Høgskolen i Telemark

Avdeling for teknologiske fag

FINAL EXAM

COURSE: PEF3006 Process Control

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

CLASS(ES): 2EET, 2PT	**DATE:** **7. Dec. 2015**	**TIME: 4 hours**	
Problem description includes:	**Number of pages (including this front page): 7**	**Number of problems: 10**	**Number of attachments: 1 (appendix)**
Accepted tools: None except paper and pen.	**The teacher will 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: 7. December 2015. Duration: 4 hours. Exam aids: None. Weight: 100% of course grade.

Teacher: Finn Aakre Haugen (finn.haugen@hit.no).

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 table of letter codes for Piping & Instrumentation diagrams (P&IDs) 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.

Problem 1 (8%)

The mathematical model of the wood-chip tank studied frequently in the course is:

$$\rho A\dot{h}(t) = K_s u(t-\tau) - w_{out}(t)$$

where ρ, A, K_s and τ are parameters. h is level, u is control signal to the feed screw, and w_{out} is the outflow of wood-chip from the tank.

Calculate the transfer function, $H_1(s)$, from u to h, and the transfer function, $H_2(s)$, from w_{out} to h.

Characterize (in qualitative terms) the dynamic properties of $H_1(s)$.

Problem 2 (12%)

a) (5%) Show in a figure (a hand-drawn plot) how the gain (K) and the time-constant (T) of a time-constant system appear in the step response of the system.

b) (4%) Find the gain and the time-constant of the following model:

$$dy/dt = -2y + 5u$$

c) (3%) Assume that two time-constant systems having gains K_1 and K_2, and time-constants T_1 and T_2, respectively, are connected in series. What is the overall gain of the resulting (serial connected) system, and what is the overall approximate time-constant?

Problem 3 (8%)

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 (10%)

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 (15%)

a) (10%) Describe feedforward control (with words and a block diagram), and give one example illustrated with Piping & Instrumentation diagram (you do not have to derive the feedforward controller function for your example).

b) (5%) Given the following process model:

   dy/dt = A*y + B*u + C*d

   where y is the prosess ouput variable, u is the control signal, d is a process disturbance, and A, B, and C are parameters. The setpoint of y is y_{sp}.

   Design (derive) the feedforward control function. Which quantities must have known values to make the feedforward control function implementable?

Problem 6 (5%)

Assume given a water tank with level control. The tank has an inlet pipeline and an outlet pipeline. An air-operated membrane control valve is in the outlet pipeline. The level controller is a PI controller. The control signal out of the controller generates a proportional air pressure operating the valve. The valve has a so-called Fail Open operation mode: The valve becomes open if the energy supply to the valve fails — here: if the air supply used to operate the valve fails.

Decide whether the PI controller shall have reverse or direct action. You must explain your answer (an answer without explanation will not be credited).

Problem 7 (10%)

Most feedback control systems become less stable if the control system loop gain increases and/or if the time-delay increases.

a) (3%) Give one practical example of increased loop gain (but select a different example than increased controller gain) and one practical example of increased loop time-delay.

b) (7%) Assume that for a given control system, the gain of the process has increased by a factor of 3 while the process time-delay has increased by a factor of 2. The controlller is a PI controller with satisfactory parameter settings (K_{p0}, T_{i0}) before these parameter changes. Calculate updated settings (K_{p1}, T_{i1}) which should be used after the parameter changes.

Problem 8 (7%)

Figure 1 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.

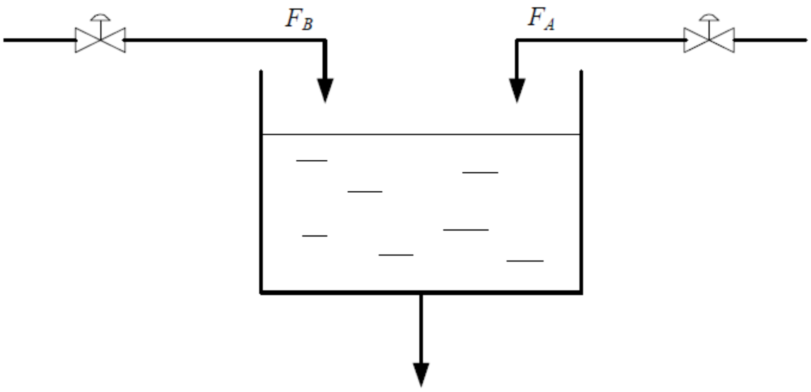

Figure 1

Problem 9 (10%)

Figure 2 shows a control valve used to manipulate the heating medium (liquid) flow into an heat exchanger where the product temperature is to be controlled using a temperature controller. The output of the temperature controller is a flow command signal to the valve, and the output of the flow controller is a valve stem position command to the stem moving mechanism.

Draw a Piping & Instrumentation diagram of the total control system according to the above requirements. You can use symbol G for position of the valve stem.

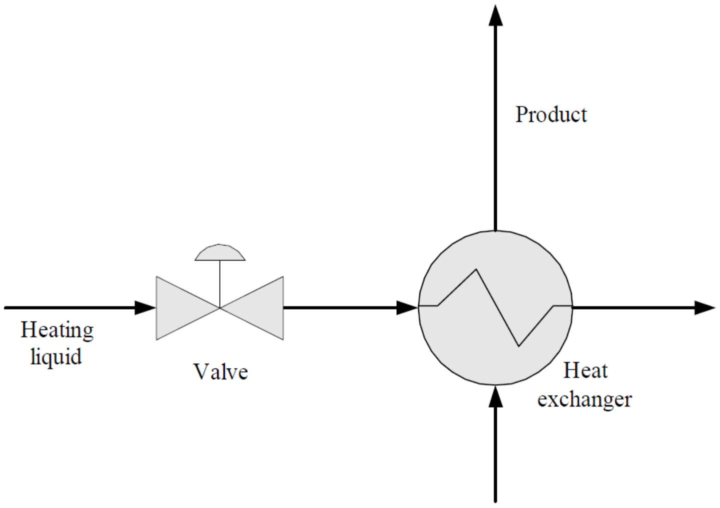

Figure 2

Problem 10 (15%)

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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PEF3006 Process Control: Formulas for exa®

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Process type	$H_{psf}(s)$ (process)	K_p	T_i	T_d
Integrator with delay	$\frac{K}{s}e^{-\tau s}$	$\frac{1}{K(T_C+\tau)}$	$c\,(T_C+\tau)$	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	$\frac{K}{(T_1s+1)(T_2s+1)}e^{-\tau s}$	$\frac{T_1}{K(T_C+\tau)}$	$\min\left[T_1,\ c\,(T_C+\tau)\right]$	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	$0,6K_{p_u}$	$\frac{P_u}{2}$	$\frac{P_u}{8} = \frac{T_i}{4}$

	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