Control of a chemical reactor: tuning by step and frequency response methods

An exothermic reaction in a continuously operating chemical reactor produces heat that has to be removed. Good temperature control is important, because the reactor and the reactants are damaged by a temperature too high whereas a temperature too low causes the reaction to stop. The temperature can be controlled by means of cooling water, which flows inside the outer wall of the reactor, the so-called cooling jacket. Usually the temperature control is implemented by cascade control, where an inner secondary controller controls the temperature of the jacket by adjusting the flow rate of the cooling water while an outer primary controller controls the reactor temperature by adjusting the setpoint of the secondary controller.

The figure shows a simplified block diagram of a chemical reactor, where the temperature is controlled as described above. Here $G_r$ denotes the transfer function from the jacket temperature $T_m$ to the reactor temperature $T_r$, $G_m$ is the transfer function from the setpoint $T_{m,\text{set}}$ of the secondary controller to the jacket temperature, $G_c$ is the transfer function of the primary controller, $T_{r,\text{set}}$ is the setpoint for the reactor temperature, and $T_d$ is an additive disturbance in the reactor temperature. Note that although $G_m$ is a feedback system (not shown explicitly) containing both the jacket dynamics and the secondary controller, it can be treated as an ordinary transfer function.

Assume that the reactor properties and the secondary controller yield the transfer functions

$$G_r = \frac{0.96e^{-3.5s}}{\tau_r s + 1}, \quad G_m = \frac{e^{-1.5s}}{\tau_m s^2 + 2\zeta\tau_m s + 1},$$

where $\tau_r$, $\tau_m$, and $\zeta$ are your personal parameters. The parameters are found under “PDC 4-5” at http://www.users.abo.fi/khaggblo/PDC/PDCpar.pdf using the code you obtain by taking the last two digits of the number you get by subtracting 15 from your student number.

1. Simulate and plot the step response of the loop transfer function $G_r G_m$.

2. Determine the parameters needed for the step-response based PID controller tuning methods in Section 7.5.

3. Tune PID controllers according to the following step-response based methods: (a) Ziegler-Nichols; (b-c) CHR with 0% overshoot for (b) regulatory and (c) setpoint control; (d) Åström-Hägglund (consider using both $b=1$ and $b=0.5$ in a controller with setpoint weighting, Eq. 7.18).

4. Do an experiment with a P controller, as described in Section 7.4.1, to determine $K_c = K_{c,\text{max}}$, which results in oscillations with constant amplitude and the oscillation period $P_c$. (As an initial guess for $K_{c,\text{max}}$, 2 times the controller gain of a P controller calculated according to Z-N for a step response can be used.)

5. Tune PID controllers according to the following frequency-response based methods: (e) Ziegler-Nichols; (f) Åström-Hägglund.

6. Simulate and plot the result of all these cases for (i) a step change in the setpoint $T_{r,\text{set}}$ (tracking control), (ii) a disturbance in $T_d$, which changes as a step response to a first-order system with the time constant 0.2$\tau_r$ (regulatory control). Start the simulation at the same initial conditions in all cases.

7. Which tuning method (a–f) do you prefer for (i) setpoint control, (ii) regulatory control, (iii) both types of control? Please motivate!