PROCESS CONTROL AND INSTRUMENTATION
(CHEN 3201)

Time Allotted : 3 hrs **Full Marks : 70**

Figures out of the right margin indicate full marks.

Candidates are required to answer Group A and any 5 (five) from Group B to E, taking at least one from each group.

Candidates are required to give answer in their own words as far as practicable.

Group – A
(Multiple Choice Type Questions)

1. Choose the correct alternative for the following: **10 × 1 = 10**

(i) For liquid level in two tanks in series, the damping coefficient can never be
(a) more than 1 (b) equal to 1 (c) less than 1 (d) zero.

(ii) The response of a system with transportation lag τ produces amplitude ratio (AR) and phase angle(φ) as
(a) AR $= \frac{1}{\sqrt{\omega^2\tau^2+1}}$, φ = -ωτ, (b) AR = 1, φ = $\tan^{-1}(-\omega\tau)$
(c) AR = 1, φ = -ωτ (d) AR = $\sqrt{\omega^2\tau^2+1}$, φ = $\tan^{-1}(-\omega\tau)$.

(iii) Time constant of a mercury-in-glass thermometer is equal to
(a) $\frac{mC}{hA}$ (b) $\frac{hC}{mA}$ (c) (mC/A) (d) $\frac{hC}{m}$

(iv) A pneumatic proportional controller is used to control a cold stream outlet temperature within 15-30 °C. The controller gain is adjusted so that output pressure goes from 3 psig to 15 psig as the measured temperature goes from 18-22 °C with the setpoint held constant. Find the controller gain Kc
(a) 5 psig/°C (b) 3 psig/°C (c) 4psig/°C (d) 1psig/°C.

(v) In Cohen-Coon controller tuning method, the process reaction curve is approximated by
(a) First order plus dead time model (b) Second order plus dead time model
(c) Dead time model (d) First order model.

(vi) Bode stability criterion states that a control system is unstable if the open loop frequency response exhibits an amplitude ratio
(a) greater than 1 at all frequencies (b) greater than 1
(c) ratio less than 1 (d) more than 1 at crossover frequency.

(vii) The value of offset in a system using PI controller is
(a) zero (b) one (c) infinity (d) depends on the process.

(viii) For an equal percentage valve, the fraction of maximum flow f is related to the fraction of maximum lift x as follows
(a) $f = x$ (b) $f = x^{1/2}$ (c) $f = x^2$ (d) $f = \alpha^{x-1}$.

(ix) Resistance temperature detectors (RTD) and thermistors have the following relation between resistance (R) and temperature (T)
(a) RTD: R increases with T, thermistor: R decreases with T
(b) Both RTD and thermistor: R increase with T
(c) Both RTD and thermistor: R decrease with T
(d) RTD: R decreases with T, thermistor: R increases with T.

(x) Hot wire anemometers are used for measuring
(a) gas flow velocity (b) fluid temperature
(c) thermal conductivity of gas (d) pressure of a gas.

Group – B

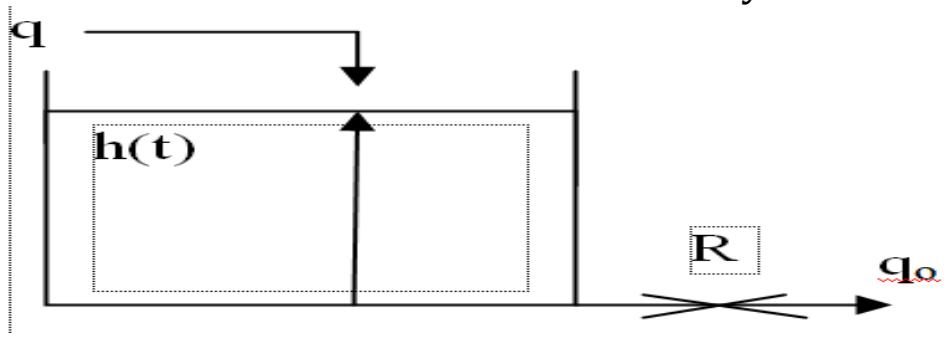
2. (a) Consider the reaction A → B is occurring at a rate $r = kC_0^2$ in a continuous stirred tank reactor where C_0 is the concentration of A in reactor. If C_i be the concentration of A in feed stream, F be the constant feed rate, V be the volume of mixture in reactor, derive the approximate transfer function relating to C_0 to C_i, assuming constant density and constant V. Also assume the system is not deviating much from the initial steady state (i.e., $C_0(0) = C_{0,s}$ and $C_i(0) = C_{i,s}$). [(CO1)(Analyze/IOCQ)]

(b) Derive the state equations of a stirred tank heater fitted with a steam coil. Identify the state variables, control objectives, disturbances and manipulated variable. [(CO1)(Analyze/IOCQ)]

6 + 6 = 12

3. (a) A thermometer having a time constant 0.16 min., is placed in a temperature bath and after the thermometer comes to equilibrium with the bath, the bath temperature is increased linearly at a rate 1° C/min. What is the difference between the indicated temperature and the bath temperature 0.1 min., after the change in temperature begins? [(CO2)(Evaluate/HOCQ)]

(b) The liquid-level system shown below has a cross-sectional area of 2.5 m^2. The outlet flow rate versus head relationship of the valve is $q_o = 8\sqrt{h}$, where q_o is flow rate in m^3/min. and h (in meter) is the liquid level above the valve. Calculate the time constant for this system if the average operating level is 4 m.



[(CO2)(Evaluate/HOCQ)]

(c) Write down the expression of amplitude ratio and phase lag when a sinusoidal input is applied to a first order system. [(CO2)(Analyze/IOCQ)]

5 + 5 + 2 = 12

Group - C

4. (a) A step change of magnitude 2 units, is introduced in a system having following transfer function $\frac{Y(s)}{X(s)} = \frac{6}{(s^2 + 2s + 8)}$.

Determine the time constant, damping factor, maximum value, and ultimate value of the response. [(CO2)(Evaluate/HOCQ)]

(b) Obtain transfer function of transportation lag. How can it be approximated using 1st order and 2nd order Padé approximation? [(CO2)(Analyze/IOCQ)]

7 + (3 + 2) = 12

5. (a) (i) Sketch a root locus diagram for the following transfer function

$$1 + \frac{K(s+4)}{s(s+1)(s+2)(s+3)} = 0$$

Mark the following in the diagram: Open loop poles and zeros, Asymptotes, Breakaway/break-in point and Portion of root locus lying on real axis.

(ii) Determine the point of intersection of the root locus with the imaginary axis and find the range of K for stability. [(CO3)(Evaluate/HOCQ)]

(b) Discuss the significance of breakaway point. If -5,-4 are two open loop poles and -2,-1 are two open loop zeros, does the closed loop pole -1.5 lie on the root locus? [(CO3)(Analyze/IOCQ)]

(4 + 4) + (2 + 2) = 12

Group - D

6. (a) Obtain the expression for offset in closed-loop responses of a first order system if unit step change in setpoint is applied to the system in the presence of a proportional controller. Sketch the closed loop response of the system. What is integral windup? [(CO4)(Remember/LOCQ)]

(b) A pneumatic PI controller has an output pressure of 10 psig when the set point and process temperature coincide. The set point is suddenly increased by 10 ^{o}C and the following data is obtained

Time, s	psig
0—	10
0+	8
20	7
60	5
90	3.5

Determine the controller gain and integral time. [(CO4)(Evaluate/HOCQ)]

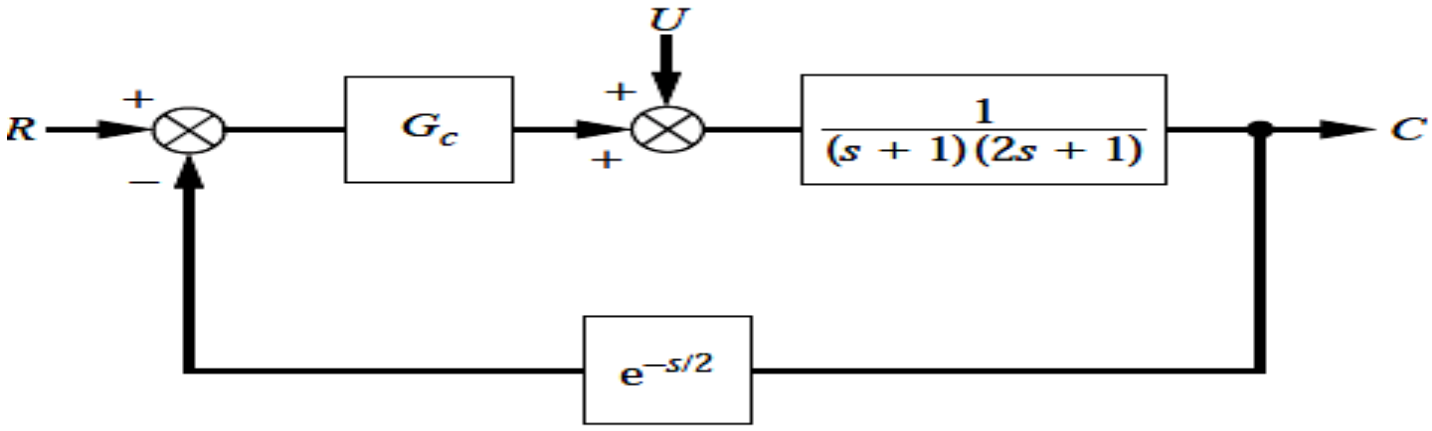
(c) Distinguish between direct and reverse acting controllers. In a flow control system comprising of a direct acting flow transmitter, and an air to open control valve, state the reason of selecting the appropriate controller (i.e., whether direct or a reverse acting). [(CO4)(Analyze/IOCQ)]

(2 + 1 + 1) + 4 + (2 + 2) = 12

7. (a) With the help of a Bode diagram (amplitude ratio versus frequency, phase lag versus frequency plot),

(i) determine the crossover frequency, gain margin and phase margin of the following feedback control system,

(ii) using Ziegler-Nichols tuning technique, determine the values of controller settings for a PID controller used for controlling the outlet concentration of a two tank chemical reactor system. (Ziegler-Nichols controller settings provided) [(CO3,CO4)(Evaluate/HOCQ)]



Ziegler-Nichols controller settings

Type of control	$G_c(S)$	K_c	τ_I	τ_D
Proportional	K_c	$0.5K_u$		
Proportional-integral (PI)	$K_c\left(1+\frac{1}{\tau_I s}\right)$	$0.45K_u$	$\frac{P_u}{1.2}$	
Proportional-integral-derivative (PID)	$K_c\left(1+\frac{1}{\tau_I s}+\tau_D s\right)$	$0.6K_u$	$\frac{P_u}{2}$	$\frac{P_u}{8}$

(b) Discuss the different types of time integral performance criteria based on which controller selection is done and explain with reasons the type of error suppressed by each criteria. [(CO3,CO4)(Remember/LOCQ)]

9 + 3 = 12

Group - E

8. (a) Define the following performance characteristics of an instrument

(i) Repeatability

(ii) Accuracy

(iii) Sensitivity

(iv) Linearity. [(CO5)(Remember/LOCQ)]

(b) Discuss the working principle of an optical pyrometer with a diagram. [(CO5)(Understand/LOCQ)]

(c) A unit step input given to a first order instrument induces a response that monotonically rises to -5% of the final value of the impressed step input in 500 ms, obtain the measurement system parameters. If time constant is halved, calculate the percent improvement in speed of response. [(CO5)(Analyse/IOCQ)]

4 + 5 + 3 = 12

9. (a) A pump supplies fluid to a heat exchanger where the pressure drop is 30 psig at a design flowrate of 1 m^3/min and the pressure drop is assumed proportional to the square of flowrate. A control valve is located at the exit of heat exchanger and the pressure downstream of the control valve is 0 psig. The pump furnishes a constant head of 40 psi over the entire flowrate range of interest. Select the rated C_v of a linear valve that is half open at the design flowrate and plot the installed characteristic of the valve. Given: 1 psi = 0.07 bar. [(CO5)(Evaluate/HOCQ)]

(b) Explain the meaning of the following codes obtained from a P & ID diagram.

(i) TY 186. Represent the instrument with an appropriate symbol if it is a discrete instrument located in field.

(ii) PRT 89. Represent the instrument with a proper symbol if it is a PLC accessible to secondary operator. [(CO5)(Analyze/IOCQ)]

(c) In a hydrodealkylation plant, toluene is converted to benzene. Represent using a PFD, the mixing of process input streams followed by heating and reaction in a packed bed reactor with appropriate symbols. Explain the meaning of each symbol. [(CO5)(Analyze/IOCQ)]

4 + (2 + 2) + 4 = 12

Cognition Level	LOCQ	IOCQ	HOCQ
Percentage distribution	16.67	39.58	43.75

Course Outcome (CO):

After the completion of the course students will be able to

1. Formulate mathematical models explaining the static and dynamic behavior of chemical processes.
2. Solve equations arising out of dynamic behavior of systems using Laplace transformation.
3. Develop the concept of stability and apply the stability criteria suitably.
4. Apply knowledge of the control strategies for different control configuration and controller tuning.
5. Specify the required instrumentation for measurement of various process parameters in chemical process plants and understanding working principles.

*LOCQ: Lower Order Cognitive Question; IOCQ: Intermediate Order Cognitive Question; HOCQ: Higher Order Cognitive Question