1.6 PRACTICAL CONSIDERATIONS

In commercial PID controllers, many modifications are made from the standard form. Some of them are

- remove derivative kick, sometimes together with proportional kick
- suppress noise sensitivity of the D-mode
- anti-reset windup
- bumpless transfer during Auto-Manual switching
- bumpless parameter change
- nonlinear compensation
- etc.

Removing Kicks

- During *regulation*, SP is kept constant in most time and changed rarely. When SP is changed, a surge signal is produced by the derivative mode which acts as a "shock" on the process. We call this phenomenon *derivative kick*.

  To remove this harmful effect, derivative is not taken on SP in most commercial PID controllers.

$$\frac{de(t)}{dt} = \frac{d}{dt}(r(t) - y(t)) \quad \rightarrow \quad -\frac{dy(t)}{dt}$$

  PID controllers with the above modification is denoted as PI-D controllers.

- A similar phenomenon can be said for P-mode. In order to mitigate *proportional kick*, some commercial controllers modifies the P-mode as follows:

$$u^P(t) = K_c[\alpha r(t) - y(t)] \quad \text{where} \;\; 0 \leq \alpha \leq 1$$

Controllers with P and D modifications are denoted as I-PD controllers.

Filtered D-mode

- For suppression of high frequency noise sensitivity, the D-mode is further modified to to take derivative on a (low-pass) filtered output signal

$$-\frac{dy(t)}{dt} \quad \rightarrow \quad -\frac{dy^F(t)}{dt} \;\; \text{where} \;\; a\frac{dy^F(t)}{dt} + y^F(t) = y(t) \;\; a \approx 3\tau_D \sim 10\tau_D$$

With such modification, the high frequency gain of the D-mode is bounded not to exceed some limit.

Bumpless A/M Transfer

$$u(t) = \underbrace{u_{bias} + \frac{K_c}{T_I}\int_0^t e(\tau)d\tau}_{u_{bias}(t)} + K_c\left[e(t) - T_D\frac{dy^F(t)}{dt}\right]$$

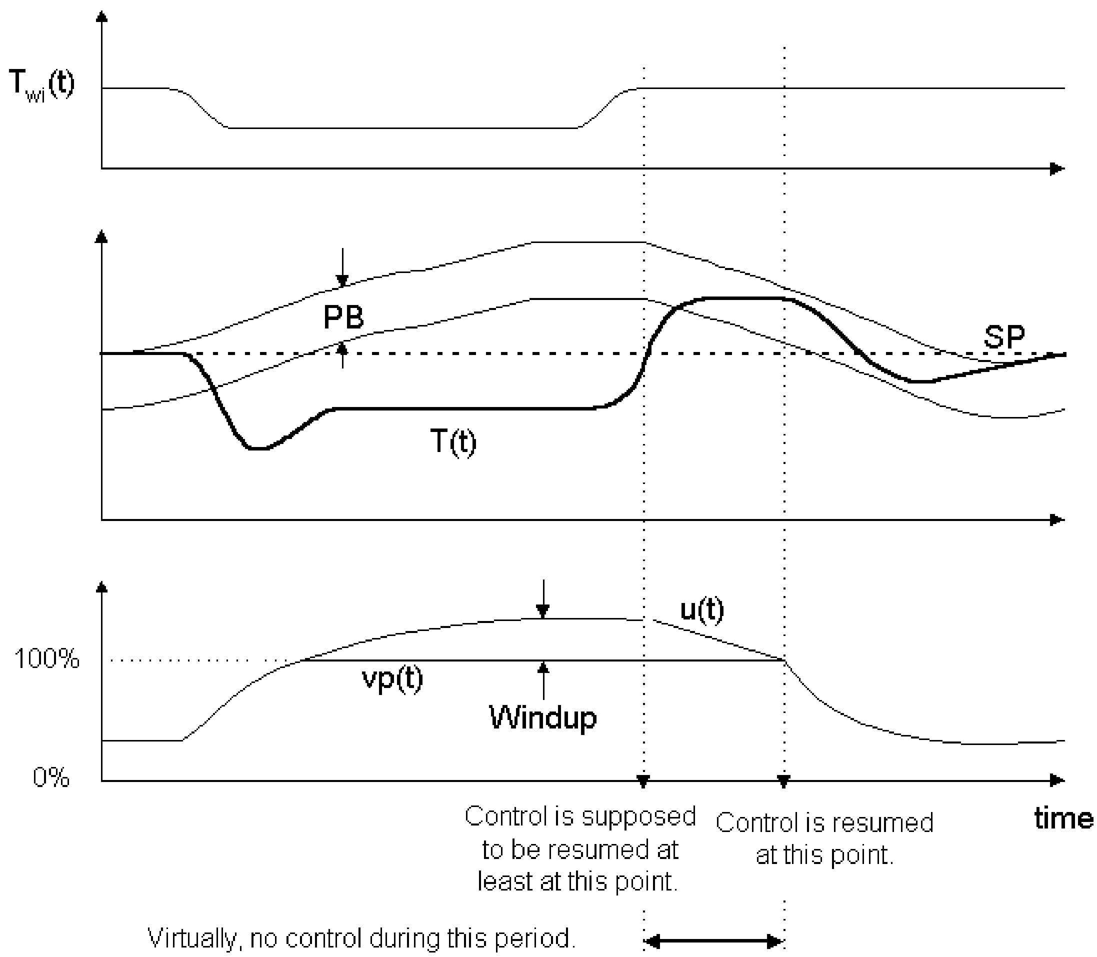
$u_{bias}(t) \quad \Rightarrow \quad u_{bias}$ at Auto to Manual switching

Bumpless Parameter Change

Even when $e(t) = 0$, adjusting K_c and/or T_I modifies the I-mode value, which in turn changes $u_{bias}(t)$.

To avoid this trouble, a special algorithm needs to be introduced in the I-mode calculation.

Anti-Windup

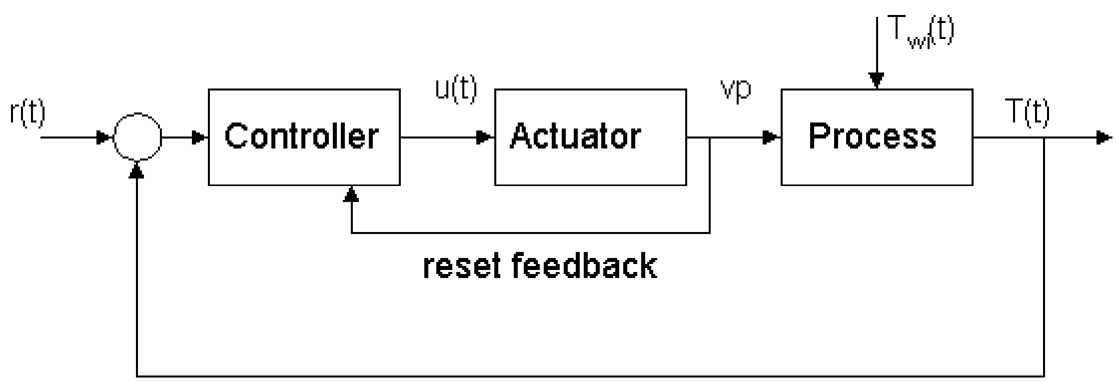


- Suppose that the actuator has saturated at 100% (0 %). Without knowing the actuator saturation, the I-mode continues error integration.
  $\rightarrow$ Integral WINDUP !!

- Once windup occurs, the actuator does not return to its normal range until the windup is removed by opposite-signed control error over a certain period.
  Control is lost for this period.

  To prevent the I-mode from being wound up, the controller needs to monitor $vp(t)$. If $vp(t)$ is observed to be stuck at a saturation limit, the controller stops integration until opposite-signed control error enters.

  This function is called **Anti-Windup**.



The anti-windup is a very important concept not only in feedback control with actuator saturation but also in various multi-loop control techniques.

A Simple but practical windup algorithm is

$$u(t) = u_{bias} + \frac{1}{T_t}\int_0^t (vp(\tau) - u(\tau))d\tau + K_c\left[e(t) + \frac{1}{T_I}\int_0^t e(\tau)d\tau + T_D\frac{de(t)}{dt}\right]$$

The equivalent discrete form is

$$\Delta u_k = \frac{h}{T_t}(vp_k - u_{k-1}) + K_c\left([e_k - e_{k-1}] + \frac{h}{T_I}e_k + \frac{T_D}{h}[e_k - 2e_{k-1} + e_{k-2}]\right)$$

where T_t is called *tracking time constant.*

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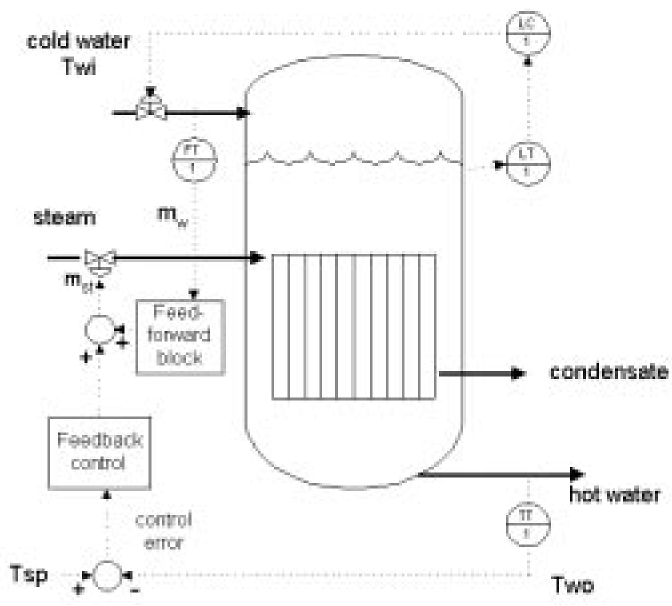
Chapter 2

MULTI-LOOP CONTROL AND FURTHER PRACTICAL ISSUES

2.1 FEEDFORWARD-FEEDBACK CONTROL

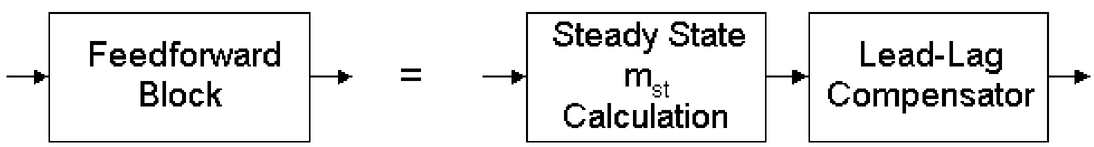
Revisit of the Heating Tank Process

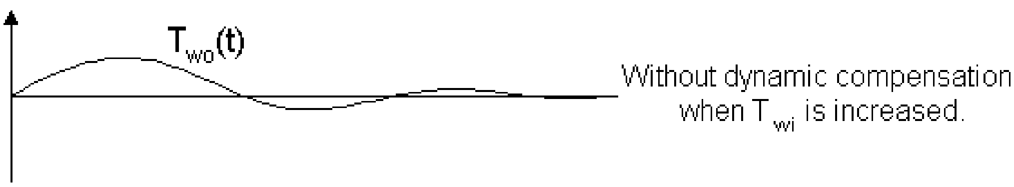


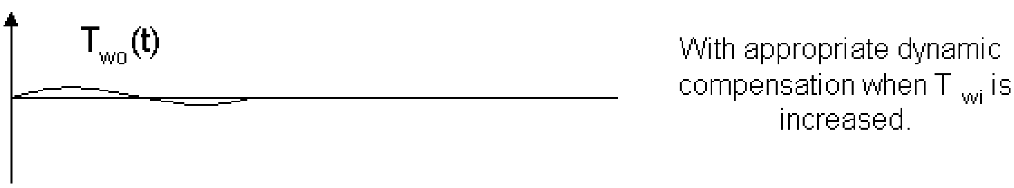
- In section 1.1, we considered feedforward control based on steady-state compensation.

$$\lambda_{st} m_{st} = m_w C p_w (T_{wo} - T_{wi}) \;\rightarrow\; m_{st} = \frac{m_w C p_w (T_{sp} - T_{wi})}{\lambda_{st}}$$

- When the time lag between T_{wi} and T_{wo} is significantly different from that of m_{st} and T_{wo}, it is necessary to introduce a dynamic compensation in addition.
  The **lead-lag** compensator is used in industrial controllers for this purpose.



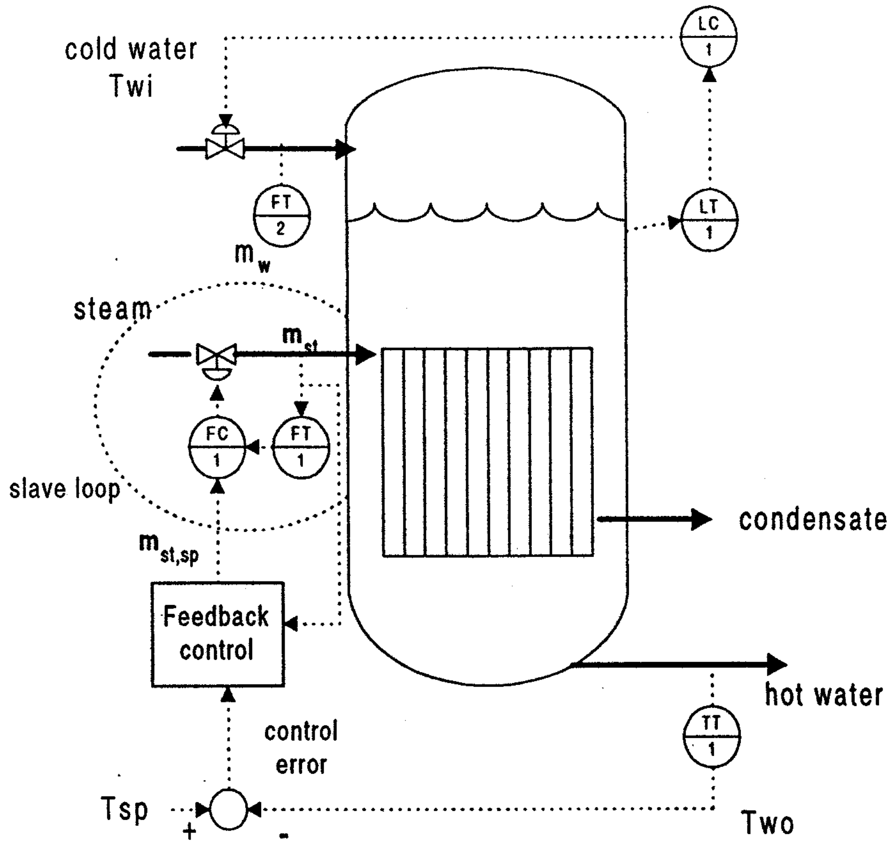


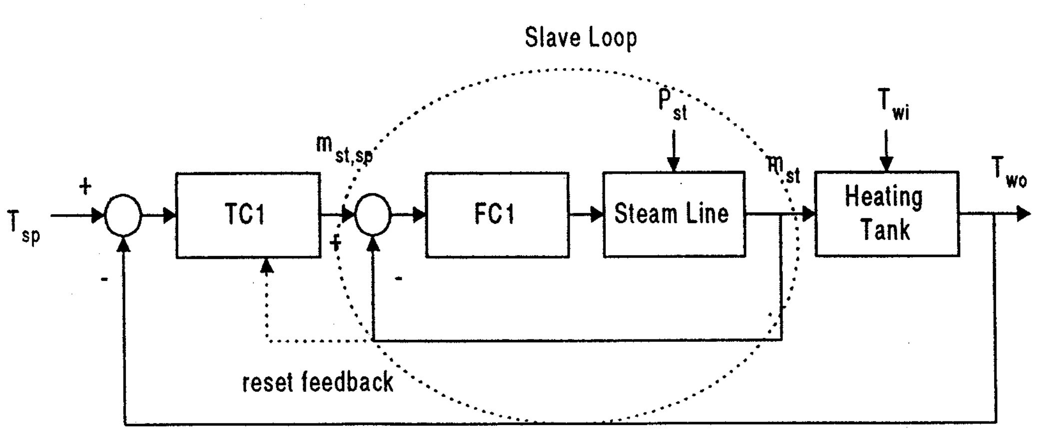


- When appropriately designed, feedforward control can considerably improve the overall control performace. In this case, feedback control plays only a trimming role.

- Feedforward control can be designed for *measurable disturbances* only.

2.2 CASCADE CONTROL





Why cascade control ?

- Reject disturbance in the slave process (P_{st} - steam pressure) before it affects the main process variable (T_{wo}).
- Linearize the slave process.
- Improve the dynamics of the slave process.

Tips for Implementation

- Satisfactory performance can be expected when the slave process is at least three times as fast as the master process in terms of time constant.

  When the master process has a time constant similar to or shorter than that of the slave process, there is little incentive for cascade control.

  Flow rate is frequently subject to disturbance in supply pressure and varies nonlinearly with valve position. But the process itself is very fast.
  $\Rightarrow$ an ideal target for cascade control.

- Since the output from the slave process is not the major process variable to control, it is not necessary to use I-mode in the slave controller. By this reason, P-control is usually employed for the slave controller.
- Reset feedback is required for output tracking as well as anti-reset windup.

- Improve the dynamics of the slave process.

Tips for Implementation

- Satisfactory performance can be expected when the slave process is at least three times as fast as the master process in terms of time constant.

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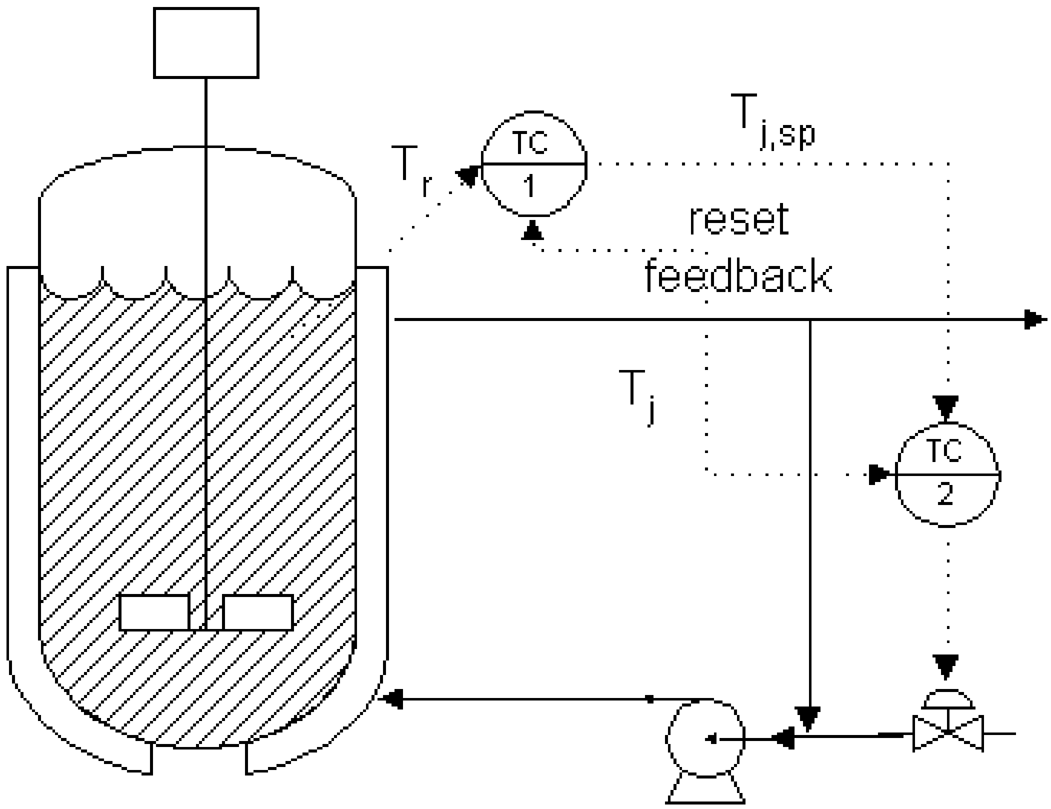
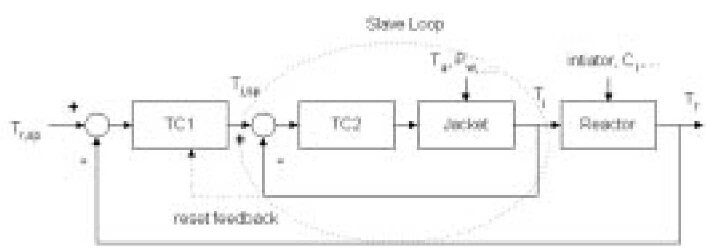
More Examples

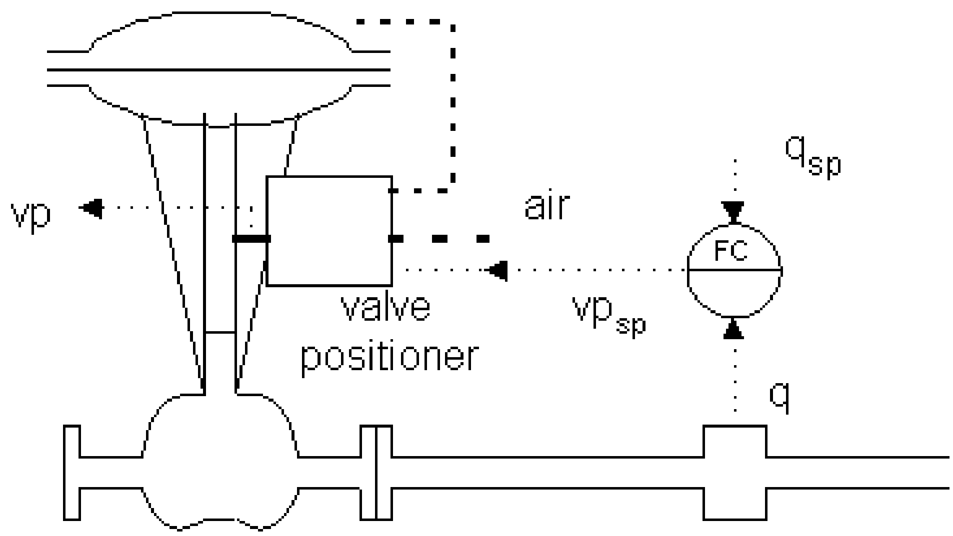
Batch Reactor

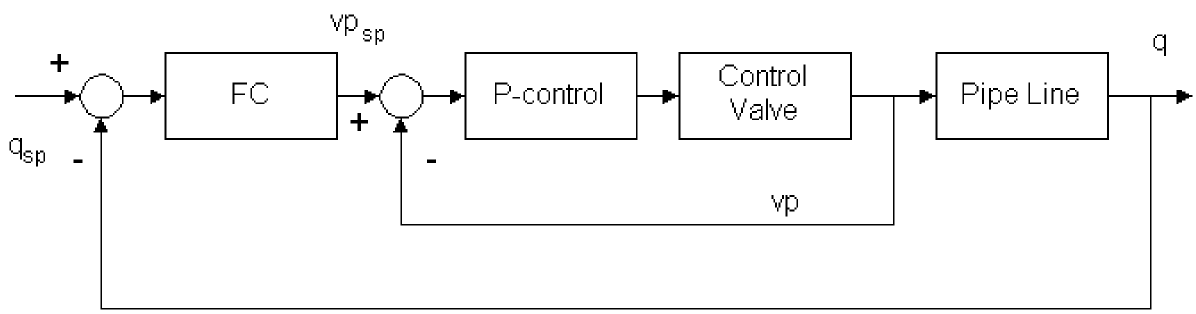




Since the jacket has a much smaller volume than the reactor, the batch reactor is considered a good target for cascade control from the viewpoint of dynamics distribution.

Flow Rate Control with a Control Valve with Positioner

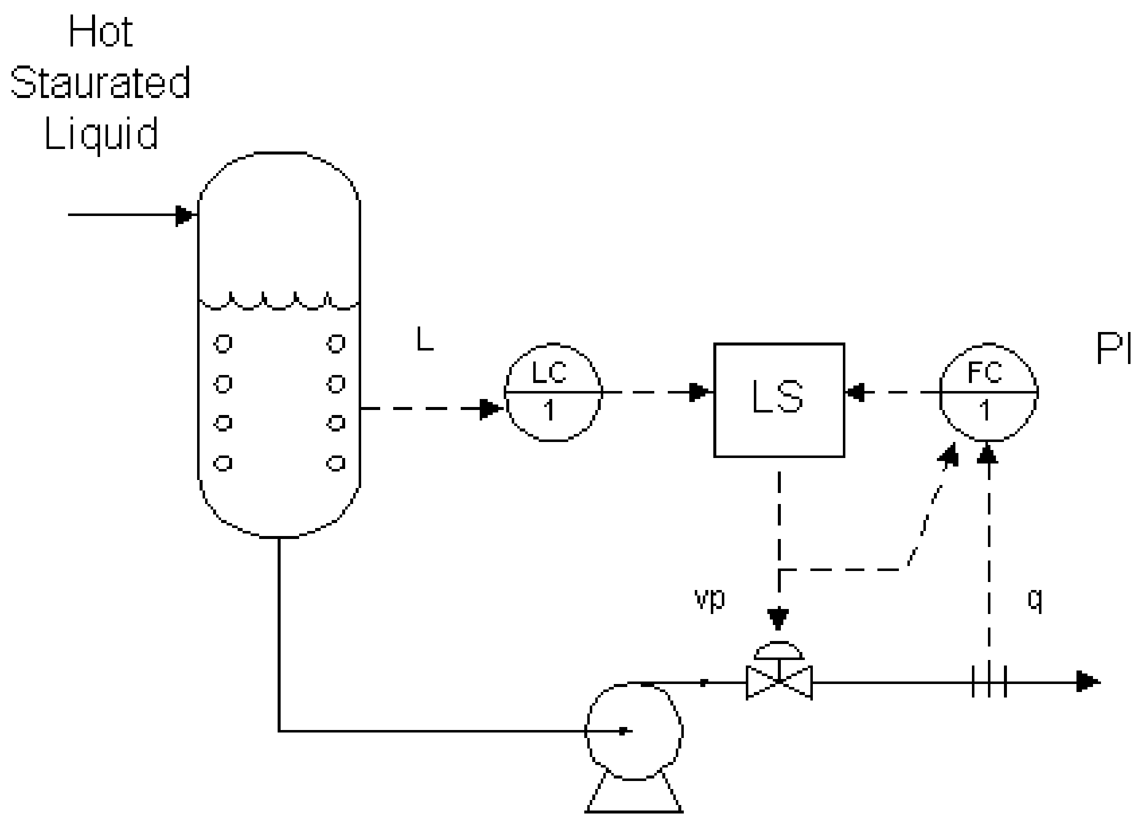




The control valve usually has a longer time constant than the pipeline itself. Therefore, FC cannot be tightly tuned.

By this reason, the positioner-control valve is not recommended for flow rate control where the process dynamics is fast compared with the valve dynamics.

2.3 OVERRIDE CONTROL



- It is assumed that only FC has an I-mode.
- Under normal condition, q is required to be kept constant.
- When L is lowered below a certain level, LC overrides the control loop and starts level control.
- When L is returned to the normal range, FC takes over the control.
- To prevent the integral in FC from being wound up when LC overrides the actuator, reset feedback is needed.

Chapter 3

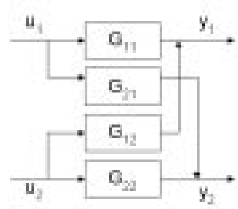
CONTROL OF MULTI-INPUT MULTI-OUTPUT(MIMO) PROCESSES

3.1 MIMO PROCESS ?

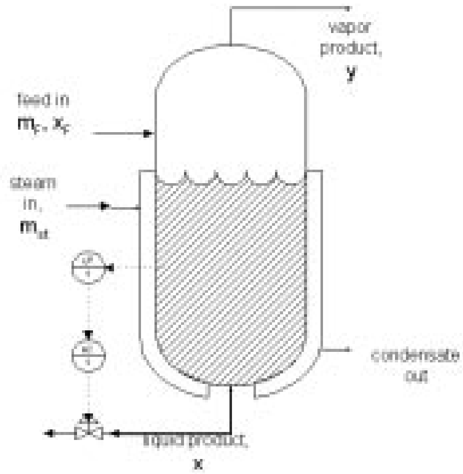
Many chemical processes have MIMO characteristics.

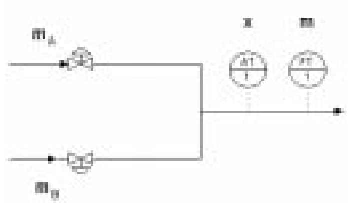
Each manipulated variable influences two or more process variables simultaneously.

This trait gives rise to difficulties in controller design, which has not been observed in SISO control.



The followings are some of the MIMO process examples:





Crude unit

Distialltion columns

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