University College of Southeast Norway

EXAMINATION INFORMATION PAGE
Written examination

Course code: PEF3006	Course name: Process Control	
Examination date: 04 December 2017	Examination time from/to: 09:00-13:00	Total hours: 4
Responsible course teacher: Docent Finn Aakre Haugen		
Campus: Porsgrunn	Faculty: Faculty of Technology, Natural Sciences and Maritme Sciences	
No. of problems: 11	No. of attachments: One (Appendix no. 1)	No. of pages incl. front page and attachments: 6

Permitted aids:

None except paper and pen. No calculator.

If you can not calculate a numerical answer by hand, it is sufficient for an acceptable answer that you set up 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.

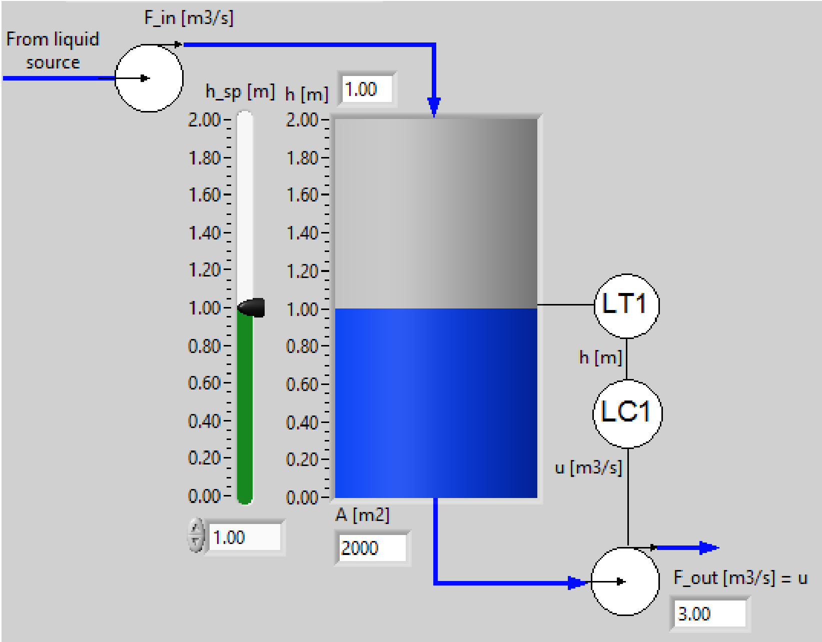
Select the type of examination paper

Spreadsheets ☐ Line sheets ☐

CANDIDATES MUST THEMSELVES CHECK THAT ALL ASSIGNMENTS AND ATTACHMENTS ARE IN ORDER.

Exam in Course PEF3006 Process Control

Problem 1 (20%)
Figure 1 shows a level control system of a liquid tank.



Figur 1

A mathematical model for the liquid level, based on mass balance, is

$$A\frac{dh}{dt} = F_{in} - F_{out}$$

Assume that the controller is a P controller:

$$u = K_c e = K_c(h_{sp} - h)$$

where u [m^3/s] is control signal and e [m] is level control error. Assume $F_{out} = u$.

a (2%) Show that the following model is the model of the level control system:

$$A\frac{dh}{dt} = F_{in} - K_c(h_{sp} - h)$$

b (5%) Assume static conditions, i.e. all variables have constant values. Express the static level value, h_s, as a function of the level setpoint h_{sp} and the inflow F_{in}.

c (5%) Generally, the transfer function from the setpoint to the process output variable is denoted the tracking transfer function, here symbolized with $M(s)$. Show that for the level control system, $M(s)$ is

$$M(s) = \frac{h(s)}{h_{sp}(s)} = \frac{-K_c}{As - K_c}$$

d (4%) From $M(s)$, find the time-constant, T_c, of the control system, and then express the controller gain, K_c, as a function of T_c.

e (2%) Poles of a transfer function are defined as the roots of the denominator polynomial of the transfer function. (The poles are the same as the eigenvalues of an equivalent state space model.) Show that the pole of $M(s)$ is

$$p = K_c/A$$

f (2%) A dynamic system is stable (strictly: asymptotically stable) if all its poles (or eigenvalues) have strictly negative real parts. For the level control system: Is it necessary that K_c is positive (i.e. the controller has reverse action mode) or negative (i.e. direct action mode) for the control system to be stable?

Problem 2 (10%)
Explain, and supplement with a figure, the principle (the behaviour) of a model-based predictive controller (MPC). Why is a state estimator, which is typically in the form of a Kalman filter, an important part of an MPC?

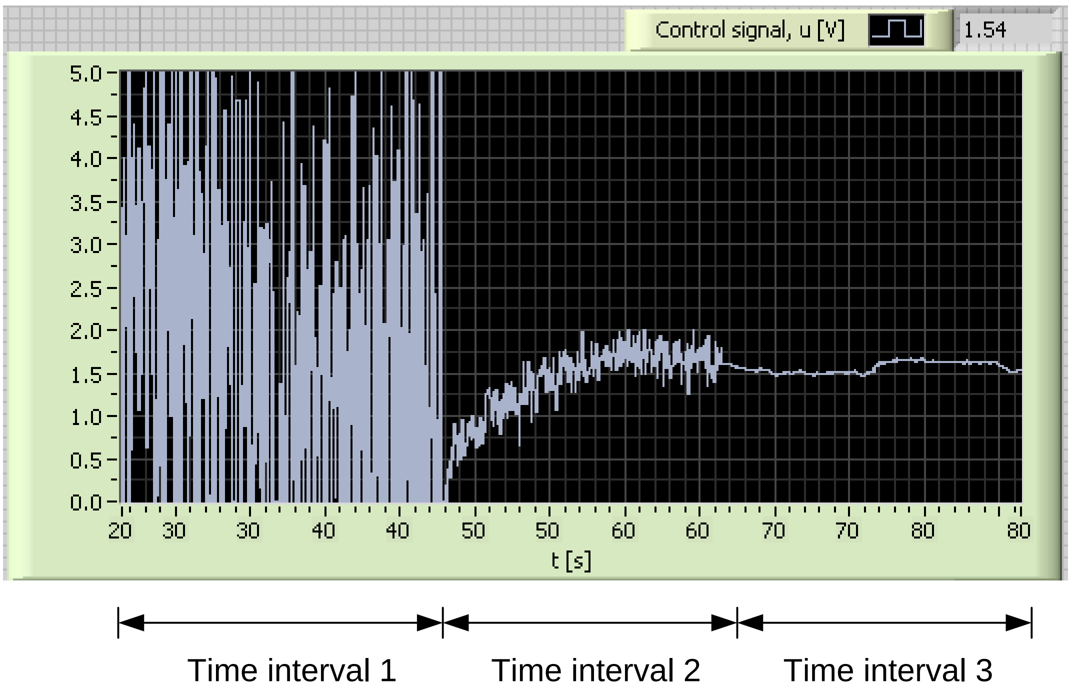
Problem 3 (5%)
What is the purpose of ratio control? Draw a Piping & Instrumentation diagram of a general ratio control system. Also, describe briefly an example of a process that requires ratio control.

Problem 4 (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 5 (5%)
A PI controller for a given process is to be tuned with the Skogestad method. When the process is excited by a step of amplitude 20% in the control signal, the response in the process measurement first shows a time delay of 1 min, and then (after the time delay has elapsed) the response rises as a ramp with a slope of 10%/min. Find appropriate PI settings.

Problem 6 (5%)
Given a process controlled by a P controller with gain equal to 2. The measured process output oscillates with a fixed amplitude and a period of 60 sec. Find appropriate PI settings.

Problem 7 (5%)
Figure 2 shows the control signal to the heating element of an air heater process which is temperature controlled. Below the plot, three time intervals are indicated.



Figur 2

For each of these time intervals, select - with an explaination of your selection - which of the following three controllers that is applied. (1) PID controller with measurement filter. (2) PI controller with measurement filter. (3) PID controller without measurement filter. (Answers without explanation are not honoured.)

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Problem 8 (10%)
a (7%) Draw a block diagram that shows the combination of feedforward control and feedback control of a process. Describe briefly how the combined control system works.
b (3%) List three examples of process disturbances which may be good candidates for feedforward control.

Problem 9 (10%)
Figure 3 shows a tank with two inlet flows. The level of tank should be controlled by manipulation of the flow F_A. It is specified that the ratio between the flows is $F_B/F_A = K$ (where K is specified). Assume that there are local flow control loops around the valves.

Draw a Piping & Instrumentation diagram of a control system according to the above requirements.

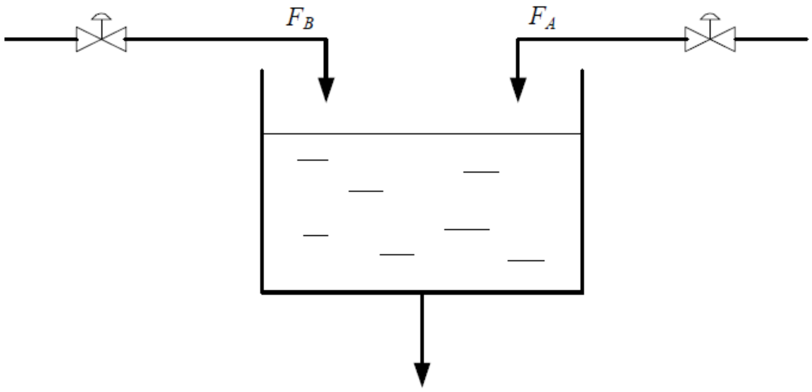

Figure 3

Problem 10 (5%)
Explain how to decide whether a PID controller shall have reverse or direct action, and give one example where you select between reverse and direct action. What is the consequence of selecting wrong between reverse and direct action (you may relate your answer to your example).

Problem 11 (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 1

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Process type	$H_{psf}(s)$ (process)	K_p	T_i	T_d
Integrator with delay	$\frac{K}{s}e^{-\tau s}$	$\frac{1}{K(T_C+\tau)}$	$c\,(T_C+\tau)$	0
Time-constant with delay	$\frac{K}{Ts+1}e^{-\tau s}$	$\frac{T}{K(T_C+\tau)}$	$\min\left[T,\, c\,(T_C+\tau)\right]$	0
Two time-const with delay	$\frac{K}{(T_1 s+1)(T_2 s+1)}e^{-\tau s}$	$\frac{T_1}{K(T_C+\tau)}$	$\min\left[T_1,\, c\,(T_C+\tau)\right]$	T_2

$$c = 2 \tag{22}$$

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

$$K_{p_p} = K_{p_s}\left(1 + \frac{T_{d_s}}{T_{i_s}}\right) \tag{24}$$

$$T_{i_p} = T_{i_s}\left(1 + \frac{T_{d_s}}{T_{i_s}}\right) \tag{25}$$

$$T_{d_p} = T_{d_s}\frac{1}{1 + \frac{T_{d_s}}{T_{i_s}}} \tag{26}$$

	K_p	T_i	T_d
P-regulator	$0,5K_{p_u}$	∞	0
PI-regulator	$0,45K_{p_u}$	$\frac{P_u}{1,2}$	0
PID-regulator	$0,6K_{p_u}$	$\frac{P_u}{2}$	$\frac{P_u}{8} = \frac{T_i}{4}$

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