Hierarchical Control

Laboratory

Exercise 1

Stirred-tank continuous-flow reactor

The aim of the exercise is modeling of a stirred-tank continuous-flow reactor, finding its static characteristics, and designing control system for the reactor.

Analyzed reactor is presented in Fig. 1.

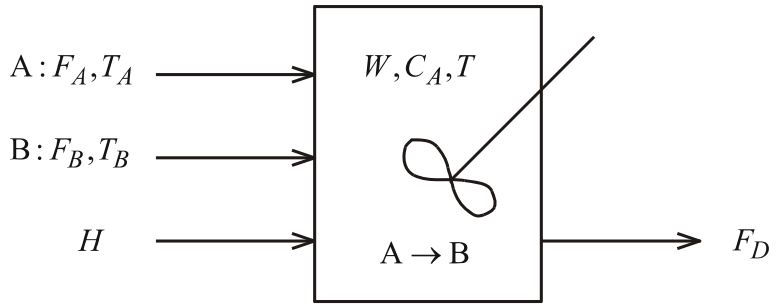

Figure 1. The reactor

It can be denoted by means of balance equations:

$$\frac{\mathrm{d}W}{\mathrm{d}t} = F_A + F_B - F_D$$
$$\frac{\mathrm{d}(WC_A)}{\mathrm{d}t} = F_A - C_A F_D - WC_A k(T)$$
$$\frac{\mathrm{d}(\mathrm{c}WT)}{\mathrm{d}t} = cF_A T_A + cF_B T_B - cF_D T + H - hWC_A k(T)$$

where:

F_A, F_B	[kg/s]	input mass flows of substances A and B,
F_D	[kg/s]	output mass flow of a mixture of A and B substances,
T_A, T_B, T	[K]	temperatures,
C_A	[kg/kg]	concentration of the substance A in the reactor,
H	[J/s]	input flow of the heat energy,
W	[kg]	mass of the whole mixture in the reactor,

$k(T)$	temperature coefficient of the reaction $\mathrm{A} \to \mathrm{B}$,
c	specific heat of both substances (under the assumption that they are equal),
h	heat of the reaction.

Balance equations lead to following state equations:

$$\frac{\mathrm{d}W}{\mathrm{d}t} = F_A + F_B - F_D$$
$$\frac{\mathrm{d}C_A}{\mathrm{d}t} = \frac{1 - C_A}{W} F_A - \frac{C_A}{W} F_B - C_A k(T)$$
$$\frac{\mathrm{d}T}{\mathrm{d}t} = \frac{T_A - T}{W} F_A + \frac{T_B - T}{W} F_B + \frac{H}{cW} - \frac{h}{c} C_A k(T)$$

1. For given parameters, using Matlab-Simulink software, create model of the reactor.
2. Simulate the reactor for given input signals and initial conditions. Observe steady-state values of all signals.
3. Assuming constant values of $W = \mathrm{const} = W(0)$ (assured by input and output flows satisfying an equation $F_A + F_B = F_D$) calculate steady state values of C_A and T.
4. Using `trim` command find steady state values of C_A and T.
5. Compare results obtained in three previous points.
6. Using `linmod` command find transfer functions $\frac{\Delta W(s)}{\Delta F_A(s)}$, $\frac{\Delta C_A(s)}{\Delta F_D(s)}$ and $\frac{\Delta T(s)}{\Delta H(s)}$ for given desired values of state variables. Calculate one of them analytically and compare the results.
7. Design and apply a diagonal controller with signal assignments: $F_A \to W$, $F_D \to C_A$ and $H \to T$, which stabilize state variables on desired levels.
8. Examine how obtained control system works.