Nonlinear Control (FRTN05)

Computer Exercise 3

Last updated: November 2016, Martin Karlsson

The following exercises should be solved with help of computer programs and simulation tools. Remember that computers can help to give insight, but you still need to understand the underlying theory.

1. Consider a tank where liquid flows in trough a controlled pump, and exits trough a hole in the bottom (those who read the basic control course at LTH will recognise this as the “water tanks” from lab one and two). A simple first order model describes the liquid level:

$$\dot{h} \quad = \quad ku - a\sqrt{h} \;\; for \quad h \geq 0 \tag{1}$$

   where k and a are constants. Use $a = 1/3000$ and $k = 1/1500$ for simulations. The inflow is controlled by a PI controller, which in the Laplace domain is give by:

$$G_c(s) \quad = \quad K \frac{1 + sT_i}{T_i s} \tag{2}$$

   The controller is designed by pole-placement to make the controlled response twice as fast as the uncontrolled response, with only a small overshoot. This gives

$$\begin{aligned} K &= \frac{1}{k}\left(2\zeta\omega - 1/T\right) \\ T_i &= \frac{Kk}{\omega^2} \\ T &= \frac{2\sqrt{h_0}}{a} \end{aligned} \tag{3}$$

   where h_0 is the operating height, ω is the desired response of the system, and ζ is the damping factor. Use $\omega = 1/6000$ and $\zeta = 0.7$ for simulation. Verify that the system responds as desired when changing from normal operation at $h = 3\,m$ to $4m$, and back. Notice that range the control operates within under the changes.

2. The pump has limitations: First of all, it can not suck liquid out of the tank. The lowest flow it can provide, is zero flow. Also, it has a maximum capacity, in this case, use $u_{max} = 1$. Insert the described saturation in the simulation.

   Investigates what happens when the reference changes from normal operation ($h = 3\,m$) to a higher value ($h = 5\,m$). Explain what happens, both to the height and the control signal (before and after the saturation)

3. Expand the above experiment, such that the reference returns to $h = 3\,m$ when the height has converged. Explain what happens, both to the height and the control signal (before and after the saturation).

4. Assuming that you can measure the saturated flow, design an integrator anti-windup scheme to solve the problem.

5. Assuming that you are aware of the saturation, but that you can NOT measure the saturated flow, design an integrator anti-windup scheme to solve the problem.

Hints and Answers

1. The control signal reaches values that are outside the restrictions specified in subtask 2.
2. Before saturation, both the height and the control signal increase. The control signal reaches saturation at $u = 1$.
3. The saturation in combination with the integral part of the controller, results in windup. Thus, when changing the reference back to $h = 3$ m, the controller still acts to keep a large height to compensate for the historical error. This behavior is undesired. After a while, the integrated error approaches 0, and the controller then acts to decrease the height.
4. See lecture slides on anti-windup.
5. See lecture slides on anti-windup.