EE185524

Dead-time compensation

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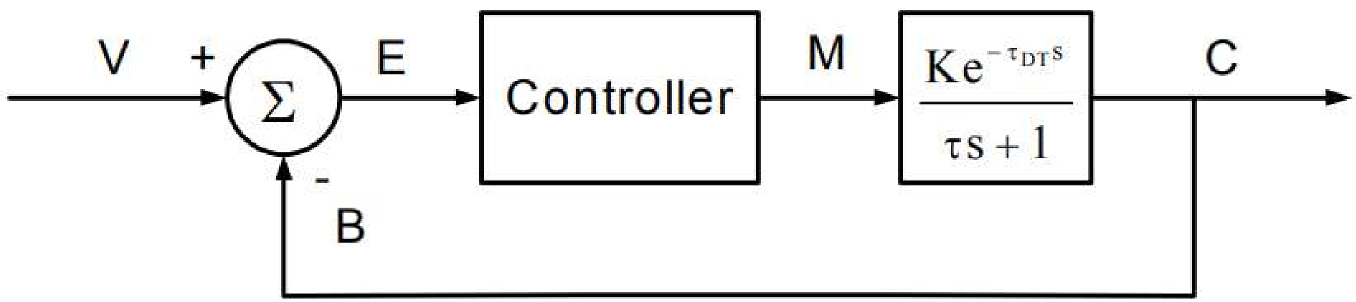
TSP DTE FTEIC ITS

Control of a 1st-order process with dead time



The most commonly used model to describe the dynamics of chemical processes is the First-Order Plus Time Delay Model. By proper choice of τ_{DT} and τ, this model can be made to represent the dynamics of many industrial processes.

Dead-time

- Time delays or dead-times (DT's) between inputs and outputs are very common in industrial processes, engineering systems, economical, and biological systems.
- Transportation and measurement lags, analysis times, computation and communication lags all introduce DT's into control loops.
- DT's are also used to compensate for model reduction where high-order systems are represented by low-order models with delays.
- Two major consequences:
  - Complicates the analysis and design of feedback control systems
  - Makes satisfactory control more difficult to achieve

Effects of dead-time (time delay)

➢ Process with large dead time (relative to the time constant of the process) are difficult to control by pure feedback alone:

➢ Effect of disturbances is not seen by controller for a while

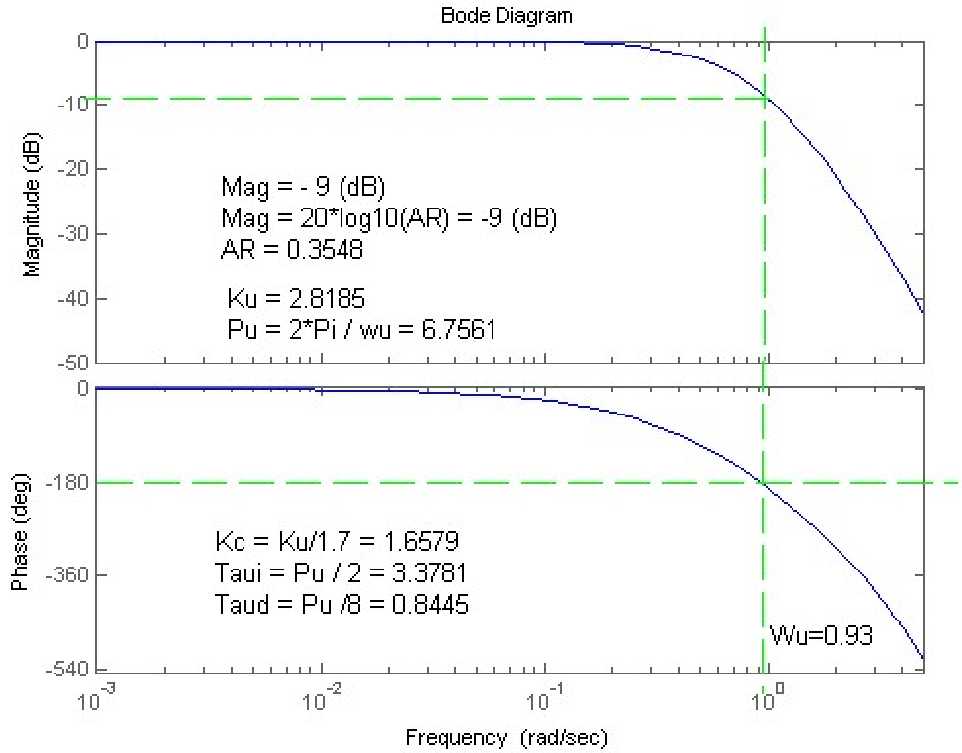
➢ Effect of control action is not seen at the output for a while. This causes controller to take additional compensation unnecessary

➢ This results in a loop that has inherently built in limitations to control

$$q_o(t) = q_i(t - \tau_{DT})u(t - \tau_{DT})$$

Example – A Bode Plot Example

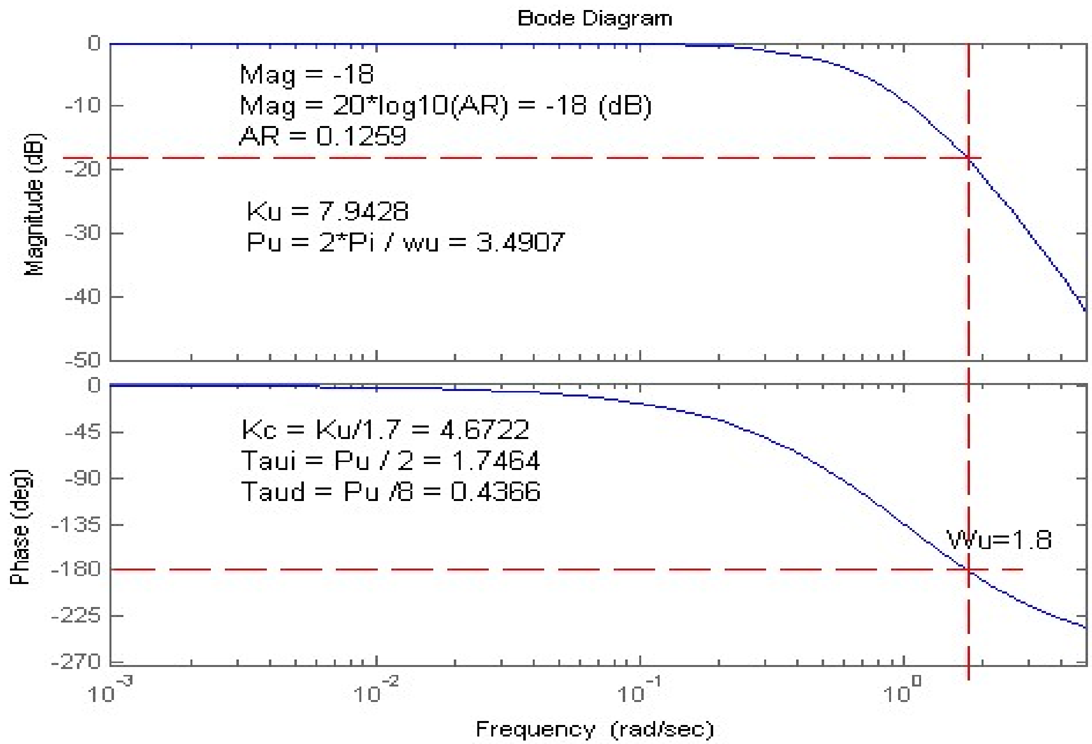
$$G(s) = \frac{e^{-s}}{(s+1)^3}$$



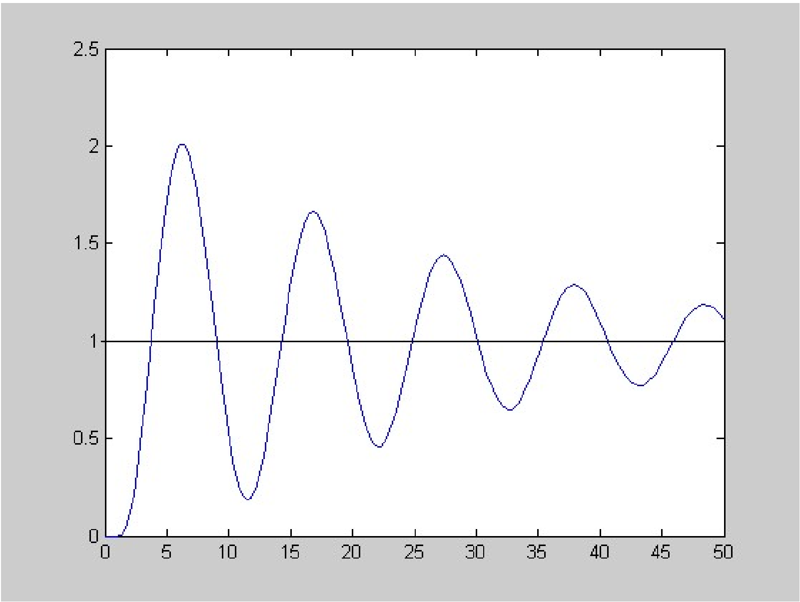

```
h=tf(1,[1 3 3 1],'inputdelay',1);
```

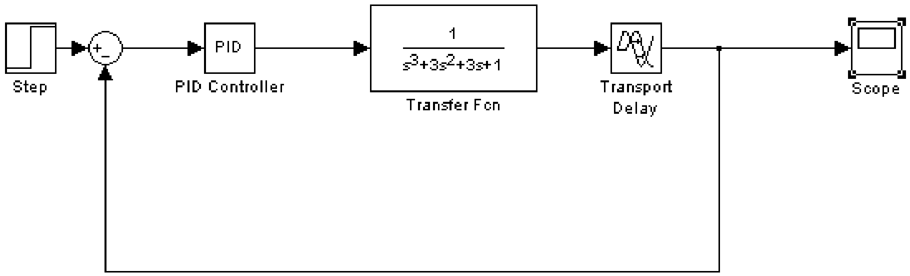
Example - continued, case without time delay

$$G(s) = \frac{1}{(s+1)^3}$$



PID Control Results - Case with delay (K_p =1, $K_i = 1, K_d = 1$)





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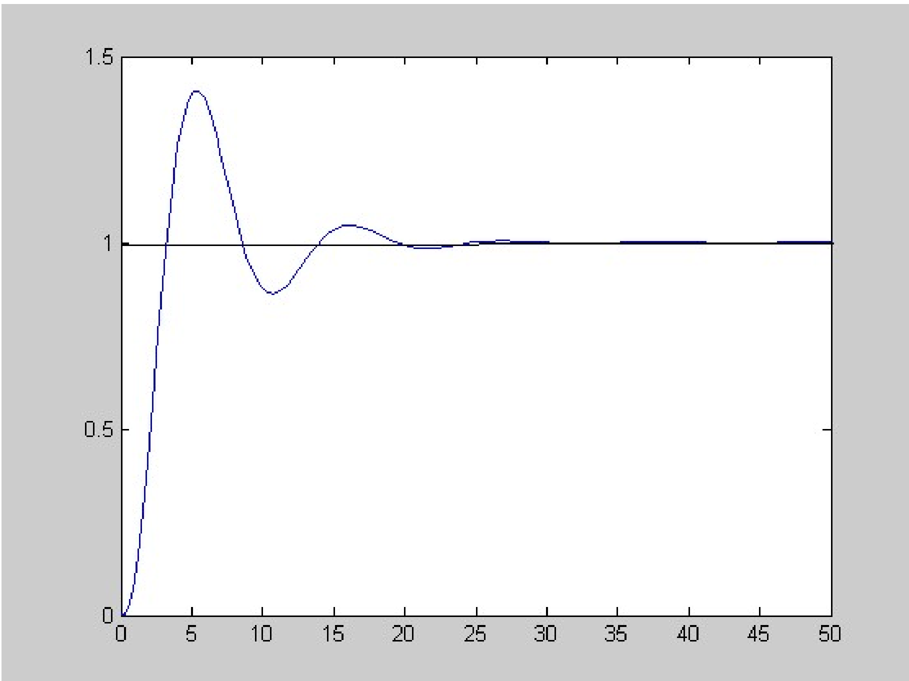
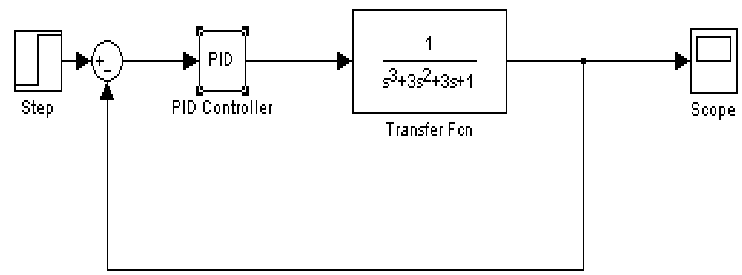




Causes of Dead-Time

- Transportation lag (long pipelines)
- Sampling downstream of the process
- Slow measuring device
- Large number of first-order time constants in series (e.g. distillation column)
- Sampling delays introduced by computer control

Dead-Time approximations

- The simplest dead-time approximation can be obtained graphically or by taking the first two terms of the Taylor series expansion of the Laplace transfer function of a dead-time element, τ_{DT}.

$$f(a)+\frac{f'(a)}{1!}(x-a)+\frac{f''(a)}{2!}(x-a)^2+\frac{f'''(a)}{3!}(x-a)^3+\cdots,$$

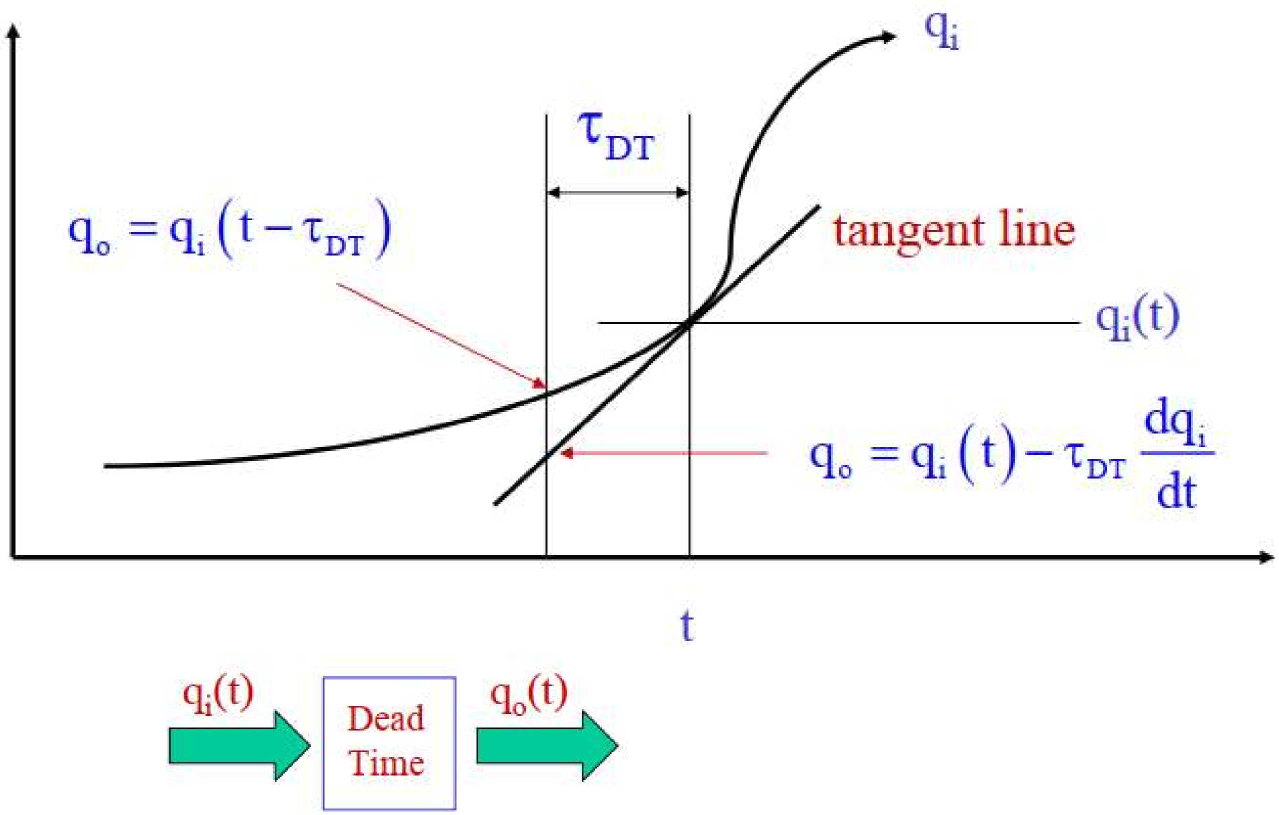
- The accuracy of this approximation depends on the dead time being sufficiently small relative to the rate of change of the slope of $q_i(t)$.

$$\frac{Q_o}{Q_i}(s)=e^{-\tau_{DT}s}\approx 1-\tau_{DT}s \qquad q_o(t)\approx q_i(t)-\tau_{DT}\frac{dq_i}{dt}$$

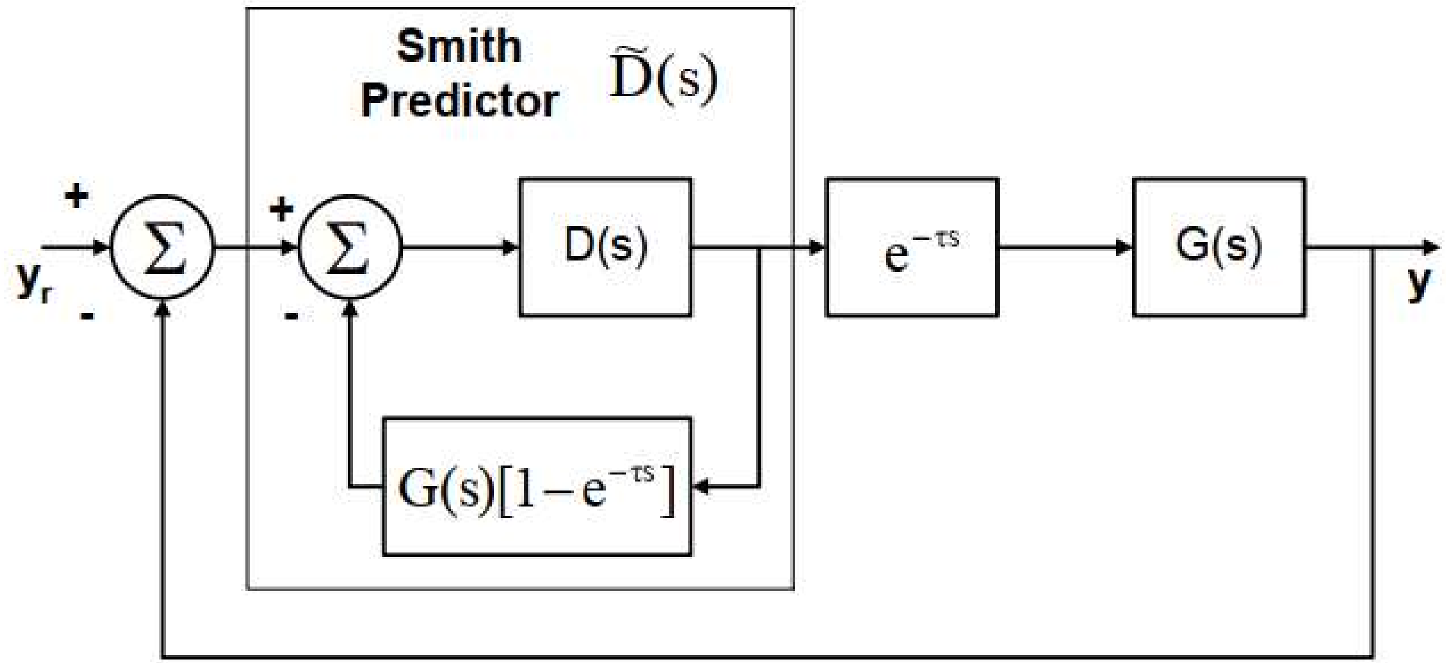
Dead-Time approximations

- If $q_i(t)$ were a ramp (constant slope), the approximation would be perfect for any value of τ_{DT}.
- When the slope of $q_i(t)$ varies rapidly, only small $\tau_{DT}{}'$ will give a good approximation.
- A frequency-response viewpoint gives a more general accuracy criterion; if the amplitude ratio and the phase of the approximation are sufficiently close to the exact frequency response curves of for the range of frequencies present in $q_i(t)$, then the approximation is valid.

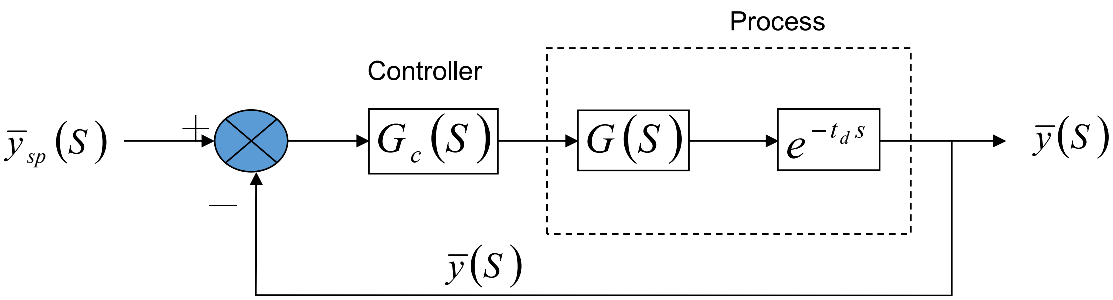
Dead-Time approximations



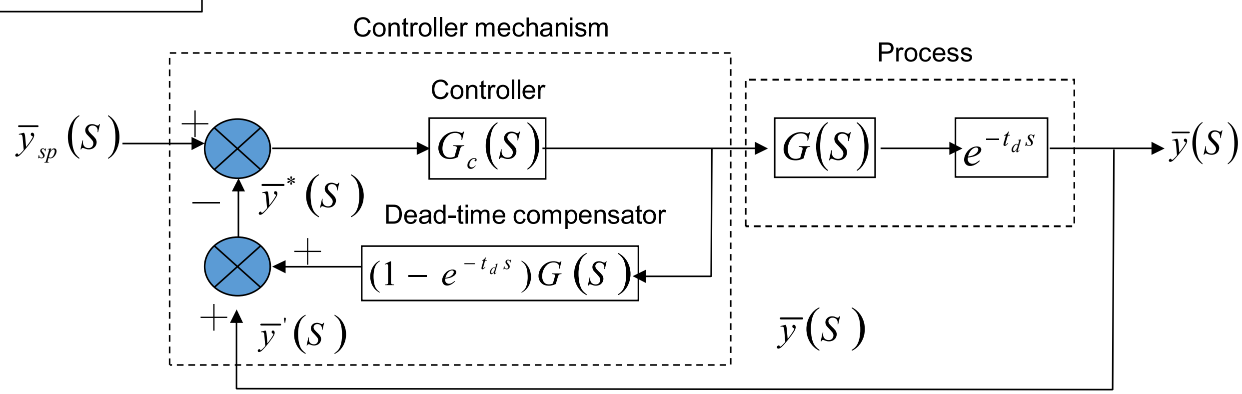
Smith predictor

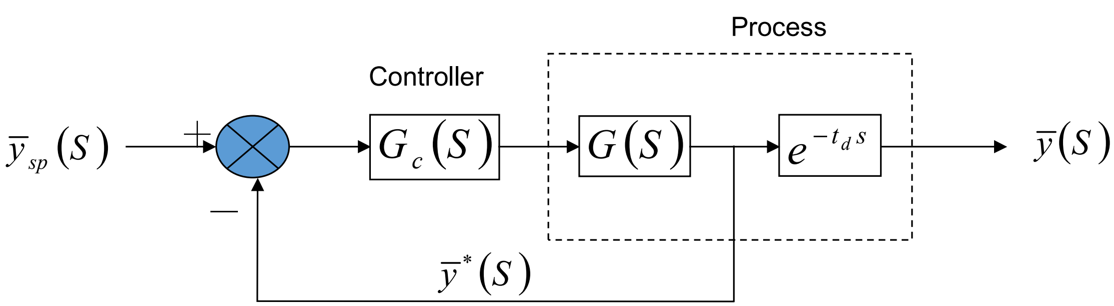


Smith predictor



In this model, $G_C\ (s)\ =\ D(s)$

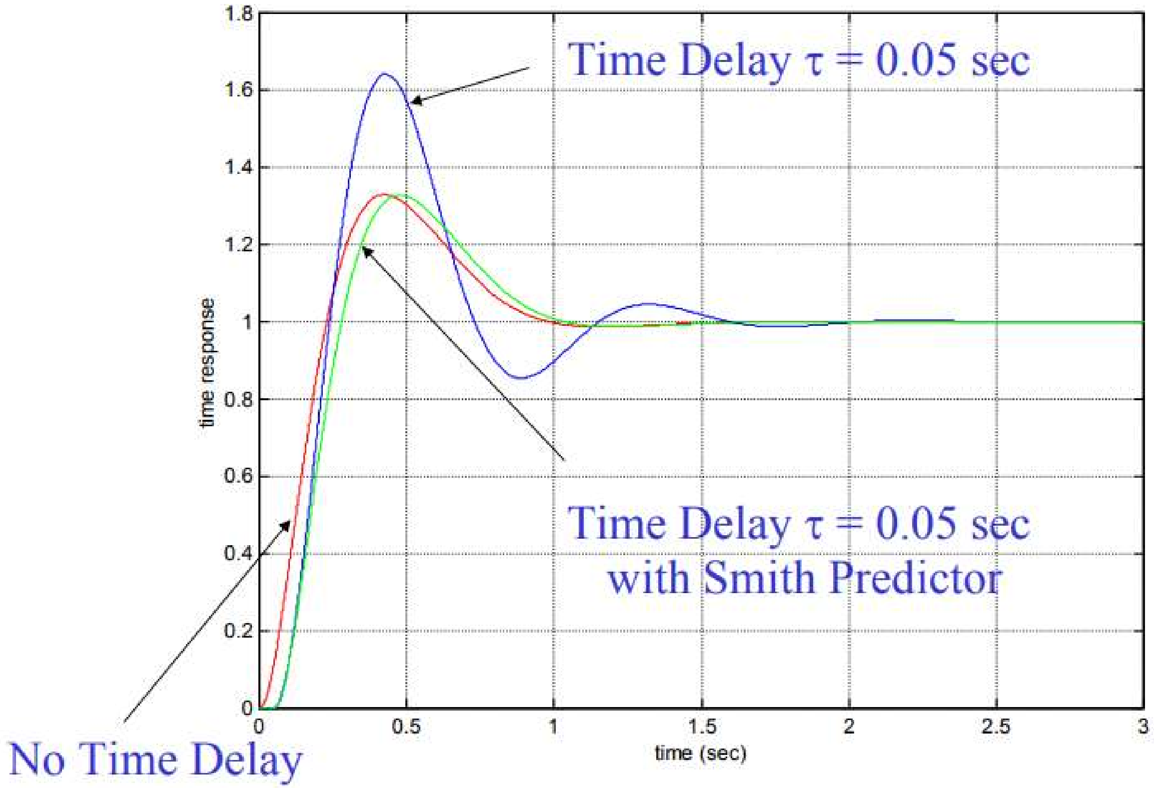




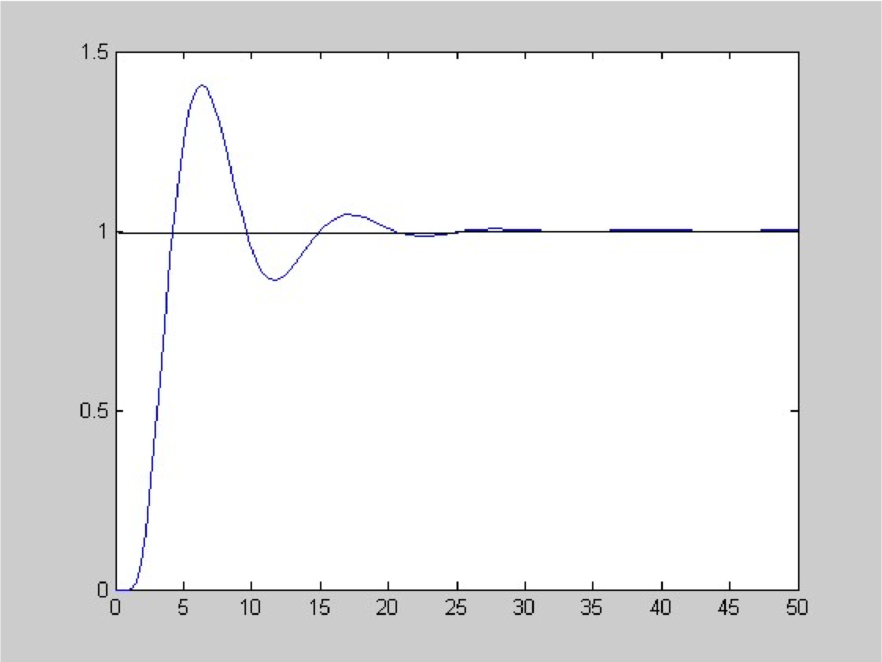
Smith predictor

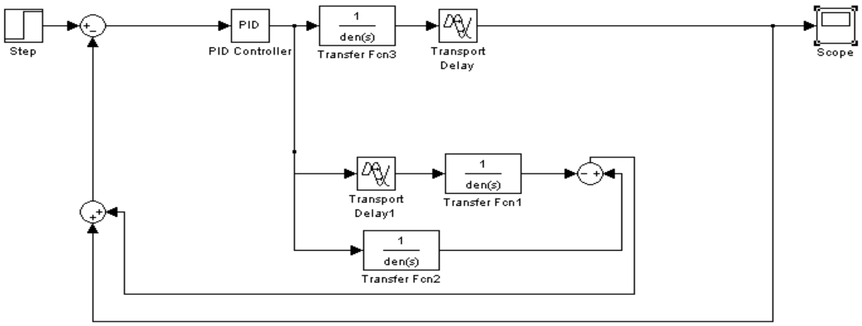
- $D(s)$ is a suitable compensator for a plant whose TF, in the absence of time delay, is $G(s)$.
- With the compensator that uses the Smith Predictor, the closed-loop transfer function, except for the factor $e^{-\tau s}$, is the same as TF of the closed-loop system for the plant without the time delay and with the compensator $D(s)$.
- The time response of the closed-loop system with a compensator that uses a Smith Predictor will thus have the same shape as the response of the closed-loop system without the time delay compensated by $D(s)$; the only difference is that the output will be delayed by τ seconds.

Step response example

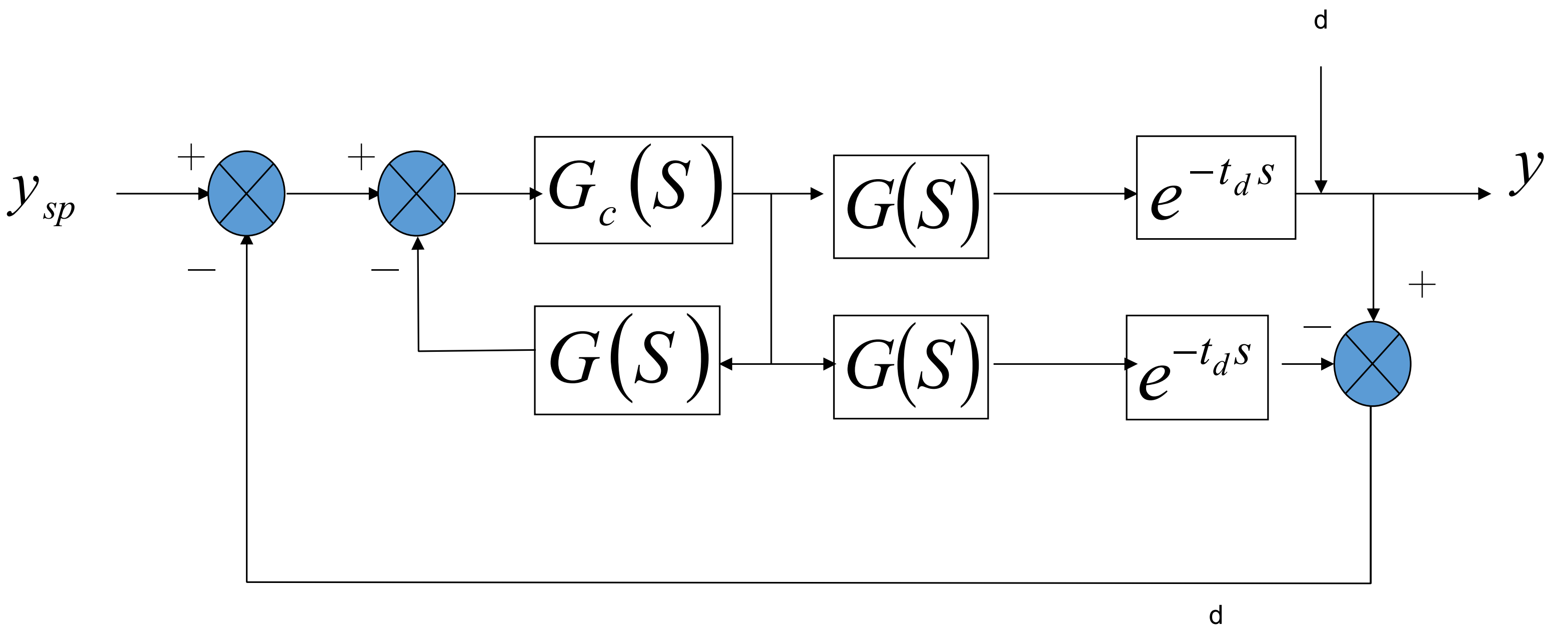


Control with Smith Predictor: (K_p =1, K_i = 1, K_d = 1)

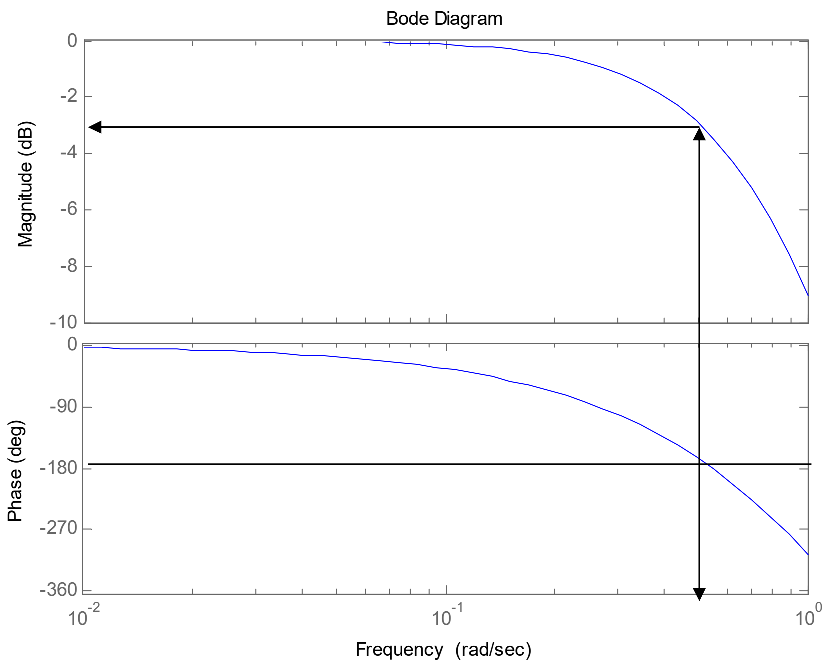




Alternate form



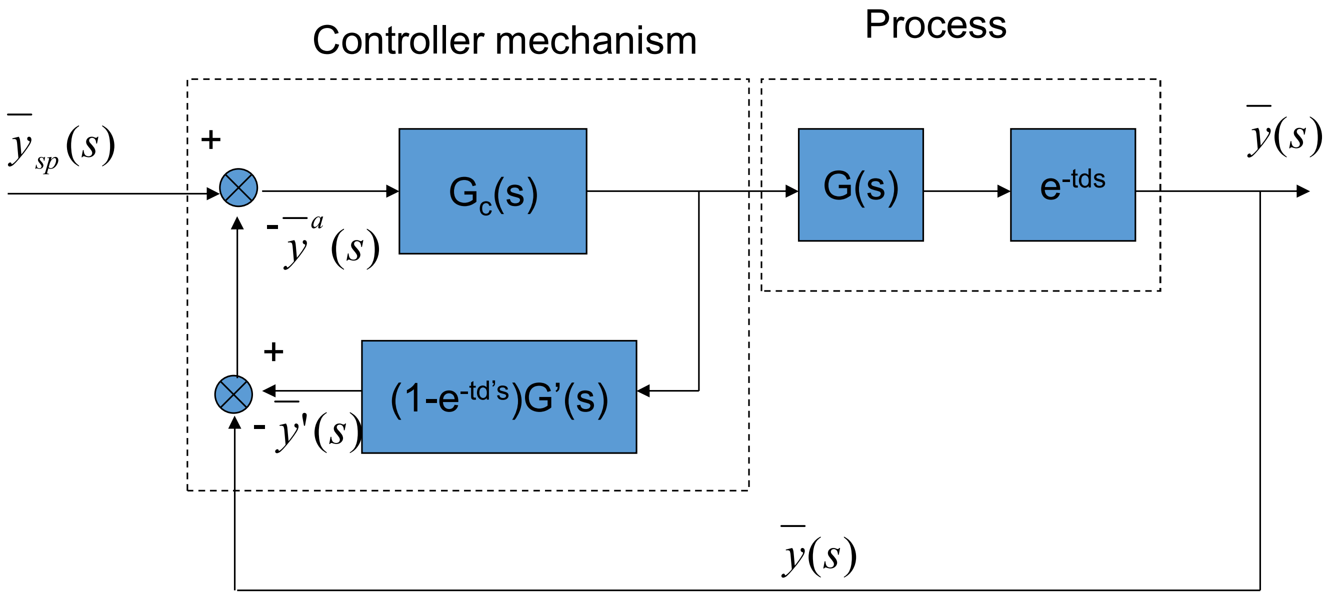
Example: Long time delay



$$G(s) = \frac{e^{-3s}}{\left(s^3 + 3s^2 + 3s + 1\right)}$$

Mag=-3.3dB=$20\log_{10}$(AR);
AR=0.6839;
Wu=0.5;Pu=2π/0.5=12.5664
Ku=1/0.6839=1.4622
Kc=0.8601
Taui=Pu/2=6.2832
Taud=Pu/8=1.5708

The Effect of Modeling Error



$$y^*(s) = \left[G_c G e^{-t_d s} + \left(1 - e^{-t'_d s}\right) G_c G'\right] \bar{y}_{sp}$$

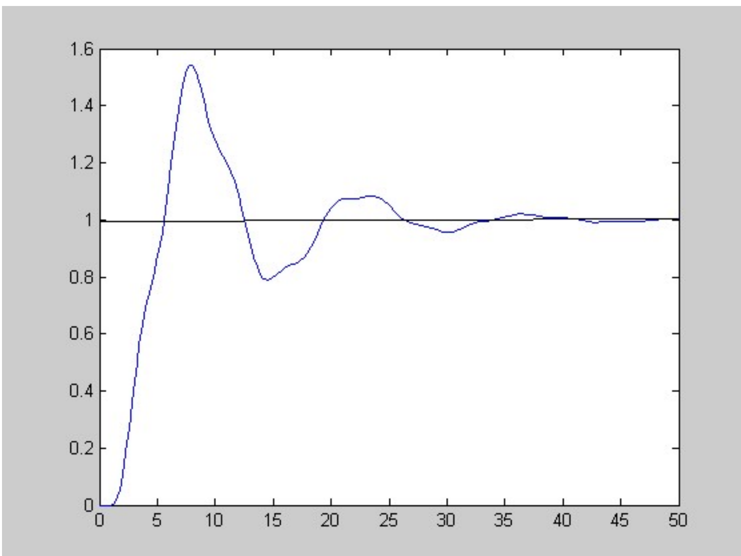
or

$$y^*(s) = G_c \left[G' + G e^{-t_d s} - G' e^{-t'_d s}\right] \bar{y}_{sp}$$

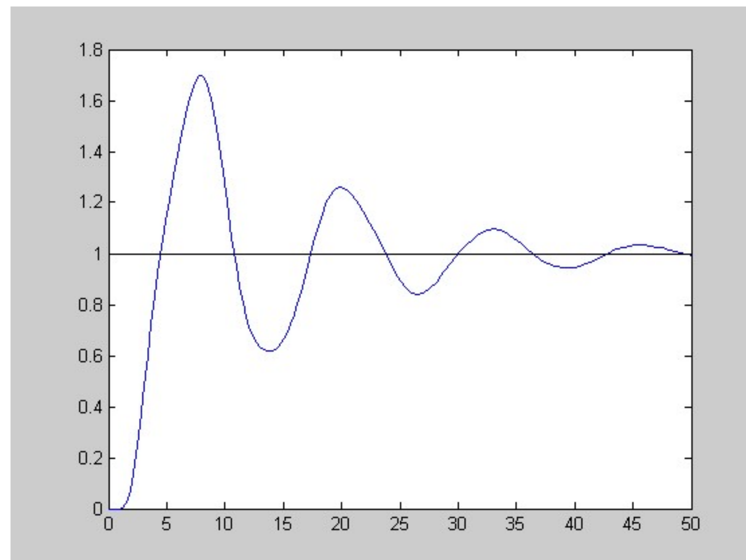
Errors in td',G' both cause the control system to degrade

Smith Predictor with Modeling Error

Plant=$e^{-s}/(s^3+3s^2+3s+1)$

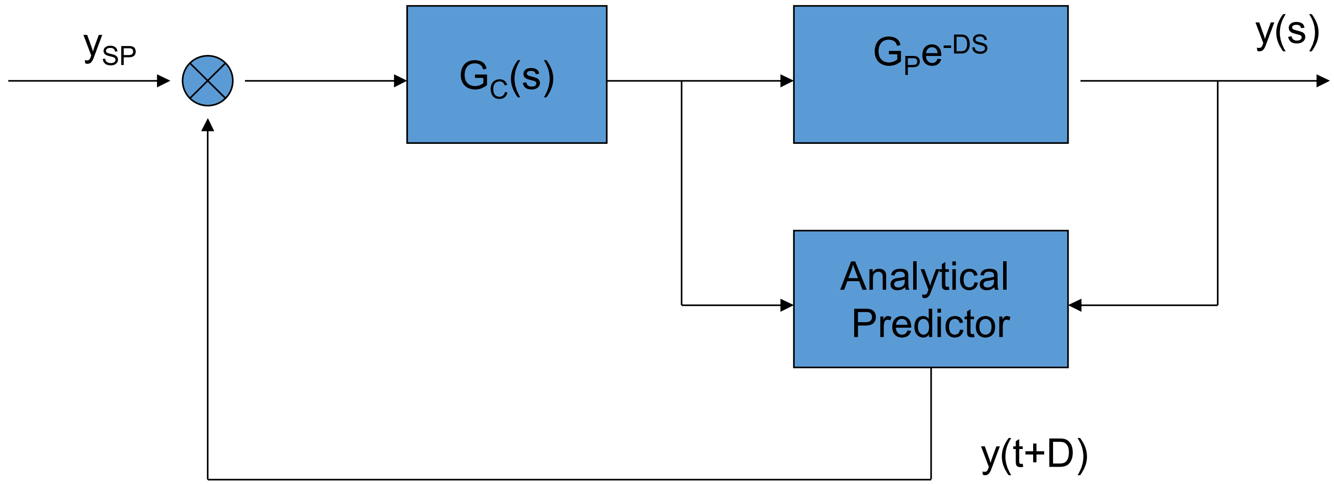


Model=$e^{-s}/(s^3+s^2+s+1)$



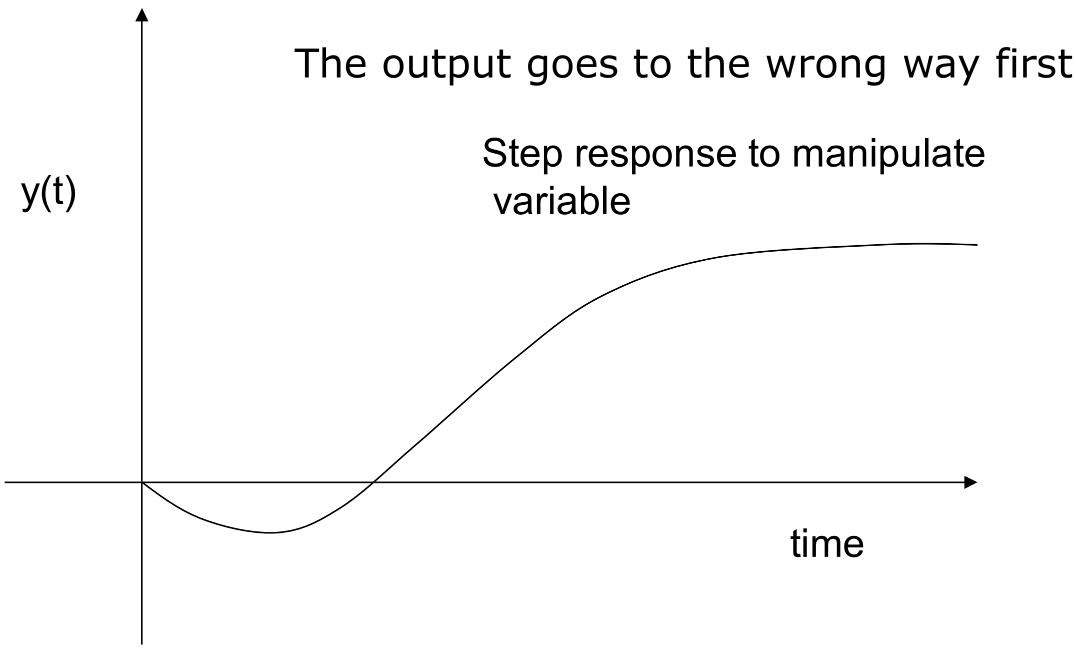
Model=$e^{-0.5s}/(s^3+s^2+s+1)$

Analytical Predictor



Analytical Predictor is a model that projects what y will be D units into the future (on-line model identification)

Processes with inverse response



Example: $y(s)=\frac{K_1}{\tau_1 s+1}-\frac{K_2}{\tau_2 s+1}$

This can occurs in (1) reboiler level response to change in heat input to the reboiler. (2) Some tubular reactor exist temperature To inlet flow rate .

Inverse response is caused by a RHP zero

Example: Inverse response of concentration and temperature to a chanbe in process flow of 0.15 ft^3/min

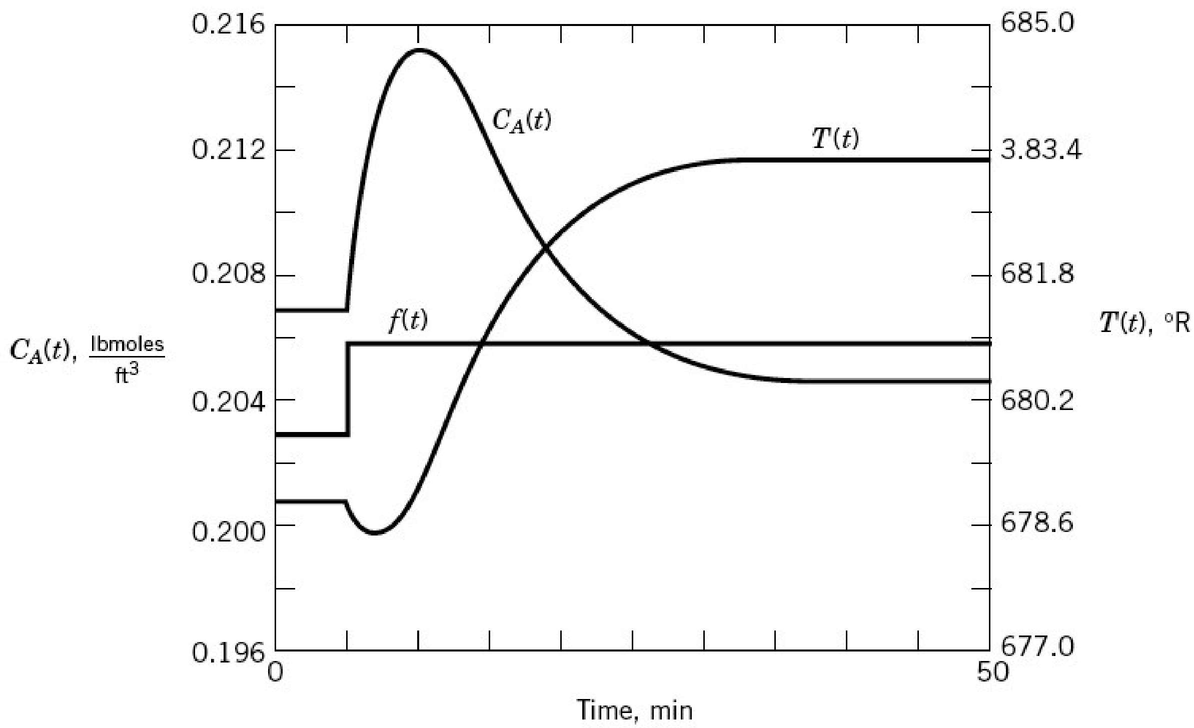
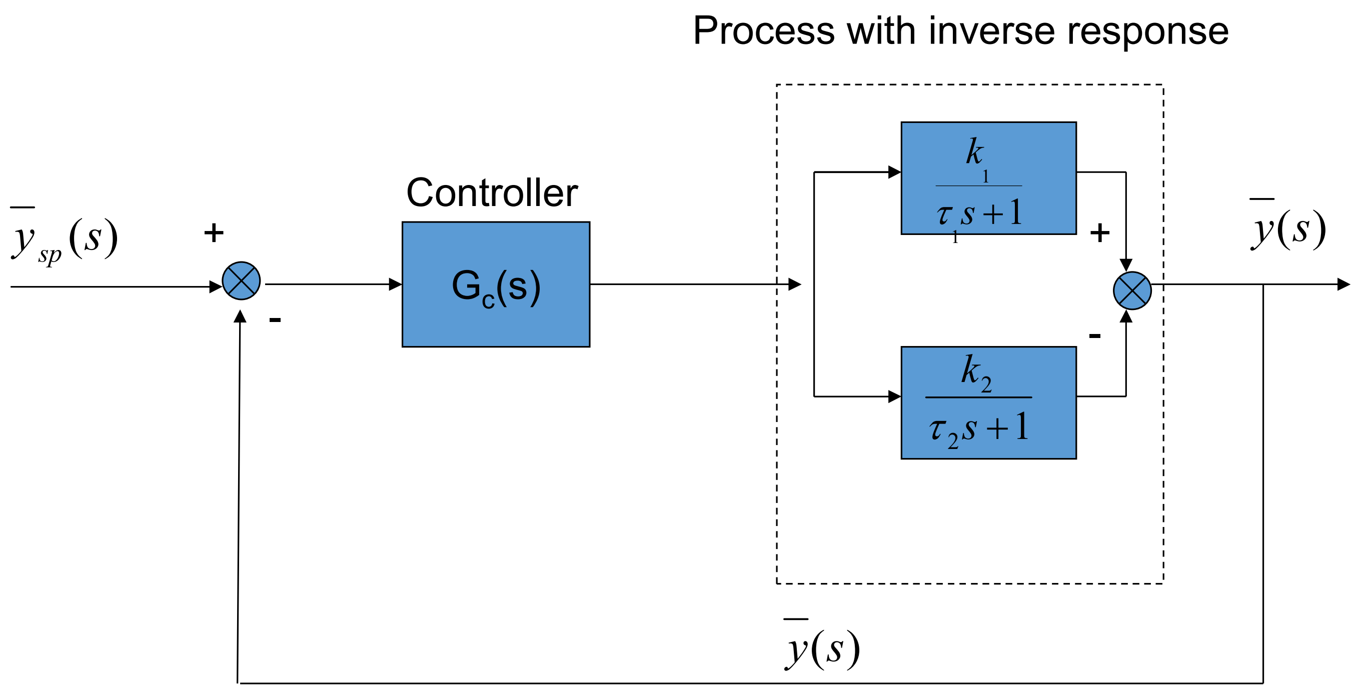
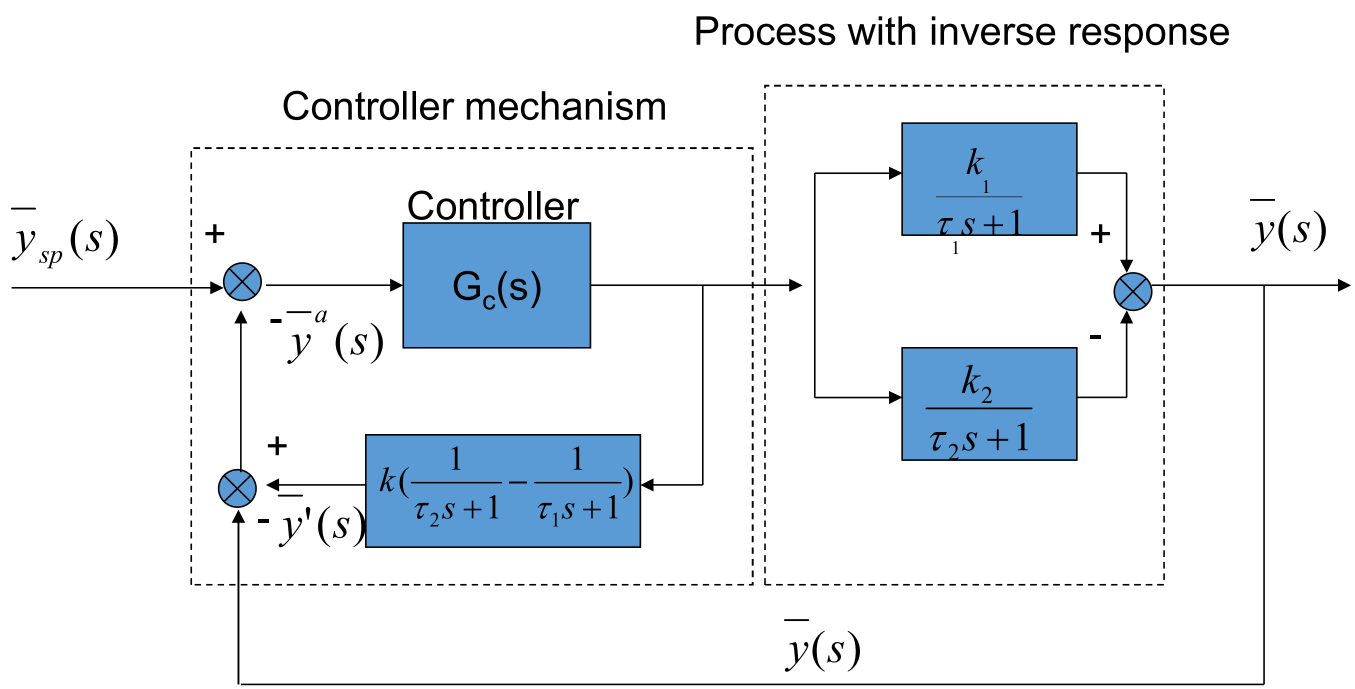


Figure 4-4.8 Inverse response of concentration and temperature to a change in process flow of 0.15 ft^3/min.



Process with inverse response
Controller
$\bar{y}_{sp}(s)$
+
-
$G_c(s)$
$\frac{k_1}{\tau_1 s+1}$
$\frac{k_2}{\tau_2 s+1}$
+
-
$\bar{y}(s)$
$\bar{y}(s)$



Process with inverse response
Controller mechanism
Controller
$G_c(s)$
$\bar{y}_{sp}(s)$
+
-
$\bar{y}^a(s)$
+
-
$\bar{y}'(s)$
$k\left(\frac{1}{\tau_2 s+1}-\frac{1}{\tau_1 s+1}\right)$
$\frac{k_1}{\tau_1 s+1}$
$\frac{k_2}{\tau_2 s+1}$
+
-
$\bar{y}(s)$
$\bar{y}(s)$

Open-loop response analysis

$$y(s) = G_c(s)\frac{(K_1\tau_2 - K_2\tau_1)s + K_1 - K_2}{(\tau_1 s + 1)(\tau_2 s + 1)}\, y_{sp}(s)$$

RHP zero at $s = -\dfrac{(K_1 - K_2)}{K_1\tau_2 - K_2\tau_1}$

$Note: if\ \dfrac{\tau_1}{\tau_2} > \dfrac{K_1}{K_2} > 1$, then s is positive

If we add to the open loop response $y'(s) = G_c K\left(\dfrac{1}{\tau_2 s + 1} - \dfrac{1}{\tau_1 s + 1}\right) y_{sp}(s)$

then $y^*(s) = y(s) + y'(s) = G_c(s)\dfrac{[(K_1\tau_2 - K_2\tau_1) + K(\tau_1 - \tau_2)]s + (K_1 - K_2)}{(\tau_1 s + 1)(\tau_2 s + 1)}\, y_s$

and if $K > \dfrac{K_2\tau_1 - K_1\tau_2}{\tau_1 - \tau_2}$ the zero is in the LHP