LUND UNIVERSITY

Department of
AUTOMATIC CONTROL

Exam in Systems Engineering/Process Control

2019-06-07

Points and grading

All answers must include a clear motivation. Answers should be given in English. The total number of points is 20 for Systems Engineering and 25 for Process Control. The maximum number of points is specified for each subproblem. Preliminary grading scales:

Systems Engineering:		Process control:	
Grade 3:	10 points	Grade 3:	12 points
4:	14 points	4:	17 points
5:	17 points	5:	21 points

Accepted aid

Authorized *Formelsamling i reglerteknik / Collection of Formulae*. Standard mathematical tables like TEFYMA. Pocket calculator.

Results

The solutions will be posted on the course home page, and the results will be transferred to LADOK. Date and location for display of the corrected exams will be posted on the course home page.

1. A process is described by the differential equation

$$\dot{y}(t) + 2y(t) = 3u(t)$$

a. Find the transfer function of the process dynamics. What can be said about stability of the system? Also write down the static gain, and any poles and zeros of the system. (2 p)

b. Design a P controller such that the closed-loop system from reference to process output has a time constant $T = 0.2$. (2 p)

c. Is the resulting closed-loop system faster or slower than the uncontrolled process? Would it ever be motivated to make a closed-loop system slower than the uncontrolled process? Why or why not? (1 p)

2. The following nonlinear system is given on state space form:

$$\dot{x}_1 = 2\sqrt{x_1} - x_2 + 3\cos(u)$$
$$\dot{x}_2 = x_1 x_2 - x_1^2 + u$$

a. The system has two stationary points corresponding to $u = u^0 = 0$. One of them is given by $(x_1, x_2) = (x_1^0, x_2^0) = (9, 9)$. Which is the other stationary point? (1 p)

b. Linearize the system around the stationary point $(x_1^0, x_2^0, u^0) = (9, 9, 0)$. (2 p)

c. For the stationary point in **b**, decide if the linearized system is stable, asymptotically stable, or unstable. If you have not solved **b**, you can still get 0.5 p for concisely explaining how you would have determined stability. (1 p)

3. Figure 1 shows the step responses of four systems. Match them to the corresponding Bode diagrams in Figure 2. As with all the problems, do not forget to motivate your answer. (2 p)

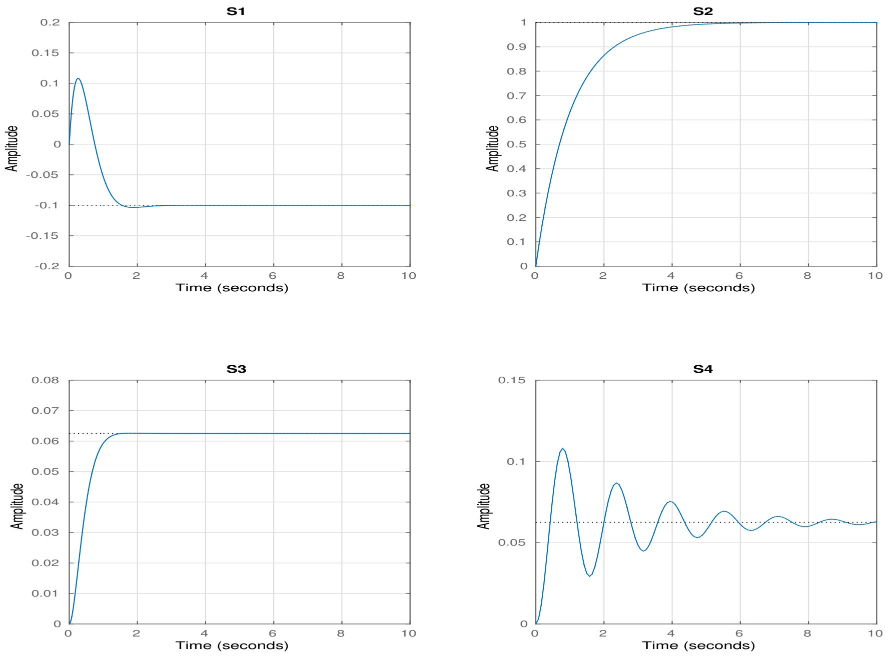

Figure 1 Step responses of the four systems in Problem 3.

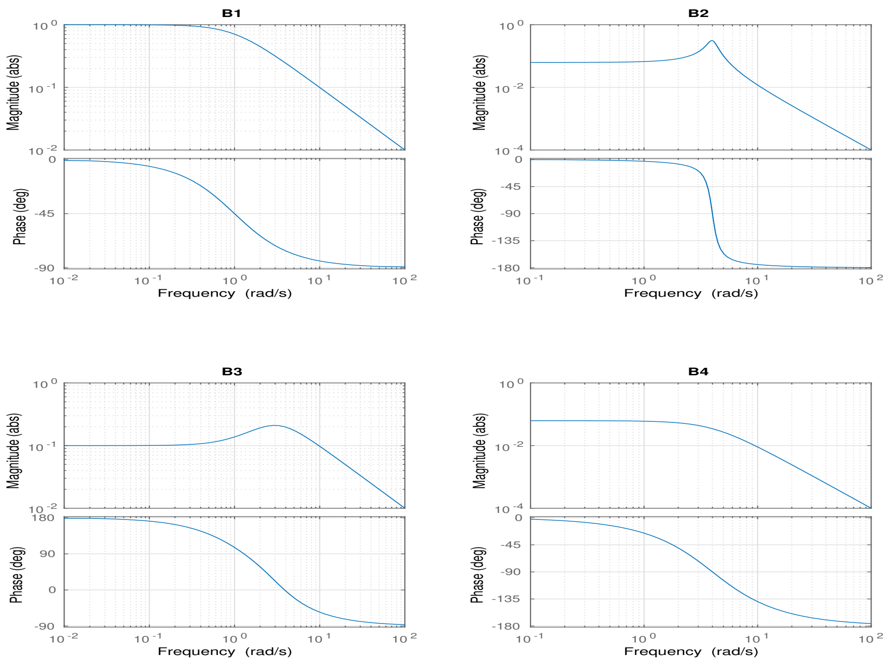

Figure 2 Bode diagrams of the four systems in Problem 3.

4. A Bode diagram of an asymptotically stable process is shown in Figure 3. Assume that the process is used in a negative feedback configuration with a P controller with transfer function $C(s) = 1$.

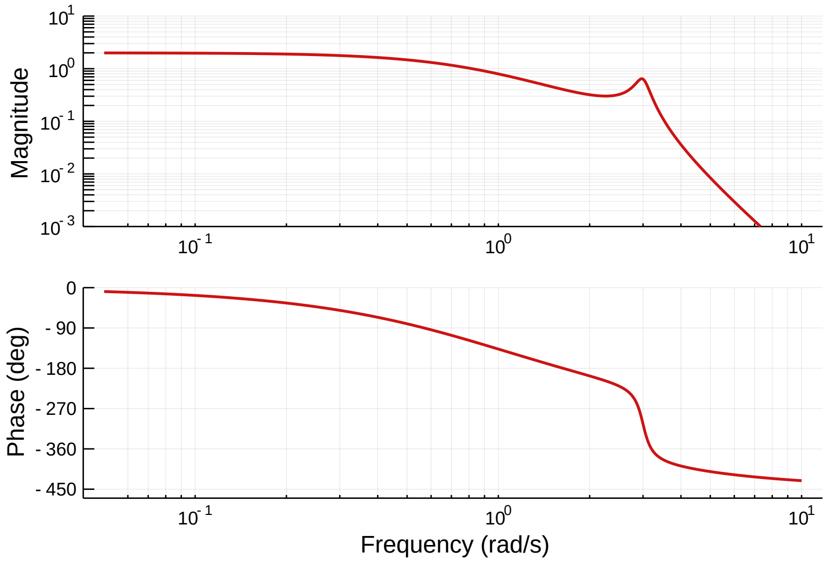

Figure 3 Bode diagram of the system in Problem 4.

a. What will the resulting gain and phase margins be? (1 p)

b. What can be said about stability of the arising closed-loop system? (0.5 p)

c. Sketch the Nyquist plot of the process. The sketch should capture the main characteristics of the process dynamics. (1 p)

d. Indicate in the Nyquist plot where and how to determine the gain and phase margins. If you did not solve **c**, use a Nyquist curve of your choice for this illustration. (1 p)

5. The block diagram of a system is shown in Figure 4.

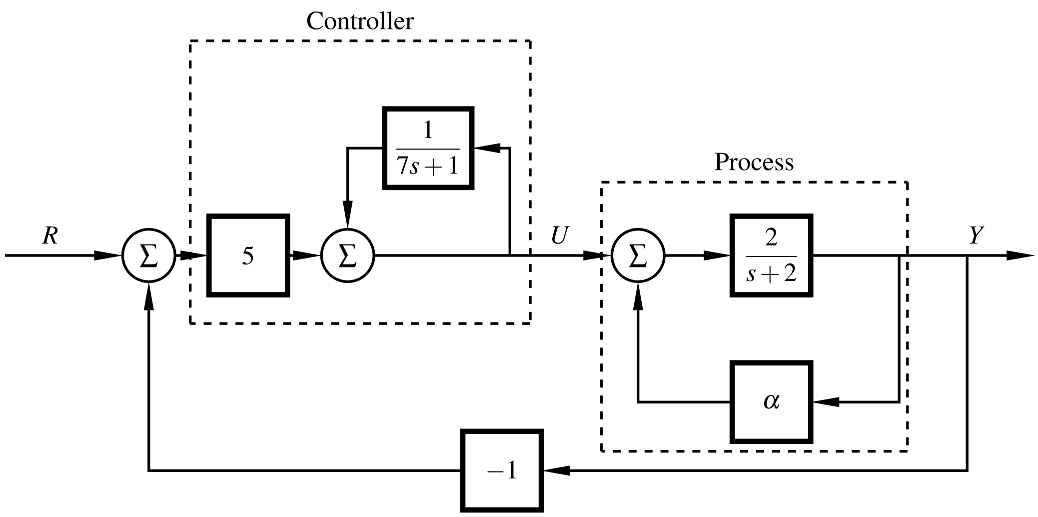

Figure 4 Block diagram of a closed-loop system in Problem 5.

a. Calculate the transfer function of the *process*. (1.5 p)

b. The process is part of a chemical plant and it is desired that it has a pole in $s=-1$. Can this be achieved, and how? (0.5 p)

c. Show that the controller from **a** is a PI controller that can be written on the form

$$C(s) = K\left(1 + \frac{1}{T_i s}\right)$$

What are the values of K and T_i? (2 p)

d. Assume that process dynamics are given by $2/s$ (which is the case for $\alpha = 1$). Design a PI controller so that all poles of the transfer function from R to Y are in $s=-1$. (1.5 p)

6. Only for Process Control (FRTN25)

The following state space model

$$\dot{x}(t) = \begin{bmatrix} -8 & 1 \\ 1 & -2 \end{bmatrix} x(t) + \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} u(t)$$
$$y(t) = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} x(t)$$

describes the dynamics of a multivariable process.

a. How many (scalar) inputs does the the process have? (0.5 p)

b. Find the multivariable transfer function matrix $G(s)$ of the process dynamics. (1.5 p)

c. Calculate the relative gain array, RGA, for the process dynamics and use it to suggest an input–output pairing for feedback control. (1.5 p)

7. Only for Process Control (FRTN25)

Make a Grafcet diagram that describes the sequence for a bead sorter process. In this process you have a sequence of beads. Each bead is either black or yellow. The process keeps track of how many beads of either color have passed through it. Below is a specification of the sequenced used to classify and count the beads. (1.5 p)

1. The start sequence is initialized in a waiting position. When the signal START becomes true, the sequence to count begins.
2. You fire a solenoid to drop one bead into the color sensor. This solenoid is fired by setting the variable FIRE to 1.
3. The inputs to the program, BLACK and YELLOW become exclusively true depending upon the color of the current bead.
4. The integer variables NUMBLACK and NUMYELLOW are used to keep track of the number of beads of the particular color.
5. The variable PRESENT tells whether there are more beads present to be counted.
6. The sequence starts again, to classify and count the next bead, once RESTART is set true at the end of the sequence.