University of South-Eastern Norway

EXAMINATION INFORMATION PAGE
Written examination

<table>
<tr><td>Course code:
PEF3006</td><td colspan="2">Course name:
Process Control</td></tr>
<tr><td>Examination date:
30 November 2018</td><td>Examination time from/to:
09:00-13:00</td><td>Total hours:
4</td></tr>
<tr><td colspan="3">Responsible course teacher:
Docent Finn Aakre Haugen (97019215, finn.haugen@usn.no)</td></tr>
<tr><td>Campus:
Porsgrunn</td><td colspan="2">Faculty:
Faculty of Technology, Natural Sciences and Maritme Sciences</td></tr>
<tr><td>No. of problems:
8</td><td>No. of attachments:
One appendix for formulas etc.</td><td>No. of pages incl. front page and attachments: 6</td></tr>
</table>

Permitted aids:

None except paper and pen. No calculator.

If you can not calculate a numerical answer by hand, it is acceptable that you present an expression from which the correct answer can be calculated with a calculator if you had one.

Information regarding attachments:

The appendix contains information which may be useful in some of the problems. You must decide yourself which information to use.

Comments:

If you think that an assumption for solving a specific problem is missing in the text, you should state an appropriate assumption yourself.

The teacher will normally not visit the exam room during the exam time.

It is not allowed to call on the teacher to ask for help for interpreting or understanding the exam problems.

Select the type of examination paper

Spreadsheets ☐ Line sheets ☐

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Exam in Course PEF3006 Process Control

Problem 1 (15%)

Figure 1 shows a tank with a level control system. The outlet pump (the actuator) is a positive displacement pump.

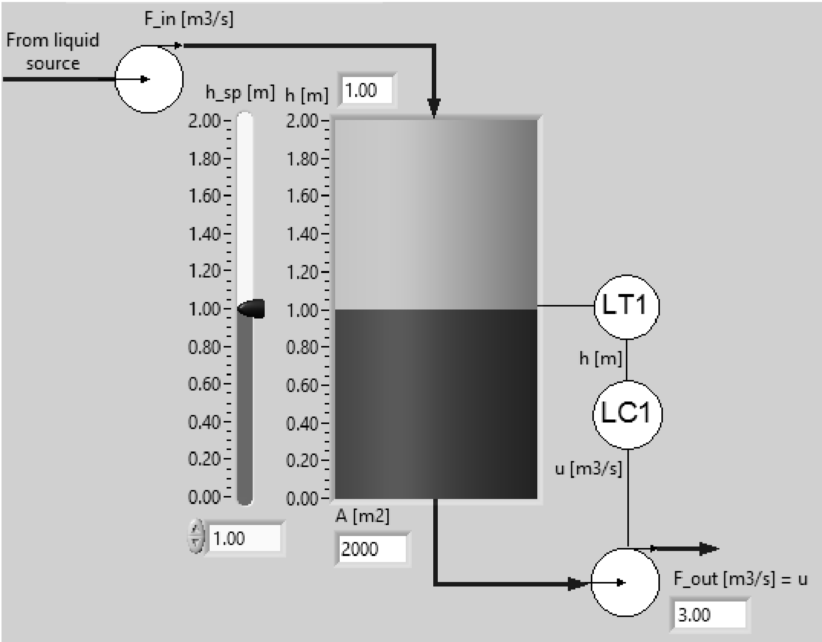

Figure 1

The process model is the following differential equation of the liquid level, derived from mass balance:

$$A*dh/dt = F_{in} - F_{out} = F_{in} - u$$

where u is the control signal generated by the level controller. The liquid surface area (tank cross-sectional area) is A = 2000 m^2.

Assume that the tank is a buffer tank aiming at attenuating inflow variations, i.e. the outflow becomes smoother than the inflow. It is specified that the level is reduced by less than 0.5 m after a stepwise reduction of the inflow of step amplitude 1 m^3/s. Tune LC1 as a PI controller. For your answer you may use the following design formula for the closed loop time-constant:

$$T_c = A*\Delta h_{max}/\Delta F_{in}$$

Problem 2 (30%)

Assume the tank in Figure 1 is used as a storage tank aiming at keeping the level at or close to its setpoint, h_{sp}. The liquid surface area (tank cross-sectional area) is A = 2000 m2.

a (10%) Assume that the dynamics of the outlet pump is represented by a time-delay τ = 10 s. Tune LC1 as a PI controller.

b (10%) F_{in} is regarded as a process disturbance. Derive a feedforward controller for the level control system.

c (5%) Shall LC1 have direct or reverse control action? Give a reason for your answer.

d (5%) Assume that the outflow pump manipulated by the level controller is a centrifugal pump. The flow through a centrifugal pump is *not* given by the rotational speed of the pump alone. Instead, the flow depends on the rotational speed and “environmental variables” or disturbances like variations of the pressure

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difference across the pump inflow and outflow. Thus, if the level controller manipulates the rotational speed of the pump directly, it may happen that the actual pump flow varies due to disturbances. Assume that such flow variations are unfortunate, and that we want the actual pump flow to follow the flow demanded by the level controller (= flow setpoint) closely, despite the disturbances. Suggest an amendment of the level control structure shown in Figure 1 to obtain the aim that the actual pump flow becomes equal (or very close to) to the flow demanded by the level controller. Your answer should be in form of a Piping and Instrumentation Diagram (P&I D) of the (amended) level control system.

Problem 3 (10%)

Explain, and supplement with a figure, the principle (the behaviour) of a model-based predictive controller (MPC). Why is a state estimator an important part of an MPC?

Problem 4 (5%)

Figure 2 shows the response in the methane flow after a setpoint change in a methane flow control system of a biogas reactor. The controller is a PI controller with controller gain = 2 (in appropriate units) and Ti = 0.8 d. The stability of the control system is deemed too bad. Retune the PI controller from the response.

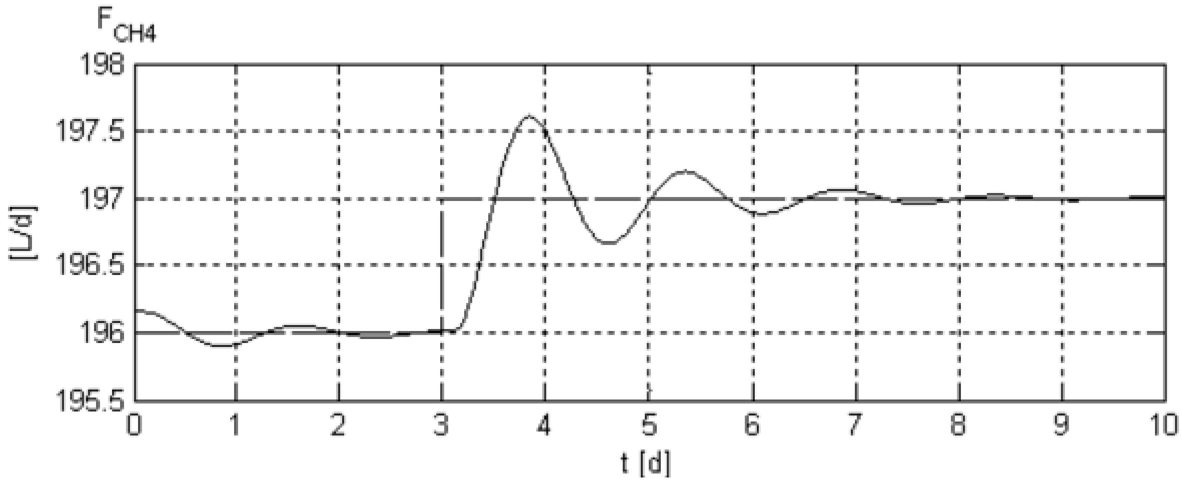

Figure 2

Problem 5 (5%)

Describe the (three) main elements of a sequential function chart (SFC), and include one example for each element. Also, show how these elements appear in an SFC (however, it is not necessary to draw a complete SFC).

Problem 6 (5%)

Why are PI controllers more often used than PID controllers in practical control systems?

Why are PI controllers more often used than P controllers in practical control systems?

Problem 7 (10%)

Derive the transfer function H(s) = u(s)/e(s) of a PID controller.

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Problem 8 (20%)

Typical basic control requirements of a continuous production line are as follows:

1. The product flow is controlled (to follow its setpoint).
2. The product quality is controlled.
3. The mass (of liquid, gas) in vessels are controlled.
4. The temperature of vessels or pipelines are controlled.

Draw a Piping & Instrumentation Diagram of a production line (imaginary or real) which is controlled according to the above requirements.

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Appendix for the exam in PEF3006 Process Control 30.11 2018:

Formulas etc. which may be useful at the exam

$$\frac{dm(t)}{dt} = \sum_i w_i(t) \tag{1}$$

$$\frac{dE(t)}{dt} = \sum_i Q_i(t) \tag{2}$$

$$E = CT = cmT = c\rho VT \tag{3}$$

$$Q = cFT \tag{4}$$

$$m\dot{v}(t) = m\ddot{x}(t) = ma(t) = \sum_i F_i(t) \tag{5}$$

$$k_1F_1(s) + k_2F_2(s) \Longleftrightarrow k_1f_1(t) + k_2f_2(t) \tag{6}$$

$$F(s)e^{-\tau s} \quad \Longleftrightarrow \quad f(t-\tau) \tag{7}$$

$$s^nF(s) \quad \Longleftrightarrow \quad \overset{(n)}{f}(t) \tag{8}$$

$$\frac{k}{s} \quad \Longleftrightarrow \quad k \qquad \text{(step of amplitude } k\text{)} \tag{9}$$

$$\frac{k}{s^2} \quad \Longleftrightarrow \quad kt \qquad \text{(ramp of slope } k\text{)} \tag{10}$$

$$\frac{k}{Ts+1} \quad \Longleftrightarrow \quad \frac{ke^{-t/T}}{T} \tag{11}$$

$$\frac{k}{(Ts+1)s} \quad \Longleftrightarrow \quad k\left(1-e^{-t/T}\right) \tag{12}$$

$$y(s) = H(s)u(s) \tag{13}$$

$$y(t) = K\int_0^t u\,d\tau \Longleftrightarrow y(s) = \underbrace{\frac{K}{s}}_{H(s)}u(s) \tag{14}$$

$$y(s) = \underbrace{\frac{K}{Ts+1}}_{H(s)}u(s) \tag{15}$$

$$y(t) = u(t-\tau) \Longleftrightarrow y(s) = \underbrace{e^{-\tau s}}_{H(s)} u(s) \tag{16}$$

$$T_r \approx \sum_i T_i \tag{17}$$

$$u = u_0 + \overbrace{\underbrace{K_p e}_{u_p} + \underbrace{\frac{K_p}{T_i}\int_0^t e\,d\tau}_{u_i} + \underbrace{K_p T_d \frac{de}{dt}}_{u_d}}^{u_e} \tag{18}$$

$$P_B = \frac{100\%}{K_p} \tag{19}$$

$$K_p = 0.8 K_{GG} \tag{20}$$

$$T_i = 1.5 T_{ou} \tag{21}$$

Process type	$H_{psf}(s)$ (process)	K_p	T_i	T_d
Integrator with delay	$\frac{K_i}{s}e^{-\tau s}$	$\frac{1}{K_i(T_C+\tau)}$	$2\,(T_C+\tau)$	0
Time-constant with delay	$\frac{K}{Ts+1}e^{-\tau s}$	$\frac{T}{K(T_C+\tau)}$	$\min\,[T,\,2\,(T_C+\tau)]$	0

$$K_i = \frac{S}{U} \tag{22}$$

$$T_C = \tau \tag{23}$$

	K_p	T_i	T_d
P	$0,5K_{p_u}$	∞	0
PI	$0.45K_{p_u}$	$\frac{P_u}{1,2}$	0
PID	$0.6K_{p_u}$	$\frac{P_u}{2}$	$\frac{P_u}{8} = \frac{T_i}{4}$

	K_p	T_i	T_d
PI	$0.32K_{p_u}$	P_u	0

Instrumentation codes:

As first letter: F = Flow. L = Level. P = Pressure. Q = Quality. T = Temperature.

As subsequent letter: C = Controller. I = Indicator. T = Transmitter (sensor). V = Valve. Y = Function (math).