Solution to exam in PEF3006 Process Control at Telemark University College

Exam date: 7. December 2015. Duration: 4 hours. Weight in final grade of the course: 100%.

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Solution to Problem 1 (8%)

The Laplace transform of the model:

$$\rho A\left[sh(s) - h_0\right] = K_s e^{-\tau s} u(s) - w_{out}(s)$$

Solving for output variable h gives

$$h(s) = \frac{1}{s} h_0 + \underbrace{\frac{K_s}{\rho A s} e^{-\tau s}}_{H_1(s)} u(s) + \underbrace{\left(-\frac{1}{\rho A s}\right)}_{H_2(s)} w_{out}(s)$$

Thus, the transfer functions are

$$H_1(s) = \frac{K_s}{\rho A s} e^{-\tau s}$$

and

$$H_2(s) = -\frac{1}{\rho A s}$$

$H_1(s)$ represents "integrator with time-delay" dynamics.

Solution to Problem 2 (12%)

a) (5%) See Figure 1.

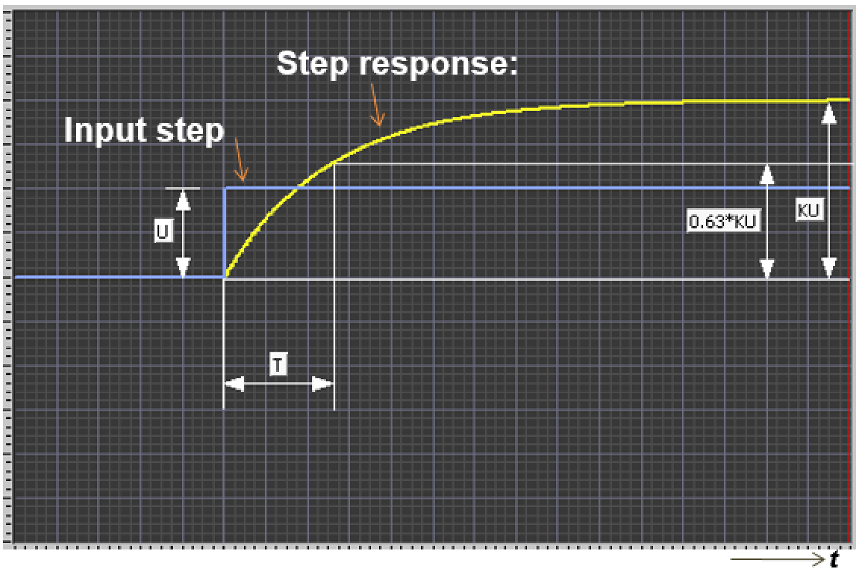

Figure 1

b) (4%) Writing the differential form on the standard form T*dy/dt + y = Ku:

0.5*dy/dt + y = 2.5*u

which gives: K = 2.5 and T = 0.5.

c) (3%) The overall gain is K_1*K_2. The overall approximate time-constant is $T_1 + T_2$.

Solution to Problem 3 (8%)

The purpose of ratio control is to control a mass flow, say F2, so that the ratio between this flow and another flow, say F1, is F2 = K*F1 where K is a specified ratio.

Figure 2 shows at the left the structure of a ratio control system in detail, and at the right compact but equivalent representation of ratio control with the symbol FFC (Flow Fraction Controller).

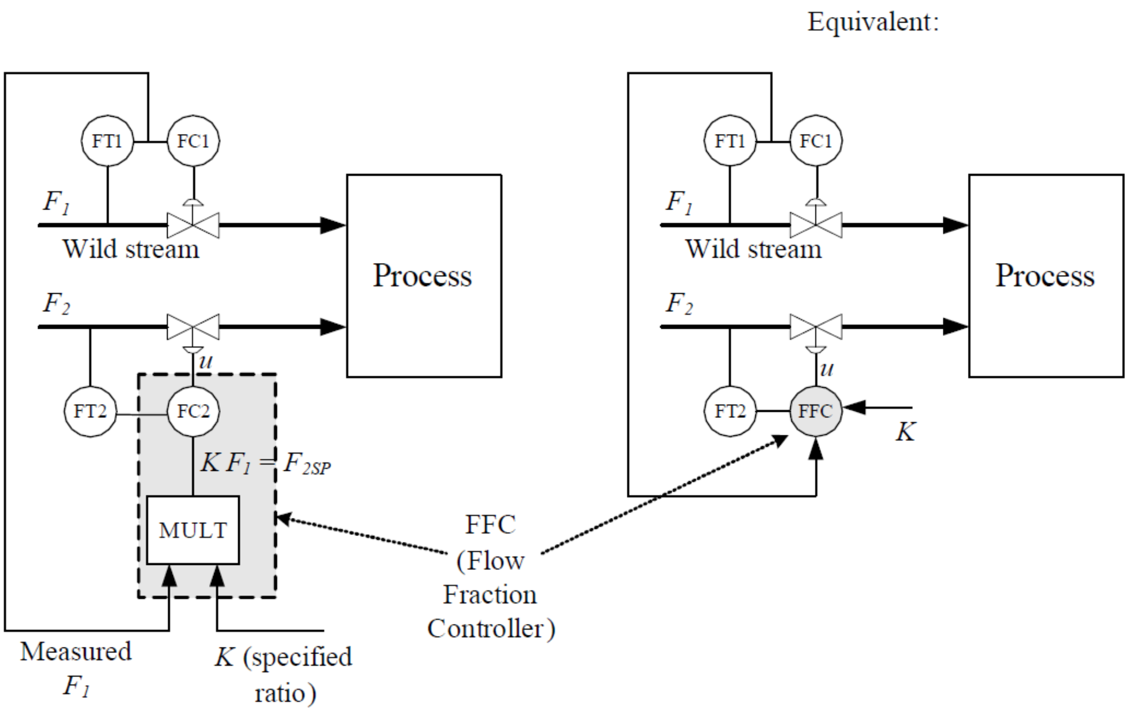

Figure 2

Example: Optimal operating condition of a burner requires a specified ratio between oil inflow and air inflow. This ratio can be obtained with ratio control: For any given oil flow, the air flow is automatically adjusted so that the ratio between the two flows are as specified.

Solution to Problem 4 (10%)

The (three) main elements of a sequential function chart (SFC) are:

- Steps defines the possible states of the control system. A step is either active or passive.
  Example: The filling step of a batch reactor.
- Actions of a step are the control actions executed by the control device (typically a PLC), e.g. opening a valve, when that step is active.
  Example: Setting the inlet valve of a batch reactor in the open position.

- Transitions are the jumps from presently active steps to their next steps. A transition from an active step to a next step takes place once the transition condition is satisfied, e.g. once a button has been pressed, or once the level in a tank has passed a certain value.
  Example: The level of the material in a batch reactor is equal to or larger than to its high limit.

Figure 3 shows an SFC (this SFC is a complete one, however, an uncomplete chart is accepted as an answer to this exam problem).

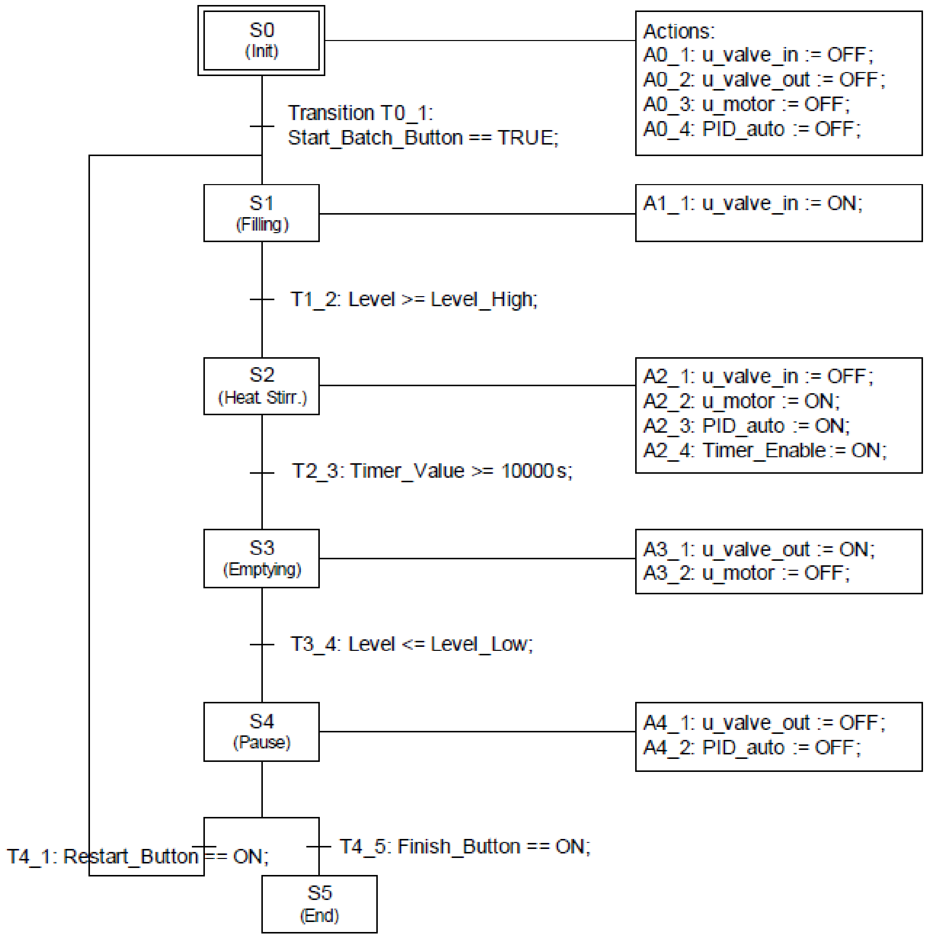

Figure 3

Solution to Problem 5 (15%)

a) (10%) Feedforward control is a control method where there is a coupling from the setpoint and/or from the disturbance directly to the control variable. The purpose of feedforward control is to obtain an improved compensation for disturbances and improved setpoint tracking compared with feedback control. Feedforward control is typically used together with feedback control. Figure 4 shows the structure of a control system with both feedforward and feedback control. (The purpose of feedback control is to reduce the control error due to the inevitable imperfect feedforward control. Practical feedforward control can never be perfect, because of model errors and imprecise measurements.)

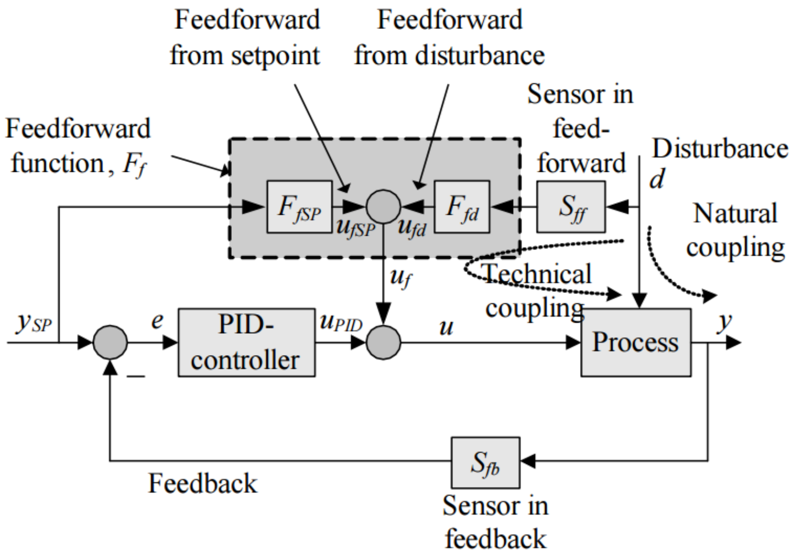

Figure 4

Example: Figure 5 shows a heated liquid tank where the tank temperature is to be controlled with feedback with PID controller in combination with feedforward control from inflow temperature which is assumed to be a varying disturbance. The feedforward control will quickly compensate for these variations.

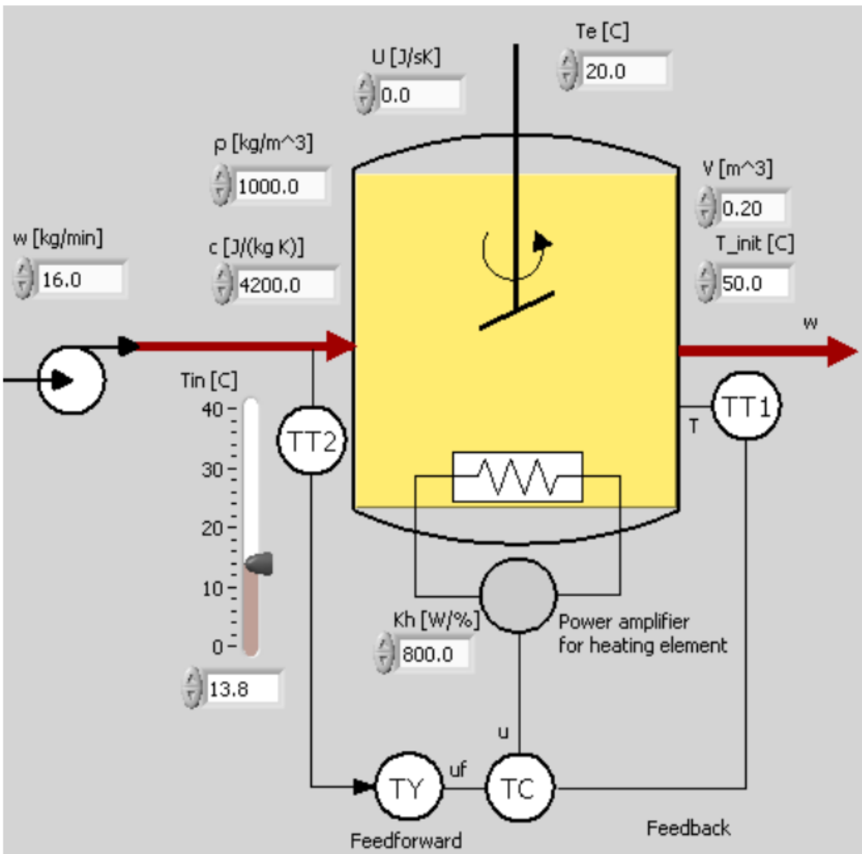

Figure 5

b) (5%) Substituting y by its setpoint, y_{sp} , and solving for u gives the feedforward control function:

$u_{ff} = (dy_{sp}/dt - A*y - C*d)/B$

All of the quantities at the right side of the above formula must have known values to make the feedforward control function implementable, i.e. y_{sp}, from which $d(y_{sp})/dt$ can be calculated, disturbance d, and parameters A, B and C. If some of these quantities are not known by definitions or design, measurements may be necessary (e.g. measurement of d).

Solution to Problem 6 (5%)

"Fail Open valve" implies that the valve opening is increased and (thereby) the flow is increased if the the air supply to the valve is decreased. Consequently, a flow increase is obtained with a control signal reduction. Assume that the level is at the setpoint, and that the level then (for some reason) increases. To bring the level back to the setpoint, the outflow must be increased. With the present valve this is achieved with a reduction of the control signal. Hence, we have the "up-down" situation described in the text-book, and consequently the controller shall have reverse action.

Solution to Problem 7 (10%)

a) (3%) We may assume as an example the level control system of a wood-chip tank (which is a common examplein the course):
   - Esamples of increased process gain: Increased feed screw capasity (screw gain). Reduced surface are of the wood-chip in the tank.
   - Example of increased process time-delay: Increased transportation time of the conveyor belt.

b) (7%) It is useful to assume that the PI controller originally is tuned using the Skogestad method assuming «integrator with time-delay » dynamics:
   $K_{p0} = 1/(2*K_{i0}*tau_0)$ and $T_{i0} = 4*tau_0$.
   An increase of the process gain of factor 3 implies
   $K_{i1} = 3*K_{i0}$
   An increase of the process time-delay by factor 2 implies
   $tau_1 = 2*tau_0$
   Thus, the new PI settings become
   $K_{p1} = 1/(2*K_{i1}*tau_1) = 1/[2*(3*K_{i0})*(2*tau_0)] = (1/6)*1/(2*K_{i0}*tau_0) = (1/6)*K_{p0}$
   and
   $T_{i1} = 4*tau_1 = 4*(2*tau_0) = 2*(4*tau_0) = 2*T_{i0}$

Solution to Problem 8 (7%)

See Figure 6.

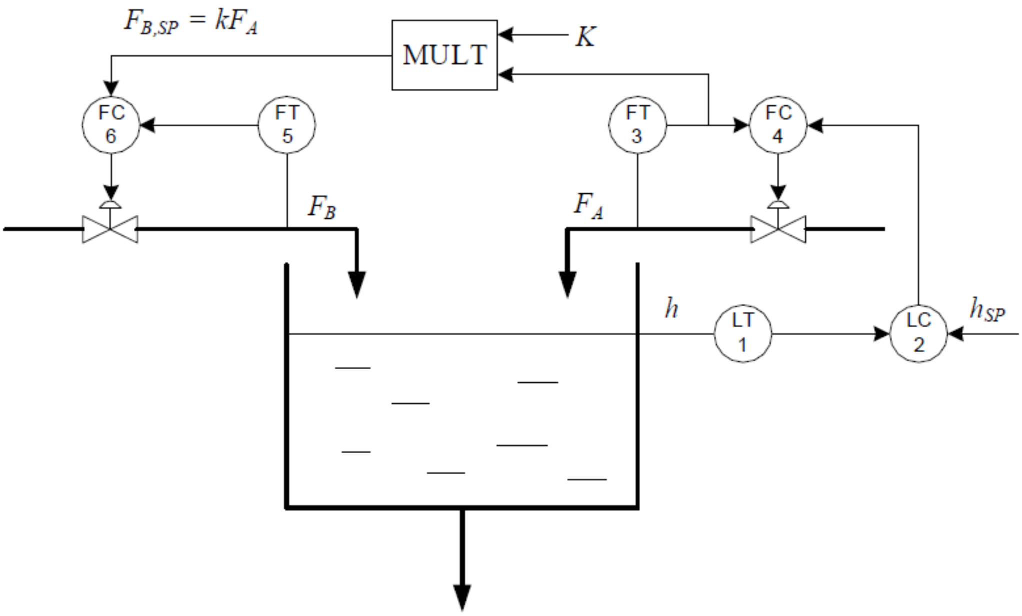

Figure 6

Solution to Problem 9 (10%)

The control system should be a cascade control with three control loops, as shown in Figure 7.

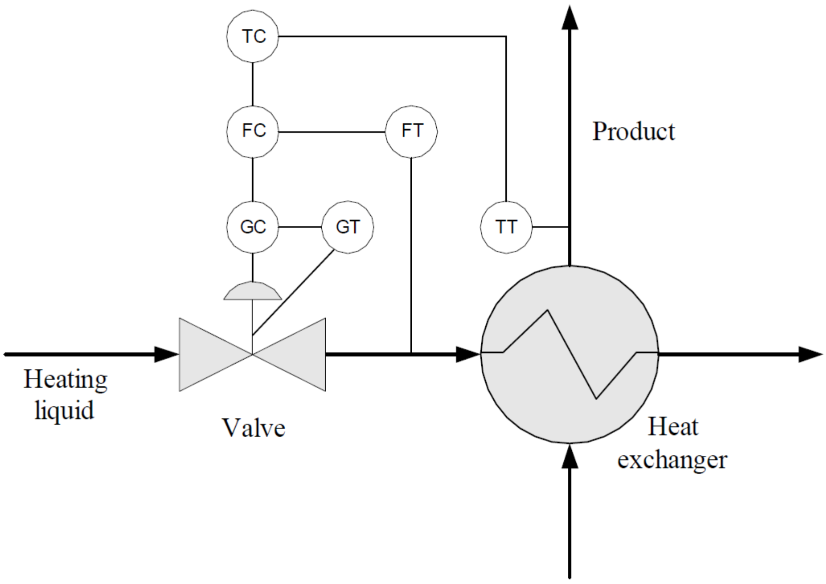

Figure 7

Solution to Proplem 10 (15%)

Figure 8 shows a possible solution (the same figure as in the textbook).

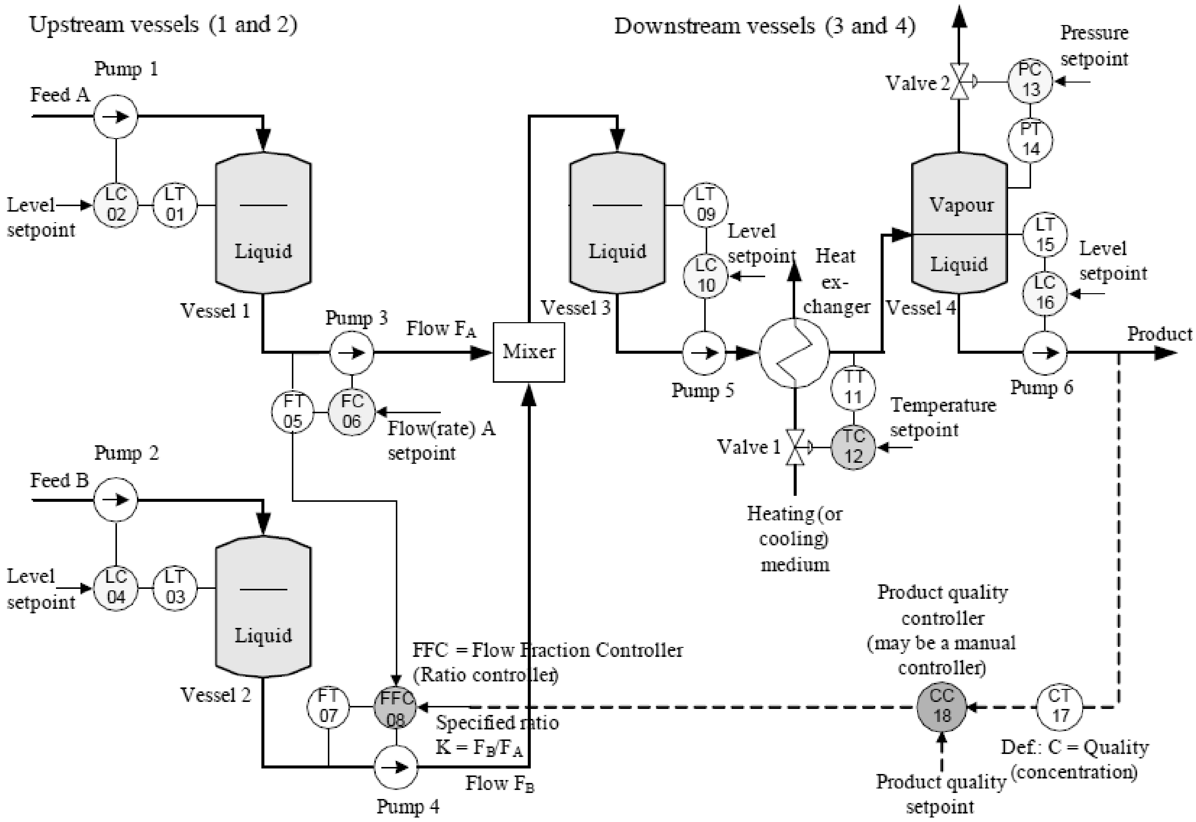
Upstream vessels (1 and 2)
Downstream vessels (3 and 4)
Pump 1
Feed A
Level setpoint
LC 02
LT 01
Liquid
Vessel 1
Pump 3
Flow F_A
Mixer
FT 05
FC 06
Flow(rate) A setpoint
Pump 2
Feed B
Level setpoint
LC 04
LT 03
Liquid
Vessel 2
FT 07
FFC 08
FFC = Flow Fraction Controller (Ratio controller)
Specified ratio K = F_B/F_A
Pump 4
Flow F_B
Liquid
Vessel 3
LT 09
Level setpoint
LC 10
Pump 5
Heat ex-changer
TT 11
Temperature setpoint
TC 12
Valve 1
Heating (or cooling) medium
Valve 2
PC 13
Pressure setpoint
PT 14
Vapour
Liquid
Vessel 4
LT 15
LC 16
Level setpoint
Pump 6
Product
Product quality controller (may be a manual controller)
CC 18
CT 17
Def.: C = Quality (concentration)
Product quality setpoint

Figure 8