Exercises for Chapter 6

1. An exothermic chemical reactor can be modeled by the FOTD model

$$P(s) = \frac{b}{s-a}e^{-sL} = \frac{K_p}{sT-1}e^{-sL}$$

a. Design a P controller for the process.

b. Design a PI controller for the process.

2. Consider λ-tuning for PI control of an FOTD model where the closed-loop pole is $-1/T_{cl}$.

a. How do gain and phase margins depend on T_{cl}?

b. Use the results to explore the properties of the standard choice with $T_{cl} = 2T$ for lag dominated and delay dominated processes.

c. Use the results to suggest a modified method where the robustness is directly related to T_{cl}.

3. Determine the ultimate gain and ultimate frequency for a process with the transfer function $e^{-\sqrt{s}}$. Correlate with the following quote from Bennet 1993 page 51. "He (Ivanoff, a process control pioneer) used empirically determined values to represent the gain and the phase of the temperature wave passing through the plant, and showed that for stability the maximum controller gain is 23.1 and that it is independent of the plant." The original reference is Ivanoff, A. Theoretical foundations of the automatic regulation of temperature. J. Institute of Fuel. 1934, pp 117-130.

4. Consider the following three processes

$$P_1 = \frac{1}{(s+1)^3} \quad P_2 = \frac{1}{(s+1)(0.1s+1)(0.01s+1)(0.001s+1)} \quad P_3 = \frac{e^{-s}}{0.02s+1}$$

a. Calculate the normalized time delay for each process and discuss their properties.

b. Download Olof Garpinger's PID design software from

https://www.control.lth.se/media/Research/PID/designpid.zip.

Use this tool to find both PI and PID controllers for P_1, P_2 and P_3 such that $M_s = M_t = 1.4$. Notice that M_t is denoted M_p in the program. You may have to change the frequency span used (option 3 in the menu) to find the optimal solution in each case. Discuss for what types of processes you can gain the most in performance by use of PID rather than PI. What are the limitations?

c. Modify the Simulink model getiae.mdl such that the program instead minimizes the ISE-value. Find PI- and PID-controllers for P_1, P_2 and P_3 such that $M_s = M_t = 1.4$ and compare the solutions with those from b).

d. Do not forget to restore getiae.mdl such that IAE is once again minimized. For $P_1(s)$, find the optimal PI controllers for different values of $M_s = M_t$ and plot the trajectory of optimal controllers in the $k_p - k_i$ plane. Compare your result with that from Exercise 2 on Chapter 4. To simplify the iteration you can use the command ds = designpid(P1,0,tf(0),defaultdes) where default values can be pre-specified in defaultdes (see newdefault.m).

e. Approximate P_1 with an FOTD model and design a new IAE-optimal PI-controller for this model such that $M_s = M_t = 1.4$. Compare the new controller parameters with those from b) and calculate the robustness measures (M_s and M_t) for the closed loop (using the nominal process model P_1).

f. Use the FOTD approximation of P_1 to find a Lambda tuned PI controller with $T_{cl} = T$. Compare IAE, M_s and M_t with the PI controllers from b) and e). Discuss the results.

5. Consider the fourth order lag process model

$$P(s) = \frac{1}{(s+1)(0.2s+1)(0.05s+1)(0.01s+1)}$$

a. Use Skogestad's SIMC method, with the standard choice of T_{cl}, to find a PI controller for the process.

b. Use Olof Garpinger's PID design software to find a PI controller with the same robustness measures as those given by SIMC.

c. Compare the two tuning methods with respect to load disturbance handling and robustness. Discuss advantages and disadvantages with the two methods.