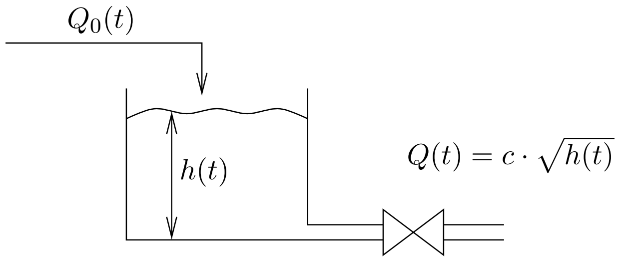
TKP4140 Process control — Midterm Exam

12. October 2017

Student number: ____________________

- Write your student number on **every** page in the indicated space.
- Write your student answers on the enclosed pages.
- Use the last two pages for details if you have too little space.
- Do not separate the enclosed pages.

1. (30 points) Consider a tank with one inflow and one outflow, as given in Figure 1. Assume constant density, $\rho = const.$



Parameters:

$$A = 10\text{m}^2$$

$$c = 10\frac{\text{m}^3}{\text{min}\sqrt{\text{m}}}$$

$$Q_0^* = 10\frac{\text{m}^3}{\text{min}} \text{ (nominal value)}$$

Figure 1: Tank system with volume $V = Ah$

(a) Formulate the dynamic mass balance and write it in the form $\frac{dh}{dt} = \ldots$

(b) What are the steady state values of $h(t)$ and $Q(t)$?

(c) Linearize the model and introduce deviation variables.

(d) Take the Laplace transform and derive the transfer function $g(s)$:

$$h(s) = g(s)Q_0(s)$$

(e) What is the value of the steady state gain and the time constant in $g(s)$?

(f) Fill in the corresponding transfer functions in the block diagram from Figure 2.

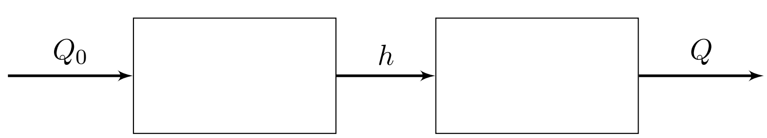


Figure 2: Block Diagram Tank System

(g) Does the block diagram from Figure 2 correspond to an open loop or a closed loop system?

2. (10 points) Given the first-order transfer function

$$g(s) = \frac{2e^{-7s}}{5s+1} \tag{1}$$

and $y(s) = g(s)u(s)$.
Consider a step change in the input:

$$u(t) = \begin{cases} 0 & \text{for} \quad t < 3 \\ 5 & \text{for} \quad t \geq 3 \end{cases} \tag{2}$$

Use the template in Fig.3 to sketch $u(t)$ and the resulting $y(t)$. Indicate the time constant, delay, and steady state value in your sketch.

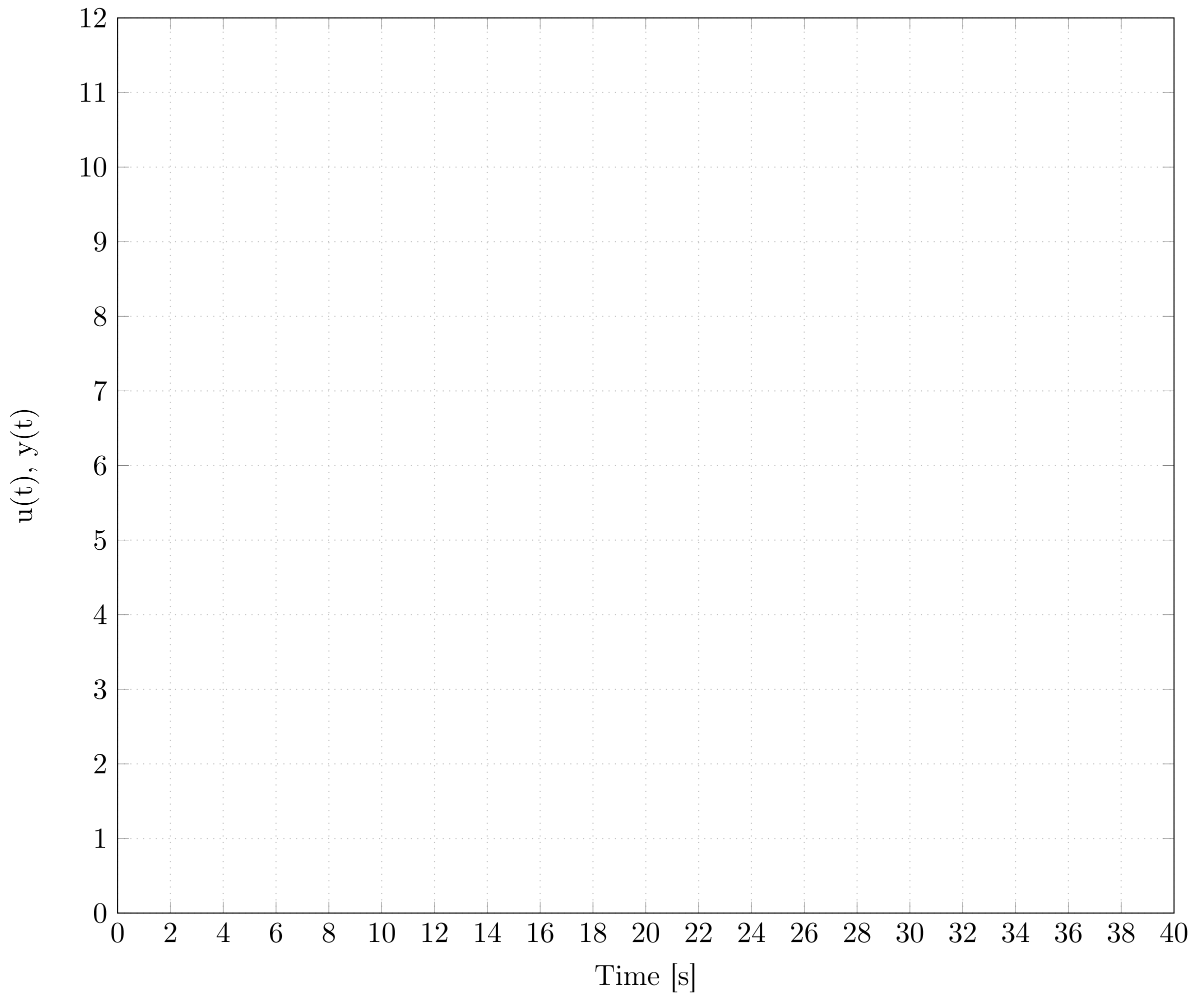


Figure 3: Step Response

3. (20 points) Consider the system in Figure 4.

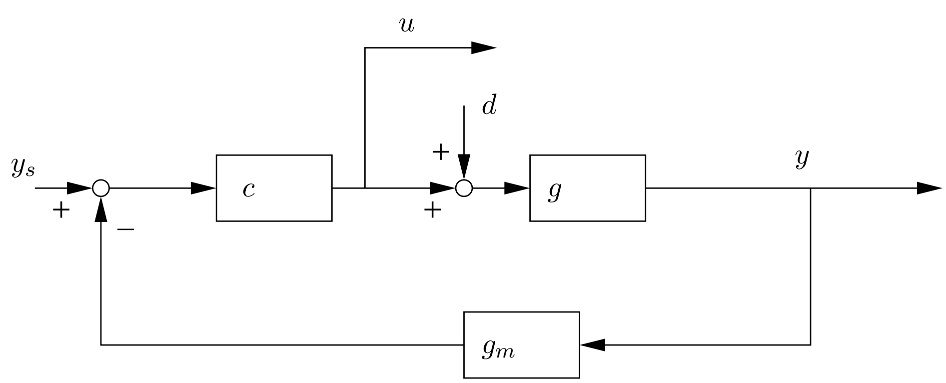


Figure 4: Block diagram

(a) Find the closed loop transfer function $T(s)$ from $y_s(s)$ to $y(s)$. Use symbols $(c(s),g(s),g_m(s))$.

(b) Find the closed loop transfer function $Q(s)$ from $y_s(s)$ to $u(s)$. Use symbols $(c(s),g(s),g_m(s))$.

(c) Find T(s) when: $g(s) = \frac{3}{5s+1}$ $\quad g_m(s) = \frac{-s+1}{s+1}$ $\quad c(s) = 1$

(d) What is the steady state gain when there is a unit step in y_s?

(e) Calculate the damping factor and the time constant of T(s).
Hint: the denominator in the second order transfer function is $\tau^2 s^2 + 2\tau\zeta s + 1$.

$\zeta =$ $\quad\quad \tau =$

(f) Does the system oscillate?

4. (20 points) Given

$$g_1 = \frac{2.5}{(6s+1)}$$
$$g_2 = \frac{2.5(s+0.8)}{(6s+1)^2}$$
$$g_3 = \frac{2.5}{(9s^2+3s+1)}$$
$$g_4 = \frac{2(-4s+1)}{(6s+1)^2}$$
$$g_5 = \frac{2e^{-4s}}{(6s+1)^2}$$
$$g_6 = \frac{2.5}{(6s+1)^2}$$

Fill in the missing values in Table 1. In the case that the results in the table do not give a unique answer, comment on your choice.

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

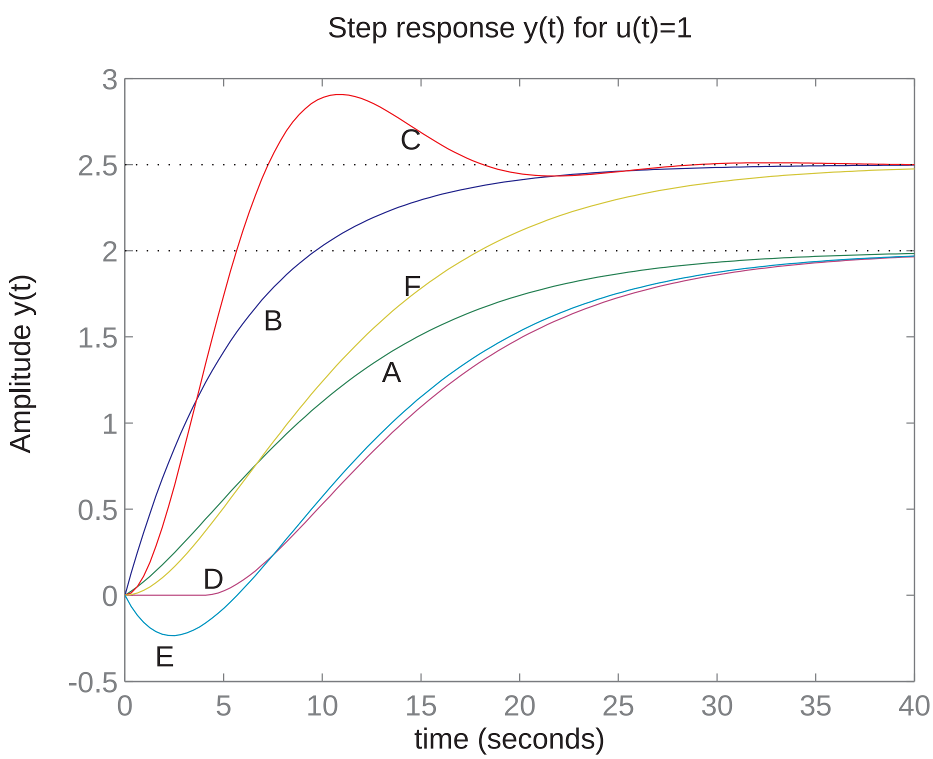


Figure 5: Step responses

Table 1: Problem 4; 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						

5. (20 points) (a) SIMC tuning rules.

   i. Write the SIMC PI tuning rules for a first-order plus delay process.

      $g(s) =$

      $K_c =$ $\tau_I =$

   ii. Write the SIMC tuning rules for cascade PID for a second-order plus delay process.

      $g(s) =$

      $K_c =$ $\tau_I =$ $\tau_D =$

   (b) By modelling and linearization, you have derived the following process transfer function

$$g(s) = \frac{3(-1.5s+1)e^{-0.5s}}{(25s+1)(3s+1)(0.8s+1)} \tag{3}$$

   i. Write the first-order plus delay approximation $g_1(s)$ using the half rule.

   ii. Write the second-order plus delay approximation $g_2(s)$ using the half rule.

   iii. Based on the approximations of $g_1(s)$ and $g_2(s)$ give the SIMC PI and PID settings. Use the standard choice $\tau_c = \theta$, where θ is the effective delay.

   iv. Would you recommend a PI or a PID controller? Explain briefly.

   (c) What would the SIMC PI tunings be for the system in Problem 3 (given Figure 4 with the transfer function from 3(c))?

Extra space if needed

Please indicate clearly which problem the solution belongs to.

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