TKP4140 Process Control

Department of Chemical Engineering NTNU

Autumn 2020 - Midterm Exam

8 October 2020

- Write your answers on a separate sheet of paper.
- Time: **95** minutes (**14:10-15:45**) + **5** extra minutes for scanning.
- Upload your answers via Blackboard not later than **15:50**.

Problem 1 (25 points)

Consider the following transfer function

$$g(s) = \frac{(-4s+1)e^{-s}}{(2s+1)^2(6s+1)}$$

(a) Approximate by a first-order model using the half-rule.

(b) Draw the response of the approximated model in Figure 1. Sketch the responses on a separate sheet of paper.

(c) Tune a PI controller using the SIMC rules (using $\tau_c = \theta$).

(d) After a first inspection, you realized that the above controller is too fast. Should you increase or decrease τ_c to slow down the response?

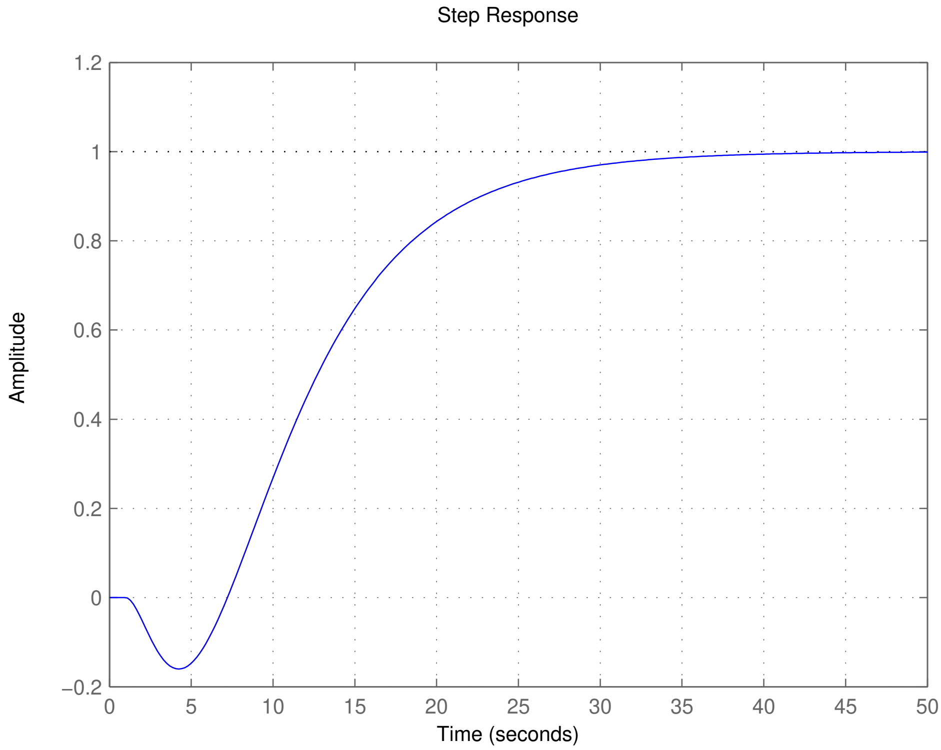

Figure 1: Response of $g(s)$ to a unit step at time 0.

Problem 2 (20 points)

Given

$$g_1 = \frac{1}{6s+1} - \frac{1.2}{2s+1}$$
$$g_2 = \frac{1}{2s+1} - \frac{1.2}{6s+1}$$
$$g_3 = \frac{0.8}{10s+1}$$
$$g_4 = \frac{0.8e^{-4s}}{10s+1}$$
$$g_5 = \frac{(10s+1)}{(8s+1)(4s^2+4s+1)}$$
$$g_6 = \frac{1}{s^2+0.4s+1}$$

Fill in the missing values (poles, zeros, steady state gain, initial gain and initial slope) in Table 1. As conclusion, identify the step responses in Figure 2.

Hint: Initial slope of response to unit step input: $\lim_{t\to 0} y'(t) = \lim_{s\to\infty} sg(s)$.

Table 1: Table for Problem 2; SS: steady state; TF: transfer function

TF	Poles	Zeros	SS gain	Initial gain	Initial slope	Conclusion
g_1						
g_2						
g_3						
g_4						
g_5						
g_6						

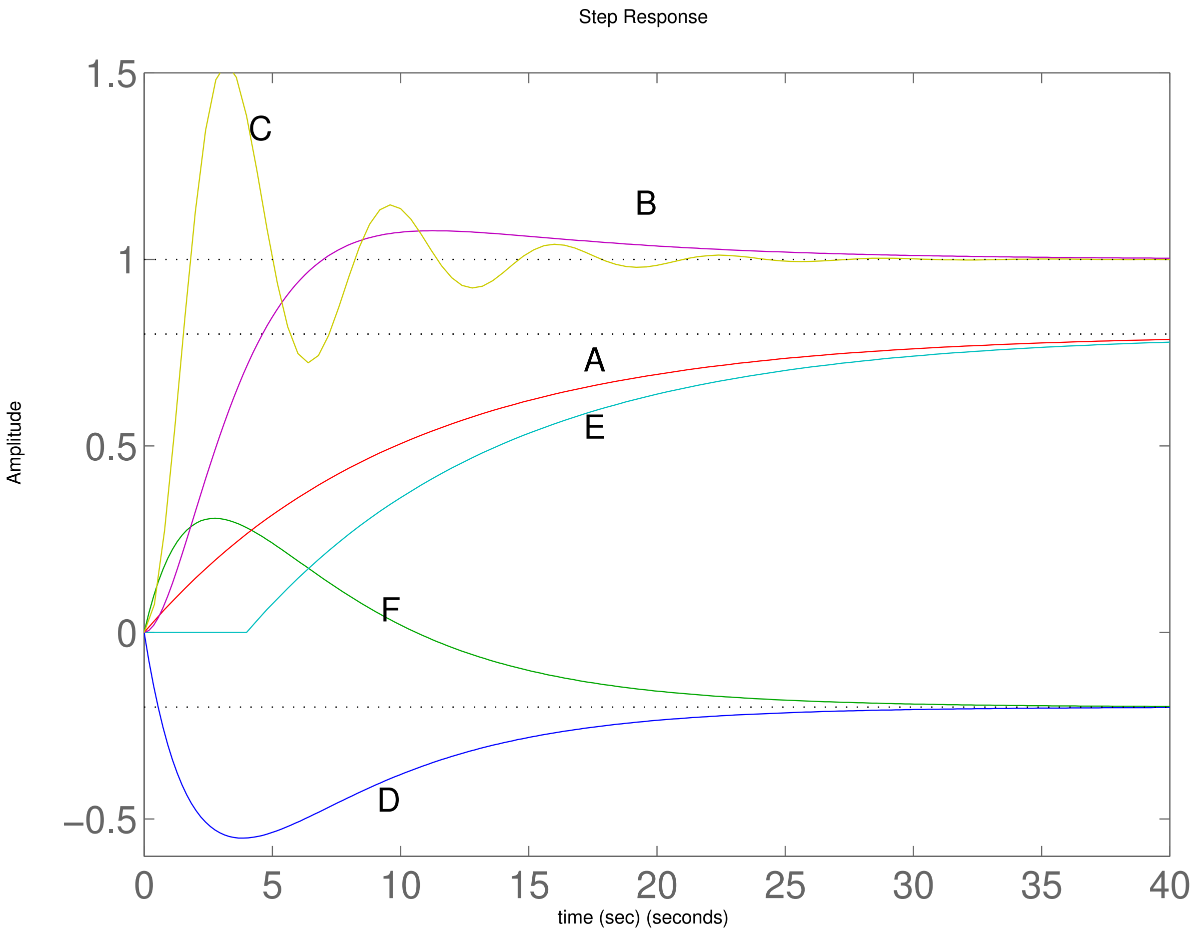

Figure 2: Step responses.

Problem 3 (25 points)

Consider the pressure tank shown in Figure 3. The inflow F_1 is taken from a reservoir with pressure P_r (and P_r does not change with F_1).

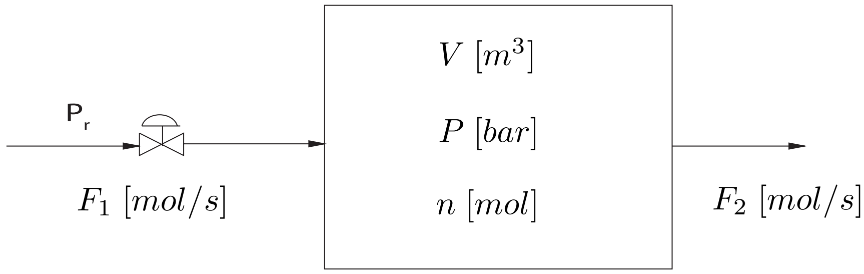

Figure 3: Pressure tank scheme

- Assume ideal gas with constant temperature T and volume V.
- Valve equation: $F_1 = C_v z \sqrt{P_r^2 - P^2}$ [mol/s] where z is the opening of the valve.
- MV: z.
- CV: P.
- DV: F_2.

Table 2: Parameters

P_r	=	12	[bar]
T	=	300	[K]
V	=	100	[m^3]
C_v	=	2	[mol/s/bar]
R	=	8.314	[J/K/mol]
F_2^*	=	2.0	[mol/s]
z^*	=	0.5	[–]

Please do the following:

(a) Formulate a dynamic model for the system.

(b) Determine the steady state value P^*.

(c) Write the model in the form $\frac{dP}{dt} = \ldots$ and linearize the dynamics in terms of deviation variables($\Delta P = P - P^*$, $\Delta z = z - z^*, \Delta F_2 = F_2 - F_2^*$).

(d) Compute the transfer function $g(s)$:

$$P(s) = g(s)z(s)$$

Problem 4 (5 points)

Indicate whether the sentences are true or false .

(a) The PID controller $c(s) = K_c \left(\frac{\tau_I s+1}{\tau_I s}\right)(\tau_D s + 1)$ is in the ideal (parallel) form.

(b) The PID-SIMC rules gives tunings for PID in cascade (series) form.

(c) For the system $y(s) = \frac{k}{\tau s+1}u(s)$, the response for a step in u is $y(t) = ke^{-t/\tau}\Delta u$.

(d) The PID in the ideal (parallel) form is more general than PID-series (cascade) form since it can have complex zeros, whereas the series form can only have real zeros.

(e) The derivative action is necessary to eliminate the steady state off-set (error).

Problem 5 (25 points)

Derive a modified SIMC PID tuning rule for a first order with delay process

$$g(s) = \frac{ke^{-\theta s}}{(\tau s + 1)} \tag{1}$$

Do the following:

(a) Write the transfer function for a PID controller $c(s)$ in cascade form.

(b) Specify a desired first-order with delay response $T(s) = y/y_s$ and introduce the tuning parameter τ_c.

(c) Draw the block diagram showing g, c, y, u and y_s and write the transfer function $T(s)$ in terms of $c(s)$ and $g(s)$.

(d) Solve this to find $c(s)$ as a function of $g(s)$ and $T(s)$.

(e) Put in the desired $T(s)$ from (b) and given $g(s)$ in (1) and derive the controller $c(s)$ (as a function of τ, θ and τ_c).

(f) What is the first-order Padé approximation (with a single pole and a RHP-zero) of a time delay?

(g) Approximate the time delay using the Padé approximation and derive a PID controller.

(h) Give the resulting PID tunings (K_c,τ_I,τ_D) and a derivative filter τ_F for the model (1).

(i) Comment on the difference with respect to the original SIMC-rule.