University of South-Eastern Norway

EXAMINATION INFORMATION PAGE
Written examination

Course code: FM1219	Course name: Control Engineering	
Examination date: 13th 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: 17	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 FM1219 Control Engineering 13th December 2019

Problem 1 (5%)

Describe briefly how you can use the gridding method of optimization, also denoted the brute force method of optimization, for adaptation of a mathematical model with unknown parameter values to a physical process from which you have time-series of data of the input and the output. (No programming code is expected in your answer.)

Problem 2 (5%)

Draw a Piping and Instrumentation Diagram (P&I D) of a concrete (practical) example of a cascade control system. Explain briefly how the cascade control system works.

Problem 3 (5%)

Why are PI controllers used more often than PID controllers in practical control systems?

Why are PI controllers used more often than P controllers in practical control systems?

Problem 4 (5%)

Assume that you are to tune a PI controller for a thermal cooling process from the following information: When the control signal to the actuator is changed as a step of amplitude 20 %, the response in the process measurement (temperature) first shows a time delay of 1 min and then (after the time delay) the response changes as a ramp with slope -10 deg C/min.

Tune the PI controller.

Problem 5 (5%)

Give a concrete example of a PID feedback control system where the PID controller must have direct action. It is necessary to give the reason for your answer.

Problem 6 (5%)

Describe the Ziegler-Nichols (ZN) method (also named the ZN closed loop method, or the ZN ultimate gain method) of PI controller tuning.

Problem 7 (5%)

Given the following mathematical model of a water tank with pump inflow and valve outflow:

$$A*dh/dt = K_1*u(t) - K_2*sqrt[h(t)]$$

where: h is level; A, K_1 and K_2 are constants; u is pump control signal. (Variables and parameters are in appropriate units.) sqrt means “square root”.

Derive a simulation algorithm of h using the Euler forward method. The time step is T_s [s].

Problem 8 (5%)

Derive the transfer function from control error, e, to control signal, u, of a PI controller.

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Problem 9 (5%)

Given a feedback control system with a PI controller with settings $K_p = 2$ and $T_i = 20$ s.

Assume that the control system becomes marginally stable with $K_p = 6$. What is the gain margin, GM, of the control system?

Assume again that $K_p = 2$ and $T_i = 20$ s. The process controlled by the PI controller has a certain time delay. Assume that the control system shows sustained oscillations with period 36 s if the time delay is increased by 4 s. What is the phase margin, PM, of the control system?

Problem 10 (5%)

The water level, h [m], in a tank with cross-sectional area A [m^2] is to be controlled with both feedback control and feedforward control. The control signal, u [m^3/s], manipulates the inflow to the tank. The outflow, F_{out} [m^3/s], from the tank is regarded as a disturbance on the level. The level setpoint is h_{sp} [m]. A mathematical model of the level is

$$A*dh/dt = u - F_{out}$$

Derive the feedforward controller.

Problem 11 (5%)

Describe briefly the (three) main elements of a sequential function chart (SFC). Also, show in a drawing how these elements appear in an SFC. You should give an example of each of the elements (select any application you want, but a complete SFC is not expected).

Problem 12 (5%)

Derive the amplitude gain function, $A(\omega)$, and the phase shift function, $\phi(\omega)$, of the following transfer function:

$$H(s) = 1/s$$

Problem 13 (5%)

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 14 (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 15 (5%)

Assume that a PI controller has been tuned to have gain 2 and integral time 7 s. Unfortunately, the stability of the control loop is too bad with these PI settings as a setpoint step change causes the process output variable to have poorly damped oscillations with period 12 s.

Retune the PI controller for (hopefully) better stability.

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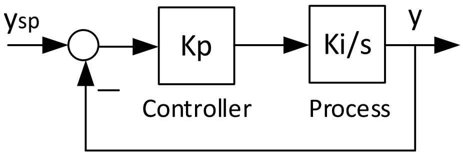
Problem 16 (10%)

The figure below shows a block diagram of a feedback control system where an integrating process with transfer function K_i/s is controlled by a P controller with transfer function K_p. Find the value of the controller gain K_p so that the control system gets a specified time constant T_c.



Problem 17 (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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11th November 2019

Formulas and Symbols for exam in FM1219 Control Engineering on 13th December 2019

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

	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	$0.6K_{p,u}$	$\frac{P_u}{2}$	$\frac{T_u}{8} = \frac{T_i}{4}$

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

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

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

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

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

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

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

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

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

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

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

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

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

$$\dot{x} = f(x,u,d,p) \tag{35}$$

$$y = g(x) \tag{36}$$

$$\dot{x} = Ax + Bu \tag{37}$$

$$y = Cx + Bu \tag{38}$$

$$x\ [\text{dB}] = 20 \log_{10} x \tag{39}$$

$$A(\omega) = |H(j\omega)| \tag{40}$$

$$\phi(\omega) = \arg H(j\omega) \tag{41}$$

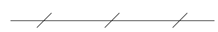
$$\text{GM} = \Delta K_u \tag{42}$$

$$\text{PM} = \frac{\Delta \tau_u}{P_u} \cdot 360° \tag{43}$$

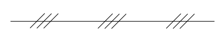
Letter code	1. letter	Subsequent modificator to 1. letter	Subsequent letter
A	Analysis		Alarm
B	Burner, Combustion		
C	User's choice		Control
D	User's choice	Differential	
E	Voltage		Sensor, Primary element
F	Flow rate	Ratio	
G	User's choice		Glass, Gauge
H	Hand		High
I	Current (electrical)		Indicate
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:

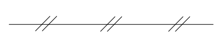
 or 

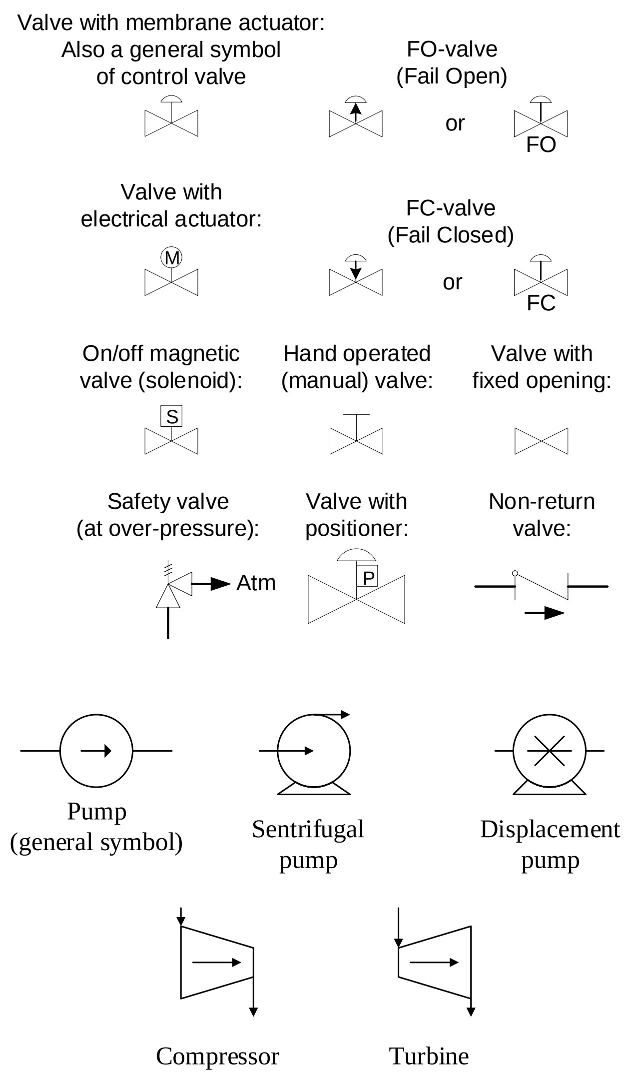
Electrical signal:

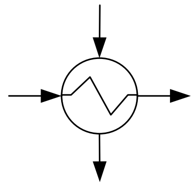
 or 

Digital signal:

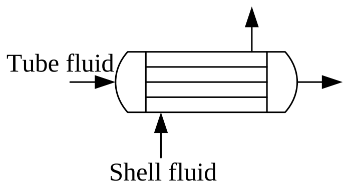
Pneumatic signal:




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

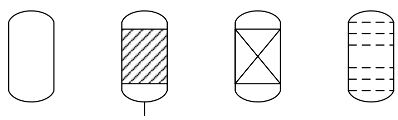


Heat exchanger
(general symbol)



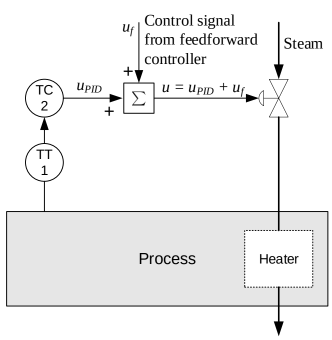
Shell-and-tube
heat exchanger

Open tank Closed tank

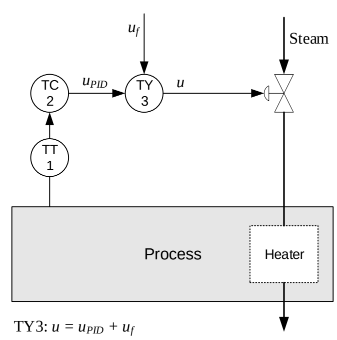


Vessel Reactor Absorber/ stripping column Destillation column

Alternative 1:



Alternative 2:



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