PROCESS CONTROL AND INSTRUMENTATION
(CHEN 3201)

Time Allotted : 2½ hrs **Full Marks : 60**

Figures out of the right margin indicate full marks.

Candidates are required to answer Group A and any 4 (four) from Group B to E, taking one from each group.

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

Group – A

1. Answer any twelve: **12 × 1 = 12**

Choose the correct alternative for the following

(i) The response of a first order system to step input after one time constant reaches
(a) the ultimate value (b) 50% of its ultimate value
(c) 63.2% of its ultimate value (d) 0

(ii) A thermometer having a time constant of 1 min is initially at 50°C. it is immersed in a bath maintained at 100°C at t=0. The temperature reading at t=1.2 minute is
(a) 70°C (b) 80°C (c) 85°C (d) 50°C

(iii) What is the purpose of the Padé approximation in process control?
(a) To simplify the mathematical model of a process
(b) To approximate a high-order transfer function with a lower-order one
(c) To design a control system for a nonlinear process
(d) To analyze the stability of a control system

(iv) What is the main advantage of using deviation variables in process control?
(a) Simplifies the mathematical model
(b) Reduces the complexity of the control system
(c) Allows for the use of linear control techniques for nonlinear processes
(d) Eliminates the need for feedback control

(v) What is the characteristic equation of a system?
(a) A polynomial equation that describes the system's behavior
(b) A differential equation that describes the system's behavior
(c) An algebraic equation that describes the system's behavior
(d) A transcendental equation that describes the system's behavior

(vi) What is the Nyquist stability criterion used for?
(a) To determine the stability of a system
(b) To design a control system
(c) To analyze the frequency response of a system
(d) To develop an empirical model

(vii) For a unit step change in setpoint, if K_p and K_c are steady state gain and controller gain respectively, K_d is the steady state gain for disturbance, the closed loop response of a first order system produces an offset

(a) 0 (b) $1/(1+K_pK_c)$ (c) 1 (d) $-K_d/(1+K_pK_c)$

(viii) The transfer function of a PD controller is

(a) $K_c(1 + 1/\tau_D s)$ (b) $K_c(1 + \tau_D s)$ (c) $K_c\tau_D s$ (d) $\frac{(1+1/\tau_D s)}{K_c}$

(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) The symbol P-101A/B in PFD diagram denotes

(a) A pump 01 located in area 100 of the plant, pump A is operating and B is idle

(b) A pump located in area 101 of the plant, pump A is operating, pump B is idle

(c) A pump 01 located in area 100 of the plant, both pumps A and B are operating

(d) A pump number 101, both pumps A and B are operating

Fill in the blanks with the correct word

(xi) The time constant of a thermocouple is expressed as_____.

(xii) The frequency where the two asymptotes intersect is called is_____.

(xiii) ON-OFF control comes when _____.

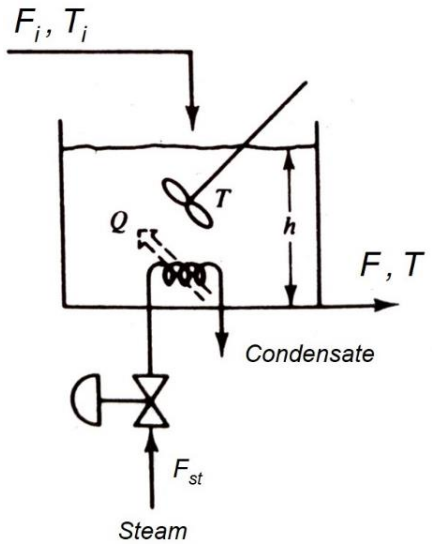
(xiv) Gain margin is defined as _____.

(xv) The flowmeter operating on the principle of change in resistance of a wire due to heat transfer from the wire to a flowing gas stream is _____.

Group - B

2. (a) Define the manipulated variables, measured variables, and unmeasured variables of a process with an examples. *[(CO2)(Apply/IOCQ)]*

(b) Describe state variables and state equation. Deduce the input-output model for the stirred tank heater using state variables as shown in the figure below. *[(CO2)(Apply/IOCQ)]*



3 + 9 = 12

3. (a) Derive the transfer function relating the inlet and outlet temperatures in a stirred tank heater starting from the input output model. *[(CO2)(Analyse/IOCQ)]*

(b) Develop the input/output model equations of a nonisothermal CSTR in terms of deviation variables and obtain the transfer function matrix. *[(CO1)(Apply/HOCQ)]*

4 + 8 = 12

Group - C

4. A step change of magnitude 2 is introduced into a system having the transfer function $G(s)$ mentioned below. Determine i) percent overshoot ii) period of oscillation iii) maximum value of Y(t), iv) ultimate value of Y(t), v) time required to reach first time to set point, and vi) time required to reach ultimate value.

$$G(s) = \frac{Y(s)}{X(s)} = \frac{3}{s^2+3s+6}$$ *[(CO3)(Analyse/HOCQ)]*

12

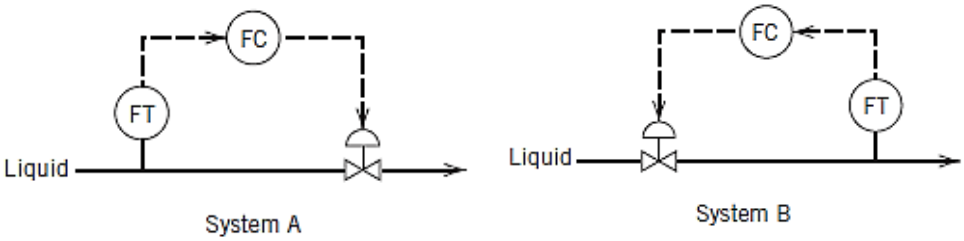
5. (a) Find the effect of a proportional controller on the response of a controlled first order process for the following condition:
(i) Unit step input in the set point.
(ii) Unit step input in the load. *[(CO2)(Analyse/HOCQ)]*

(b) Define a stable and unstable system with net schematic diagram. *[(CO4)(Remember/LOCQ)]*

8 + 4 = 12

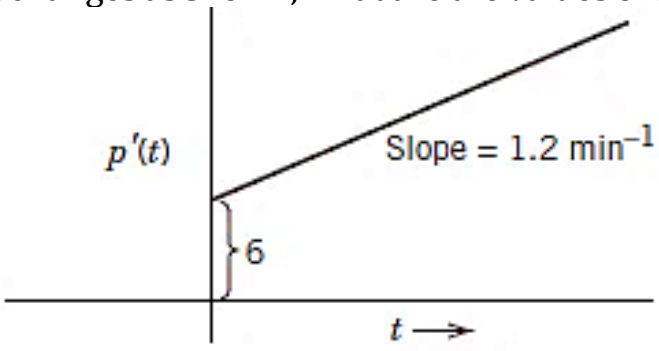
Group - D

6. (a) Distinguish between direct and reverse acting controllers with examples. Two possible feedback control loop configurations are shown in the figures below. The control valve in system I is air to open and in system II is air to close. Identify whether the controllers are direct acting or reverse acting and explain your answer.



[(CO3)(Analyse/HOCQ)]

(b) If the measured input to a PI controller is a step change (Y_m=2/s), and controller output changes as shown, what are the values of controller gain and integral time?



[(CO3)(Apply/HOCQ)]

(c) Derive the transfer function expression of a PID controller. *[(CO3)(Apply/IOCQ)]*

(3 + 3) + 3 + 3 = 12

7. (a) A pneumatic P controller is used to control a cold stream outlet temperature within 60-120°C. The controller gain is adjusted so that the output pressure goes from 3 psig-15 psig as the measured temperature goes from 70-75°C with the setpoint held constant.
   (i) Find the controller gain and proportional band
   (ii) Assume the gain is reduced by 4, find the error in temperature that causes the control valve to move from fully closed to fully open.
   (iii) Comment on the results obtained. *[(CO3)(Analyse/IOCQ)]*

   (b) Consider PI control of the following second order process

$$G_p(s) = \frac{5}{(s+1)(0.5s+1)}$$

   (i) Plot the open loop Bode diagram and determine the crossover frequency, gain margin, phase margin and ultimate gain
   (ii) Using Ziegler Nichols settings, specify the gain and integral time of the controller.

Ziegler Nichols settings for a PI controller are as follows: $K_c=0.45\ K_{cu}$, $\tau_I=P_u/1.2$.
[(CO4)(Apply/HOCQ)]

4 + 8 = 12

Group - E

8. (a) With the aid of a process flow diagram of sulphuric acid production process, explain the various steps of sulphuric acid manufacturing. Explain all the symbols/streams shown in the diagram. Write the necessary reactions.
[(CO5)(Analyse/IOCQ)]

   (b) With the aid of a diagram, explain the working principle of an optical pyrometer.
[(CO5)(Remember/LOCQ)]

(4 + 2 + 2) + 4 = 12

9. (a) In a response test of a thermometer, which was suddenly put in a bath at 100°C, following data was obtained. (mm graph needed)

Time, t(s)	0	1	3	6	8	11	15	18
Temperature, T(°C)	30	50	65	80	90	95	98	99

   (i) Find the time constant of the thermometer
   (ii) Find the steady state error if the thermometer is used to measure temperature of the liquid cooling at a rate of 1°C every 6 s. *[(CO5)(Apply/HOCQ)]*

   (b) If the input to a first order instrument of time constant 20 s is 100 sinωt, what maximum value of frequency can be impressed so that dynamic error is limited to $\pm 10\%$? If the input frequency is kept at the same value, what should be the reduced time constant to bring the dynamic error to $\pm 0.5\%$? Obtain the time lag in the two cases. *[(CO5)(Analyse/IOCQ)]*

   (c) List the dynamic characteristics of instruments. *[(CO5)(Understand/LOCQ)]*

(4 + 3) + 3 + 2 = 12

Cognition Level	LOCQ	IOCQ	HOCQ
Percentage distribution	22.92	22.92	54.16