Solution to exam in FM1219 Control Engineering

Exam date: 13th December 2019. Duration: 4 hours. Weight in final grade of the course: 100%. Aids: None.

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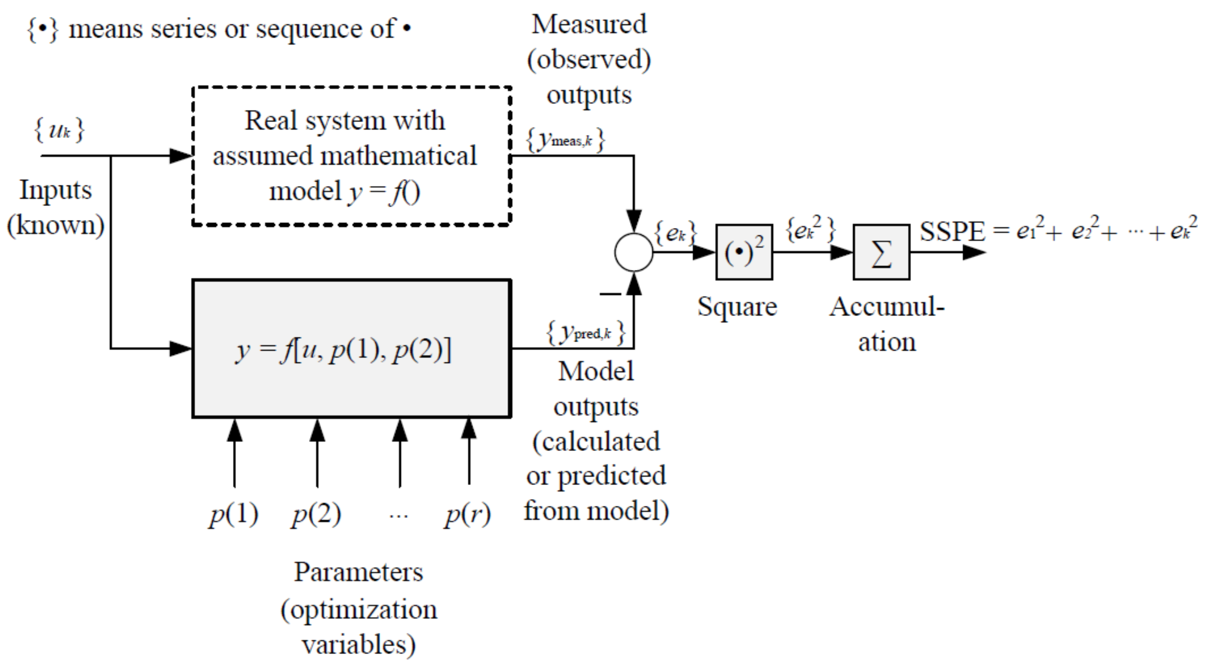
Solution to Problem 1 (5%)

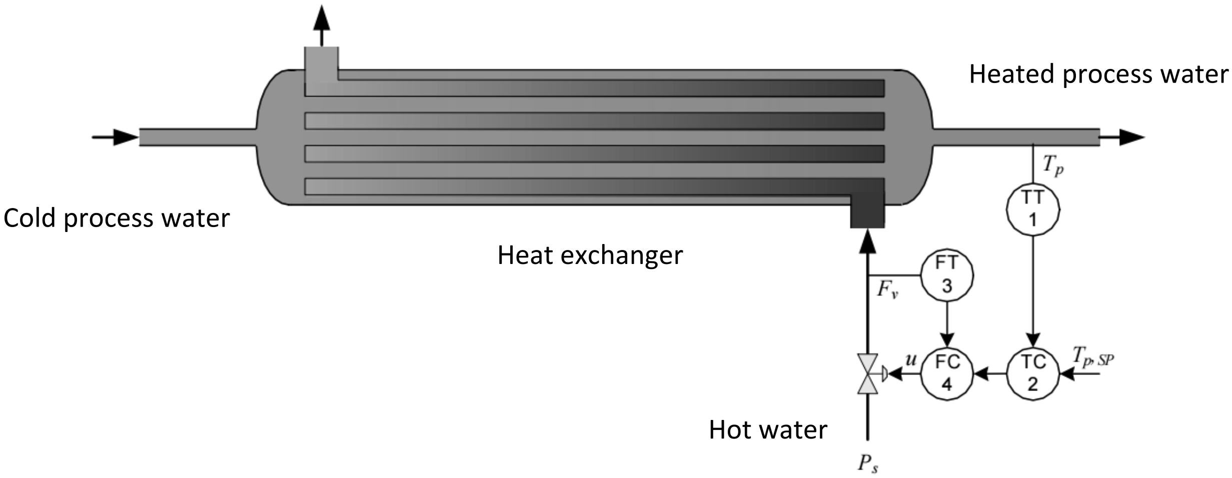
- Program a simulator based on the model.
- Define arrays of possible values of each of the model parameters which are to be estimated.
- Run the simulator for all possible combinations of the unknown parameter values. This can be realized with nested for loops.
- For each of the simulations calculate the sum of squared prediction errors (sspe), which is used as optimization criterion. The sspe is the sum of squared errors or deviations between the real (measured) output and the simulated output.
- Select as the ultimate (optimal) parameter values that combinination of the parameter values which minimizes the sspe.

The figure below illustrates the above (the figure is from the textbook).



Solution to Problem 2 (5%)

One example: The figure below shows a P&I D of a temperature controlled heat exchanger in which a cold process water flow is heated using hot water. The control structure is cascade control where the primary loop is a temperature control loop for the temperature of the outflow of the heat exchanger. The secondary loop is a flow control loop of the hot water stream that compensates for variations in the hot water flow caused by variations in the pressure supply (disturbance), so that the flow variations are minimized, which minimizes variations in the temperature of the heat exchanger outflow.



Solution to Problem 3 (5%)

PI controllers are used more often than PID controllers in practical control systems because the derivative term "amplifies" measurement noise through the regulator, which gives a noisy control signal, which can cause unnecessary wear on the actuator.

PI controllers are used more often than P controllers in practical control systems because the integral term ensures zero steady-state control error, while for most processes the error differs from zero without the integral term, as in a P controller.

Solution to Problem 4 (5%)

We can use the Skogestad PI tuning method assuming integrator with time delay process dynamics.

Given:

tau = 1 min

U = 20 %

S = -10 deg C/min

Calculation:

Ki = S/U = (-10 deg C/min)/(20 %) = (-0.5 deg C/min)/%.

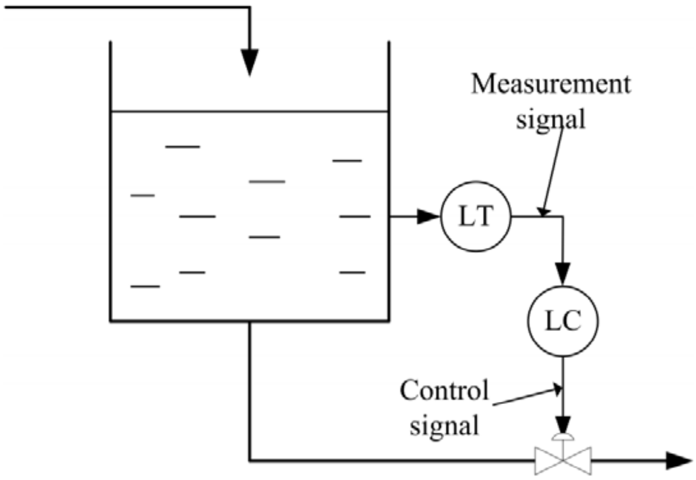
PI settings:

Kp = 1/(2*Ki*tau) = 1/[2*(-0.5 deg C/min)/%)*1 min] = -1 %/(deg C/min)

Ti = 4*tau = 4*1 min = 4 min

Solution to Problem 5 (5%)

One example: 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.



The controller should have direct action. Reason: Assume a positive change of the control signal to the valve, which then opens more. This cause the level to decrease; hence, the process gain is negative, which requires a negative controller gain, which per definition is direct action.

An alternative explanation: Assume the level is at its setpoint initially. Then, assume an increase (change upwards) in the level measurement. This requires the control signal to be increased (change upwards) to get the level back again to the setpoint. Hence, there is an “up-up” situation, which implies that the controller should have direct action.

Solution to Problem 6 (5%)

The Ziegler-Nichols method for PI controller tuning: First, bring the process to or close to the normal or specified operation point by adjusting the nominal control signal u_0 (with the controller in manual mode). Then, ensure that the controller is a P controller, i.e. set $T_i = \infty$ (or very large) and $T_d = 0$, with $K_p = 0$. Then, with the controller in automatic mode, increase K_p by trial-and-error to the the value K_{p_u} which causes the the control loop to become marginally stable, i.e. there are sustained oscillations in any signal in the loop. From these oscillations, read off the period, P_u. Then, calculate proper PI settings as $K_p = 0.45K_{p_u}$ and $T_i = P_u/1.2$ to be applied in the controller.

Solution to Problem 7 (5%)

At discrete time k (short notation of time t_k):

$$A*dh_k/dt = K_1*u_k – K_2*sqrt(h_k)$$

Euler forward approximation:

$$dh_k/dt = (h_{k+1} – h_k)/T_s$$

Substituting dh_k/dt with the Euler forward approximation, and solving for h_{k+1}:

$$h_{k+1} = h_k + Ts*[(K_1/A)*u_k – (K_2/A)*sqrt(h_k)]$$

Solution to Problem 8 (5%)

Taking the Laplace transform of the continuous-time PI controller (disregarding the u_{man} term) gives:

$$u(s) = K_p*e(s) + (K_p/T_i)*(1/s)*e(s)$$

which gives the following transfer function from e to u:

$$u(s)/e(s) = K_p + (K_p/T_i)*(1/s)$$

Solution to Problem 9 (5%)

$$GM = 6/2 = 3$$

$$PM = (4/36)*360 \text{ degrees} = 40 \text{ degrees}$$

Solution to Problem 10 (5%)

Inserting h_{sp} for h and solving for u gives the feedforward controller:

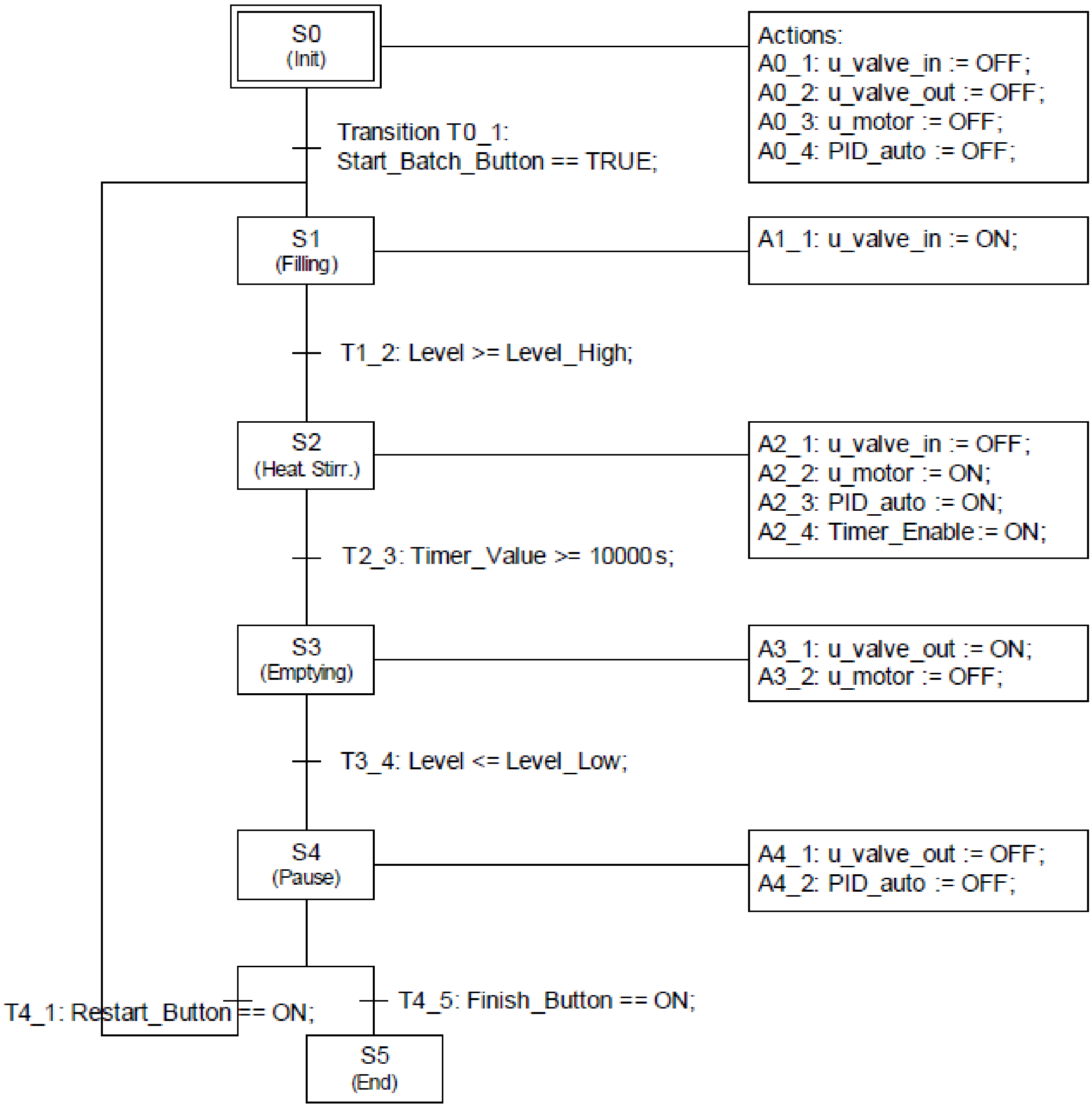
$$u_{ff} = A*dh_{sp}/dt + F_{out}$$

Solution to Problem 11 (5%)

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.

The figure below shows an SFC for a batch reactor (this SFC is a complete one, however, an uncomplete chart is accepted as an answer).



Solution to Problem 12 (5%)

Inserting s = jω in H(s):

$$H(j\omega) = 1/(j\omega) = 1/(\omega j) = 1/(\omega * e^{j\pi/2}) = (1/\omega)*e^{j(-\pi/2)}$$

(j is a complex number of amplitude 1 and angle $\pi/2$.)

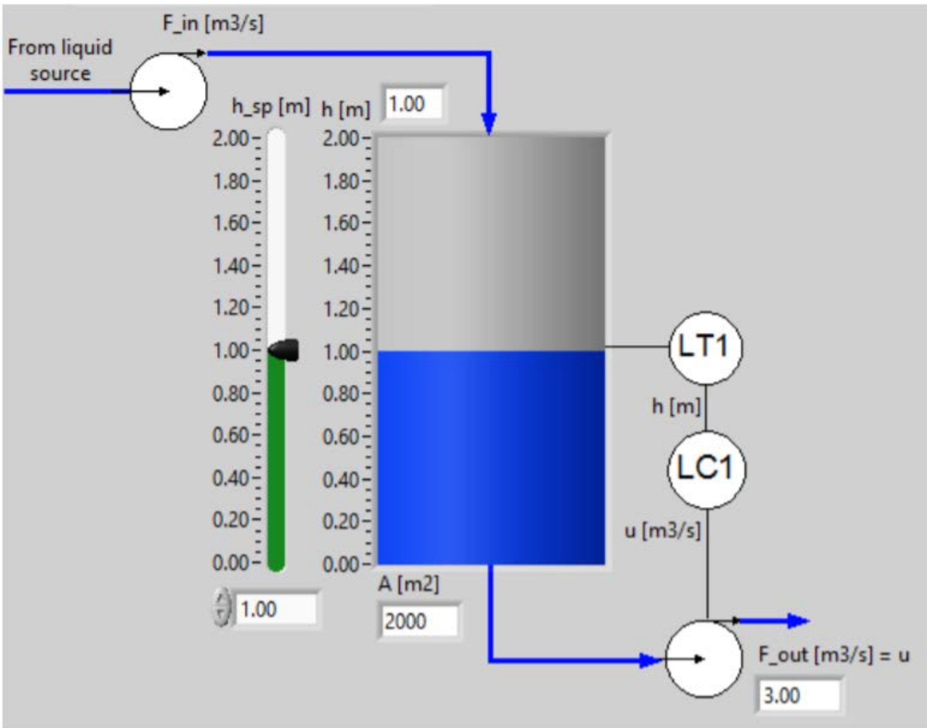
This gives:

$$A(\omega) = 1/\omega$$

$$\phi(\omega) = -\pi/2 \text{ [rad]}$$

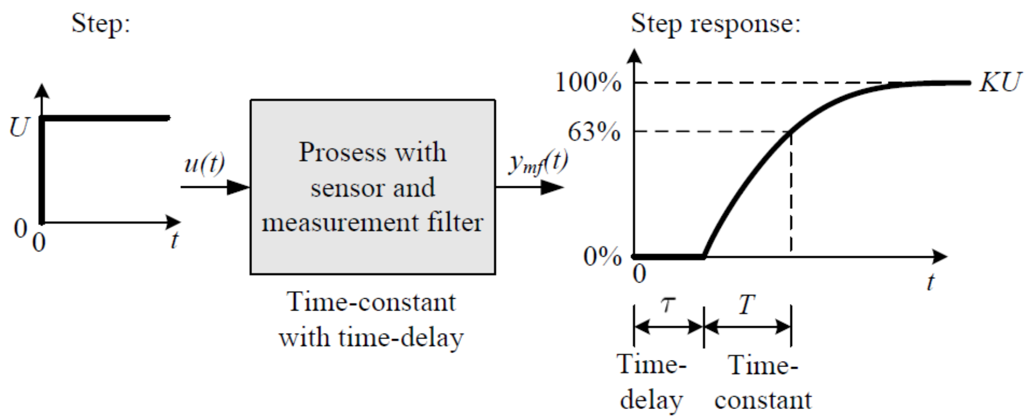
Solution to Problem 13 (5%)

The figure below shows a Piping and Instrumentation Diagram of a control system for the averaging level control of a tank. The inflow is assumed changing. There are two main requirements of the control system: (1) The outflow should be as smooth as possible. (2) The level of the tank should not exceed a given high limit nor a given low limit. Requirement 1 indicates that the level controller (LC1) is tuned for as soft (or smooth, or slow) control as possible. Requirement 2 indicates that the controller is *not too slow*, otherwise the level may exceed the limits at e.g. an approximate step change in the inflow (or a change in its mean or bias). The Skogestad method for PI setting is very suitable for tuning the level controller (however, details of the controller setting are not presented here).



Solution to Problem 14 (5%)

See the figure below (where "Process ..." is "system").



Solution to Problem 15 (5%)

We can use the “repeated Ziegler-Nichols method”:

$$\underline{\underline{K_c = 0.45*2 = 0.9}}$$

$$\underline{\underline{T_i = 12/1.2 = 10 \text{ s}}}$$

Solution to Problem 16 (10%)

From the block diagram:

$$y(s) = (Ki/s)*Kp*[y_{sp}(s) – y(s)]$$

which gives the following transfer function from ysp to y:

$$y(s)/y_{sp}(s) = T(s) = 1/[s/(Ki*Kp) + 1] = 1/(Tc*s + 1)$$

Thus,

$$Tc = 1/(Ki*Kp)$$

which gives

$$Kp = 1/(Ki*Tc)$$

Solution to Problem 17 (15%)

The figure below shows one possible solution (the same as in the textbook). The dashed signal lines of the quality control loop assumed that an online production quality sensor is available (which, however, may not often be the case).