University of South-Eastern Norway

EXAMINATION INFORMATION PAGE
Written examination

Course code: PEF3006	Course name: Process Control	
Examination date: 4th December 2019	Examination time from/to: 09:00-13:00	Total hours: 4
Responsible course teacher: Docent Finn Aakre Haugen (97019215, finn.haugen@usn.no)		
Campus: Porsgrunn	Faculty: Faculty of Technology, Natural Sciences and Maritme Sciences	
No. of problems: 13	No. of attachments: One appendix with formulas etc.	No. of pages incl. front page and attachments: 10

Permitted aids:

None except paper and pen. No calculator.

If you can not calculate a numerical answer by hand, it is acceptable that you present 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:

It is not allowed to call on the teacher to ask for help for interpreting or understanding the exam problems.

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.

Select the type of examination paper	Spreadsheets	X	Line sheets ☐

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

Exam in Course PEF3006 Process Control

Problem 1 (10%)

Provide a brief description, including a Piping and Instrumentation Diagram (P&I D), of averaging level control. You do not need to include controller tuning formulas in the answer.

Problem 2 (10%)

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

Problem 3 (10%)

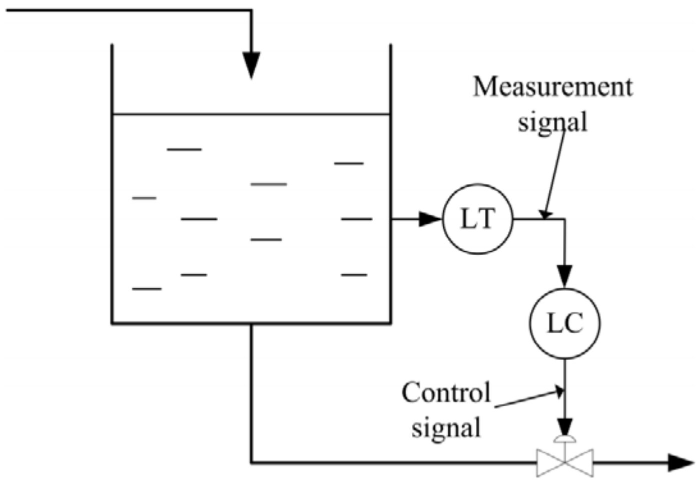
Explain the principle of model-based predictive control (MPC).

Problem 4 (5%)

Explain the Skogestad method for tuning a PI controller assuming “integrator with time delay” process dynamics.

Problem 5 (5%)

The figure below shows a level control with a control valve assumed to provide increased opening, and hence increased flow, when the control signal to the valve is increased. Should the controller have direct or reverse action? It is necessary to give the reason for your answer.



Problem 6 (5%)

Assume that in a Ziegler-Nichols experiment for tuning a PI controller, the control system oscillates with sustained oscillations of period 12 seconds when the controller gain is 10. Find the PI controller settings (1) with the original Ziegler-Nichols method and (2) with the Relaxed Ziegler-Nichols settings.

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

Problem 7 (5%)

Given the following differential equation model of a time constant filter:

$$T_f * dy/dt = u - y$$

where u is the input signal, y is the output signal and T_f [sec] is the filter time constant.

Derive a time-discrete filter algorithm for y, i.e., y_k =..., based on Euler's backward discretization method. The time step is T_s [sec].

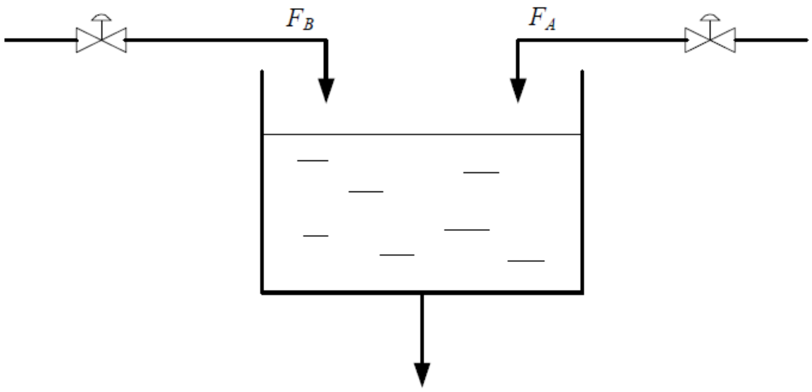
Problem 8 (5%)

Given the model of the time constant filter as in Problem 7. Calculate the transfer function from u to y.

Problem 9 (5%)

The figure below 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). There should be local flow control loops around the valves.

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



Problem 10 (10%)

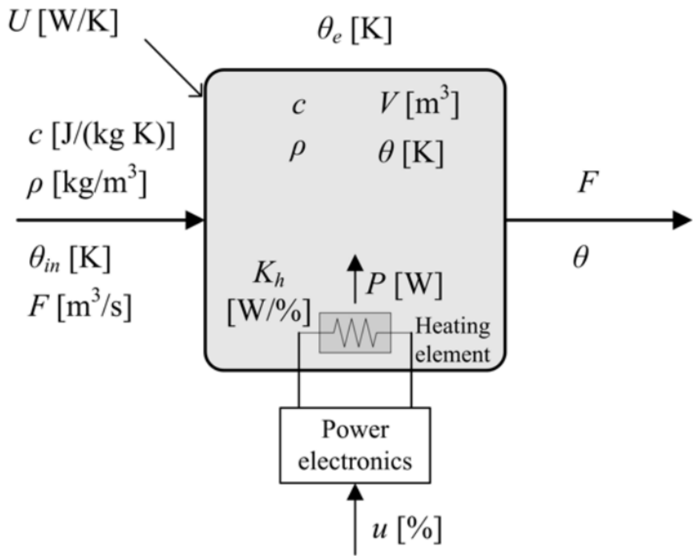
The figure below shows a liquid tank with continuous liquid inflow and outflow. A mathematical model of the liquid temperature based on energy balance is given below.

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

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.

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



Assume that the tank temperature is to be controlled by feedforward control (in addition to feedback control).

Derive a feedforward controller, neglecting the time delay (i.e. assuming it is zero). Which measurements does your feedforward controller need 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. However, a feedforward controller neglecting the time delay may still be useful.)

Problem 11 (5%)

Given a system assumed to have "time constant with time delay" dynamics. Draw the step response of the system where you indicate how the model parameters gain, time constant and time delay appear in the response (no calculation is required).

Problem 12 (5%)

Find the gain and the time constant of the following model:

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

Problem 13 (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.

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

University of South-Eastern Norway

Finn Aakre Haugen (finn.haugen@usn.no)

11th November 2019

Formulas and Symbols for exam in PEF3006 Process Control on 4th December 2019

$$x_{k+1} = x_k + T_s \dot{x}_k \tag{1}$$

$$x_k = x_{k-1} + T_s \dot{x}_k \tag{2}$$

$$\frac{k}{s} \quad \Longleftrightarrow \quad k \qquad \text{(step of amplitude } k\text{)} \tag{3}$$

$$\frac{k}{s^2} \quad \Longleftrightarrow \quad kt \qquad \text{(ramp of slope } k\text{)} \tag{4}$$

$$k\frac{n!}{s^{n+1}} \quad \Longleftrightarrow \quad kt^n \tag{5}$$

$$\frac{k}{Ts+1} \quad \Longleftrightarrow \quad \frac{ke^{-t/T}}{T} \tag{6}$$

$$\frac{k}{(Ts+1)s} \quad \Longleftrightarrow \quad k\left(1 - e^{-t/T}\right) \tag{7}$$

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

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

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

$$sF(s) \quad \Longleftrightarrow \quad \dot{f}(t) \tag{11}$$

$$\frac{1}{s}F(s) \quad \Longleftrightarrow \quad \int_0^t f(\tau)d\tau \tag{12}$$

$$\lim_{s\to 0} sF(s) \quad \Longleftrightarrow \quad \lim_{t\to\infty} f(t) \tag{13}$$

$$\dot{y}(t) = Ku(t) \tag{14}$$

$$H(s) = \frac{K}{s} \tag{15}$$

$$T\dot{y} = Ku - y \tag{16}$$

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

$$H(s) = e^{-\tau s} \tag{18}$$

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

$$u = u_{\text{man}} + K_p e + \frac{K_p}{T_i} \int_0^t e \, d\tau + K_p T_d \dot{e} \tag{20}$$

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

	K_p	T_i	T_d
P controller	$0.5K_{p,u}$	∞	0
PI controller	$0.45K_{p,u}$	$\frac{P_u}{1.2}$	0
PID controller	$0.6K_{p,u}$	$\frac{P_u}{2}$	$\frac{T_u}{8} = \frac{T_i}{4}$

$$K_p = 0.25K_{p,u} \tag{22}$$

$$T_i = 1.25P_u \tag{23}$$

$$K_p = 0.45K_{p,0} \tag{24}$$

$$T_i = \frac{P_{u,0}}{1.2} \tag{25}$$

$$K_{p,u} = \frac{4A_u}{\pi A_y} = 1.27\frac{A_u}{A_y} \tag{26}$$

$$\frac{y(s)}{y_{\text{sp}}(s)} = \frac{1}{T_c s + 1} e^{-\tau s} \tag{27}$$

$$K_p = \frac{1}{K_i \left(T_c + \tau\right)} \tag{28}$$

$$T_i = 2\left(T_c + \tau\right) \tag{29}$$

$$T_c = \tau \tag{30}$$

$$K_p = \frac{1}{2K_i\tau} \tag{31}$$

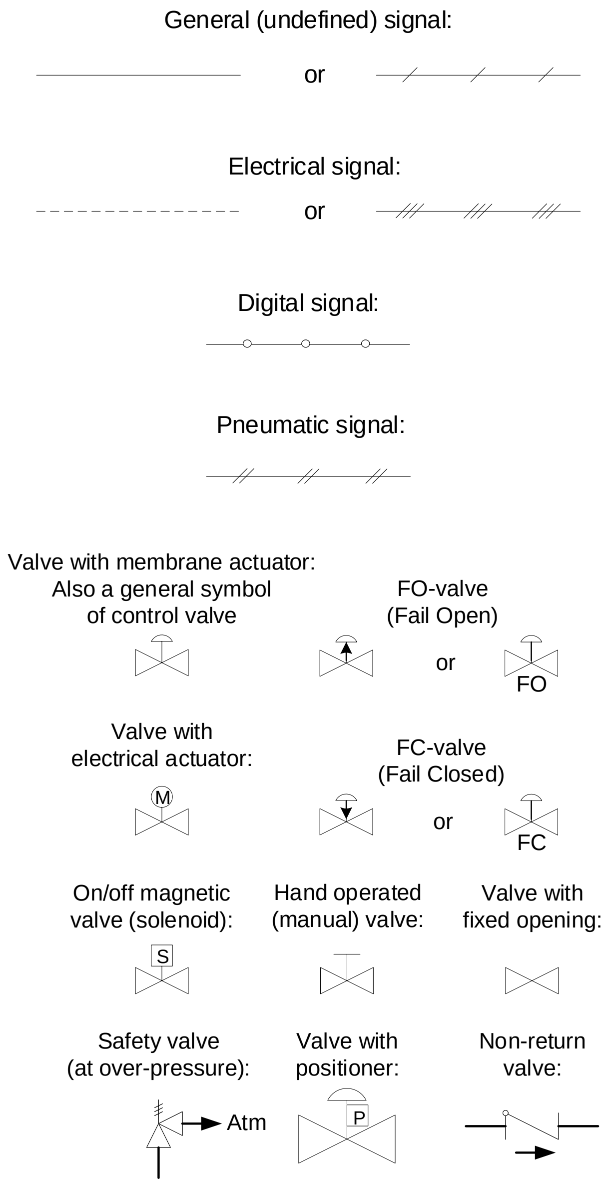
$$T_i = 4\tau \tag{32}$$

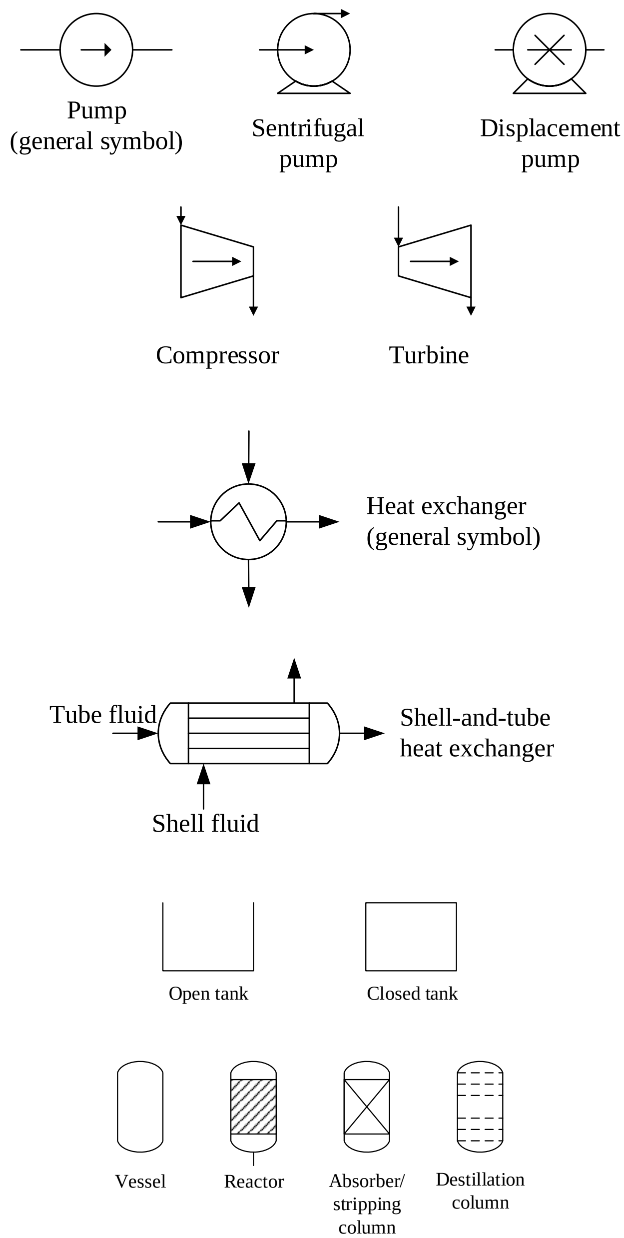
$$K_p = \frac{0.9}{K_i\tau} \tag{33}$$

$$T_i = 3.3\tau \tag{34}$$

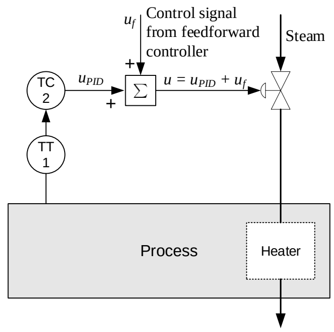
Letter code	1. letter	Subsequent modificator to 1. letter	Subsequent letter
A	Analysis		Alarm
B	Burner, Combustion		
C	User's choice		Control
D	User's choice	Differential	
E	Voltage		Sensor, Primary element
F	Flow rate	Ratio	
G	User's choice		Glass, Gauge
H	Hand		High
I	Current (electrical)		Indicate
J	Power		
L	Level		Low
P	Pressure		
Q	Quantity	Integrate, Totalize	
R	Radiation		Record
S	Speed, Frequency		Switch
T	Temperature		Transmit
V	Vibration		Valve
W	Weight, Force		
Y			Computation
Z	Position	Safety Instrumented System (Interlock)	

Code	**Equipment**
C	Column
D	Drum
F	Furnace
H	Heat exchanger
K	Compressor
M	Motor
P	Pump
R	Reactor
T	Tank
V	Valve. Vessel

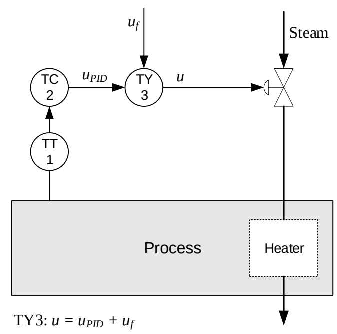

General (undefined) signal:
or
Electrical signal:
or
Digital signal:
Pneumatic signal:
Valve with membrane actuator:
Also a general symbol
of control valve
FO-valve
(Fail Open)
or
FO
Valve with
electrical actuator:
M
FC-valve
(Fail Closed)
or
FC
On/off magnetic
valve (solenoid):
S
Hand operated
(manual) valve:
Valve with
fixed opening:
Safety valve
(at over-pressure):
Atm
Valve with
positioner:
P
Non-return
valve:


Pump
(general symbol)
Sentrifugal
pump
Displacement
pump
Compressor
Turbine
Heat exchanger
(general symbol)
Tube fluid
Shell-and-tube
heat exchanger
Shell fluid
Open tank
Closed tank
Vessel
Reactor
Absorber/
stripping
column
Destillation
column

Alternative 1:



Alternative 2:



TY3: $u = u_{PID} + u_f$