Telemark University College
Faculty of Technology

FINAL EXAM

COURSE: PEF3006 Process Control

LECTURER: Finn Aakre Haugen

The grade on this exam counts 100% in the final grade in this course.

CLASS(ES): 2EET, 2PT	**DATE: 11. Dec. 2014**	**TIME: 4 hours**	
Problem description includes:	**Number of pages (including this front page): 6**	**Number of problems: 8**	**Number of attachments: 1 (appendix)**
Accepted tools: None except paper and pen.	**The teacher will normally not visit the exam room during the exam time.**		
IT IS THE RESPONSIBILITY OF EACH CANDIDATE TO CHECK THAT THE PROBLEM DESCRIPTION IS COMPLETE AND IN ACCORDANCE WITH THE ABOVE MENTIONED SPECIFICATIONS. **Please use ball point pen (unless the exam is computer based). It is vital that the examiner is able to read your problem solution in full detail.**			

Telemark University College

Exam in Course PEF3006 Process Control

Date: 11. December 2014. Duration: 4 hours. Exam aids: None. Weight: 100% of course grade.

Teacher: Finn Aakre Haugen.

The teacher will normally not visit the exam room.

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

The appendix contain a list of formulas and a list of letter codes for P&I Ds (Piping & Instrumentation Diagrams) which may be useful in some of the problems. You must decide yourself which information to use.

You can answer in Norwegian or in English.

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1. Figure 1 shows a liquid tank with continuous liquid inflow and outflow. Homogeneous conditions in the liquid is assumed. A

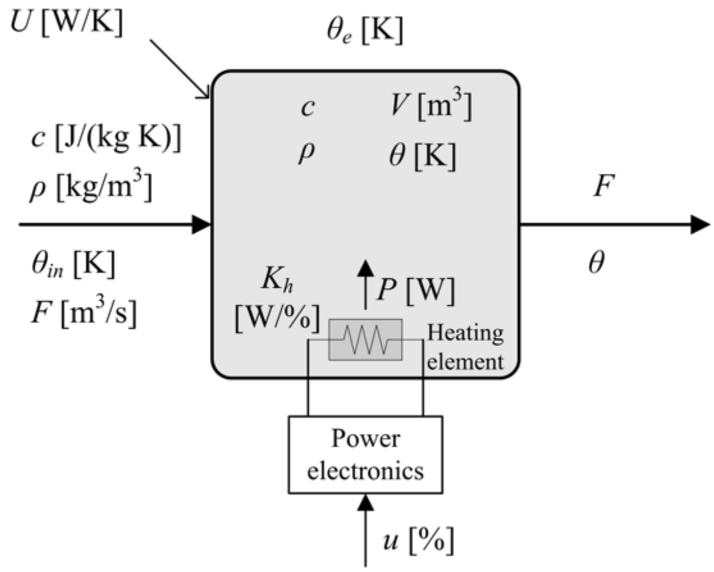

Figure 1: Liquid tank

mathematical model of the liquid temperature based on energy balance is

$$c\rho V\dot{\theta}(t) = \underbrace{K_h u(t-\tau)}_{P} + c\rho F\left[\theta_{in}(t) - \theta(t)\right] + U\left[\theta_e(t) - \theta(t)\right] \quad (1)$$

where τ [s] is a time-delay.

(a) (10% weight) Show that the transfer function from u to θ is

$$H(s) = \frac{\theta(s)}{u(s)} = \frac{K_h}{c\rho V s + c\rho F + U} e^{-\tau s} \quad (2)$$

(b) (10%) Find the gain, K, and the time-constant, T, of the transfer function Eq. (2).

2. Assume that the tank temperature in Figure 1 is to be controlled by a PI controller. The temperature measurement used by the controller is in unit of K, and the control signal generated by the controller is u in unit of %.

   (a) (5%) Draw a P&I D of the control system.

   (b) (10%) Tune the PI controller using the Skogestad tuning method assuming $F = 0$ and $U = 0$ in Eq. (2). (It can be shown that assuming these parameter values for the controller tuning, the control system will be stable for any non-zero values of F and U. In other words, the tuning will be robust, of safe. Thus, the assumption is beneficial.)

   (c) (10%) Assume that the control system also includes feedforward control. Derive a feedforward controller from Eq. (1), assuming for simplicity that $\tau = 0$. Assume that the temperature setpoint is θ_{SP}. Does your feedforward controller require that some variables are measured with sensors to make it (the feedforward controller) implementable? Which variables?

3. (10%) 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. Tune a PI controller for the process.

4. (5%) Why are most PID controllers used as PI controllers in practical control systems?

5. (15%) Draw a general block diagram of a cascade control system (it is not necessary to assume a specific process). Explain how the system works. What is the main benefit of cascade control comparing with single loop control?

6. (10%) Give one practical example of a control system where the controller must have direct action (draw a P&I D of the control system), and explain why direct action is needed in the example. What is the consequence of selecting reverse action instead of direct action in the example?

7. (5%) Draw a P&I D of a general ratio control system. What is the purpose of ratio control?

8. (10%) List the (three) main elements of a sequential function chart (SFC). Describe briefly the purpose of each of these elements.

APPENDIX

$$\frac{dm(t)}{dt} = \sum_i w_i(t) \tag{3}$$

$$\frac{dE(t)}{dt} = \sum_i Q_i(t) \tag{4}$$

$$E = CT = cmT = c\rho VT \tag{5}$$

$$Q = cFT \tag{6}$$

$$m\dot{v}(t) = m\ddot{x}(t) = ma(t) = \sum_i F_i(t) \tag{7}$$

$$k_1F_1(s) + k_2F_2(s) \Longleftrightarrow k_1f_1(t) + k_2f_2(t) \tag{8}$$

$$F(s)e^{-\tau s} \quad \Longleftrightarrow \quad f(t-\tau) \tag{9}$$

$$s^nF(s) \quad \Longleftrightarrow \quad \overset{(n)}{f}(t) \tag{10}$$

$$\frac{k}{s} \quad \Longleftrightarrow \quad k \qquad \text{(step of amplitude } k\text{)} \tag{11}$$

$$\frac{k}{s^2} \quad \Longleftrightarrow \quad kt \qquad \text{(ramp of slope } k\text{)} \tag{12}$$

$$\frac{k}{Ts+1} \quad \Longleftrightarrow \quad \frac{ke^{-t/T}}{T} \tag{13}$$

$$\frac{k}{(Ts+1)s} \quad \Longleftrightarrow \quad k\left(1 - e^{-t/T}\right) \tag{14}$$

$$y(s) = H(s)u(s) \tag{15}$$

$$y(t) = K\int_0^t u\,d\tau \Longleftrightarrow y(s) = \underbrace{\frac{K}{s}}_{H(s)} u(s) \tag{16}$$

$$y(s) = \underbrace{\frac{K}{Ts+1}}_{H(s)} u(s) \tag{17}$$

$$y(t) = u(t-\tau) \Longleftrightarrow y(s) = \underbrace{e^{-\tau s}}_{H(s)} u(s) \tag{18}$$

$$T_r \approx \sum_i T_i \tag{19}$$

$$u = u_0 + \overbrace{\underbrace{K_p e}_{u_p} + \underbrace{\frac{K_p}{T_i}\int_0^t e\,d\tau}_{u_i} + \underbrace{K_p T_d \frac{de}{dt}}_{u_d}}^{u_e} \tag{20}$$

$$P_B = \frac{100\%}{K_p} \tag{21}$$

$$K_p = 0.8 K_{GG} \tag{22}$$

$$T_i = 1.5 T_{ou} \tag{23}$$

Process type	$H_{psf}(s)$ (process)	K_p	T_i	T_d
Integrator + delay	$\frac{K}{s}e^{-\tau s}$	$\frac{1}{K(T_C+\tau)}$	$c\,(T_C+\tau)$	0
Time-constant + 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 + 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

$$c = 2 \tag{24}$$

$$T_C = \tau \tag{25}$$

$$K_{p_p} = K_{p_s}\left(1 + \frac{T_{d_s}}{T_{i_s}}\right) \tag{26}$$

$$T_{i_p} = T_{i_s}\left(1 + \frac{T_{d_s}}{T_{i_s}}\right) \tag{27}$$

$$T_{d_p} = T_{d_s}\frac{1}{1 + \frac{T_{d_s}}{T_{i_s}}} \tag{28}$$

	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	$0.6K_{p_u}$	$\frac{P_u}{2}$	$\frac{P_u}{8} = \frac{T_i}{4}$

Table 1 shows the most commonly used letter codes used in Piping & Instrumentation Diagrams (P&I Ds).

	As first letter	As subsequent letter
A	Alarm	
C		Controller
D	Density. Difference	
F	Flow. Fraction (ratio)	
G	Position	
H	Hand controlled	
I		Indicator
L	Level	
P	Pressure	
Q	Quality	
S	Speed	
T	Temperature	Transmitter (sensor)
V	Viscosity	Valve
Y		Function (e.g. mathematical)
Z		Secure control (e.g. interlock)

Table 1: Common letter codes used in Piping&Instrumentation Diagrams