Multi-loop control

1 measurement + 1 MV => simple feedback control

>1 + 1 MV => cascade, ratio, override control

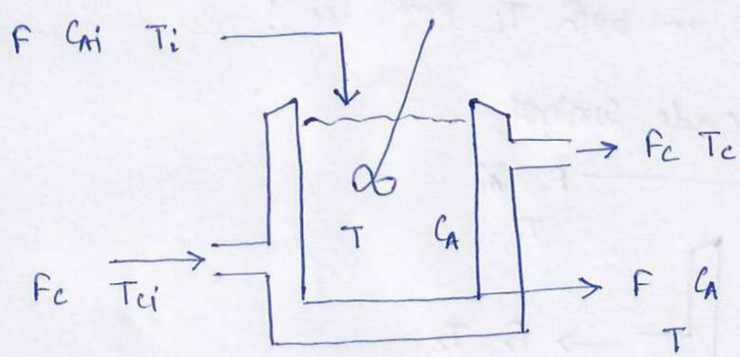
1 + >1 => split range control.

Cascade control

- More than 1 measurement & 1 MV
- Dual-loop controller → Primary/master control loop; → Secondary/slave control loop.

Motivation

o Jacketed CSTR : open loop

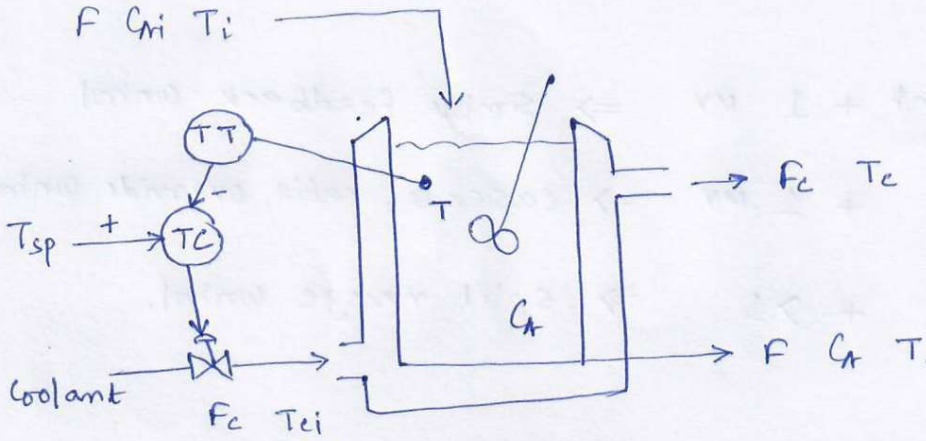


- Exothermic reaction $A \rightarrow B$.
- Exo. heat removed by coolant stream
- $F_i = F_o = F = \text{Const.}$
- Control Obj : $T = T_{sp}$.

CV	MV	LV
T	F_c	T_i, T_{ci}

$C_{Ai} = \text{Const.}$

o Jacketed CSTR : Simple feed back control.

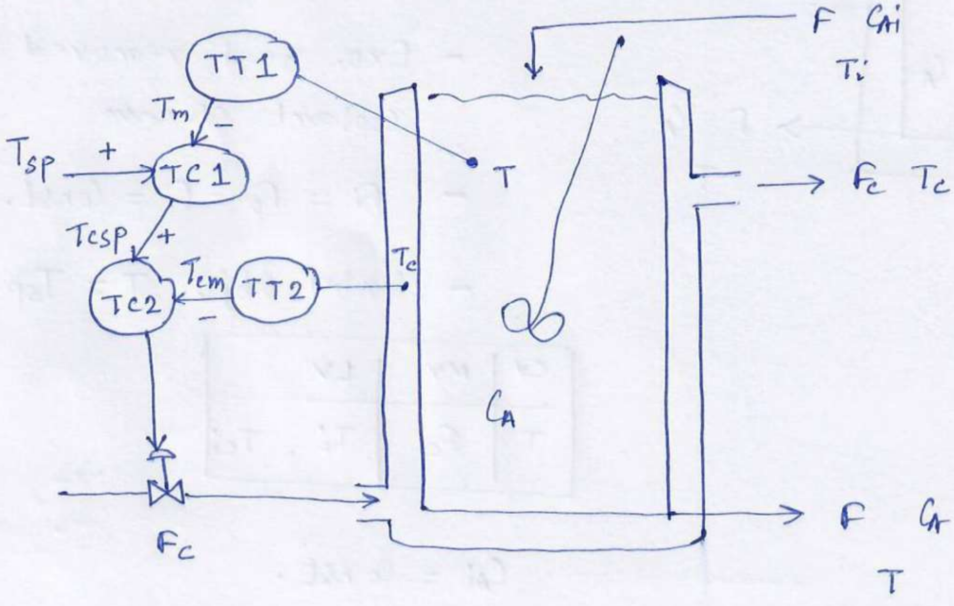


- T responds much faster to changes in T_i than to changes in T_{ci}

- Thus, the simple FBC is "more" effective to reduce the effect of disturbance in T_i and "less" effective to reduce the effect of disturbance in T_{ci}.

can we have controller that is effective (equally) to reduce the effect of disturbance in both T_i and T_{ci} ?

o Jacketed CSTR : cascade control.



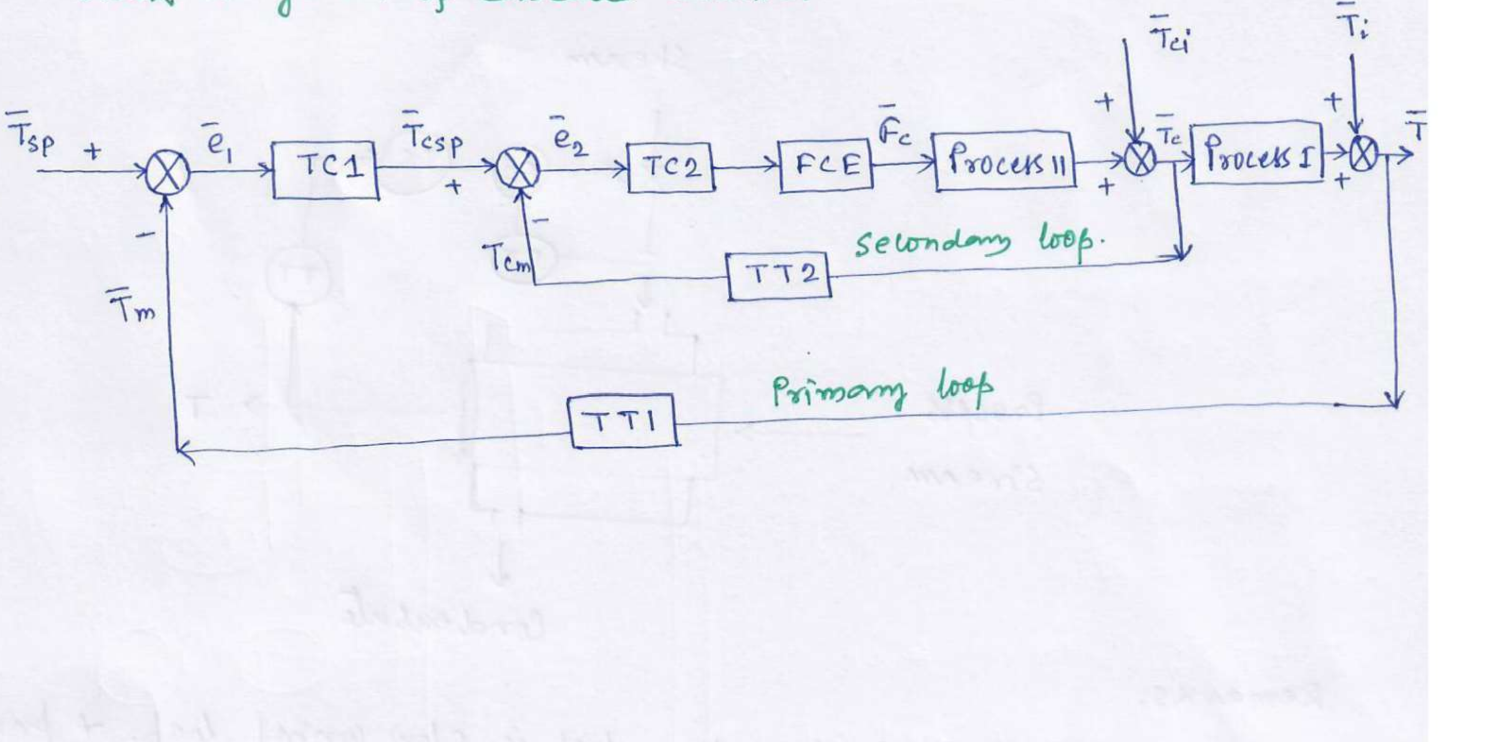
- T is effected by both T_i and T_{ci} @ TC1 takes care
- T_c is effected by T_{ci} @ TC2 takes care

LV

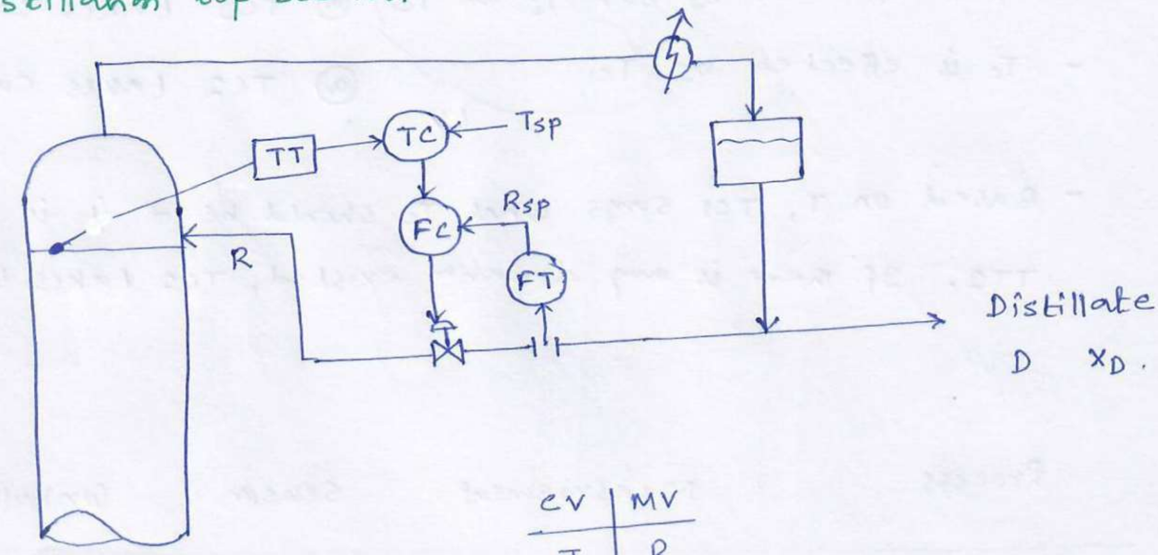
- Based on T, TC1 says what T_c should be & it is verified by TT2. If there is any deviation existed, TC2 takes corrective measures

Process	Measurement	Sensor	Controller	
Process I : reactor (excluding jacket)	T	TT1	TC1	Primary
Process II : Jacket	T_c	TT2	TC2	Secondary

Block diagram of cascade Controller



Ex. Distillation top section

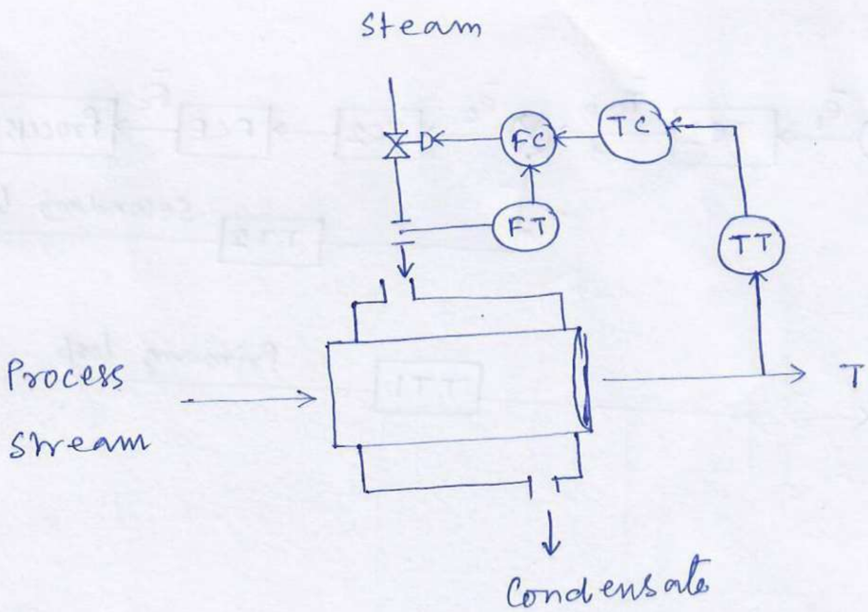


CV	MV
T	R

TC → Primary controller

FC → Secondary controller

Ex. Heat exchanger



Remarks.

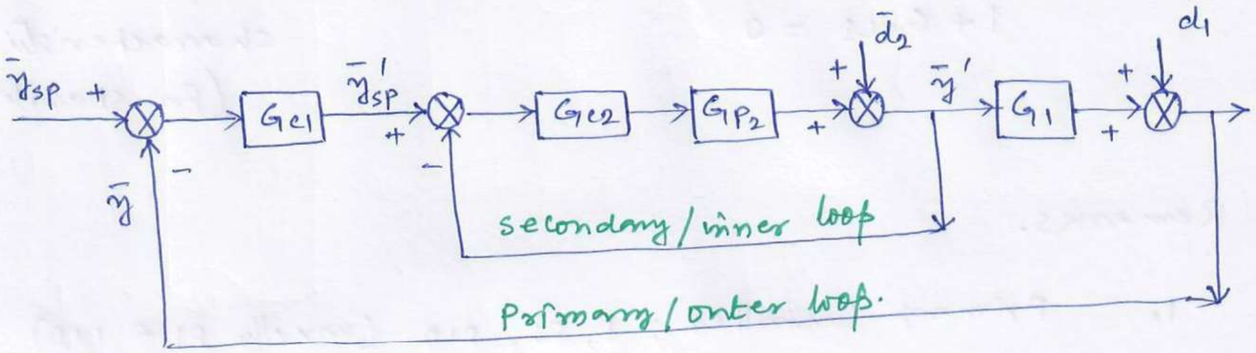
1. In most of the cases, secondary loop is flow control loop. & primary loop is temp or comp control loop.

2. $(\text{Time Constant})_{\text{Primary}} > (\text{Time Constant})_{\text{secondary}}$.

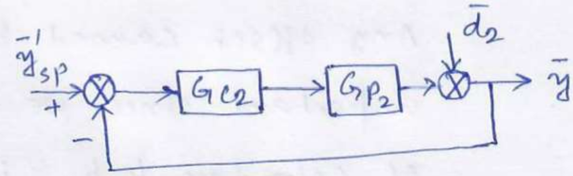
closed-loop behavior of cascade controller.

- Block diagram of a general cascade system with

$$G_{m1} = G_{m2} = G_f = 1$$



- For the secondary loop

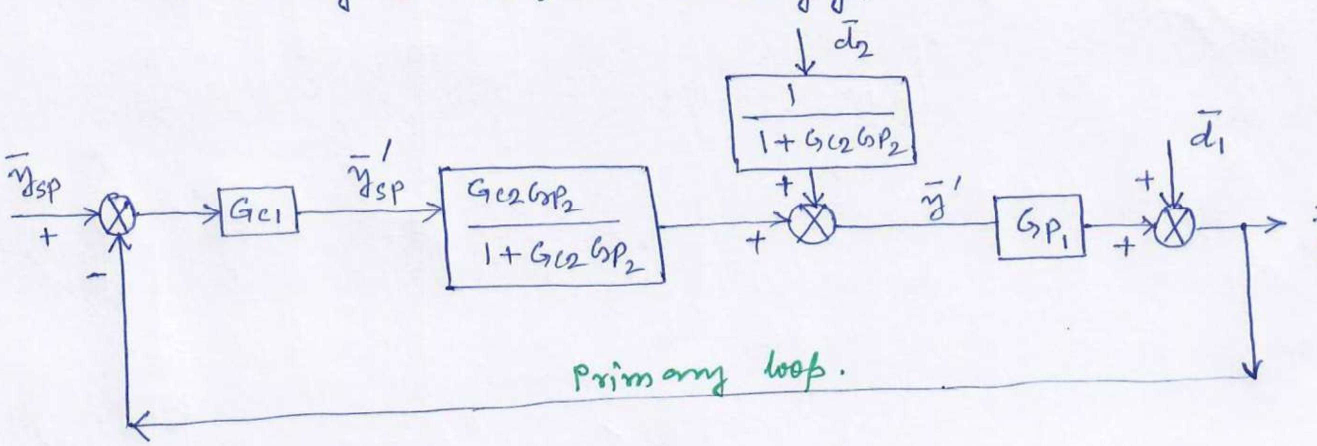


$$G_{secondary} = G_{OL2} = G_{c2} G_{P_2} \quad \text{--- open-loop TF}$$

$$\bar{y}'(s) = \frac{G_{c2} G_{P2}}{1 + G_{c2} G_{P_2}} \bar{y}'_{sp} + \frac{1}{1 + G_{c2} G_{P_2}} \bar{d}_2 \quad \text{--- closed-loop TF.}$$

$$1 + G_{OL2} = 0 \quad \text{---- characteristic eqn (for stability)}$$

- Block dig is modified accordingly.



o For the primary loop, the overall open-loop TF is:

$$G_{primary} = G_{OL1} = G_{c1} G_{p_1} \left(\frac{G_{c2} G_{p2}}{1 + G_{c2} G_{p_2}} \right) \quad \text{--- OLTF}$$

$$1 + G_{OL1} = 0 \quad \text{--- characteristic eqn (for stability)}$$

Remarks.

1. Primary controller: P, PI, PID (usually PI & PID).
   Secondary controller: P, PI (usually P-only).

   Any offset caused by P-only in the secondary loop is not so important since we are not interested in controlling the output of secondary loop (i.e., T_c for jacketed CSTR).

2. Dynamics of secondary loop is much faster than that of primary loop.

Ex. cascade control.

Primary loop: $G_{P1} = \frac{1}{(0.5s+1)(s+1)}$, $G_{m1} = 1$

Secondary loop: $G_{P2} = \frac{1}{1.5s+1}$, $G_{m2} = 1$, $G_f = 1$

Tune the cascade control scheme using PI for primary loop and P-only for secondary loop. Use Z-N method.

Solution. For secondary loop

$$G_{OL2} = G_{c2} G_{p2} = \frac{K_{c2}}{1.5s+1} \equiv \text{1st-order TF}$$

we are free to use any large value of K_{c2} (adopt 5).

✓ For primary loop

$$G_{OL1} = G_{c1} G_{p1} \frac{G_{c2} G_{p2}}{1 + G_{c2} G_{p2}} = \frac{5/6 \ K_{c1}}{(0.5s+1)(s+1)(0.25s+1)}$$

where $G_{c1} = K_{c1}$ (for the use of Z-N method for tuning).

✓ Finding ω_{co}

$$\phi = -180^0$$

$$\tan^{-1}(-0.5\,\omega_{co}) + \tan^{-1}(-\omega_{co}) + \tan^{-1}(-0.25\,\omega_{co}) = -180^0$$

$$\omega_{co} = 3.74 \text{ rad/min}$$

✓ Finding ultimate period (P_u).

$$P_u = \frac{2\pi}{\omega_{co}} = 1.68 \text{ min/cycle}$$

✓ Finding ultimate gain (K_u)

$$AR = 1$$

$$\frac{5/6 \, K_u}{\sqrt{(0.5\omega_{co})^2+1}\,\sqrt{(\omega_{co})^2+1}\,\sqrt{(0.25\omega_{co})^2+1}} = 1$$

$$K_u = 13.48$$

✓ Tuning control parameters (Z-N method)

Secondary controller (P) : $K_{c2} = 5$

Primary controller (PI) : $K_{c1} = \frac{K_u}{2.2} = 6.13$ $\qquad \tau_{i1} = \frac{P_u}{1.2} = 1.4$

Remark.

It is not recommended to select a very large K_{c2}, rather select it in coordination with the resulting values of K_{c1}.

Override or Constraint Control

- During normal operation of plant or during startup or shutdown
  - Some abnormal situations may arise.
  - that lead to destruction of equipment and/or operating personnel.

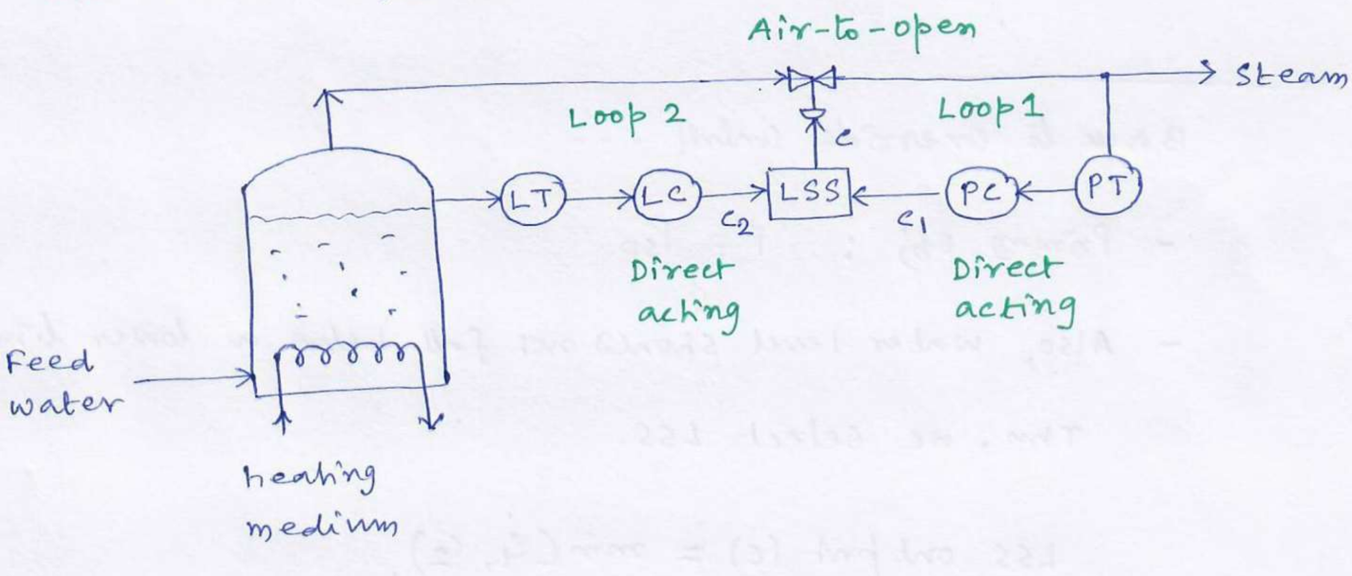
- In such situations, priority is given to avoid the abnormal situation, rather than better control. A special type of switch is used:

  HSS - High selector switch
  - prevents to exceed the upper limit (constraint)

  LSS - Low selector switch
  - prevents to exceed the lower limit (constraint)

  Thus called Constraint Control

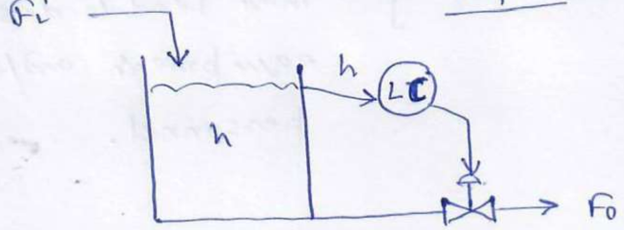
Ex. A boiler system



Direct acting control : If the input signal to the controller increases, the output signal must increase in case of direct acting control.

CV	MV
h	Fo

If h ↑ : the controller should increase Fo.



So LC ≡ direct acting

$$F_o = F_{os} + K_c (h_{sp} - h)$$

If h ↑ , $(h_{sp} - h) \to -ve$

Fo can increase only if K_c is −ve.

✓ So for direct acting controller, K_c is −ve.

✓ Reverse acting controller we can have for

CV	MV
h	Fi

If h ↑ , controller needs to decrease Fi.

And it has +ve K_c.

Back to Override control ...

- Primary obj : $P = P_{sp}$.
- Also, water level should not fall below a lower limit

Thus, we select LSS.

LSS output $(c) = \min(c_1, c_2)$.

Consider the following case.

- Initially, pre. control loop is in action

  LSS output $c = c_1$ (i.e., $c_1 < c_2$).

- Suddenly water level falls belower lower limit

  ✓ LC reduces its output to 0 ($= c_2$). As a result

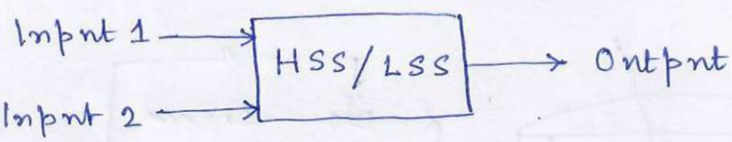
  - Pre. inside the boiler rises
  - boiling rate ↓
  - liq. level improves.

  ✓ Since $c_2 (= 0) < c_1$

  LSS output $c = c_2$. (initially there was $c = c_1$)

  ✓ LC "overrides" the PC ⓐ thus the name "override control".

Remarks.



HSS

If Input 1 > Input 2 Then

  HSS output = Input 1

Else

  HSS output = Input 2

End if

LSS

If Input 1 < Input 2 Then

LSS output = Input 1

Else

LSS output = Input 2

End if

split - range control

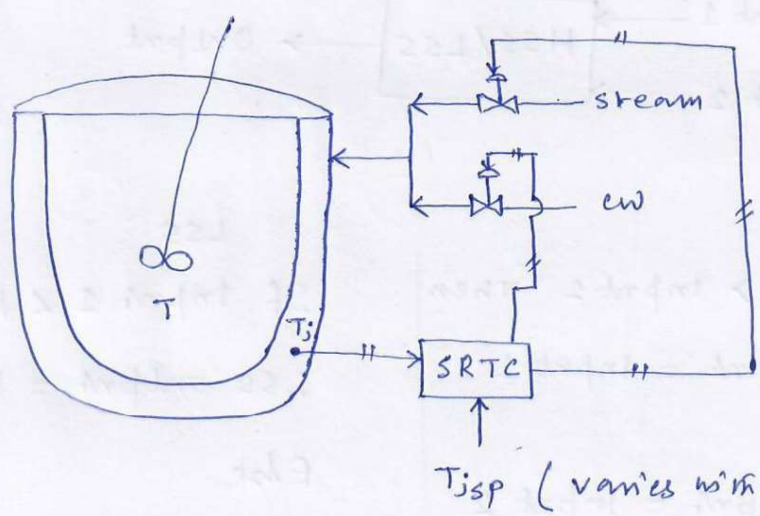
- 1 meast + more than 1 MV
- provides added safety and operational optimality
- Not so common in chem. Engg.

Ex. A nonisothermal batch reactor

- specified Temp program 15°C at the beginning
  100°C at the end
  (atm. temp = 25°C say)

- cooling medium : cooling water (5°C)
  Heating medium : steam (115°C).

Both cw and steam are required in order to span the temp range of interest.



SRTC → split-range temp control

cw → cooling water