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) 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 = $\tan^{-1}(-\omega\tau)$.

(ii) An example of an open loop second order under damped system is

(a) Liquid level in tank
(b) U-tube manometer
(c) Thermocouple in a thermo well
(d) Two non-interacting first order systems in series.

(iii) What is the phase lag of a sinusoidal response of a first order system?

(a) 60^0 (b) 120^0
(c) $\leq 90^0$ (d) 180^0

(iv) The amplitude ratio for the sinusoidal response of a _____ is 1.

(a) first order system (b) second order system
(c) transportation lag (d) none of these

(v) The control system involved in air temperature adjustment so that the optimal fuel air ratio is achieved in a combustion system is

(a) ratio control (b) programmed adaptive control
(c) split range control (d) auctioneering control.

(vi) In a proportional controller, increasing K_c

(a) reduces the offset (b) increases offset
(c) eliminates offset (d) doesn't have any effect on the offset.

(vii) Transfer function of a PID controller is

(a) $K_C(1+\tau_D s+\frac{1}{\tau_I s})$

(b) $K_C(1+\frac{1}{\tau_D s}+\tau_I s)$

(c) $K_C(1+\tau_D s+\tau_I s)$

(d) $K_C(1+\frac{1}{\tau_D s}+\frac{1}{\tau_I s})$

(viii) A closed loop system is stable if
(a) poles of the system have negative real parts
(b) poles of the system have positive real parts
(c) poles of the system are complex
(d) poles of the system are imaginary.

(ix) The symbol TY165 indicates
(a) temperature recorder in zone 1, equipment number 6 and transducer number 5
(b) temperature controller in zone 1, equipment number 6 and transducer number 5
(c) temperature transducer in zone 1, equipment number 6 and transducer number 5
(d) temperature transmitter in zone 1, equipment number 6 and transducer number 5.

(x) The platinum-rhodium thermocouple shows linearity in the temperature range
(a) 100-1500 °C
(b) 500-1500 °C
(c) 100-500 °C
(d) 1100-1500 °C.

Group- B

2. (a) Mention the needs for process control in a chemical industry. [(CO1)(Analyze/LOCQ)]

(b) Consider the reaction $A \longrightarrow B$ is occurring at a rate $r = kC_0$ 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 transfer function relating to C_0 to C_i, assuming constant density and constant V. [(CO1)(Analyze/IOCQ)]

(c) A thermometer initially at 100^0C is dipped at t=0 into an oil bath, maintained at 150^0C. If the recorded temperature is 130^0C after 1 minute, find the time constant of the thermometer. [(CO1)(Evaluate/HOCQ)]

3 + 6 + 3 = 12

3. (a) Give an example of a feed-back control system. [(CO1)(Remember/LOCQ)]

(b) A stream of solution containing dissolved salt flows at a constant volumetric flow rate **q** into stirred tank of constant holdup volume **V**, The concentration of salt in the entering stream **x** varies with time. Determine the transfer function relating the outlet concentration **y** to the inlet concentration **x**. [(CO1)(Analyze/IOCQ)]

(c) The liquid-level system shown below (Fig.1) has a cross-sectional area of $2.2m^2$. The outlet flow rate vs. head relationship of the valve is $q_o = 9\sqrt{h}$, 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 3 m.

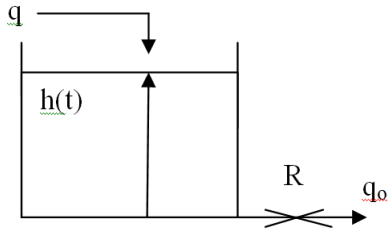

Fig.1

[(CO2)(Evaluate/HOCQ)]

2 + 5 + 5 = 12

Group - C

4. (a) Obtain the impulse response from a underdamped 2nd order system.

[(CO2)(Analyze/LOCQ)]

(b) A step change of magnitude 2 units, is introduced in a system having following transfer function

$$\frac{Y(s)}{X(s)} = \frac{8}{(s^2 + 1.8s + 9)}$$

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

5 + 7 = 12

5. (a) Plot a root locus diagram for the following characteristic equation:

$$1 + \frac{K}{[s(s+3)(s^2+2s+2)]} = 0$$

[(CO3)(Evaluate/HOCQ)]

(Locate the poles, zeros and show the breakaway points and asymptotes in the graph)

(b) Distinguish between the different time integral performance criteria.

[(CO3)(Understand/LOCQ)]

8 + 4 = 12

Group – D

6. (a) A PID controller is at steady state with output pressure of 9 psig. The set point and pen point are initially together. At t=0, the set point is moved away from the pen point at a rate of 0.5 mm/min. The motion of the set point is in the direction of lower readings. If the knob settings are Kc=2 psig/mm of pen travel, integral time =1.25 min and process time constant is 0.4 min, represent graphically the variation of output pressure with time. [(CO3)(Evaluate/IOCQ)]

(b) "After the elapse of one integral time, the proportional action is repeated in a PI controller" — Justify the claim with a rough sketch of controller output versus time plot. [(CO4)(Justify/IOCQ)]

(c) An electric temperature controller has output range of 4-20 mA and a chart calibration of 10-150 °C.
If output is 12 mA at 80 °C, when Kc is 0.5 mA/ °C, determine
(i) the proportional band
(ii) controller output at 100 °C. [(CO4)(Evaluate/HOCQ)]
6 + 3 + 3 = 12

7. (a) "Choice of control action for the secondary controller in a cascade control system is proportional control while that of the primary controller is PI or PID" — Justify the claim explaining the mechanism of cascade control action.
[(CO4)(Analyze/IOCQ)]

(b) For a process with the following response to a unit step input to a control valve, obtain the approximate controller settings using Cohen-Coon tuning rules for P and PI controllers.

t	0	2.82	4.8	6.3	7.7	10.2	13.2	18.1	23.7	31.2	38	50
y	0	0.06	0.13	0.19	0.27	0.39	0.52	0.67	0.80	0.92	0.97	1.00

Given:

Type of control	Parameter setting
Proportional (P)	$K_c = \frac{1}{K_p}\frac{T}{T_d}\left(1 + \frac{T_d}{3T}\right)$
Proportional-integral (PI)	$K_c = \frac{1}{K_p}\frac{T}{T_d}\left(\frac{9}{10} + \frac{T_d}{12T}\right)$
	$\tau_I = T_d\frac{30 + 3T_d/T}{9 + 20T_d/T}$

[(CO3)(Evaluate/IOCQ)]

(c) Analyze the significance of gain and phase margin in controller tuning.
[(CO3)(Analyze/IOCQ)]
3 + 6 + 3 = 12

Group - E

8. (a) Explain the static characteristics of instruments. [(CO5)(Remember/LOCQ)]
(b) A first order temperature measuring instrument has a rise time of 0.1 s. The instrument is initially at room temperature of 20 °C for a long time. Then it is suddenly put into a water bath at 120 °C. What temperature will the instrument read after 0.05 s? [(CO5)(Evaluate/HOCQ)]
(c) "Inherent characteristics of a control valve are always same as the installed characteristics" — Justify. [(CO5)(Justify/IOCQ)]
5 + 4 + 3 = 12

9. (a) Represent different types of valves using proper symbols.
[(CO5)(Understand/LOCQ)]
(b) A pump furnishes a constant head of 40 psi over the entire flowrate range of interest. The heat exchanger pressure drop is 30 psig at a flowrate of 50 m^3/min

and can be assumed to be proportional to q^2. Select the rated C_v of the valve and plot the installed characteristics of the following cases:
(i) A linear valve that is half open at the design flowrate
(ii) An equal percentage valve(R= 50) that is sized to be completely open at 110% of the design flowrate. [(CO5)(Evaluate/HOCQ)]

(c) "High precision measurements always have high accuracy". State whether the statement is true or false and justify your claim. [(CO5)(Analyze/IOCQ)]

3 + 6 + 3 = 12

Cognition Level	LOCQ	IOCQ	HOCQ
Percentage distribution	22.92	39.58	37.5

Course Outcome (CO):

After the completion of the course students will be able to

1. Develop models of simple chemical processes, understand the dynamic and static behavior of the processes.
2. Perform linearization of nonlinear systems, understand transfer functions and solve equations using Laplace transforms.
3. Understand working principles of different types of controllers, and develop ideas on different control strategies.
4. Unravel the notion of stability in control systems through different techniques, get an idea on different stability criteria, and successfully evaluate the performance criteria of feedback controllers.
5. Understand the working principles of different measuring elements, control valves and develop basic concepts on process flow diagram and piping and instrumentation diagrams of chemical process plants.

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