Telemark University College
Faculty of Technology

FINAL EXAM

COURSE: PEF3006 Process Control

LECTURER: Finn Haugen

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

CLASS(ES): 2EET, 2PT	**DATE: 17. Dec. 2013**	**TIME: 4 hours**	
Problem description includes:	**Number of pages (including this front page): 5**	**Number of problems: 13**	**Number of attachments: 1**
Accepted tools: None except paper and pen.	**The teacher will not be visiting 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: 17. December 2013. Duration: 4 hours. Exam aids: None. Weight: 100% of course grade.

Teacher: Finn Haugen.

The teacher will 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 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. (10% weight) Draw a (general) block diagram of a feedback control system. Describe the function (purpose) of each of the blocks and signals in your block diagram.

2. (10%) Draw a Process & Instrumentation Diagram (P&ID) for one concrete example of a feedback control system (the example may be simple). Explain how the control systems works.

3. (5%) Find the transfer function from u to y for the following differential equation:

$$a\dot{y}(t) = bu(t - \tau) - y(t) + cd(t) \tag{1}$$

4. (5%) Explain why a P (proportional) controller typically gives non-zero steady-state (static) control error.

5. (5%) Comparing on-off control and PI control: List important benefits and drawbacks of the two controllers.

6. (5%) Why is a measurement filter needed in most practical control systems?

7. (10%) Describe the Ziegler-Nichols method for PI controller tuning.

8. (10%) Tune a PI controller for a process which has the following step response: When the step amplitude is 10%, the response in the process output measurement is time-delayed 5 sec. After the time-delay has elapsed, the response is like a ramp having slope 20%/s.

9. (10%) Describe cascade control, and give one concrete example (draw a P&ID).

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).

11. (5%) Describe split-range control, and give one example (draw a P&ID).

12. (10%) Given the following process model:

$$\dot{y}(t) = a\sqrt{y(t)} + bu(t) + cd(t) \tag{2}$$

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?

13. (10%) Explain why reducing the measurement span (range) of a sensor which is used to measure the process output variable, can cause stability problems for a control loop. (Assume that the measurement signal connected to the controller, covers the standard range of milliamperes, i.e. 4-20 mA, before and after the change of the span.)

APPENDIX

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

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

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

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

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

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

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

$$s^n F(s) \iff \overset{(n)}{f}(t) \tag{10}$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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	$\frac{K}{Ts+1}e^{-\tau s}$	$\frac{T}{K(T_C+\tau)}$	$\min\,[T,\ c\,(T_C+\tau)]$	0
Two time-const + delay	$\frac{K}{(T_1s+1)(T_2s+1)}e^{-\tau s}$	$\frac{T_1}{K(T_C+\tau)}$	$\min\,[T_1,\ c\,(T_C+\tau)]$	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.

	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