{G_d}{G_p} = F_i \rho C_p$$

FFC

FBC

Adv.

1. No instability pb.
2. Takes action beforehand
3. Good for slow systems

Disadv.

1. Requires modelling of process (Plant / model)
2. Parameter identification
3. FFC cannot take care of unmeasured load variable.

Answer to last class Ques

→ To solve this we use FFC + FBC

→ Override/constraint control scheme

no. of measu > 1 manipulated variable = 1

- During normal operatn of the plant/shut down/start-up condition, some abnormal /dangerous situations may arise & it may lead to destruction of equipment along with operating personnel.

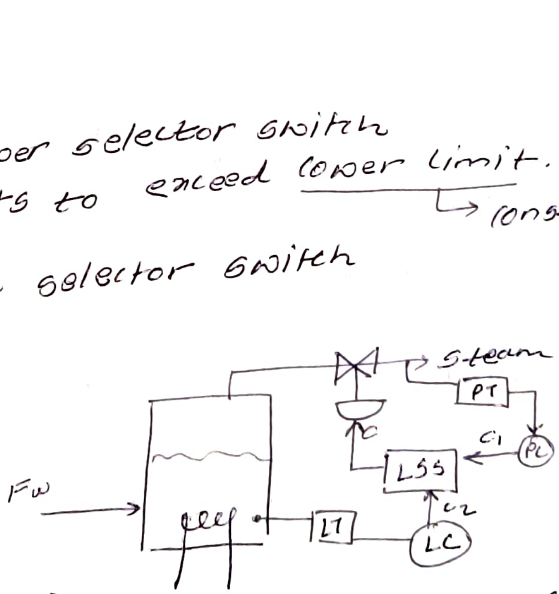
∴ We use switch.

Switch

LSS : Lower selector switch
→ prevents to exceed lower limit.
→ constraint

HSS : High selector switch

eg -



control obj:

$P = P_{SP}$

$h \not< h_{min}$

∴ we use LSS

$C = \min(C_1, C_2)$

* PC & LC are both direct action controllers provided
* the control valve is air to open.

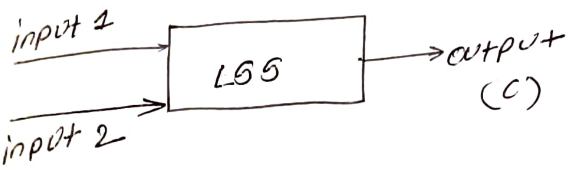
Situation: 1. $c = c_1$ .... $(c_1 < c_2)$

Suddenly ⇒ $h < h_{min}$

∴ set $c_2 = 0$

Now, $(c_1 > c_2)$

2. $c = c_2$ ... (LC overrides pressure controller)



if (input 1 < input 2)

c = input 1

else

c = input 2

end.

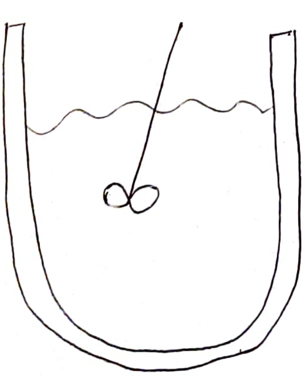
→ split range control.

no. of measurements = 1 MV > 1

It provides additional safety and operational optimality

• split range control are not common in che.

Non-isothermal batch reactor:



• for unsteady state process T_{SP} changes dynamically.

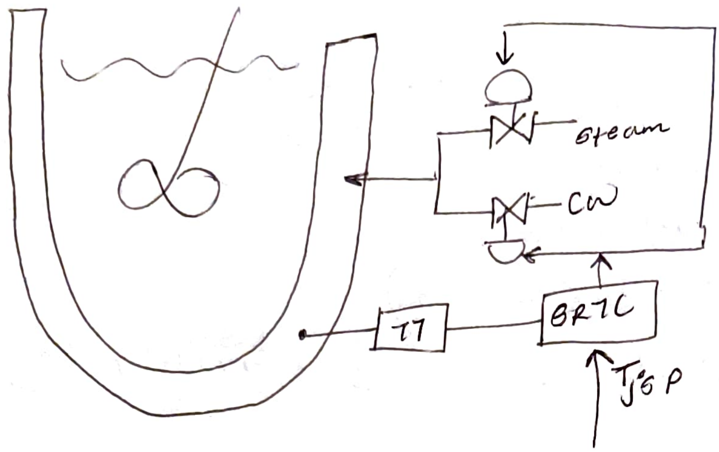
eg- $T_{SP} = 54 + 71\exp(-2\times10^{-3}t)$

$T(t=0) = 15°C$ ← non-linearity in between

$T(t=t_f) = 100°C$

Similarly, we can generate jacket setpoint, T_{JSP}

ex

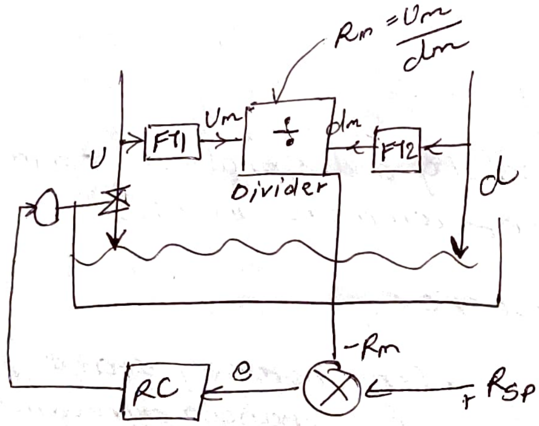


→ Ratio Control scheme

1. no. of measured V > 1
   MV = 1
2. Special ~~type~~ type of FFC
3. $R = \frac{u}{d}$ ← MV, PV — 2 process streams (commonly flow rate)

d ⇒ wild stream

ex-



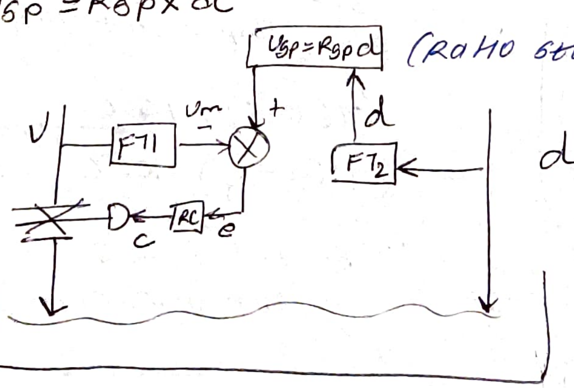
Ratio controller (RC) = P / PI / PID

∵ d is measured

∴ in essence Ratio controller is a special type of FFC.

Another scheme: Ratio station

$U_{sp} = R_{sp} \times d$



exam... process, Distillation reflux, ...
chamber (fuel to air ratio)

which ratio control scheme is better?

Adaptive Control

PI: $u = K_c e + \frac{K_c}{\tau_i}\int e\,dt$

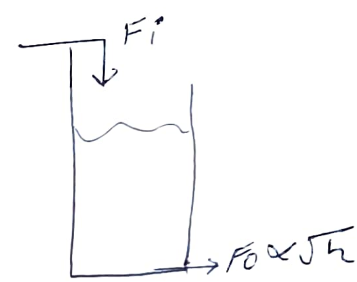
$K_c, \tau_i =$ constant.

- Controllers having variable parameters are called adaptive controllers

Why do we need this?

1. process non-linearity
2. Non-stationary.

Model:



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

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

$$F_i - \beta\sqrt{h} = A\frac{dh}{dt}$$

$$F_i = A\frac{dh}{dt} + \beta\sqrt{h}$$

$$\beta\sqrt{h} = \beta\left[\sqrt{h_{ss}} + \frac{h \times 1}{2\sqrt{h_{ss}}} + \frac{h^2}{2!} \times \frac{-1}{4} h_{ss}^{-3/2}\right].$$

$\frac{dh^{1/2}}{dh}$

$\Rightarrow \frac{1}{2}(h)^{-1/2}$

$\frac{1}{2}(h)^{-1/2}$

$\frac{1}{2} \times \frac{-1}{2}(h)^{-3/2}$

$$\beta\sqrt{h} = \beta\left[\sqrt{h_{ss}} + \frac{(h-h_{ss})}{2\sqrt{h_{ss}}} - \frac{(h-h_{ss})^2}{2!}\frac{1}{4(h_{ss})^{3/2}}\right]$$

$$\beta\sqrt{h} = \beta\sqrt{h_{ss}} + \frac{\beta}{2\sqrt{h_{ss}}}(h-h_{ss})$$

in terms of deviation variables

$$A\frac{d}{dt}(h-h_s) + \beta\sqrt{h} - \beta\sqrt{h_s} = F_i - F_{is}.$$

$$A\frac{dh'}{dt} + \frac{\beta}{2\sqrt{h_s}}h' = F_i'$$

$$\frac{2A\sqrt{h_s}}{\beta}\frac{dh'}{dt} + h' = \frac{2\sqrt{h_s}}{\beta}F_i'$$

$$\tau_p \frac{dy}{dt} + y = k_p u$$

$\tau_p = \frac{2A\sqrt{h_s}}{\beta}$ $\quad K_p = \frac{2\sqrt{h_s}}{\beta}$ ... τ_p, k_p are dependent on h_{ss} (s.s.)

$k_c, \tau_i = f(k_p, \tau_p)$

∴ controllers need to be adaptive.

• Criteria ~~for~~ for changing k_c & τ_i

1. ISE
2. Phase margin, gain margin
3. One-quarter decay ratio.

• Programmed/scheduled Adapting controller

eg - GSAC, combustion chamber

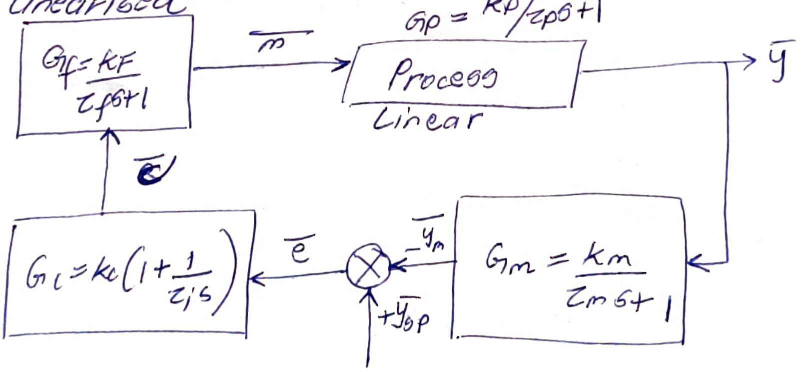
• Self Adapting controller

- MRAC, STR → self tunning controller.

Model reference adaptive control

→ 14/02/25

Gain scheduling adaptive control.



$k_f, \tau_f = f$(ss condition)

known experimentally

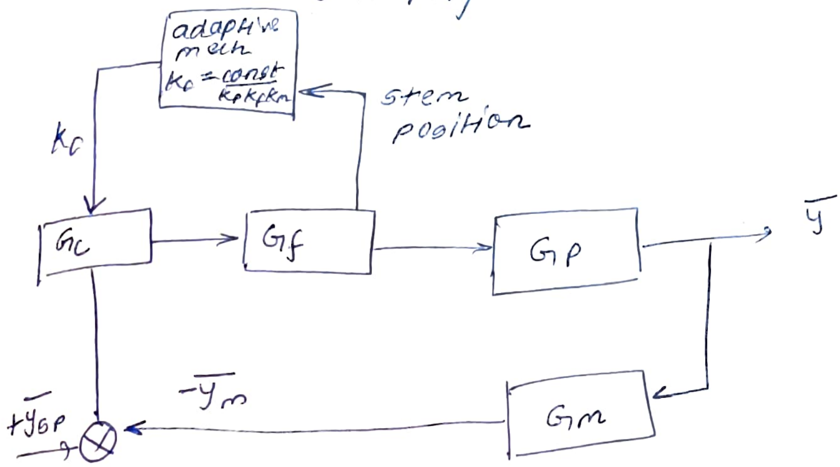
Koverall (overall gain) $= k_p k_f k_m k_c =$ constant ---- [to keep stability margin constant]

$K_c = \dfrac{const}{K_p K_f K_m}$ → K_p & K_m are fixed

control valve :

$K_f = \dfrac{\text{stem position}}{3\text{-}15 \text{ psig}}$

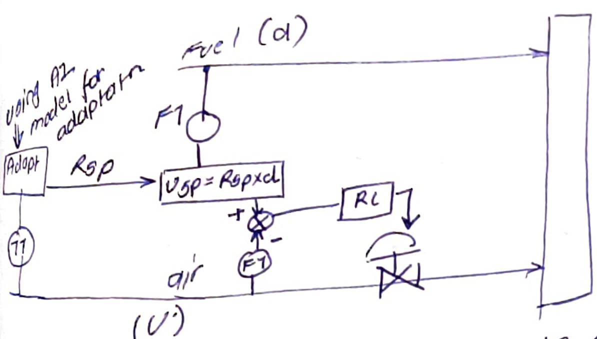
(gain) $K = \dfrac{\text{change in output}}{\text{change in input}}$



→ limitation:

1. Above can be only done for P-only controller, since we are finding K_c & not τ_i.
2. No way of correcting K_c.

• Combustn chamber (adaptive ratio control)



Fuel — Air ↓ — Incomplete combustion & T↓

Air ↑ — Overheating & T↑

∴ F/A = optimal.

Air temperature changes continuously, therefore we need adaptive control.

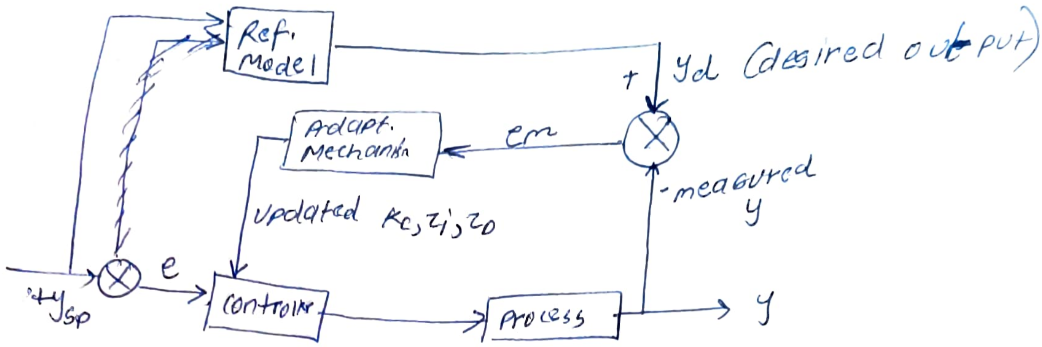
obj: maintain T of combustion chamber.

Air T↑ then reduce flow rate of air

∴ $R_{sp} = (F/A)_{optimal}$ needs to change

• Make the above scheme for divider in ratio control scheme

→ MRAC (Modell reference adaptive control)



Adaption mechanism,

$$ISE = \int e_m^2 \, dt \quad \text{---- integral square error}$$

$$= \int (y_d - y)^2 \, dt$$

$$\frac{dISE}{dK_c} = \frac{dISE}{d\tau_i} = \frac{dISE}{d\tau_D} = 0$$

Ref model is required to use this method

What is reference model?

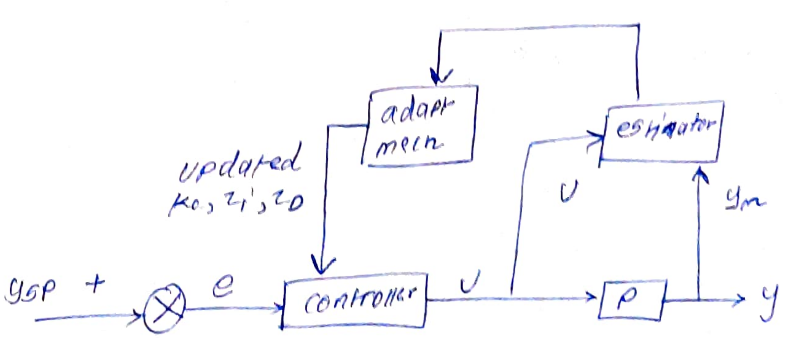
$$\bar{y}_d = \frac{G_c G_p G_f}{1 + G_c G_p G_f G_m} \bar{y}_{sp} \quad \text{--- CLTF}$$

$$\bar{y}_d = \frac{1}{\lambda s + 1} \bar{y}_{sp} \quad \text{---- Desired CL response}$$

└-- does not contain k_c, τ_i, τ_D

∴ we make $k_c, \tau_i, \tau_D = f(\lambda)$

→ STR



Estimator:

$$\frac{y}{\Delta V} = \frac{K_p e^{-t_d s}}{\tau_p s + 1}$$

y & V are known, $\therefore$ K_p, τ_p & t_d can be estimated.

K_c, τ_i, τ_D can directly be corelated with K_p, τ_p & t_d using Cohen-Coon settings.

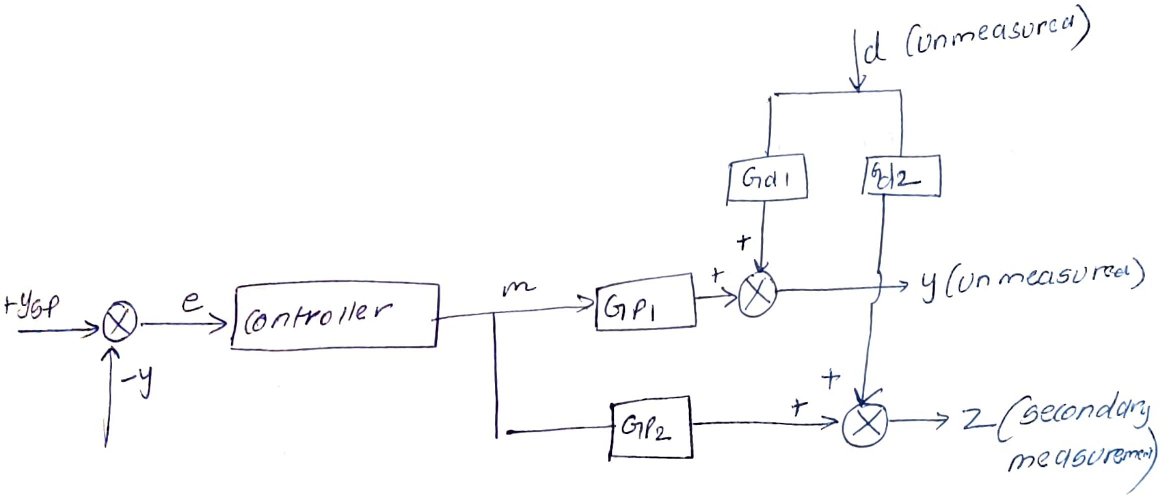
→ Inferential Control scheme

* FBC: P-family $\quad V = V_s + K_c(y_{sp} - y)$ $\quad$ × CV ⇒ measured.

suppose CV is not measureable then FBC cannot be used.

* FFC: model $\quad G_c = \frac{G_d}{G_p}$ $\quad$ × LV = measured

$\therefore$ We need Inferential control scheme



$$y = G_{p_1} m + d G_{d_1} \quad — ①$$

$$z = G_{p_2} m + d G_{d_2} — ②$$

$d = ?$

$$\frac{y - G_{p_1} m}{G_{d_1}} = d$$

$$z = G_{p_2} m + \left(\frac{y - G_{p_1} m}{G_{d_1}}\right) G_{d_2}$$

$$\to z - \frac{y G_{d_2}}{G_{d_1}} = m\left(G_{p_2} - \frac{G_{p_1} G_{d_2}}{G_{d_1}}\right)$$

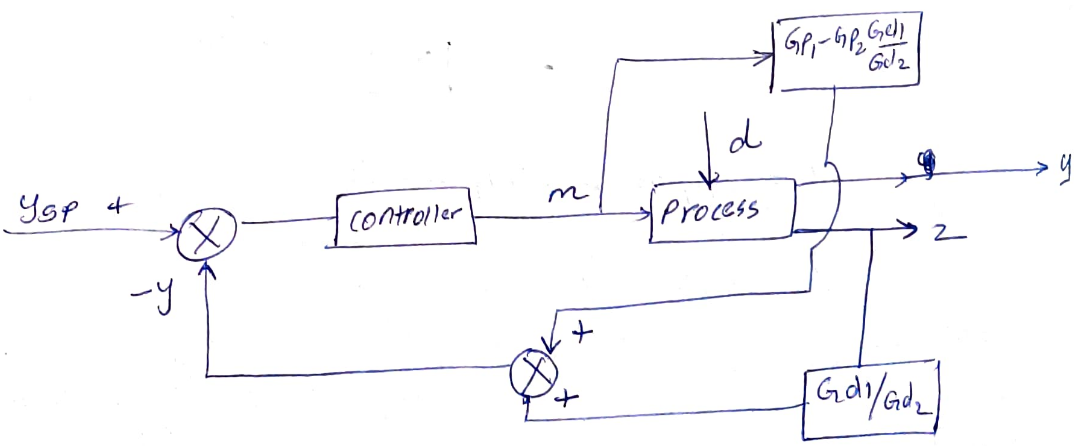
$$\frac{z - y\frac{G_{d_2}}{G_{d_1}}}{\left(G_{p_2} - \frac{G_{p_1} G_{d_2}}{G_{d_1}}\right)} = m$$

$$d = \frac{y - G_{P_1}\left\{\dfrac{z - y\dfrac{G_{d_2}}{G_{d_1}}}{G_{P_2} - G_{P_1}\dfrac{G_{d_2}}{G_{d_1}}}\right\}}{G_{d_1}}$$

$$d\,G_{d_1} = y - \frac{G_{P_1} z}{G_{P_2} - G_{P_1}\dfrac{G_{d_2}}{G_{d_1}}} + \frac{G_{P_1} y \dfrac{G_{d_2}}{G_{d_1}}}{G_{P_2} - G_{P_1}\dfrac{G_{d_2}}{G_{d_1}}}$$

$$\frac{d\,G_{d_1} + \dfrac{G_{P_1} z}{G_{P_2} - G_{P_1}\dfrac{G_{d_2}}{G_{d_1}}}}{\left(1 + \dfrac{G_{P_1}\dfrac{G_{d_2}}{G_{d_1}}}{G_{P_2} - G_{P_1}\dfrac{G_{d_2}}{G_{d_1}}}\right)} = y$$

$$y = \left(G_{P_1} - G_{P_2}\frac{G_{d_1}}{G_{d_2}}\right)m + \frac{G_{d_1}}{G_{d_2}} z$$



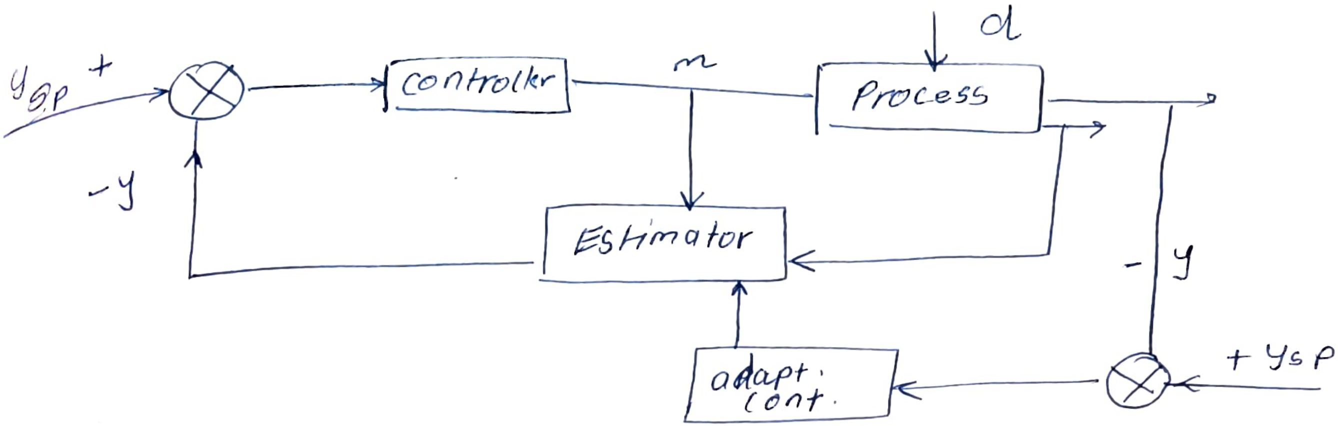
Remarks:

1. y is infered from measured z. ∴ It is called interential control scheme.
2. Imperfect model is a major limitation

3. example : Distillation column

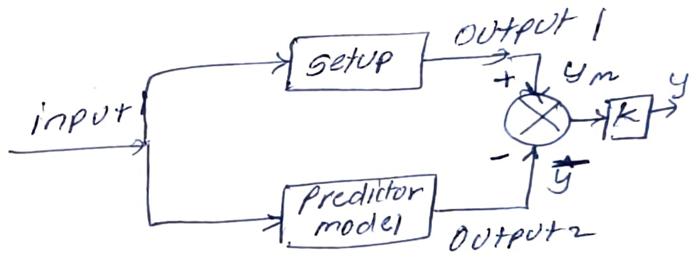
$z = 7$

$y = x_0$



→ Predictor

$$\begin{cases} \dot{x} = f(x,u) \\ y = h(x) \end{cases}$$



$$\dot{\bar{x}} = \underbrace{f(\bar{x}, u)}_{\text{predictor}} + \underbrace{K(y_m - y)}_{\text{corrector}}$$

constant $K \equiv$ Luernberger observer

variable $K \equiv$ extended Kalman filtering