Exercises for Chapter 3

1. Suppose that we have a PI controller

$$u = K\left(e + \frac{1}{T_i}\int e(\tau)d\tau\right),$$

and that $u = e = 0$ initially. Consider a unit step change in the control error at time $t = 0$. Calculate the control signal $u(t)$.

After how long time has the control signal reached the values K and $2K$, respectively?

2.

a. Derive $F(s)$ on page 75 in the course book, i.e. (3.20)

b. For a PI controller, compare the choice of $F(s)$ with the reference filter $\tilde{F}(s) = 1/(sT_f + 1)$, where T_f is an arbitrary filter time constant. Discuss advantages and disadvantages with both options.

c. Compare $F(s)$ and $\tilde{F}(s)$ for PID control as well. Can you suggest any reference filters that are better than these two choices?

3.

a. Discuss advantages and disadvantages with the two different PID parameter choices k_p, k_i, k_d versus K, T_i, T_d.

b. Assume that you use PI control for the process $P(s) = 1/(s + 1)^4$, with controller parameters $k_p = 0.43$ and $k_i = 0.19$. Vary the proportional gains K and k_p separately. Compare how they affect performance and robustness. Measure performance with both the Integrated Absolute Error and the Integrated Error during a unit step disturbances on the process input. Measure robustness as the minimum distance from the open loop Nyquist plot to the point -1. Also vary the integral time T_i and gain k_i separately to compare how the different parametrizations affect robustness and performance.

4. Discuss benefits and drawbacks with the two different choices of noise filtering, given on page 73, both for PI and PID control. If the system is discretized, how does your choice of sampling period affect noise filtering?

5. Read the paper *A Candidate to Replace PID Control: SISO-Constrained LQ Control* by Pannocchia, Laachi and Rawlings. Focus on the first example on pages 1185-1186. Why does the PID controller perform so badly compared to the LQ controller? Is there anything one can do to improve the performance?

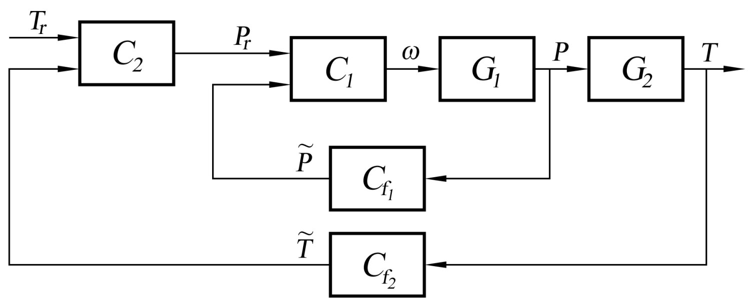
6. Data files for this exercise can be downloaded from the course webpage.

a. Derive a model of the process that gives the step response captured in data1.mat. The file contains a matrix where the first column holds the time stamps, the second gives the input signal and the third column are the measurements of the process output.

b. Derive a model of the process that gives the step response captured in data2.mat. The matrix is ordered in the same way as in a).

c. The file data3.mat contains several logged signals from a Friction Stir Weld on SKB's machine in Oskarshamn during a step response test on the outer loop. Time contains the time stamps, Torque holds the motor torque needed to achieve a certain rotational speed of the welding tool, *Spindle_Speed* holds measurements of the tool rotational speed, *Power_Input* contains the power that is actively added to the system and its values are proportional to the torque multiplied with the spindle speed. *Power_Ref* is the reference for the power input which is typically set by the outer cascade controller in the SKB solution. *Spindle_Temp* gives the weld temperature when measured from the inside of the tool probe, which is the signal we want to control.

The process and control structure is given below.



where $C_{f1} = C_{f2} = -1$, ω the rotational speed, P the power input, T the spindle temperature, and P_r is the power input reference. C_1 is a PI controller which was active during the step response tests in order to keep the power input in steady state.

First of all, find a process model of the process from power input reference to spindle temperature. Secondly, derive a process model, G_2, from power input to temperature if the inner control loop is controlled by the PI controller with $K = 1.07$ and $T_i = 0.36$. The process from rotational speed to power input is

$$\frac{0.12 \cdot 4.6^2}{s^2 + 2 \cdot 0.8 \cdot 4.6 \cdot s + 4.6^2}.$$

d. Load data4.mat which contains data from a different friction weld. Discuss reasons for why the process responds differently depending on if the power input increases or decreases.

e. Discuss suitable methods for system identification in industry.