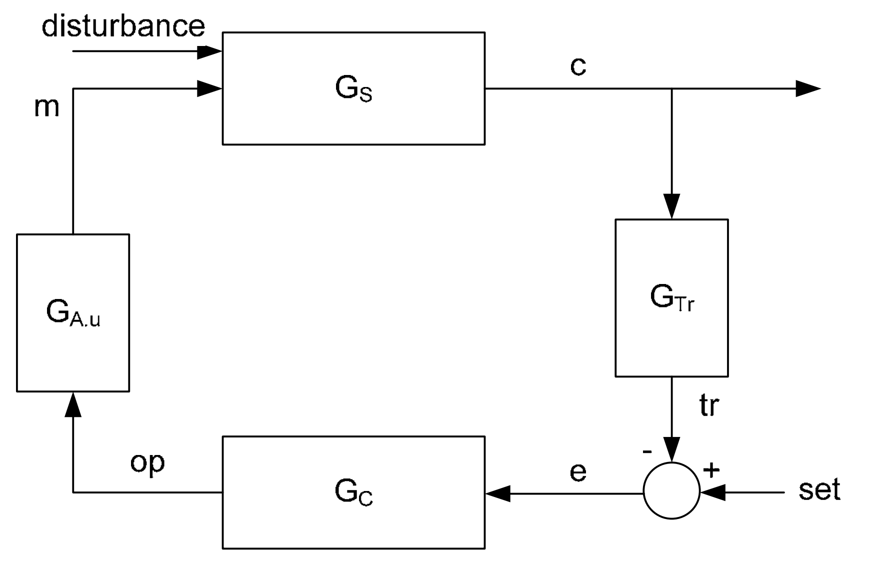
Process control laboratory practice

Controller tuning

Introduction

The main aim of process control is automatization of a process. This means that one or more process variables have to be kept on a prescribed level despite of external disturbances in order to maintain a stable operation. Figure 1 shows the common block diagram of a negative feedback loop.



c: controlled variable
tr: control (transmitted) signal
set: set point signal
e: error signal
op: command (operation)
m: manipulated variable
G: transfer function
S: process
Tr: transmitter
C: controller
A.u: actutator unit or final control element

Figure 1. Block diagram of a negative feedback loop

Transfer function of a PID controller consists of the following parameters: A_P, A_I, A_D, as shown in Eq. (1.1):

$$G_C\left(s\right) = A_P + \frac{A_I}{s} + A_D s \qquad (0.1)$$

Controller tuning means setting the controller’s parameters in order to get good control performance.

Control performance can be defined or specified in the time domain with the following parameters:

- Overshoot (Δy_{max}) which is the maximal difference between set point and control signal before the system gets in to the new steady state.
- Steady-state offset (*OFF*) – difference between set point and control signal in the (new) steady state.
- Response time (T_{resp}) – or controlling time, the time it takes for the amplitude of the oscillation to decay to some fraction (e.g. ±0.1) of the final change of the control signal.
- Integrated square error (*ISE*) – integral of the error signal’s square in time $ISE = \int_0^\infty e^2 dt$.

Several tuning tables giving controller settings are offered in handbooks. These are based on some performance criteria applied to an appropriate process model. In this work, two tuning procedures are investigated: (1) tuning based on step response function, (2) and Ziegler Nichols method.

Tuning based on response function

Transfer function of multi capacity processes can be approximate by the expression

$$G(s)=\frac{A_S e^{-T_H s}}{T_E s+1} \tag{0.2}$$

with the parameters dead time (T_H), effective time constant (T_E) and steady state process gain (A_S). The parameters of the process model can be determined from the process reaction curve, as shown in Figure 2. The process reaction curve is the open loop response of the controlled variable (*c* on Fig 1.) to a unit step input in the manipulated variable (*m* on Fig. 1.). All elements of the control loop must be included in the response, except the controller.

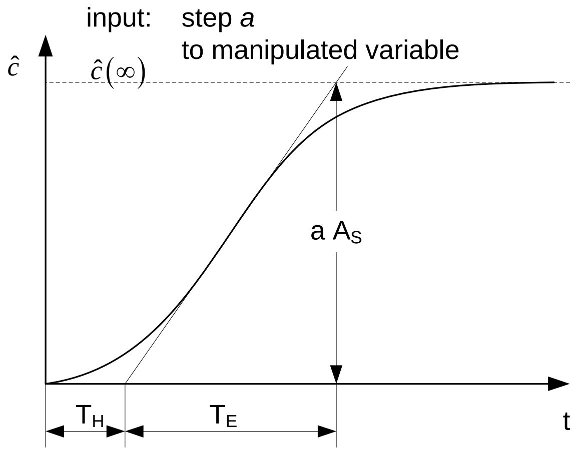


Figure 2. Step response function of a multi capacity.

Based on the recorded parameters T_H, T_E, A_S the controller parameters can be calculated as it shown in Table 1.

Controller	K	T_I	T_D
P	T_E/T_H	∞	0
PI	$0.9\ T_E/T_H$	$3.33\ T_H$	0
PID	$1.2\ T_E/T_H$	$2\ T_H$	$0.5\ T_H$

Table 1.

Recommended controller parameters are:

$$A_P=\frac{K}{A_S} \qquad A_I=\frac{A_P}{T_I} \qquad A_D=A_P T_D \tag{0.3}$$

Ziegler Nichols tuning with the cycling method

Ziegler Nichols tuning method provides recommendations for optimal controller tuning on the basis of the critical period (T_{Crit}) and critical gain ($A_{P,crit}$) of the control loop. The two parameters can be determined experimentally by the cycling method.

The experiment is the following:

1. Compile and close the control loop (see Figure 1.) Set the set point of the controller.
2. Eliminate *I* and *D* control modes (A_I=0 and A_D=0)
3. Set A_P to a small value (i.e. 0.5)
4. Apply a unit step disturbance.

5. Observe the output of the control loop (controlled variable). If no oscillation occurs, increase A_P and repeat step 4 until uniform oscillation occurs. If the amplitude of the oscillation increases, A_P must be decreased.
6. Controller gain A_P causing constant amplitude oscillation is the critical one $A_{P,crit}$. Periodical time of the oscillation is the critical period (T_{Crit}).
7. Use Table 2. to calculate the optimum controller settings.

Recommended tuning parameters

Controller	A_P	T_I	T_D
P	$0.5\ A_{P,crit}$	∞	0
PI	$0.45\ A_{P,crit}$	$T_{Crit}/1.2$	0
PID	$0.6\ A_{P,crit}$	$0.5\ T_{Crit}$	$T_{Crit}/8$

Table 2.

$$A_P = A_P \qquad A_I = \frac{A_P}{T_I} \qquad A_D = A_P T_D \tag{0.4}$$

Tasks

Aim of the laboratory practice is the determination of the optimal tuning parameters for a P, a PI and a PID controller attached to the same process. Controllers and tuning methods are compared and classified based on the tuning performance determined for each option.

During the laboratory practice, the system shown in Figure 3 is investigated. The model can be loaded from the hard disk under file name FIR03_PID.mdl. The process consisting of four unknown linear elements is controlled by a negative feedback loop. Transmitter and actuator elements are considered to be proportional ones; their gain factors are included in the black boxes. Disturbance enters the system at the manipulated variable (m), the controller (PID) keeps the controlled variable (c) at the desired level (Set point).

Control performance can be obtained from the Scope and Integrated square error (ISE) blocks. Controlled variable can be analysed in detail with the figure;plot(signal.time,signal.signals(1).values) command, typed into the MatLab's command window.

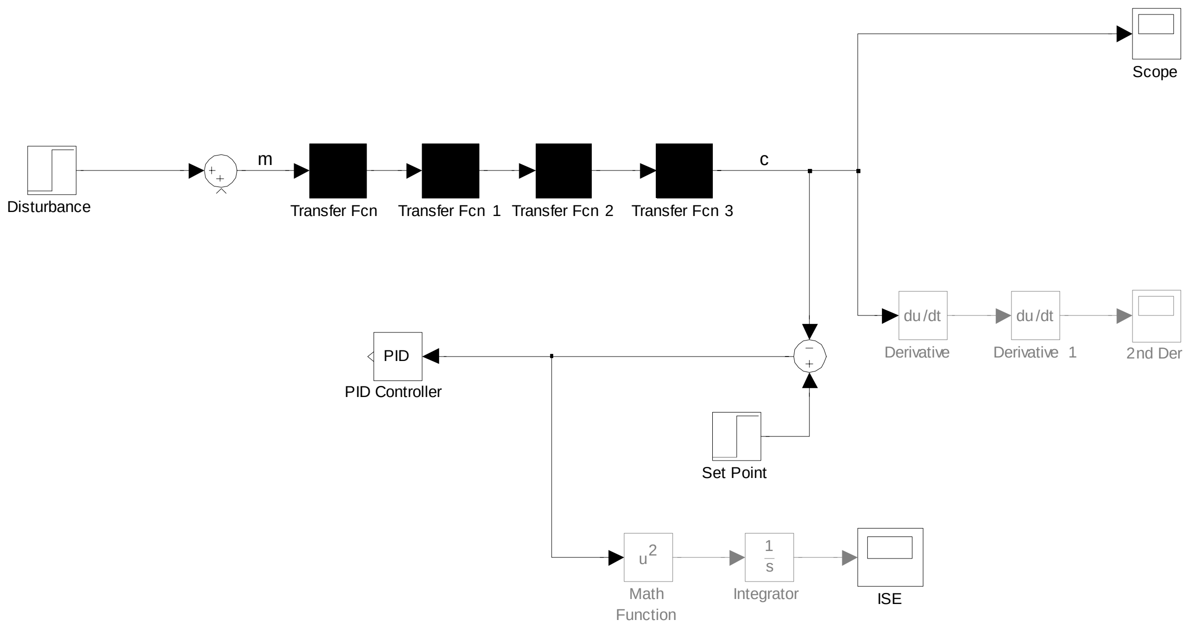


Figure 3. Model of the negative feedback loop.

T 1. Tuning based on response function

1.1. Apply a step input signal at the manipulated variable for the opened loop. View the process reaction curve.

1.2. Determine the magnitude of A_s, T_E and T_D from the curve. For the determination of the time constants, type *FIR03_resp* command[1] in the command window. Record your data and calculation results in your lab-report.

1.3. Use the parameters determined in the previous steps together with the expressions in Table 1 for the determination of the control parameters. Record your calculation results in your lab-report.

1.4. Set the optimal tuning parameters for a P controller. Run the simulation and determine the control performance (Δy_{max}, *OFF*, T_{reps}, *ISE*). Record your calculation results in your lab-report.

1.5. Repeat 1.4 for PI and PID controllers.

T 2. Ziegler Nichols method

2.1. Close the control loop, and use the cycling method to determine the value of $A_{P,crit}$.

2.2. Use the *figure* command to determine T_{Crit}.

2.3. Determine the optimal control parameters with the help of Table 2.

2.4. Set the optimal tuning parameters for a P controller. Run the simulation and determine the control performance (Δy_{max}, *OFF*, T_{reps}, *ISE*). Record your calculation results in your lab-report.

2.5. Repeat 1.4 for PI and PID controllers.

T 3. Comparison of the tuning methods and controllers

Summarize your results in your lab report. Compare the control performance of the two tuning methods, classify them. Highlight the advantages and disadvantages of the two methods.

Compare also the three controllers, P, PI, and PID. Classify them based on the control performance data. Write your conclusions to your lab report.

[1] *[The command plots the reaction curve, fits a line to the inflection point and writes the two interceptions to the screen: first_intersection, where the fitted line crosses the y=0 line, and second_intersection where the line crosses the y(inf) line.]*

Name	Controller tuning	Date

Scheme of the analysed system:

1.) Tuning base on the step response function

Magnitude of the step: ______ A_S=______ T_D=______ T_E=______

	Tuning						Characterisation			
Controller	K	A_P	T_I	A_I	T_D	A_D	Δy_{max}	OFF	T_{resp}	ISE
P										
PI										
PID										

2.) Ziegler Nichols method

$A_{P.crit}$=________ T_{Crit}=_________

Ziegler-Nichols:

	Tuning					Characterisation			
Controller	A_P	T_I	A_I	T_D	A_D	Δy_{max}	OFF	T_{resp}	ISE
P									
PI									
PID									