G1. Answer true or false for each statement. Each problem is worth +5 points when the answer is correct, but it costs -5 points if the answer is wrong.

- Process control is an important class in chemical engineering.
- The egg appeared before chicken in the beginning.
- A 1st-order process is also called a low-pass filter since low frequency content of input is attenuated much more than high frequency one.
- A high-order ODE can be converted to 1st-order ODE by using additional states.
- A liquid storage tank with a small pipe outlet at the bottom of the tank without valve is an integrating system.
- A noise filter with larger time constant shows slower tracking to the true signal with less noise reduction.
- A short-duration rectangular pulse input can be used as an alternative of an ideal impulse input through which the transfer function of a process can be obtained.
- A signal filter with large filter time constant implies fast tracking of true signal.
- A transfer function is a Laplace transform of the unit impulse response of a process.
- A valve at toxic storage exit line should be air-to-close type for safety reasons.
- An nth-order ODE can be converted to 1st-order ODE systems by adding n additional states.
- An occurrence of a malfunctioning control valve results an increase of DOF.
- An occurrence of an unadjustable control valve results an increase of DOF.
- An oversized control valve uses less energy at the cost of imprecise flow control.
- An undersized control valve uses less energy at the cost of imprecise flow control.
- Anti-reset windup function will be beneficial for P-controller as well as PI-controller.
- Eliminating both P-kick and D-kick is always advantageous.
- Eliminating the proportional kick would be beneficial for all cases.
- Filtering can eliminate the noise of a signal without degrading the measuring accuracy.
- For a given pump discharge P, by selecting suitable \( C_v \) value, the maximum flow requirement can be obtained easily.
- For a heat exchanger for cooling by adjusting flow rate of cooling water, the reverse acting mode should be chosen when P-controller is used.
- For a jacket-cooled exothermic reactor, the cooling water valve should be air-to-close type for safety reasons.
- For a pressure control system by adjusting outlet flow rate of holding tank, reverse acting mode should be chosen when P-controller is used.
- For a pressure vessel for some toxic materials, the outlet flow control valve should be air-to-open type for safety reasons.
- For a temperature control system by adjusting flow rate of cooling water, reverse acting mode should be chosen when P-controller is used.
- For bumpless transfer from manual to auto mode, initial controller output value should be set as current MV value at the time of switch.
- For flow measurement with DP cell for a given range, the use of larger size orifice results more accurate measurement.
- For flow measurement with DP cell for a given range, the use of smaller size orifice results wider measurement span.
- For high-pressure reactor, the cooling water valve should air-to-open type.
- For PID control system, decreasing \( \tau_i \) generally results less oscillatory action.
- For PID control system, decreasing \( \tau_i \) generally results more oscillatory action.
- For PID control system, decreasing \( \tau_i \) results more conservative action.
- For PID control system, increasing \( \tau_i \) results more conservative action.
- For thermocouples such as J, K, or N type are most widely used in industrial applications.
- For thermocouples, usually N type is used for cryogenic application and S type for high temperature application.
- For thermocouples, usually T type is used for cryogenic application and S type for...
high temperature application.

- Generally, the feedback control (FB) is superior to feedforward control (FF) since FB acts fast when the DV changes.
- Heavy noise filtering uses large filter time constant than the light filtering and the heavy filtering implies fast tracking of true signal.
- If D-mode control is used for control, the control performance is enhanced due to the predictive capability using slope information of error for noisy measurements.
- If one CV is not required to control anymore, the DOF is decreased.
- In industries, RTD’s are more widely used than thermocouples due to their accuracy and cost.
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- In industries, thermocouples are more widely used than RTD’s due to their costs.
- In industries, thermocouples are more widely used than RTD’s due to their costs.
- Large filter time constant for analog filter implies faster tracking of true signal.
- Large filter time constant for analog filter implies slower tracking of true signal.
- Large proportional band (PB) can eliminate steady state offset.
- Light noise filtering uses shorter filter time constant than the heavy filtering and the light filtering results fast tracking of true signal at the cost of less noise reduction.
- Negative degree of freedom in model implies that there is no solution.
- Open-loop underdamped process can be easily found in chemical processes.
- P-control cannot eliminate the steady-state offset for all cases.
- Process control is an important class in chemical engineering.
- Pulse width modulation is used to adjust the voltage level of AC power in inverter.
- Since Laplace transform is linear, \( \mathcal{L}\{a f_1(t) * b f_2(t)\} = \mathcal{L}\{a f_1(t)\} * \mathcal{L}\{b f_2(t)\} \)
- Since the feedforward control uses the information on DV, it can effectively compensate the effect of DV on CV with the accurate model.
- The anti-reset windup is preferred to be used even though l-mode is not used.
- The chemical and biological engineering is a very promising field in engineering.
- The chicken appeared before egg in the beginning.
- The commodity-producing large plants usually use servo control since they mainly produce products of same quality for large volume.
- The DP cell is widely used for flow measurement even though the pressure drop and the maintenance cost are relatively high, because it is cost effective.
- The egg appeared before chicken in the beginning.
- The equal percentage value shows more linear characteristic than linear value in all cases.
- The equal percentage valve shows more linear characteristic than linear valve when it is used to adjust the flow rate of a process.
- The equal percentage valve shows more linear characteristic than linear valve if it is used with process.
- The equal percentage valve shows more linear characteristic than linear valve when it is used to adjust the flow rate of a process.
- The feedback control uses the information on CV while the feedforward control uses the information on DV.
- The final value theorem has limitation, but the initial-value theorem does not.
- The final value theorem implied \( f(\infty) = \lim_{s \to 0} sF(s) \) whether \( f(\infty) \) is converged or not.
- The flow rate through orifice is proportional to the square root of differential pressure and linearly proportional to the cross-sectional area of the hole.
- The inherent characteristic of control valves should be used to select the size of control valve.
- The inverter for flow control can save energy compared to the conventional flow control in the sense that the pressure drop is smaller.
- The NIR sensor can detect the concentration of inorganic compound.
- The P-mode in PID-control may not eliminate steady-state offset, but D-mode can.
- The PI-control is equivalent to P control if the reset time is zero.
- The reset feedback is used to compensate the reset windup.
- The reset windup can happen when large error is maintained for long time with P-control.
- The reset windup for PI controller can be prevented by using positional form.
- The reset windup may happen during startup which takes long time with PI-control.
- The rpm of an AC motor can be adjusted by voltage level using inverter.
The smaller filter time constant results in better noise reduction but slower response.

The steady-state offset of P-controller can occur because the bias value of the controller cannot be altered for the changes, such as load change.

The steady-state offset can be eliminated with PI-controller because the I-mode provides the effect of changing bias value of PI controller.

The steady-state offset can be eliminated with PI-controller because the steady-state controller output can be altered through the integration of error for the changes, such as load change.

The steady-state offset can occur with P-only controller because the bias value of P controller is not correct for different situations.

The steady-state offset of P-controller can occur because the bias value of the controller cannot be altered for the changes, such as load change.

The thermocouples such as J, K, or N type are most widely used in industrial applications than others.

The use of inverter instead of valve for flow control with pump can save energy due to decrease of pressure drop in the flow system.

Using superposition principle, \[ L\{af_1(t) * bf_2(t)\} = L\{af_1(t)\} * L\{bf_2(t)\}. \]

When DP cell is used for measuring flow rate, oversized orifice makes the flow measurement less accurate.

When the DOF of a model is positive, the model has infinite number of solutions.

When the error is defined as SP-PV, the direct-acting mode has negative \( K_c \) value.

G2. Answer the following questions briefly.

- Explain the advantages and disadvantages of P, I, D modes of PID controller.
- Explain the effect of changing \( K_c \) and \( \tau_I \) of PI controller on the set point change.
- Explain the signal generated by DP cell transmitter for a flow rate and also the signal conversion thereafter to the actual reading of the flow rate.
- What are the characteristics of the step response of a 1st-order process?
- What are the measures of performance of a process control system?
- State how to calculate the benefit of the process control for the economic justification, quantitatively.
- State at least three industrial standard instrumentation signal levels and explain what the pros and cons of using current signals are.
- Explain the applications of feedback and feedforward control concepts when you are driving a car.
- State at least three industrial standard instrumentation signal levels and explain what the advantages of using current signals are.
- List the three kinds of representative valve plug and state the characteristics for each.
- State how to calculate the benefit of the process control for the economic justification, quantitatively.
- Explain how to get the installed characteristics of a control valve with equations?
- Write down the equation for PID controller in time domain.
- What are the characteristics of the step response of a 1st-order process?

\[ \begin{align*}
\text{Find } y(t) \text{ for } & \quad \frac{d^2 y}{dt^2} + 2 \frac{dy}{dt} + 2y = 2S(t-3) \text{ where } y(0) = y'(0) = 0 \\
\text{Find } y(t) \text{ for } & \quad \frac{d^2 y}{dt^2} + 6 \frac{dy}{dt} + 25y = e^{-t} \text{ where } y(0) = y'(0) = 0 \\
\text{For a distillation column with DOF}=2, \text{ two MV's will be decided to attain two CV's targets. If one target is not needed anymore, what can you do with extra DOF?} \\
\text{Convert a general } n\text{-th order linear ODE to a set of } 1\text{-th order ODE's.} \\
\text{Find the Laplace Transform of a unit triangular pulse of width } t_w. \\
\text{Solve for the Laplace transform of } te^{-at}\sin(2t). \\
\text{What is the Laplace transform of } t(sin(\omega t))? \\
\text{What is the Laplace transform of } t(cos(\omega t))? \\
\text{What is the Laplace transform of } t^2e^{at}(sin(\omega t))? \\
\text{Find } y(t) \text{ for } Y(s) = \frac{e^{-s}}{(s+1)^2(s^2+4s+5)} \frac{1}{s+3} \\
\text{Find } y(t) \text{ for } Y(s) = \frac{e^{-s}}{(s+1)^2(s^2+2s+5)} \\
\end{align*} \]
• Find \( y(t) \) for \( Y(s) = \frac{s+1}{s(s^2 + 2s + 10)}e^{-5s} \)
• Find \( y(t) \) for \( Y(s) = \frac{s+1}{s(s+2)(s+3)}e^{-0.5s} \) and \( Y(s) = \frac{s+3}{s(s^2 + 2s + 5)}e^{-3s} \)

G3.
• Derive the Laplace transform of the following signal.

G4.
• Linearize the following ODE with respect to \( T, T_i, T_c \), and \( C_A \) around initial steady state \( T_{00}, T_{i0}, T_{c0} \) and \( C_{A0} \). Then, find transfer function, \( T(s)/T_c(s) \).

\[
V\rho C_p \frac{dT}{dt} = q\rho C_p(T_i - T) + (-\Delta H)VkC_A + UA(T_c - T) \quad (k=k_0\exp(-E/RT))
\]
• For the following system,
  a) Find \( X(s) \).
  b) Determine the final value of \( x(t) \) as \( t \to \infty \).
  c) Find \( y(t) \).

• For PID controller,
  a) Write down the PID controller equation in time domain and find the transfer function between controller output and error.
  b) What is the reset windup and what are the consequences of it?
  c) How would you suggest modifying this equation to prevent the derivative kick?
  d) State more than one way to prevent the reset windup?
  e) Explain the effects of the tuning parameters in PID controller on the step change in set point?
  f) What is bumpless transfer?

• For a typical second-order process,
  a) Write down the transfer function in standard form.
  b) Find the AR and phase angle as a function of input frequency.
  c) Discuss the asymptotic behavior of AR and phase angle obtained in b).

• For each mode of PID controller, explain the advantages and disadvantages
  a) P mode
  b) I mode
  c) D mode
  d) Also, explain what the reset windup and the remedy of it are.
G5. Solve as directed.

- A student is maintaining the weight, \( w_0 = 60 \text{ Kg} \) while taking \( u_0 \) Kcal/day from food and studying \( n_0 \) hours/day besides the normal school life. The relevant data are as follows:

  - Body weight: \( w(t) \) Kg,
  - Food consumption per day: \( u(t) \) Kcal/day
  - Basal metabolic rate + normal school life: \( 30w \) Kcal/day
  - Energy consumption rate for an hour of study per day: \( 120 \) Kcal/hr/day
  - Conversion between energy and body weight: \( 6 \text{ Kcal/g} \)

  a) Find \( u_0 \) to maintain the current body weight if the student studies 3 hours every day.
  b) Model the body weight change for relevant inputs, and find the transfer functions between output variable \( w \) and inputs, food consumption rate, \( u \) and study hour, \( n \).
  c) If the student eats 10% more than usual with same study hour, what will be his weight after all? (Solve the ODE by inverse Laplace transform using \( U(s) \).)
  d) If the student reduces study hour to 1 hr/day with same food consumption rate in a), what will be the body weight in the long run? (Use final value theorem if possible.)

- A human with 70kg of body weight drank some amounts of soju in at the rate of \( u \) (g of soju)/hr. Using the data below, answer the following questions when \( x \) denotes alcohol contents (g of ethanol/100mL of blood) in blood.

  - Volume of blood: \( 0.07 \text{ L/(kg of body weight)} \)
  - Alcohol content of soju: 20% (20g/100mL of soju)
  - Alcohol decomposition rate: \( 0.175x \) g/hr/(kg of body weight)

  Assumptions: Heart pumping is so efficient so that the alcohol is well mixed in blood system and the alcohol in the stomach is absorbed about 10% into blood system.

  a) Find a model to describe the blood alcohol level with time.
  b) If a human takes a bottle of soju (360mL) in one shot from a sober state, how long will it take the alcohol level drops below 0.05%?
  c) Repeat the question b) when a human drank 2 cups of soju in one shot. (1 cup=50mL)

- Even though it is very difficult, there is one way to estimate the time of death (TOD) for a cadaver in criminal investigation. That is to apply dynamic process modeling technique. (Warning: This method should be regarded as only one of the clues to estimate the TOD.) Using the following information, establish a model for temperature change of a dead body based on energy balance and answer the questions.

  - The body temperature \( (T) \) was 36.5°C before death.
  - The body mass is \( w \) Kg, the average heat-transfer coefficient for whole body area is \( UA \), the constant heat capacity is \( Cp \), and the ambient temperature is \( Ta \).

  a) Find a model to describe the body temperature with time depending on \( Ta \).
  b) If \( Ta \) changes 15°C to 5°C from the time of death to +5hrs and stays at 5°C afterward, find the change in body temperature. (Use \( wCp/UA=5\text{hr.} \))
  c) What are the limitations of this simple model and the ways to improve the accuracy?

- A drug is ingested into gastrointestinal tract (GIT) and distributed to blood stream (BS), and then it is absorbed by organs. Let \( u \) be the drug ingestion rate \([\text{mass/time}]\), \( x_1 \) be the amount of drug in GIT \([\text{mass}]\), \( x_2 \) be the amount of drug in BS \([\text{mass}]\). From the clinical experiments, it is found for a patient that the distribution rate from GIT to BS is \( k_1x_1 \) \([\text{mass/time}]\) and the consumption rate by organ from BS is \( k_2x_2 \) \([\text{mass/time}]\). The patient is drug-free initially.

  a) Construct a model to monitor the drug level in mass in GIT and BS.
  b) Find the transfer functions related to drug levels of GIT and BS regarding drug ingestion rate.
  c) If the patient ingested a drug tablet of 500mg, calculated the drug levels in GIT and BS with time for the following conditions.

\[ k_1=10 \text{ [mg/mg·min]}, \quad k_2=5 \text{ [mg/mg·min]} \]
The extraction is carried out in a single, perfectly mixed, extraction stage as shown in the figure. Assume that the outlet flow concentrations, \( x_1 \) and \( y_1 \), achieve equilibrium and the densities are constant. The flows, \( G \) and \( L \), are volumetric flow rate and \( Q \) is the mass transfer rate between phases. The relevant equations are as follows:

\[
Q = K_L a (x_1 - x_1^*) V_L \\
x_1^* = f_{eq}(y_1)
\]

a) Find the dynamic model to predict the concentration changes in two streams.
b) For given inlet conditions denoted by overbar, find the steady-state values of the outputs when \( y_1 = m x_1^* \).
c) Find the transfer function between \( y_1 \) and \( L \) based on the reference point found in b).

In a highway, a traffic jam length \( l(t) \) of 2km has been formed due to some reason. Data: Each car occupies: 5 [m/car], A car leaves every 2.5sec at the end of jam, Incoming car rate to jam: \( u(t) \) [cars/sec] (Assume single lane highway.)
a) Obtain a model for the length of traffic jam depending on time.
b) Find the transfer function for \( L(s)/U(s) \), and what is the nature of the process?
c) How long will it take to escape the traffic from the start point of traffic in minute?
d) If \( u(t) = 2 \), how long will it take the jam goes away?

An irreversible reaction of A to B in otherwise inert medium proceeds according to the relation, \( 2A \rightarrow 2B \). The reaction is exothermic with a heat of reaction, \( -\Delta H \). The reaction rate (based on reaction of A) in a stirred-tank reactor of volume \( V \) is \( r_A = k c_A^2 \) where \( k = k_0 e^{-E/RT} \) with appropriate units. The reaction system is shown schematically in the drawing. Assume that fluid properties are constant. A cooling coil with coolant at temperature \( T_c \) and heat transfer area \( A_c \) is used to remove energy from the reacting mixture.
a) Write the dynamic equations for the system variables, \( c_A \), \( c_B \), and \( T \). Be sure to specify the inputs for your model assuming the level is perfectly controlled.
b) Modify the dynamic equations in (a) using the assumptions that the amount of energy removed from the reactor is \( Q \) (constant). Then develop the transfer function between outlet concentration of A and inlet temperature \( (C_A(s)/T_i(s)) \).

A jacketed vessel is used to cool a process stream as shown in the figure. The tank and jacket are well mixed and heat loss is negligible from the system. When the overall heat transfer coefficient \( U \) is given as \( Kq_{0.8} \) with heat transfer area \( A_j \):
a) Write down the model equations for \( T \) and \( T_j \).
b) State additional assumptions if needed for simplification.
c) Assuming \( T_j \) is constant; find \( T(s)/Q(s) \).

(Ex3-7) With the assumptions for simplification,
a) Write down the model equations in ODE.
b) Find \( C_2(s)/C_1(s) \).
c) Find the unit step response of \( c_2(t) \).

For a 2nd order process with a denominator, \( (\tau^2 s^2 + 2\zeta \tau s + 1) \) (0 < \( \zeta < 1 \)), and no zeros,
a) Find the pole locations.
b) Draw the poles in complex plane and find the length from the origin and the angle from the negative real axis.
c) Discuss the effects of the pole location on step response in terms of the length and angle in b).