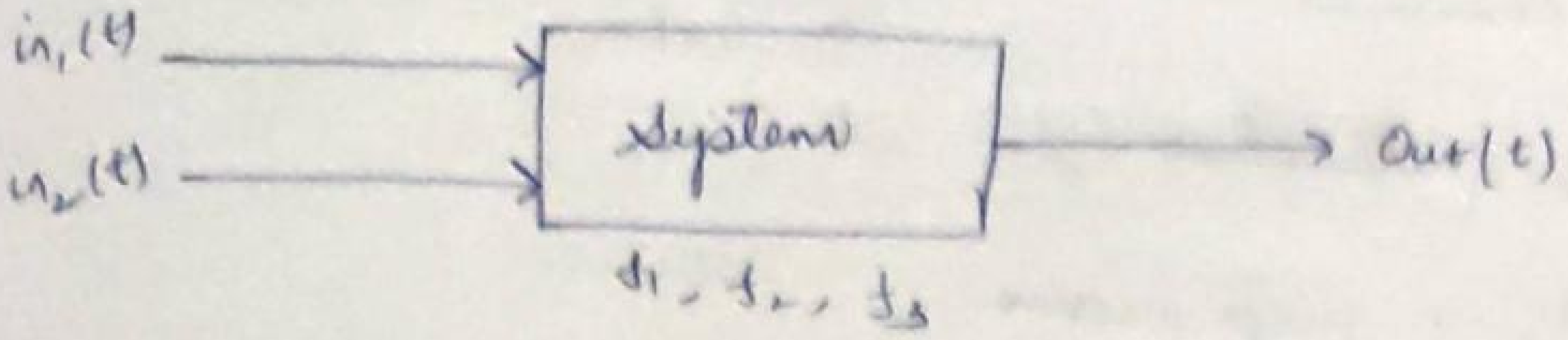
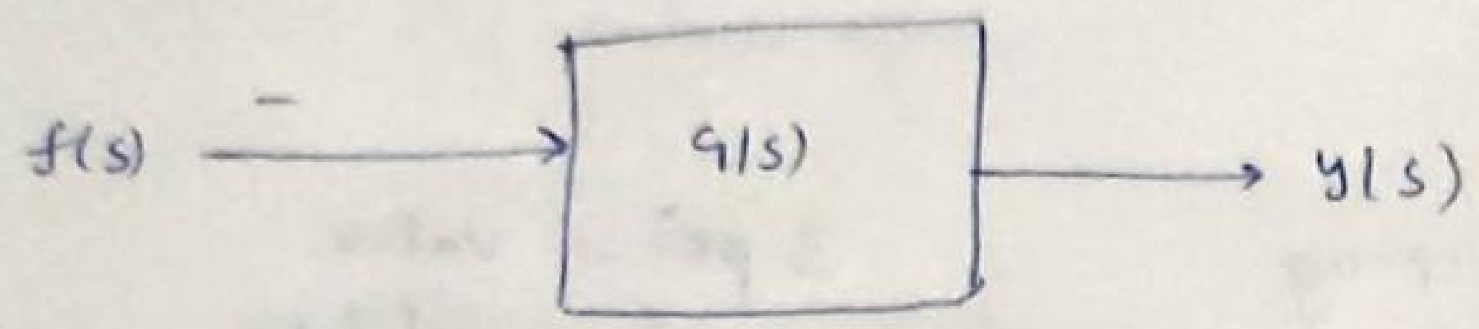
JC



→ time domain

By writing ~~to~~ ① Mass balance
② Momentum
③ Energy

} we can find relation between input and output.

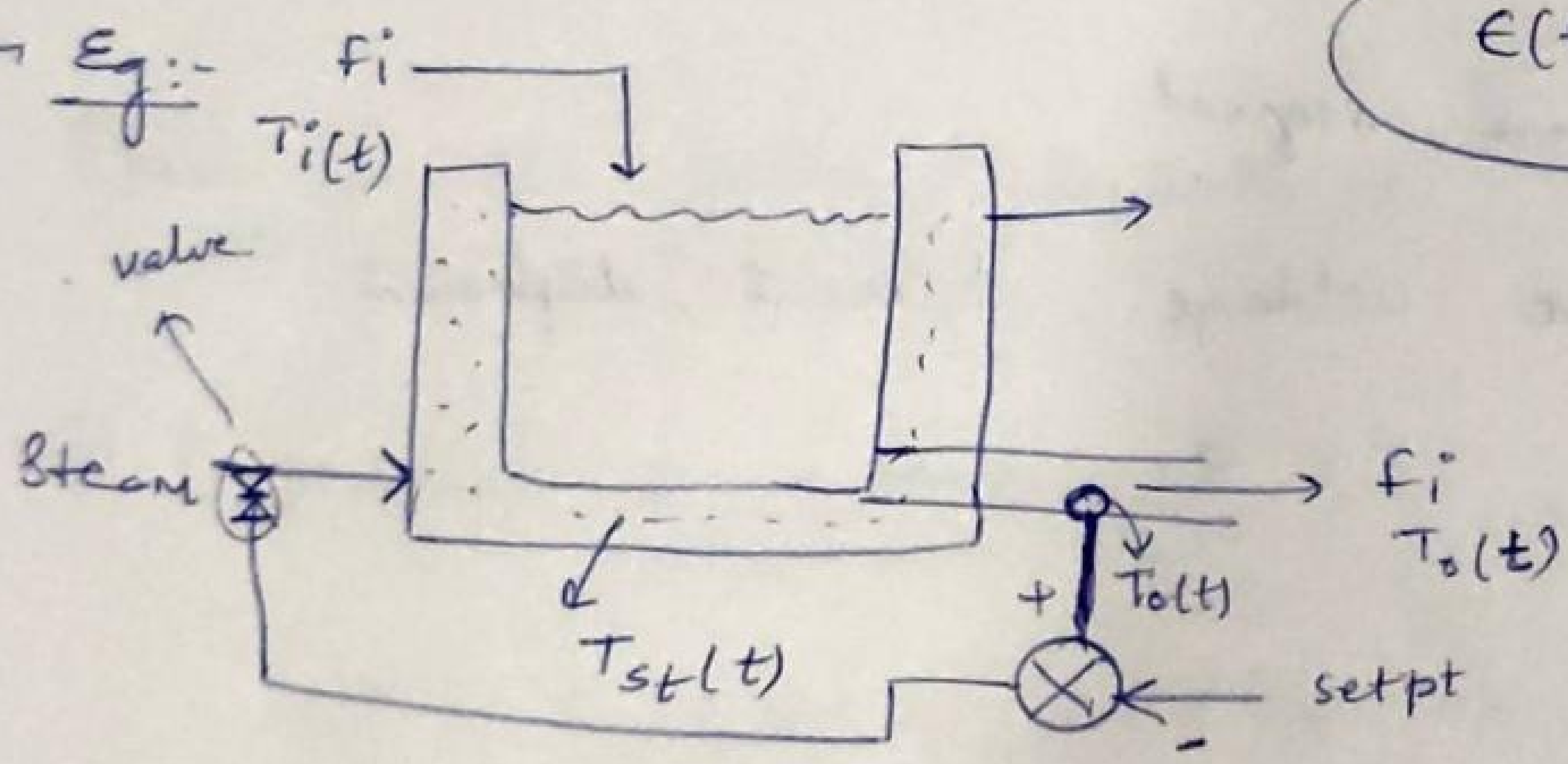


→ laplace domain

→ Analysis and design of feedback control system

- Something has occured wrong in output, on that we change some parameters and try to control it

→ Eg:-



$$\epsilon(t) = T_{sp} - T_m(t)$$

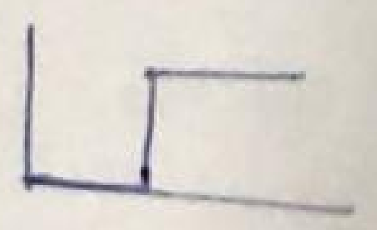
$f_i = f_0 \rightarrow f_i \pm f(t)$

$T_i = f(t)$

$T_o(t)$ will depend on how much steam we pass.

We want the outlet temp to be same (no jump)

$T_i(t)$ =



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→ Final control element → valve → who executes the control action → In chemical processes it is generally a valve

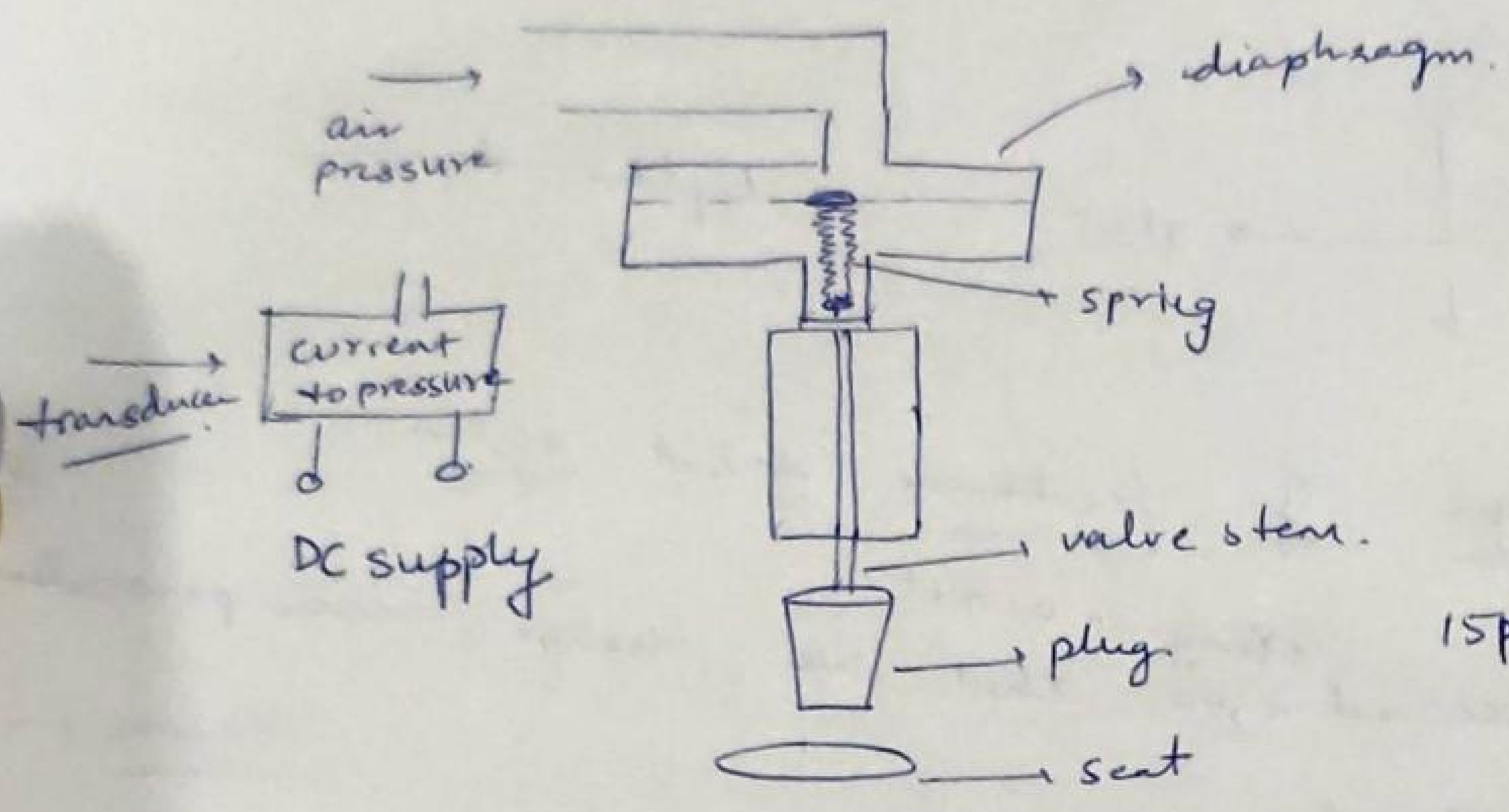
→ Controller → Makes the decision

→ Control valve (3 Psi, 15Psi)

gauge pressure

range of P

Spring diaphragm



3 psi → valve is completely open.

15psi → completely closed

→ pneumatic system → air pressure signal

→ Measuring device will give voltage, current, displacement

→ set pt → will give voltage

→ Control valve.

↑ → pneumatic signal

Controller

Controller

recieves an error signal and provides pneumatic signal to control valve.

→ $T > T_{sp}$ → controller output → close valve → 15psi

$T < T_{sp}$ → controller output → open valve → 3psi

} ON-OFF Controller

Pressure to close

↓

opposite is also possible

✓ pressure to close valve

→ ① proportional controller

- takes error signal and releases the signal which is proportional to error

$$\boxed{c(t) = k_c\, \epsilon(t) + c_s}$$

$c(t)$ → controller; $\epsilon(t)$ → error; c_s → steady state

becoz $\epsilon(t)=0$ $c(t)=0$ → 0psi → open which is not true ∴ we need c_s

$\boxed{c(t) = k_c\, \epsilon(t)}$

→ c_s → bias of controller

→ k_c → proportional gain

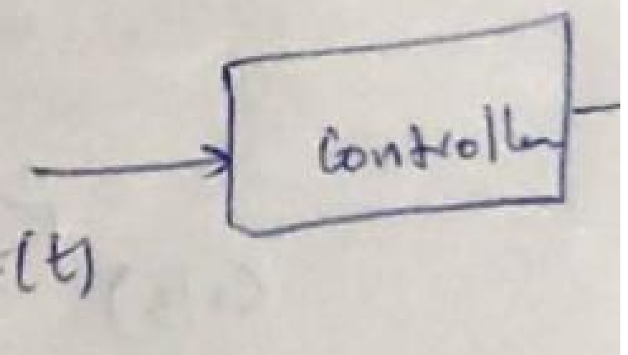
→ 9psi → 50% valve open.

→ ② Integral controller (PI controller)

$$\boxed{c(t) = k_c\, \epsilon(t) + c_s + \left(\int_0^t \epsilon(\tau)\, d\tau\right)\frac{k_c}{\tau_I}}$$

↓

action corresponding to past error.



→ Error in the future (derivative)

→ ③ Proportional - I - D controller

$$c(t) = k_c\, \epsilon(t) + c_s + \frac{k_c}{\tau_I}\int_0^t \epsilon(\tau)\, d\tau + \tau_D k_c \frac{d\epsilon}{dt}$$

→ $c(t) = k_c\, \epsilon(t) + c_s$

$$\cancel{\mathcal{L}(c(t)) = k_c\, \mathcal{L}(\epsilon(t)) + \mathcal{L}(c_s)}$$

$$\cancel{c(s) = k_c\,(\epsilon(s)) + \frac{c_s}{s}}$$

$$c'(t) = k_c\, \epsilon'(t)$$

$$\bar{c}(s) = k_c\,(\bar{\epsilon}(s))$$

$G(s) = k_c$

$\rightarrow \quad c(t) = k_c\, \epsilon(t) + \int_0^t \epsilon(\tau)\, d\tau + c_s$

$c'(t) = k_c\, \epsilon'(t) + \left(\int_0^t \epsilon'(\tau)\, d\tau\right) \frac{k_c}{\tau_I}$

$\bar{c'}(s) = k_c\, \bar{\epsilon'}(s) + \left(\frac{1}{s}\, \bar{\epsilon'}(s)\right) \frac{k_c}{\tau_I}$

$\boxed{\frac{\bar{c'}(s)}{\bar{\epsilon'}(s)} = k_c + \frac{k_c}{\tau_I}\frac{1}{s}}$

transfer function

$\rightarrow \quad c(t) = k_c\, \epsilon(t) + \int_0^t \epsilon(\tau)\, d\tau + c_s + \tau_D k_c \frac{d\epsilon}{dt}$

$\bar{c'}(s) = k_c\, \bar{\epsilon'}(s) + \frac{k_c}{\tau_I}\frac{1}{s}\, \bar{\epsilon'}(s) + \tau_D k_c s\, \bar{\epsilon'}(s)$

$\boxed{\frac{\bar{c'}(s)}{\bar{\epsilon'}(s)} = k_c + \frac{1}{s}\frac{k_c}{\tau_I} + \tau_D k_c s}$

$G(s)$

Analysing separatey

P: $c(t) - c_s = k_c\, \epsilon(t)$

$c'(t) = k_c\, \epsilon'(t)$

$\bar{c'}(s) = k_c\, \bar{\epsilon'}(s)$

$\boxed{G(s) = k_c}$

Integral and differential are not used individually

I: $c(t) = c_s + \frac{k_c}{\tau_I} \int_0^t \epsilon(\tau)\, d\tau$

$c'(t) = \frac{k_c}{\tau_I} \int_0^t \epsilon'(\tau)\, d\tau$ $\quad \boxed{G(s) = \frac{k_c}{\tau_I}\frac{1}{s}}$

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D : $c(t) - c_s = k_c \tau_D \frac{d\,e(t)}{dt}$

$$c'(t) = k_c \tau_D \frac{d\,e(t)}{dt}$$

$$\boxed{G(s) = k_c \tau_D s}$$

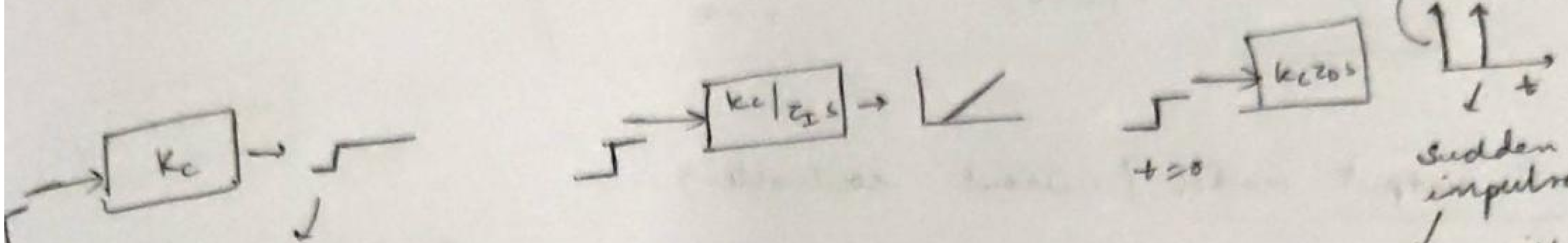
[valve will take care instead of pressure to open we can]

k_c, τ_D will take care. they can b +ve

more pressure to close valve

for $e \downarrow \, e_t \uparrow$

$c(t) - c_s$

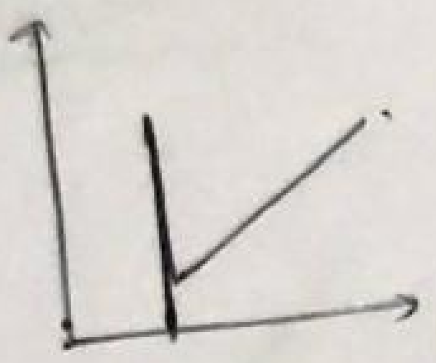


will only change by const

sudden impulse

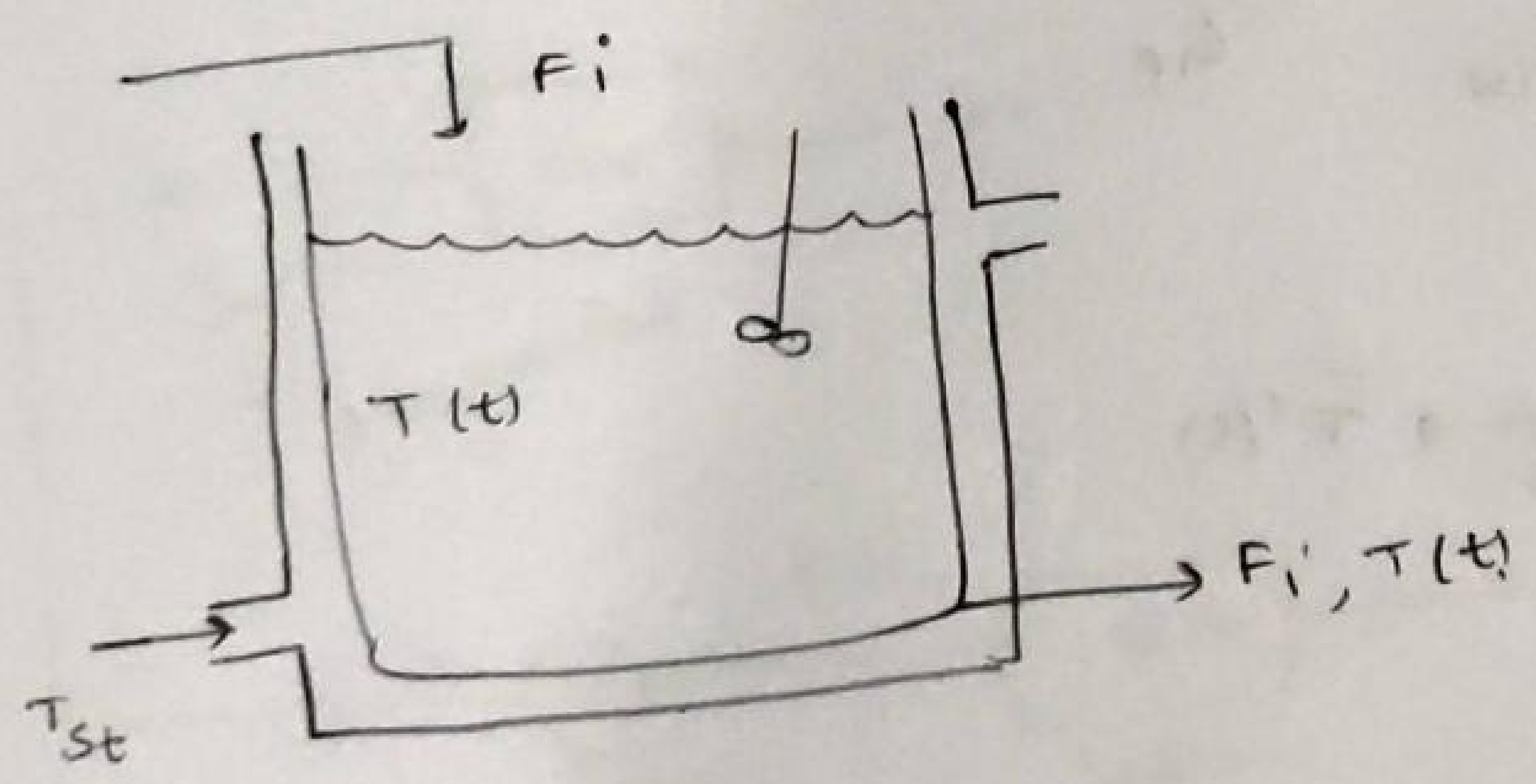
it will give 15 psi signal it wants to give

→ PID



~ PI

DYNAMIC BEHAVIOR OF FEEDBACK CONTROLLED PROCESS



$$V \rho c_p \frac{dT}{dt} = F_i \rho c_p T_i + U A_t (T_{st} - T) - F_i (\rho c_p T)$$

$$\boxed{\frac{dT}{dt} = \frac{F_i}{V} (T_i - T) + \frac{U A_t (T_{st} - T)}{V \rho c_p}}$$

$$\tau = \frac{V}{F_i}$$

$$\boxed{\frac{dT}{dt} = \frac{T_i}{\tau} + K T_{st} - \underbrace{\left(\frac{1}{\tau} + k\right)}_{a} T}$$

$$\frac{dT}{dt} = \frac{T_i}{\tau}$$

$$\boxed{\frac{dT}{dt} + aT = \frac{T_i}{\tau} + K T_{st}}$$

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$$\frac{dT'}{dt} + aT' = \frac{1}{\tau} T_i' + k T_{st}'$$

$$s\,\bar{T}'(s) + a\,\bar{T}'(s) = \frac{1}{\tau}\bar{T}_i'(s) + k\,\bar{T}_{st}'(s)$$

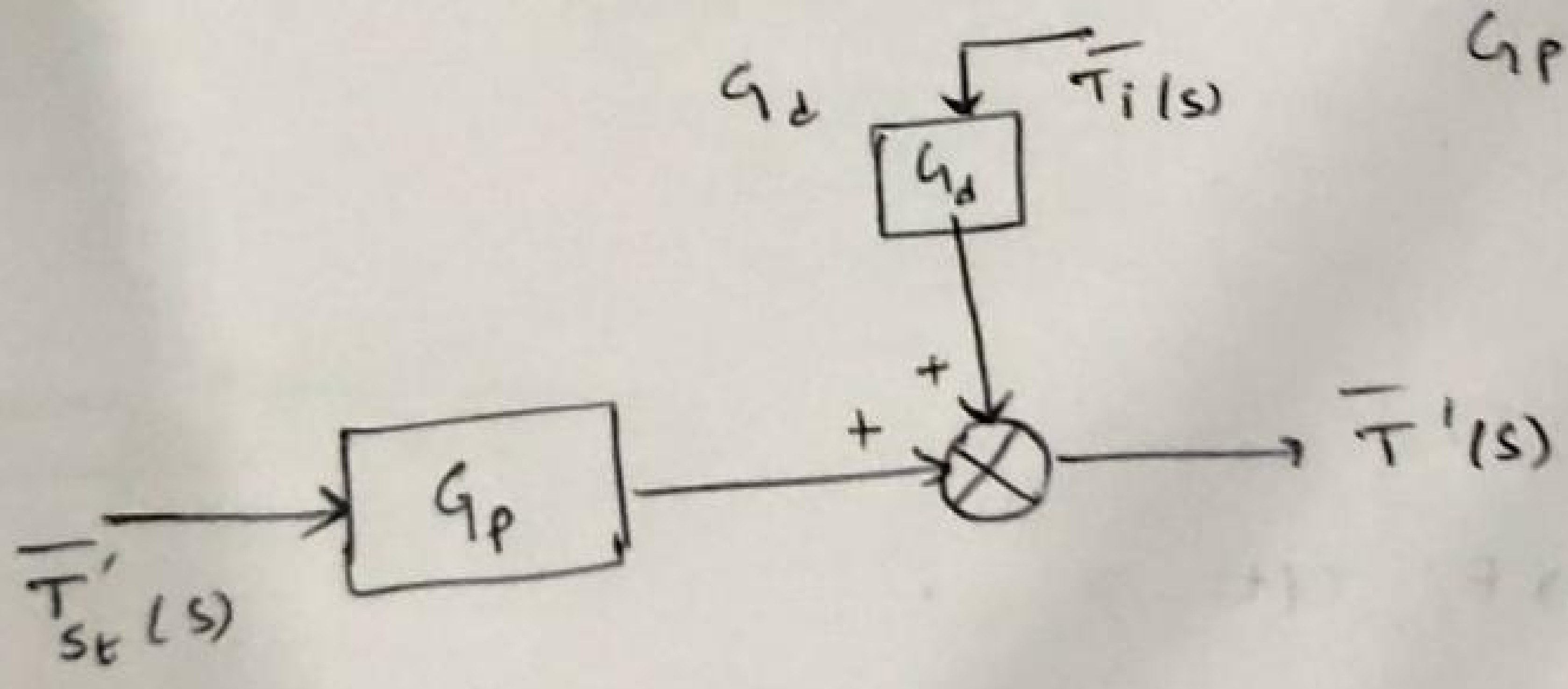
$$\boxed{\bar{T}'(s) = \frac{1}{\tau(s+a)}\bar{T}_i'(s) + \frac{k}{s+a}\bar{T}_{st}'(s)}$$

Input-output model (without controller)

$$\boxed{\bar{T}'(s) = \frac{\frac{1}{\tau}}{s+a}\bar{T}_i'(s) + \frac{k}{s+a}\bar{T}_{st}'(s)}$$

$$\bar{T}'(s) = \frac{\frac{1}{\tau}\,\frac{1}{a}}{\frac{1}{a}s+1}\bar{T}_i'(s) + \frac{k\,\frac{1}{a}}{s/a+1}\bar{T}_{st}'(s)$$

$$\bar{T}'(s) = \underbrace{\frac{k_d}{\tau_p s+1}}_{\text{disturbance}\;G_d} T_i'(s) + \underbrace{\frac{k_m}{\tau_p s+1}}_{\text{manipulative}\;G_P} T_{st}'(s)$$



$k_d = ?$ $\quad$ $F_i = 200\,L/min$ $\quad$ $V = 1\,m^3$

$k_m = ?$ $\quad$ $\rho = 1000\,kg/m^3$ $\quad$ $U = 1500\,W/m^2K$

$\tau_p = ?$ $\quad$ $C_p = 4.2\times10^3\,J/kgK$ $\quad$ $A_t = 5\,m^2$

$$\tau = \frac{V}{F_i}$$

$$\tau = \frac{1}{200\times10^{-3}} = 5\,min$$

$$a = \frac{1}{\tau} + k$$

$$k = \frac{UA_t}{V\rho c_p}$$

$$k = 1.785 \times 10^{-3}$$

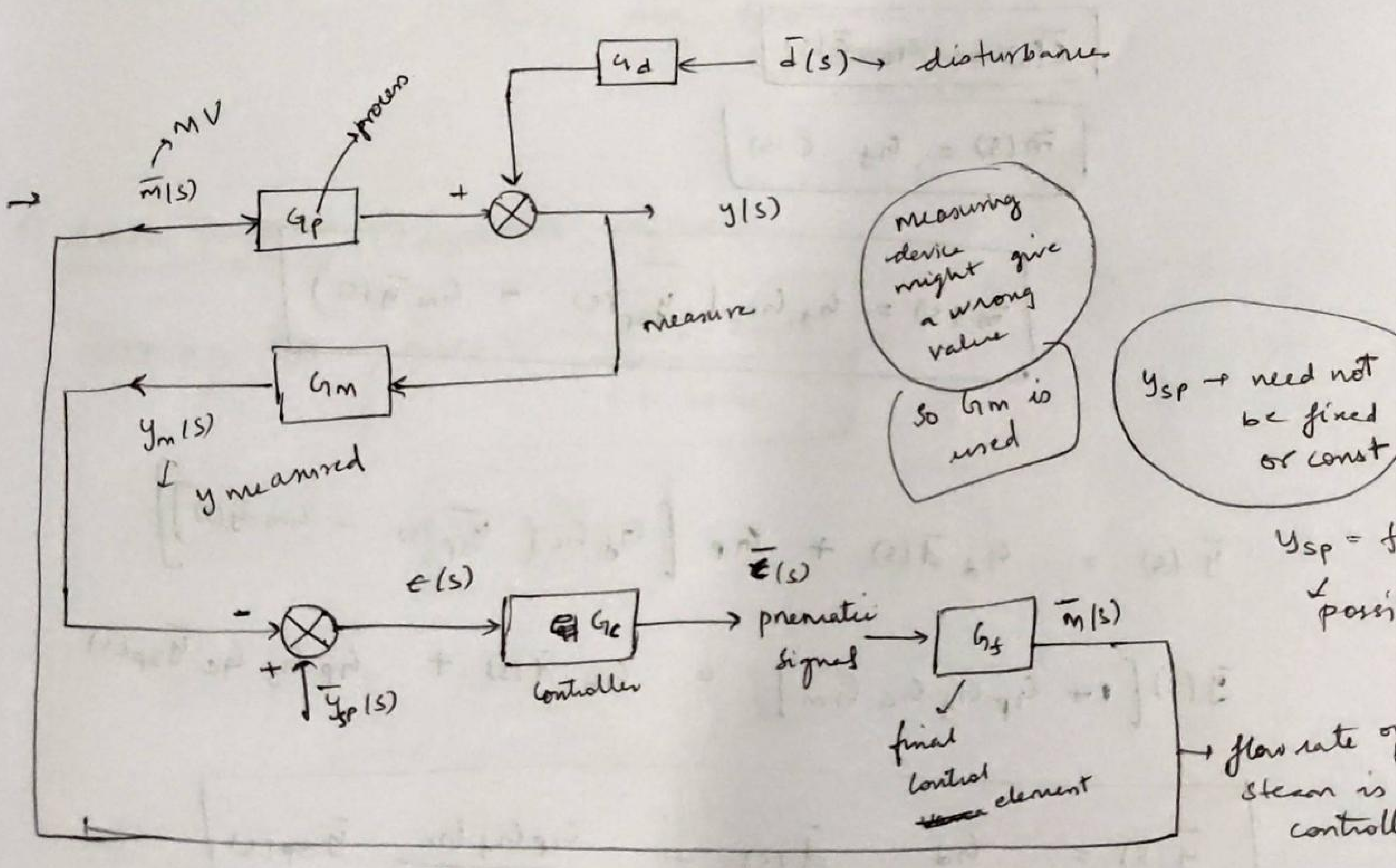
$$a = 5.119 \times 10^{-3}$$

$$\boxed{\tau_p = 195 \text{ sec}}$$

$$K_d = \frac{1}{\tau}\frac{1}{a} = 0.65$$

$$K_M = k\frac{1}{a} = 0.348$$

<u>With controller</u>



$G_M \rightarrow$ will give relation between actual temp and measured.

$\rightarrow$ $\bar{y}_{sp} \rightarrow$ input
$\rightarrow$ $\bar{d}(s) \rightarrow$ disturbance

} we want to know how change in $\bar{y}_{sp}(s)$, $\bar{d}(s)$ will affect $y(s)$

$$\rightarrow \quad y(s) = (\quad) \, \bar{y}_{sp}(s) + (\quad) \, \bar{d}(s)$$

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

~~$+ \bar{y}_m(s)$~~

~~$y_{sp}(s) - y_m(s) =$~~

$$\boxed{\bar{y}_m(s) = G_m \bar{y}(s)}$$

$$\boxed{\bar{\epsilon}(s) = \bar{y}_{sp}(s) - \bar{y}_m(s)}$$

$$\boxed{\bar{c}(s) = G_c \, \bar{\epsilon}(s)}$$

$$\boxed{\bar{m}(s) = G_f \, \bar{c}(s)}$$

$$\boxed{\bar{m}(s) = G_f G_c (\bar{y}_{sp}(s) - G_m \bar{y}(s))}$$

$$\bar{y}(s) = G_d \, \bar{d}(s) + G_p \left[G_f G_c (\bar{y}_{sp}(s) - G_m \bar{y}(s)) \right]$$

$$\bar{y}(s) \left[1 + G_p G_f G_c G_m \right] = G_d \, \bar{d}(s) + G_p G_f G_c \, \bar{y}_{sp}(s)$$

$$\boxed{\bar{y}(s) = \frac{G_d}{1 + G_p G_f G_c G_m} \bar{d}(s) + \frac{G_p G_f G_c}{1 + G_p G_f G_c G_m} \bar{y}_{sp}(s)}$$

Closed loop $\rightarrow$ G_p, G_f, G_c, G_m $\rightarrow$ so all will come in the denominator

$\rightarrow$ between $\bar{y}(s)$ and $\bar{d}(s)$ $\rightarrow$ G_d $\rightarrow$ numerator (everything in the forward path

$\rightarrow$ between $\bar{y}(s)$ and $\bar{y}_{sp}(s)$ $\rightarrow$ $G_p G_f G_c$ $\rightarrow$ numerator

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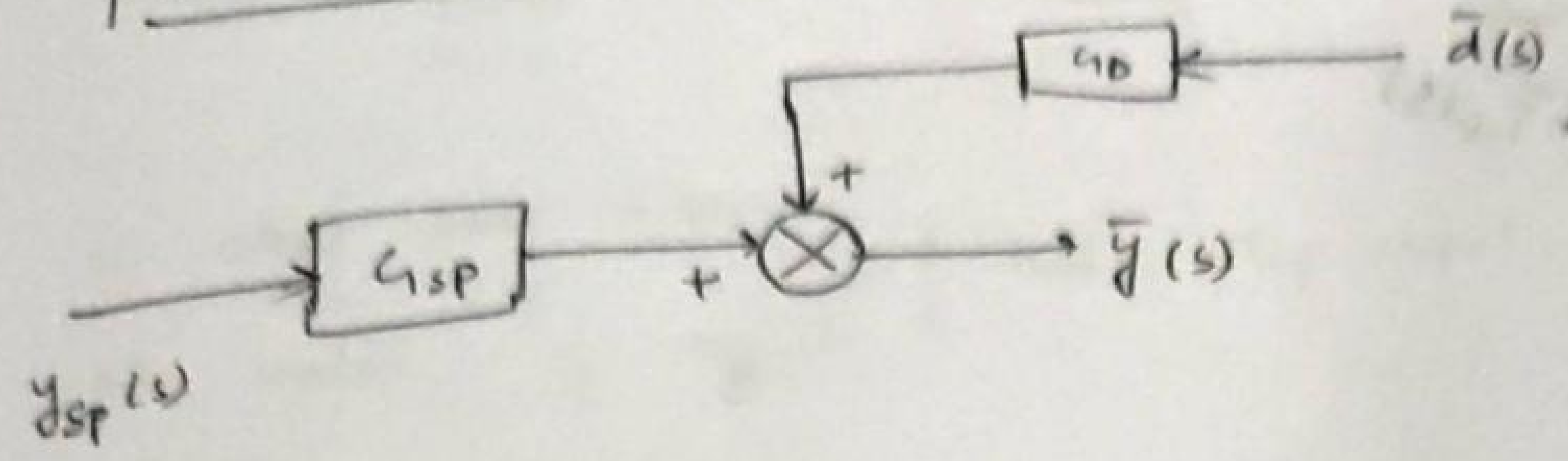
$$\boxed{y(s) = G_{sp}\,\bar{y}_{sp}(s) + G_D\,\bar{d}(s)}$$



$\boxed{G_m = 1} \rightarrow$ ideal

$\boxed{G_f = 1} \rightarrow$ Whatever comes from control is flow signal

(a) set point change only, $\bar{d}(s) = 0 \rightarrow$ servo problem $\rightarrow$ servant

$\bar{d}(s) \neq 0 \rightarrow$ regulator problem

(b) $\bar{y}_{sp}(s) = 0$. → no set point change

↓ despite any disturbance

T ~~should~~ should be same.

1) Servo problem (Proportional controller)

~~$\bar{y}(s) = G$~~

$$\boxed{\bar{y}(s) = \frac{G_p G_c\,\bar{y}_{sp}(s)}{1 + G_p G_c}}$$

$$\boxed{G_c = K_c} \qquad \boxed{G_p = \frac{K_p}{\tau_p s + 1}}$$

$$\bar{y}(s) = \left[\frac{K_c\,K_p/(\tau_p s+1)}{1 + (K_p K_c/\tau_p(s)+1)}\right]\bar{y}_{sp}(s)$$

$$\boxed{\bar{y}(s) = \frac{K_p K_c}{\tau_p s + (K_p K_c + 1)}\,\bar{y}_{sp}(s)}$$

$$\boxed{\bar{y}(s) = \left[\frac{K_p K_c/1+K_pK_c}{\left(\frac{\tau_p}{1+K_pK_c}\right)s + 1}\right]\bar{y}_{sp}(s)} = \frac{K_p'}{\tau_p' s + 1}\,\bar{y}_{sp}(s)$$

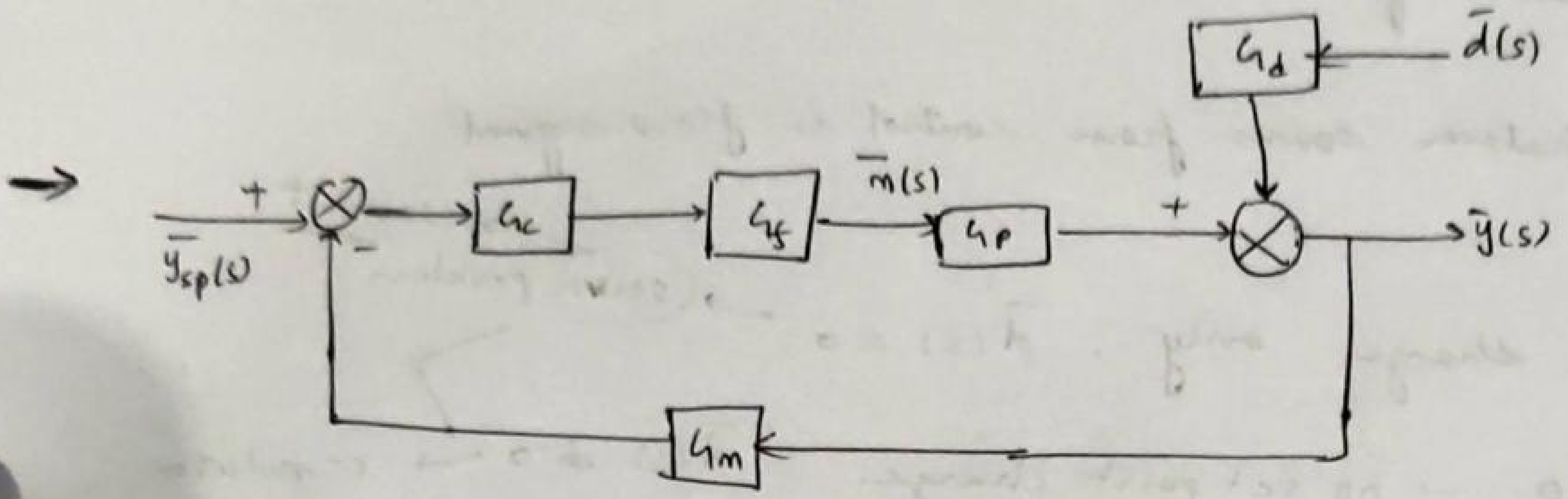
↓

controlled process } Cont

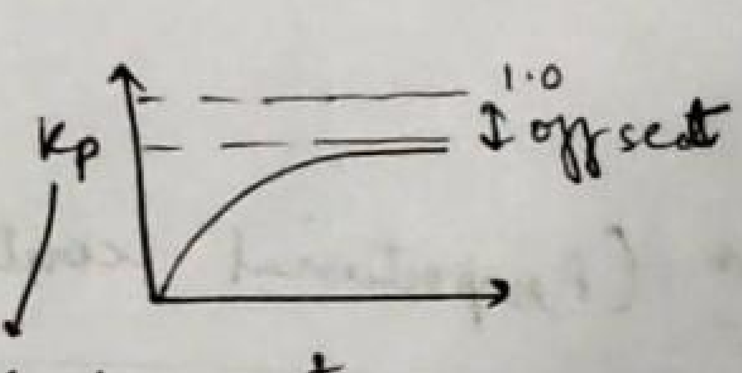
$$\boxed{\bar{y}(s) = \frac{k_p}{\tau_p s+1}\,\bar{y}_{sp}(s)} \rightarrow \text{uncontrolled process}$$

$\bar{y}_{sp}(s) \rightarrow \bar{T}_{st}'(s)$

→ $k_p' = \dfrac{k_p k_c}{1+k_p k_c}$

→ 

$$\bar{y}(s) = \frac{k_p k_c/(1+k_p k_c)}{\dfrac{\tau_p}{1+k_p k_c}s+1}\,\bar{y}_{sp}(s) \rightarrow \text{1st order system}$$



① 1st order system

② steady-state gain has changed

③ τ_p also decreased $\dfrac{\tau_p}{1+k_p k_c}$

④ offset without controller $= 0.65$ $(1-0.35)$ [desired value − value it has reached after a long time]

without controller

⑤ offset :- $1 - \dfrac{k_p k_c}{1+k_p k_c}$

with controller $= \dfrac{1}{1+k_p k_c}$

$k_c \uparrow$, offset $\downarrow$

if k_c increases recklessly, system can become unstable

→ uncontrolled process → set pt change is step change in the manipulative variable. $[T_{st}(t)]$

INTEGRAL CONTROL ACTION :

$$G_c = \frac{k_c}{\tau_I s}$$

1) close loop response
2) value of offset

} unit step input in set pt

$$\bar{y}(s) = \frac{G_p G_c \; \bar{y}_{sp}(s)}{1 + G_p G_c}$$

$$G_p = \frac{k_p}{\tau_p s + 1} \qquad G_c = \frac{k_c}{\tau_I s}$$

$$\bar{y}(s) = \frac{\frac{k_p}{\tau_p s + 1} \times \frac{k_c}{\tau_I s} \; \bar{y}_{sp}(s)}{1 + \frac{k_p k_c}{(\tau_p s + 1)(\tau_I s)}}$$

$$\bar{y}(s) = \frac{k_p k_c}{(\tau_p s)(\tau_I s) + \tau_I s + k_p k_c} \; \bar{y}_{sp}(s)$$

$$\boxed{\bar{y}(s) = \frac{k_p k_c}{\tau_p \tau_I s^2 + \tau_I s + k_p k_c} \; \bar{y}_{sp}(s)} \longrightarrow \text{2nd order system}$$

oscillation

actual system is 1st order but as soon integral controller is used, it is 2nd order

$$\bar{y}(s) = \frac{1}{\frac{\tau_p \tau_I}{k_p k_c} s^2 + \frac{\tau_I}{k_p k_c} s + 1} \; \bar{y}_{sp}(s)$$

$$\boxed{k_p' = 1}$$

$$\tau^2 = \frac{\tau_p \tau_I}{k_p k_c} \qquad \tau_p' = \sqrt{\frac{\tau_p \tau_I}{k_p k_c}}$$

τ

$$2 \zeta \tau = \frac{\tau_I}{k_p k_c}$$

$$2 \zeta \sqrt{\frac{\tau_p \tau_I}{k_p k_c}} = \frac{\tau_I}{k_p k_c}$$

$$\boxed{\zeta = \frac{1}{2} \sqrt{\frac{\tau_I}{k_p k_c \tau_p}}} \rightarrow \zeta$$

→ final value theorem :- $y(t) \rightarrow 1$

$$\lim_{s \to 0} [s f(s)] \longrightarrow \text{final value}$$

$$\bar{y}(s) = \frac{1}{\tau^2 s^2 + 2\tau \zeta s + 1} \; \bar{y}_{sp}(s) \rightarrow \frac{1}{s}$$

→ value of offset = $\underline{0}$.

unit change in set pt

→ Simulink :- Mux → both input and output together] in scope

adding time delay :-

→ we cannot have more k_c to remove the offset & we need
bcos oscillation might start :- } integral controller

→ stability :- Bounded input → Bounded output

→ $y(s) = \frac{1}{s+a} \cancel{y_{sp}(s)} \frac{1}{s}$

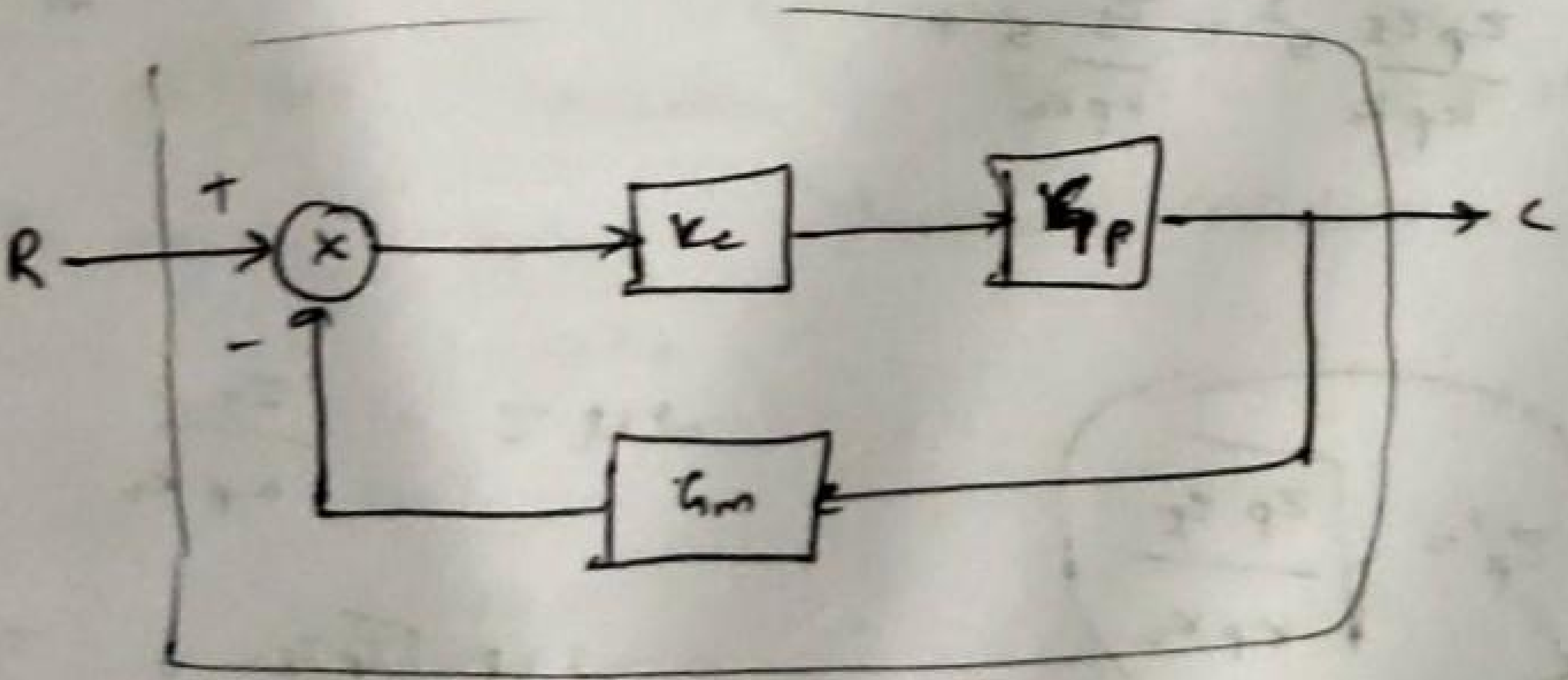
$$y(s) = \frac{1}{s+a} \cdot \frac{1}{s}$$

$$y(s) = \left(\frac{1}{s} - \frac{1}{s+a}\right)\frac{1}{a}$$

$$\boxed{y(t) = \frac{1 - e^{-at}}{a}}$$

should have e^{-ct} → so that system is stable

∴ poles must be $\underline{-ve}$.



→ servo problem

$$C = \frac{K_c G_P}{1 + G_p G_m K_c} R$$

$1 + G_p G_m K_c$ → characteristic eqn $\quad G_p G_m K_c = G_{OL}$

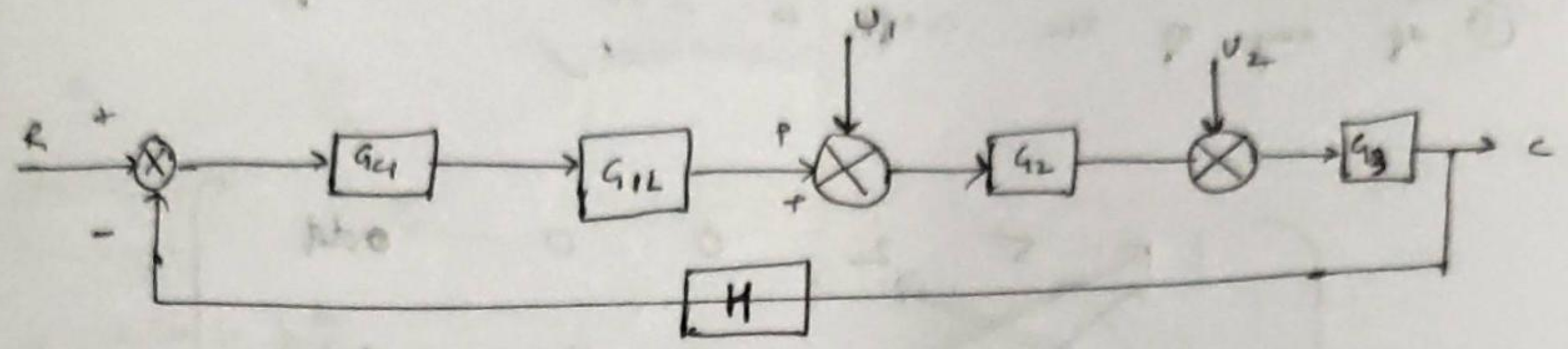
roots of this polynomial will determine stability

→ $1 + G_{OL} = 0$ → characteristic eqn of the system

. stability: roots of the eqn < 0

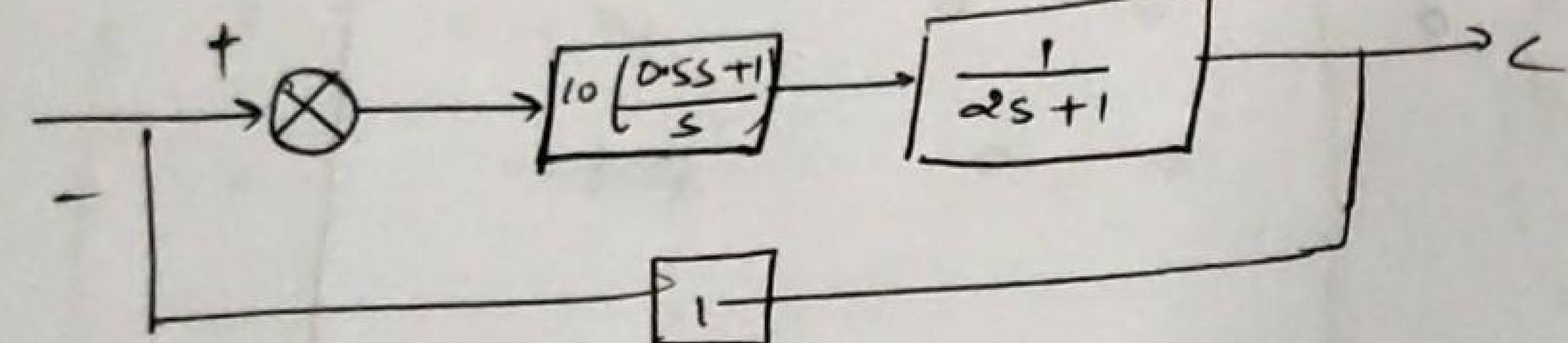
for complex roots, real part < 0

Q)



$$C = R\left(\frac{G_c G_{1L} G_2 G_3}{1 + G_c G_{1L} G_2 G_3 H}\right) + U_1\left(\frac{G_2 G_3}{1 + G_c G_{1L} G_2 G_3 H}\right) + U_2\left(\frac{G_3}{1 + G_c G_{1L} G_2 G_3 H}\right)$$

→ Q) R



$$C = \frac{R\left(10\left(\frac{0.5s+1}{s}\right)\left(\frac{1}{2s+1}\right)\right)}{1 + 10\left(\frac{0.5s+1}{s}\right)\left(\frac{1}{2s+1}\right)}$$

$$C = \frac{R(10(0.5s+1)(1))}{s(2s+1) + 10(0.5s+1)} R$$

Stable

$$C = \frac{R(10(0.5s+1))}{2s^2 + 6s + 10} R$$

characteristic eqn $= 2s^2 + 6s + 10$

$2s^2 + 6s + 10 = 0$

$$s = \frac{-6 \pm \sqrt{36 - 4(2)(10)}}{2(2)}$$

$$s = \frac{-6 \pm \sqrt{36 - 80}}{4}$$

$$s = \frac{-6 \pm 16.63}{4}$$

→ Routh test for stability

$\boxed{s^4 + 3s^3 + 5s^2 + 4s + 2 = 0}$

$a_0 \quad a_1 \quad a_2 \quad a_3 \quad a_4$

① if any of the coeff. is −ve the system is unstable ✓

Routh array

$$\begin{bmatrix} 1 & 5 & 2 & 0 & 0 \\ 3 & 4 & 0 & 0 & 0 \\ \frac{15-4}{3} & \frac{6-0}{3} & 0 & 0 & \\ \frac{\frac{44}{3}-\frac{18}{3}}{11/3} & 0 & & & \\ \frac{6}{3} & & & & \end{bmatrix} \begin{array}{l} \to \text{odd} \\ \to \text{even} \\ \\ \\ \\ \end{array}$$

$$\begin{bmatrix} 1 & 5 & 2 & 0 & 0 \\ 3 & \cancel{4} & 0 & 0 & 0 \\ 11/3 & 6/3 & 0 & & \\ 6/11 & & & & \\ 6/3 & & & & \end{bmatrix}$$

no +ve coefficient

∴ polynomial doesn't have any +ve root.

column → 1st column

$\boxed{\text{NO sign change} \to \text{stable}}$

1st column

Eg:- 1/ 1 ~~8~~ / −11/3

$$\begin{bmatrix} 1 \\ -3 \\ -11/3 \\ -26/11 \\ 6/3 \end{bmatrix}$$

1st column

sign change = 2

∴ 2 +ve real part in the root.

8) $s^3 + 2s^2 + (2 + k_c)s + \frac{k_c}{\tau_I} = 0$

So we can tell for what value of k_c the system is stable

$$\begin{bmatrix} 1 & 2+k_c & 0 & 0 \\ 2 & \frac{k_c}{\tau_I} & 0 & 0 \\ \frac{\left(2(2+k_c) - \frac{k_c}{\tau_I}\right)}{2} & 0 & & \\ \frac{\frac{\left(2(2+k_c) * \frac{k_c}{\tau_I}\right)\frac{k_c}{\tau_I}}{2}}{\frac{2(2+k_c)-k_c/\tau_I}{2}} & & & \end{bmatrix}$$

$$\begin{bmatrix} 1 & 2+k_c & 0 & 0 \\ 2 & k_c/\tau_I & 0 & 0 \\ \frac{4+2k_c-\frac{k_c}{\tau_I}}{2} & 0 & 0 & 0 \\ \frac{k_c}{\tau_I} & 0 & 0 & 0 \end{bmatrix}$$

linear system control

$$\frac{4 + 2k_c - \frac{k_c}{\tau_I}}{2} > 0$$ ✓ for stability

Amplitude ratio (AR) $= \frac{k_p}{\sqrt{1+\tau_p^2 w^2}}$

$\phi = \tan^{-1}(-\tau_p w)$

phase

→ To get amplitude ratio (AR) and ϕ of any transfer function ① substitute $s = jw$.

② ~~---~~ take $|G(jw)| \Rightarrow$ amplitude ratio

③. take ϕ of $G(jw) = \phi$ $\tan^{-1}(b/a)$ → $a+ib$ form

$$G_p(s) = \frac{k_p}{\tau_p s+1} = \frac{k_p}{\tau_p(jw)+1}$$

$$= \frac{k_p(-\tau_p wj+1)}{(\tau_p(jw)+1)(-\tau_p wj+1)} = \frac{k_p(-\tau_p wj+1)}{(\tau_p^2 w^2+1)}$$

$$= \frac{\cancel{k_p(-\tau_p wj+1)}}{\cancel{\sqrt{\tau_p}}}$$

~~$\tan^{-1}(\phi) =$~~

$$\boxed{\tan^{-1}(-\tau_p w) = \phi}$$

Q) $G(s) = \frac{k_p}{s}$

$$G(jw) = \frac{k_p \times j}{jw \times j} = \frac{-k_p j}{w}$$

$AR = \frac{k_p}{w}$

$\tan^{-1}(b/a) = -\pi/2$

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Q) $G(s) = \dfrac{k_p}{\tau_p^2 s^2 + 2\xi\tau_p s + 1}$

$s \to j\omega$ $|G(s)| = |G_1(s)\,G_2(s)\,G_3(s)| = |G_1(s)| \cdot |G_2(s)| \cdot |G_3(s)|$

$\to \phi(G(j\omega)) = \angle G_1 + \angle G_2 + \angle G_3$.

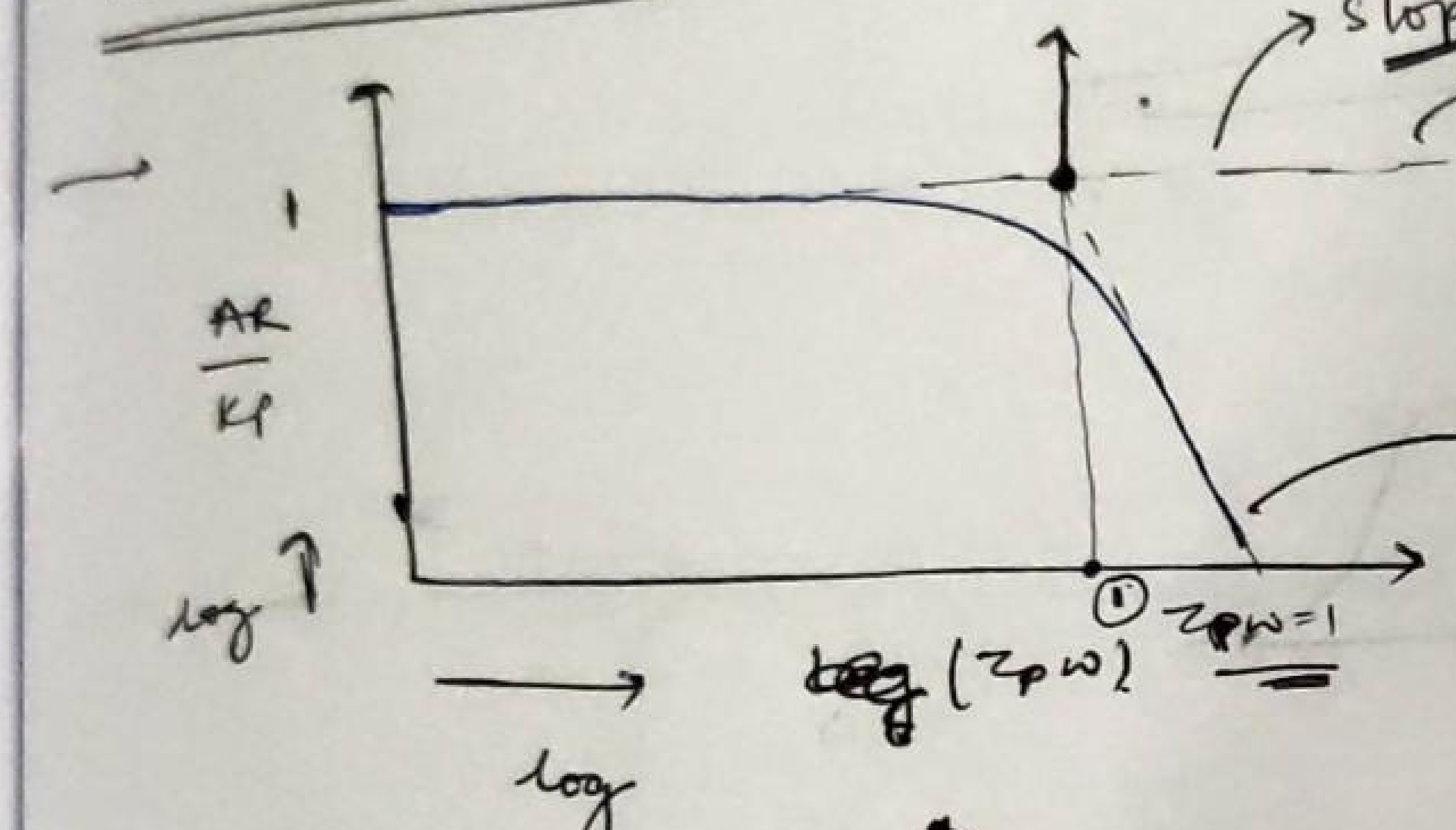
→ Behavior of the system (stability) is analysed using a pair of plots ① AR v/s ω ② ϕ v/s ω → [Bode's diagram]

1st order system

corner frequency

→ slope 0 → low frequency asymptote

log-log plot



slope = -1 → high frequency asymptote

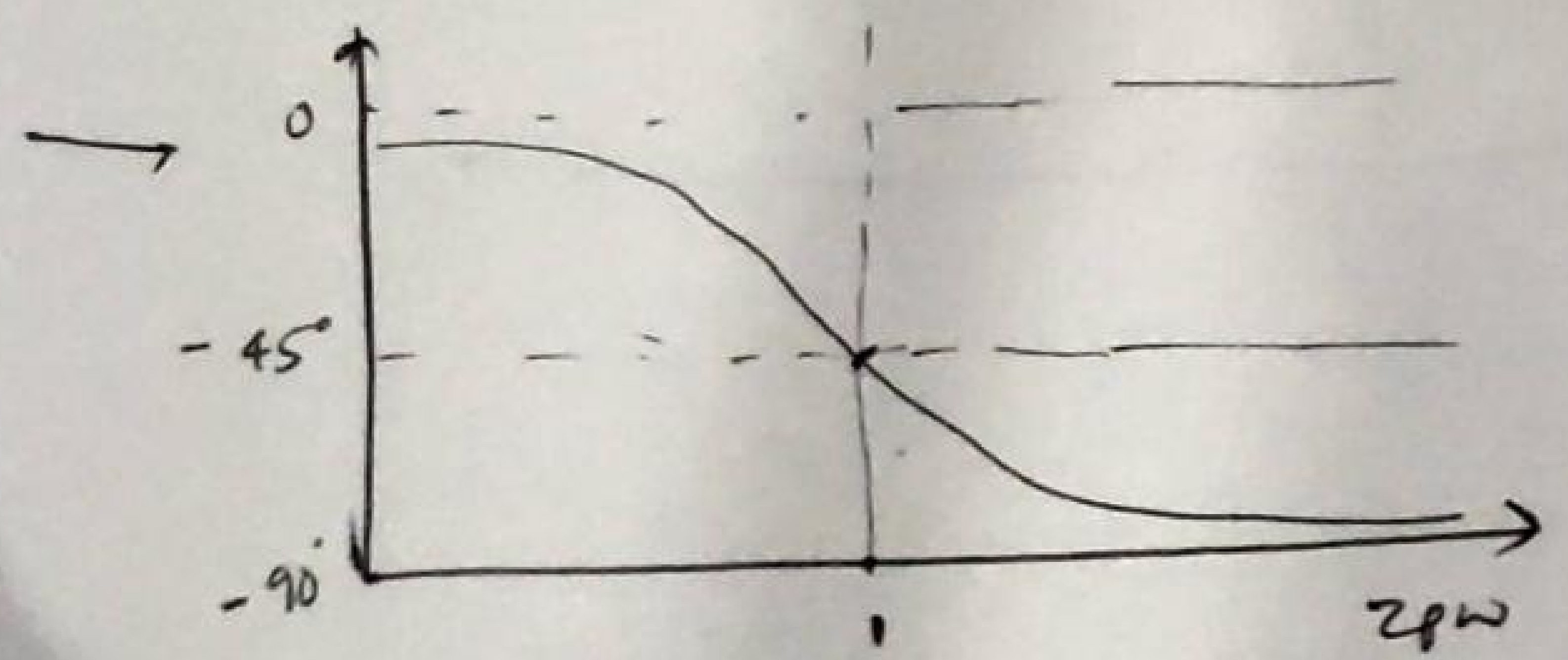
$$\boxed{\frac{AR}{k_p} = \frac{1}{\sqrt{1+(\tau_p\omega)^2}}}$$

$\tau_p\omega << 1 \to \dfrac{AR}{k_p} \approx 1$

$\log\left(\dfrac{AR}{k_p}\right) = (\log 1) = 0$ slope = 0

$\tau_p\omega >> 1 \to \dfrac{AR}{k_p} \approx \dfrac{1}{\tau_p\omega}$ st line with slope = -1

$\log\left(\dfrac{AR}{k_p}\right) = -\log(\tau_p\omega)$

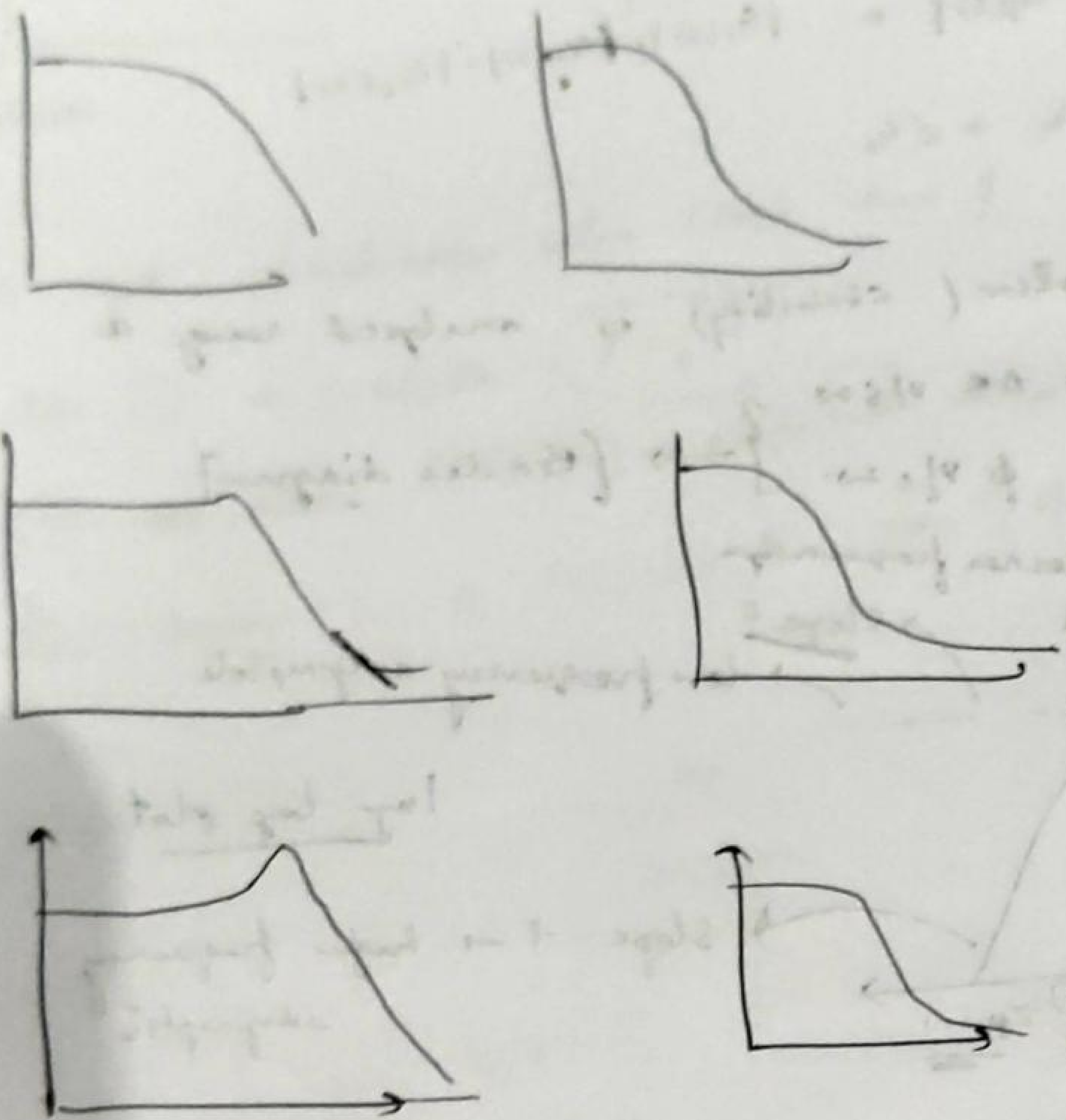


linear scale

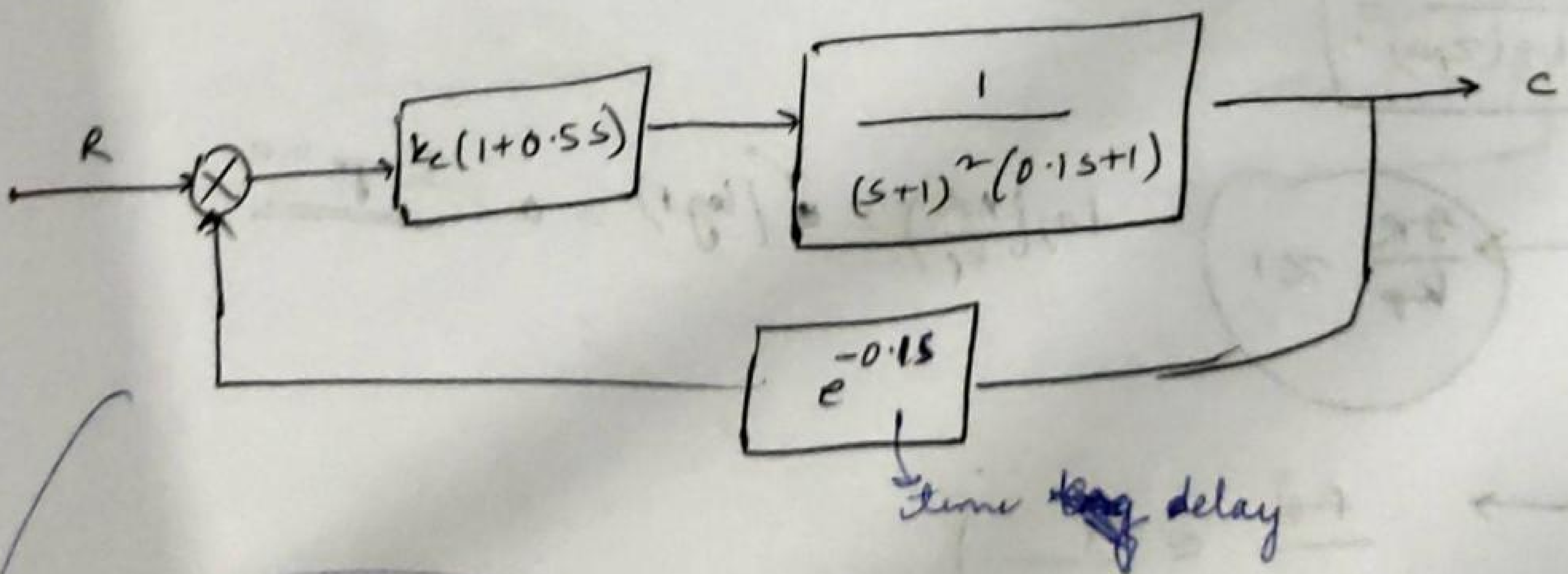
Semi log

corner frequency where high and low frequency curves meet -

→ Second order system –



Q)



1W

$G_R = k_c(1+\tau_D s)$

If $AR < 1$ for all frequency

∴ system is stable always

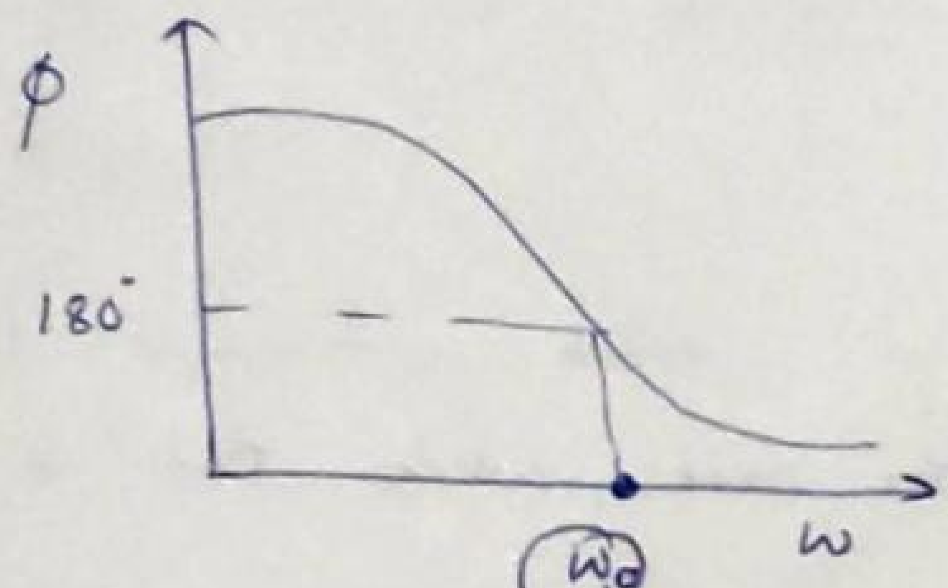
Stability of a control system using Bode diagram

Bode's stability criteria :- (only for monotonous Bode plots)

If AR > 1 ~~taken~~ at ω_0, the system is unstable.

Cross over frequency :- ω at which $\phi = -\pi \rightarrow 180^\circ$ phase lag.

Bodes frequency response open loop

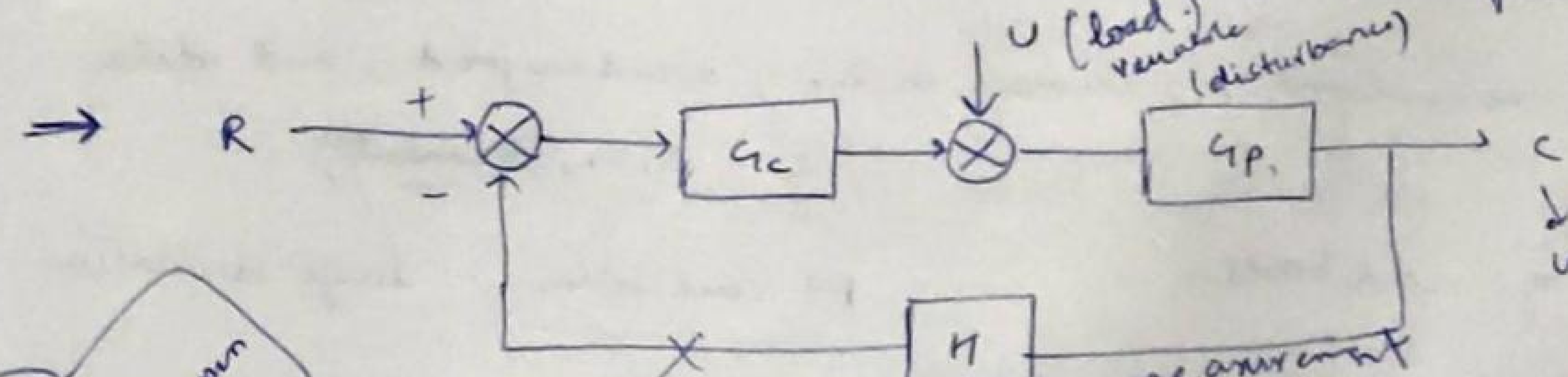


Cross over frequency.

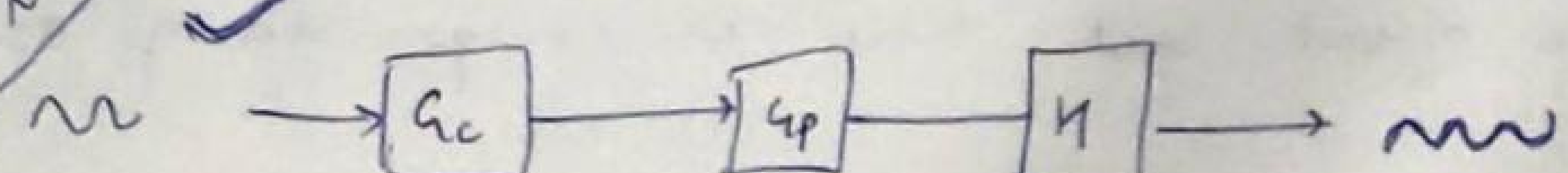
To verify whether the system is stable or unstable, get Bodes ~~Bo~~ open loop plot

Bode's plots

~~its~~ takes open loop TF rather than closed loop



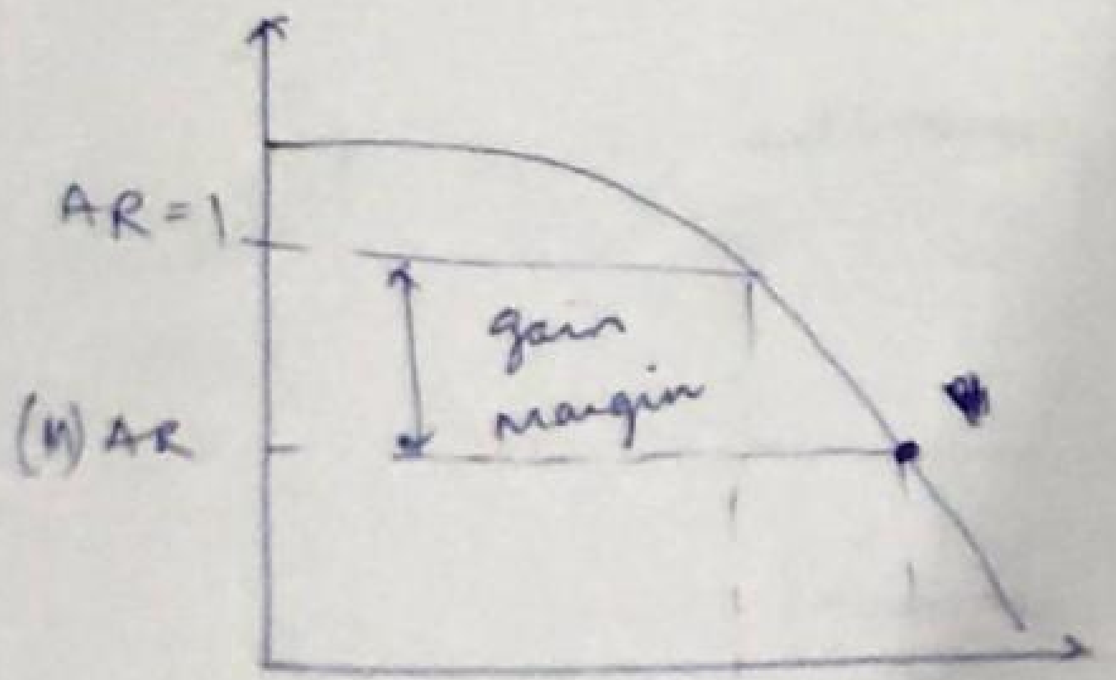
for response consider open loop

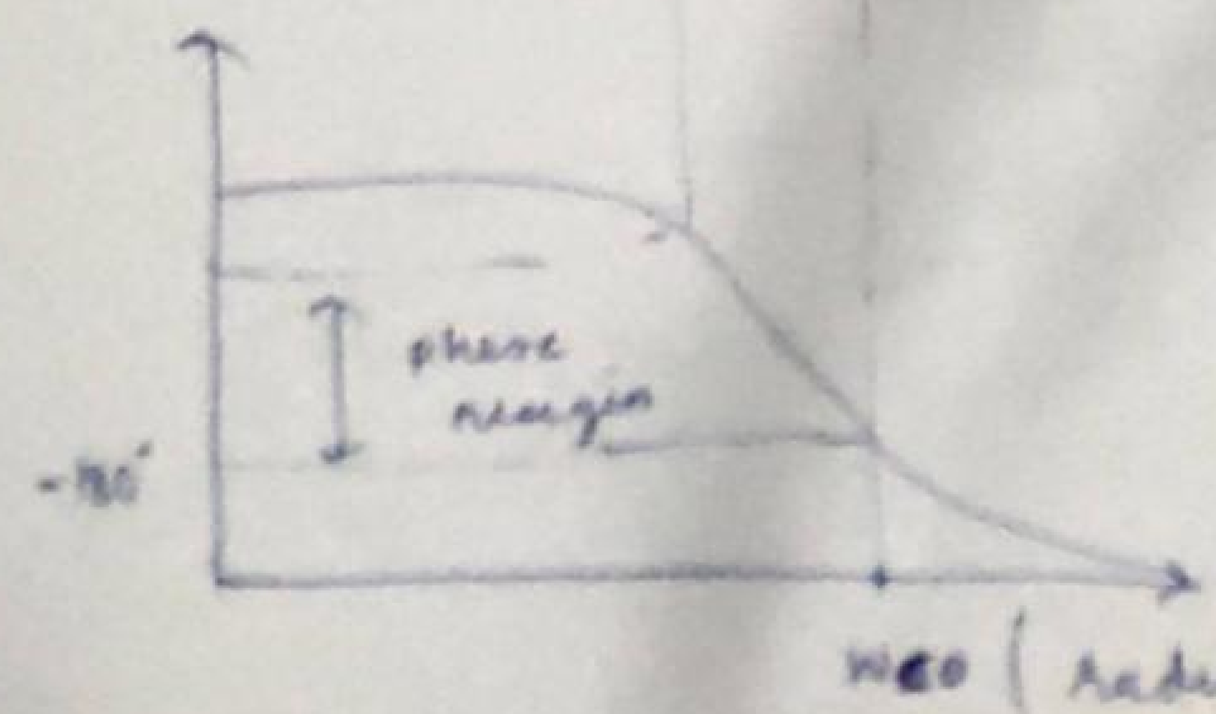


(frequency response)

Open loop TF :- $TF = G_c G_p M$

Phase margin and gain margin





ultimate gain (Max value of gain when system is critically stable)

$K_u = \frac{1}{M} > 2.$

to find K_u, set $K_c = 1$

y axis → $\frac{AR}{K_c} = M$ at -180° → ω_{co}, then set AR =

$K_u = 1/M$

recommended value of phase margin $= 30^\circ$

ultimate period of oscillation

$P_u = \frac{2\pi}{\omega_{co}} = \frac{\text{min}}{\text{cycle}}$

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Zigler Nicols controller setting

$k_c = k_u/2$ → only proportional

PI → $k_u/2.2$, $P_u/1.2 = \tau_I$

PID → $k_u/1.7$, $P_u/2 = \tau_I$, $\tau_D = P_u/8$

1) Controller selection
2) Performance measure
3) Tuning of controller for the case where the analytical model (transfer function) is not available.

Controller selection (restrictions :- second order, overdamped, and delay in measurement)

→ Oscillation is becoz of controller
∴ tuning is necessary

PI controller :- huge oscillation

→ PI controller eliminates offset but there is large no. of oscillat

→ PID → offset ≠ 0

→ P controller → a fewer no. of oscillations

→ PID is best is all the parameters are tuned.

→ if offset is tolerable go with proportional controller

→ if oscillation is permissible → PI controller

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Performance measure

→ Quantitative

should be min as possible for good performance

focus on large error

(a) Integral of sq error = $\int_0^t [\epsilon(z)]^2 \, dz$ → ISE

(b) Integral of absolute error = $\int_0^t |\epsilon(z)| \, dz$ → IAE

depending on time

(c) Integral of time weighted absolute error → $\int_0^t z|\epsilon(z)| \, dz$

ITAE

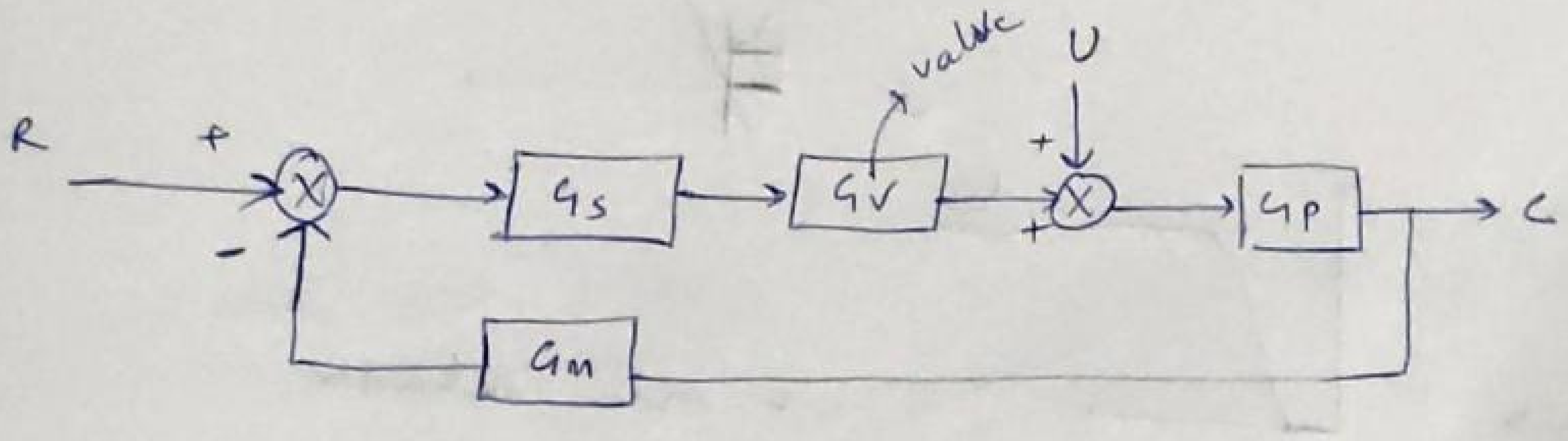
small errors at long time will get penalized

It will penalize all values equally

→ When to use which performance measure depends on chemical process

→ Optimiser will minimize error by changing the values.

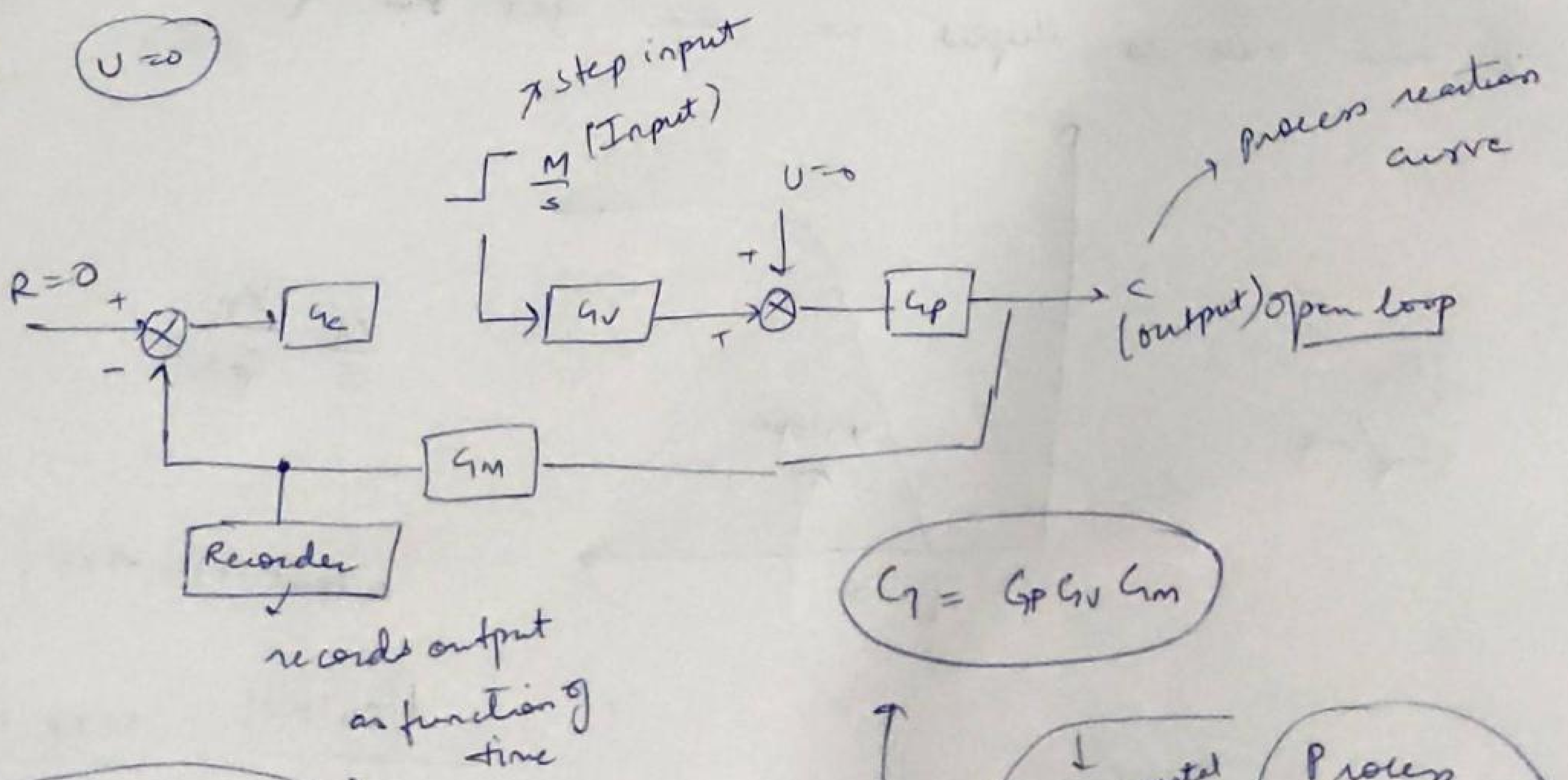
Tuning of controller (don't know process TF)



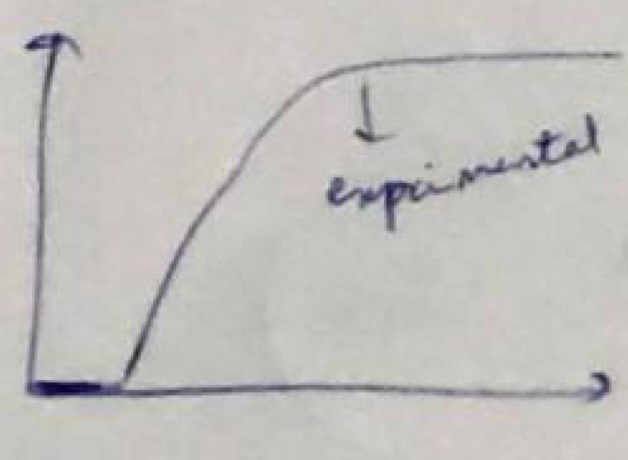
→ Combined TF is obtained by opening the loop.

R=0   U=0

Cohen and Coon



$G = G_p G_v G_m$

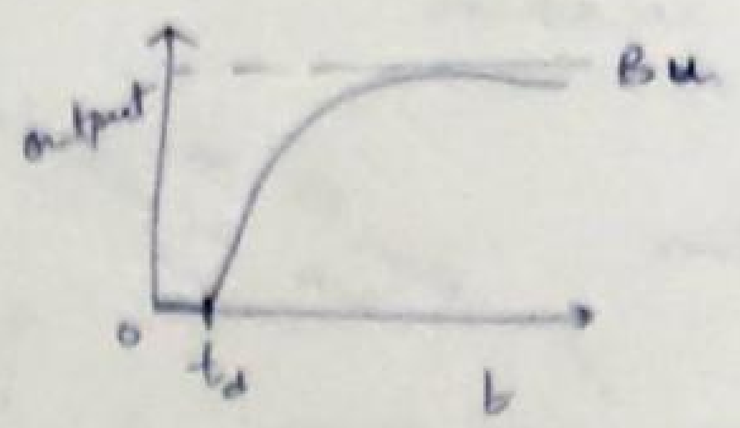


Process reaction curve

$$G = \frac{k_p}{\tau_p s + 1} e^{-t_d s}$$

$output(t) = [\quad]$

$\overline{output}(s) = \left(\frac{M}{s}\right)\left(\frac{k_p e^{-t_d s}}{\tau_p s+1}\right)$

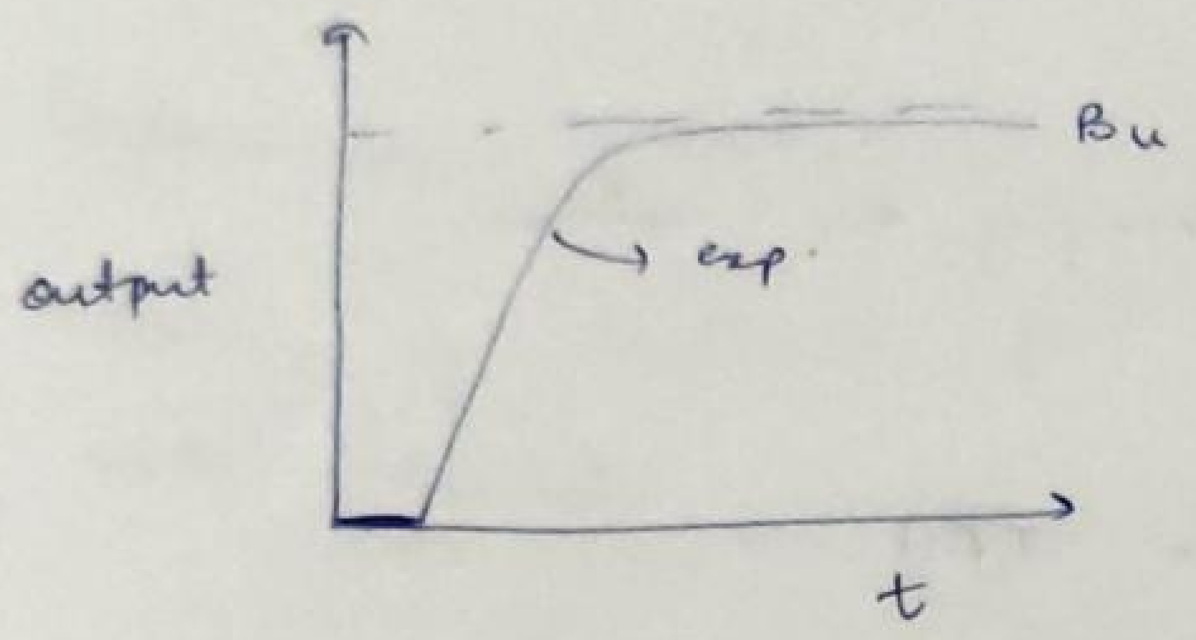


→ use final value theorem → to find k_p → final value = $\underline{M k_p}$

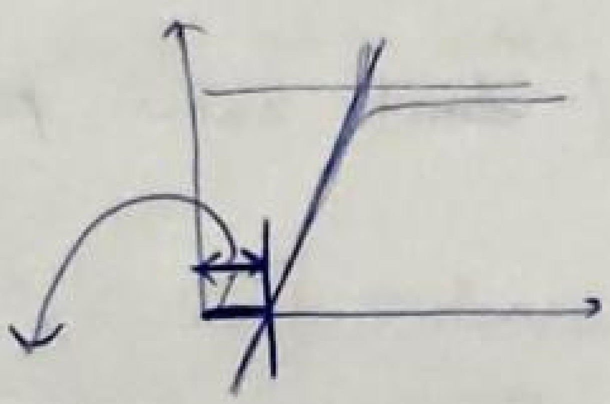
→ $\lim_{t \to \infty} f(t) = \lim_{s \to 0} s\bar{F}(s)$ $\qquad$ $Bu = M k_p$

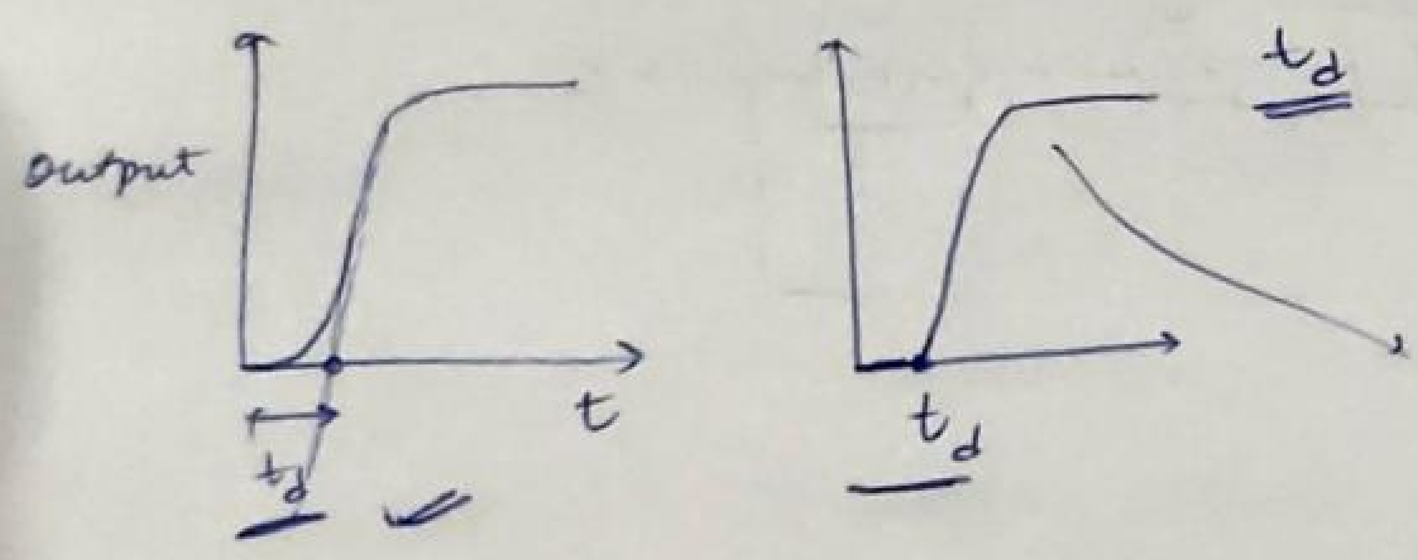
→ t_d = time delay, time the system takes to respond

→



try to ~~find~~ fit straight line to curve (when it hits the x-axis is t_d)



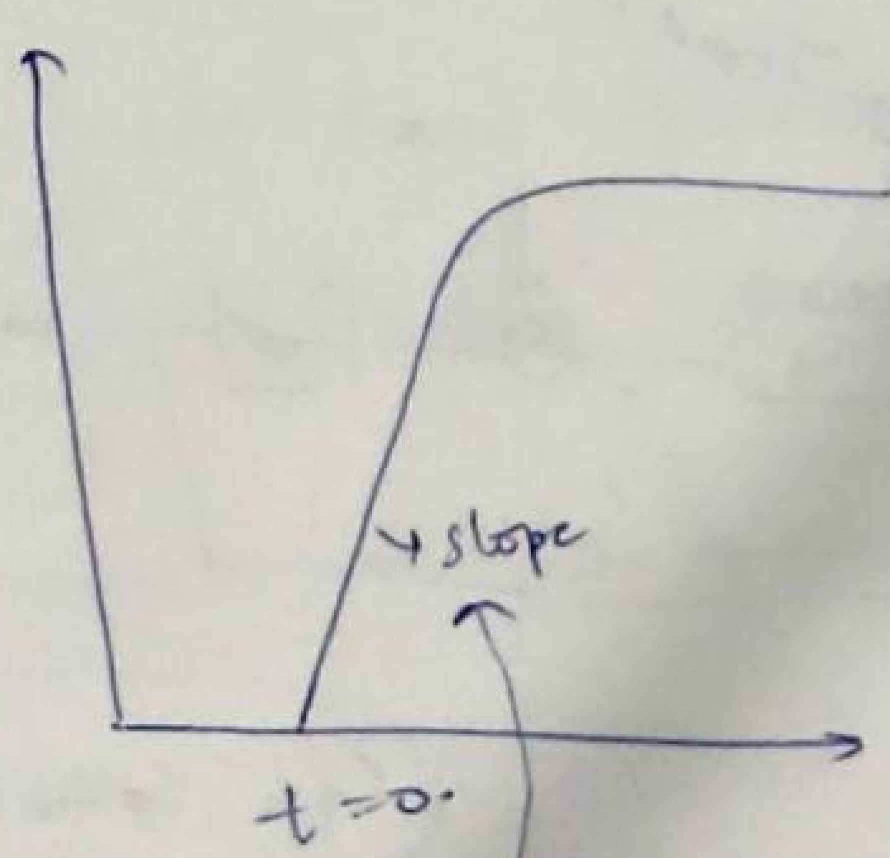


1st order behavior

→ to know k_p, t_d, τ_p

→ if time axis is shifted we can get ~~rid of~~ $e^{-t_d s}$

after shifting



$\frac{M}{s} \frac{k_p}{\tau_p s+1}$

$output(t) = M k_p \left[1 - e^{-t/\tau_p}\right]$

$\frac{d(output)}{dt} = \frac{M k_p e^{-t/\tau_p}}{\tau_p}$

* $\frac{M k_p}{\tau_p}$ = slope

$\left.\frac{d(output)}{dt}\right|_{t=0} = \frac{M k_p}{\tau_p}$

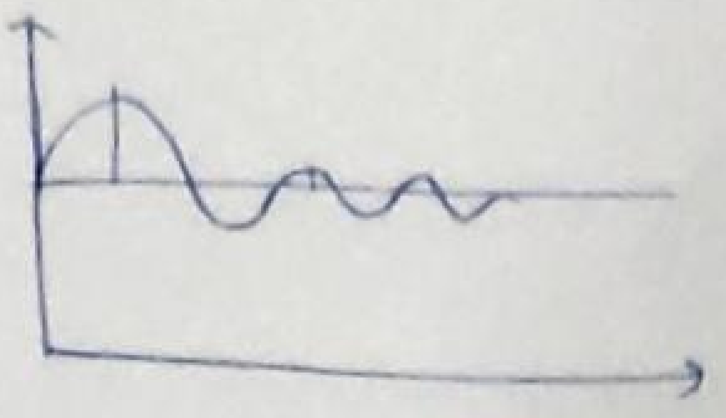
τ_p can be found out

$\tau_p = \frac{M K_p}{slope}$

→ Cohen and coon

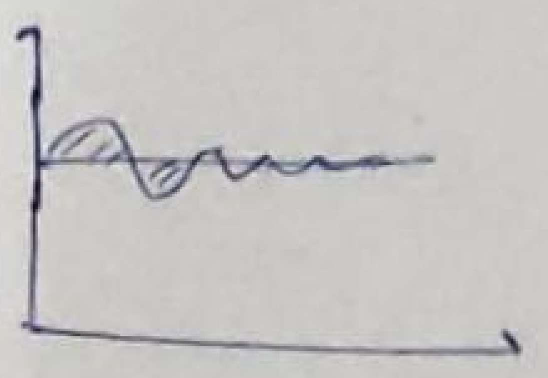
→ ① 1/4 th decay ratio :-

major criteria for performance ratio



② min offset

③ Min area under load response curve



Proportional : $k_c = \frac{1}{k_p}\left(\frac{\tau_p}{t_d}\left(1 + \frac{t_d}{3\tau_p}\right)\right)$

cohen and coon setting

PI :- $k_c = \frac{1}{k_p}\left[\frac{\tau_p}{t_d}\left(0.9 + \frac{t_d}{12\tau_p}\right)\right]$, $\tau_I = t_d \frac{30 + 3\, t_d/\tau_p}{9 + 20\, t_d/\tau_p}$

~~PID~~ :-

Try zigler and cohen, coon setting : and check which is better.

will give similar response.

→ 1st order system may become 2nd if there is some transport delay