University College of Southeast Norway

EXAMINATION INFORMATION PAGE
Written examination

Subject code: PEF3006	Subject name: Process Control	
Examination date: 14 December 2016	Examination time from/to: 09:00-13:00	Total hours: 4
Responsible subject teacher: Docent Finn Aakre Haugen		
Campus: Porsgrunn	Faculty: Technology	
No. of problems: 10	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 (10%)
Derive the transfer function from control error *e* to control signal *u* of a PID controller.

Problem 2 (10%)
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.

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 (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 (10%)
Figure 1 shows a wood chip tank with a feed screw and a conveyor belt (the belt has constant speed). The level is to be controlled. The control signal u acts on the feed screw (making it rotate). There is a torque disturbance acting on the screw causing variations in the screw rotational speed. This disturbance can not be measured directly. There is another disturbance — a flow disturbance — acting between the screw and the belt causing variations in the mass flow. This flow disturbance can be measured directly and continuously with an appropriate sensor.

Design an appropriate control structure for this process, and draw a Piping & Instrumentation Diagram for your solution. (Your answer may consist of the diagram with a short explanation of the structure.)

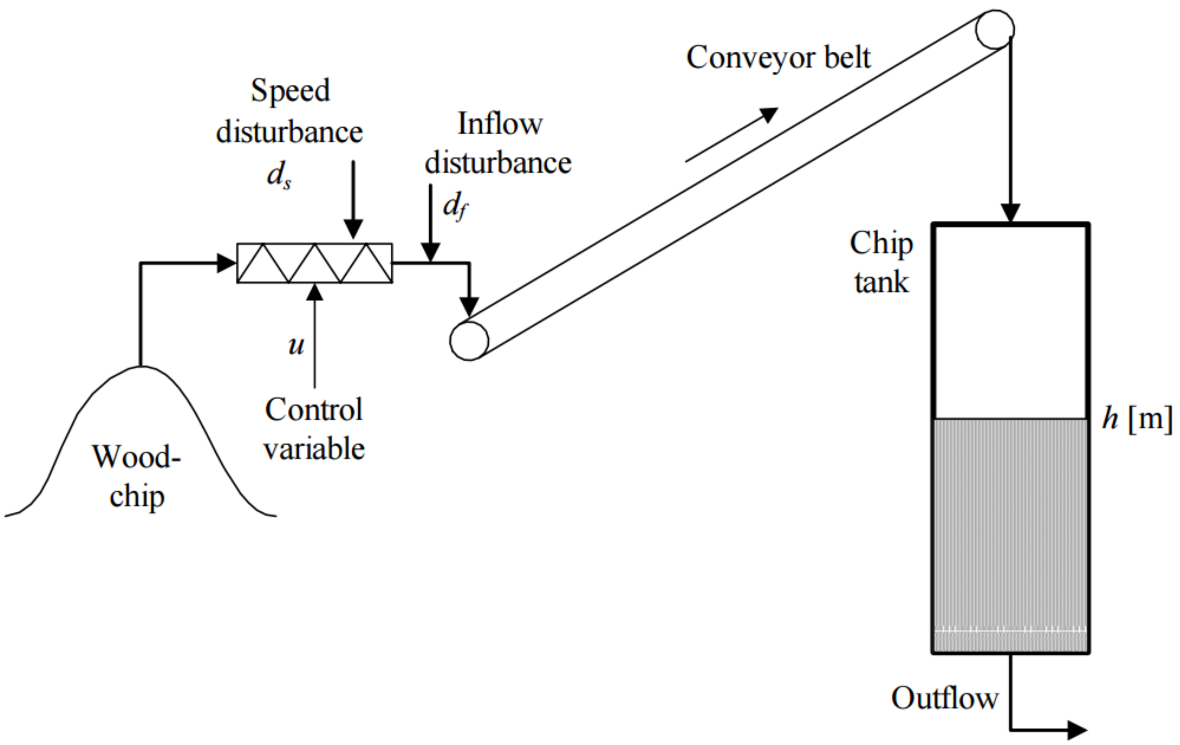

Figure 1

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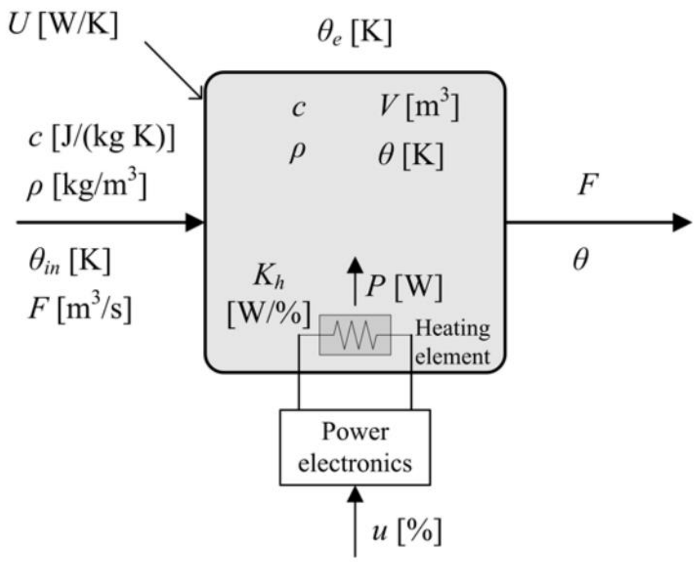
Problem 6 (5%)
Why are PI controllers more often used than PID controllers in practical control systems?
And why are PI controllers more often used than P controllers in practical control systems?

Problem 7 (10%)
Describe the Ziegler-Nichols (ZN) method (also named the ZN closed loop method, or the ZN ultimate gain method) of PI controller tuning. How is "acceptable resulting stability" of the control system defined by Ziegler and Nichols?

Problem 8 (10%)
Figure 2 shows a liquid tank with continuous liquid inflow and outflow. A mathematical model of the liquid temperature based on energy balance is given below.

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

where τ [s] is a time-delay.
The time-delay represents the effect of imperfect mixing, i.e. the observed time-delay from some change in the control signal of the heating element to the corresponding change in the temperature measurement.



Figur 2

Assume that the tank temperature is to be controlled by feedforward control in addition to feedback control. Derive a feedforward controller, neglecting time-delay (i.e. assuming it is zero). Which measurements does your feedforward controller require (to be realizable)?

(A comment about the time-delay in the given model: If the time-delay is not neglected in the derivation of the feedforward controller, it turns out that the feedforward controller will be a function of *future* values of pertinent variables, which may be impossibe to implement in practice. A feedforward controller neglecting the time-delay may still be useful.)

Problem 9 (10%)
Assume that for a given control system, the process gain has increased by a factor of 3 while the process time-delay has increased by a factor of 2. The controller is a PI controller with satisfactory parameter settings (K_{p0}, T_{i0}) before the process parameter values changed. Calculate updated settings (K_{p1}, T_{i1}) which should be used after the process parameter values changed.

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Problem 10 (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.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

$$T_r \approx \sum_i T_i \quad (17)$$

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

$$P_B = \frac{100\%}{K_p} \quad (19)$$

$$K_p = 0.8 K_{GG} \quad (20)$$

$$T_i = 1.5 T_{ou} \quad (21)$$

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

$$c = 2 \quad (22)$$

$$T_C = \tau \quad (23)$$

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

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

$$T_{d_p} = T_{d_s}\frac{1}{1 + \frac{T_{d_s}}{T_{i_s}}} \quad (26)$$

	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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