

22CGB014
Instrumentation & Control

Semester 1 2022/23

In-Person Exam paper

This examination is to take place in-person at a central University venue under exam conditions. The standard length of time for this paper is **2 hours**.

You will not be able to leave the exam hall for the first 30 or final 15 minutes of your exam. Your invigilator will collect your exam paper when you have finished.

Help during the exam

Invigilators are not able to answer queries about the content of your exam paper. Instead, please make a note of your query in your answer script to be considered during the marking process.

If you feel unwell, please raise your hand so that an invigilator can assist you.

You may use a calculator for this exam. It must comply with the University's Calculator Policy for In-Person exams, in particular that it must not be able to transmit or receive information (e.g. mobile devices and smart watches are **not** allowed).

Answer **ALL** questions.

Each question carries 25 marks.

Candidates should show full working for calculations and derivations.

1. (a) You have been tasked with designing the control system for a compressor knock-out drum, which is used to remove condensed liquids (e.g., natural gas liquids, water) from a natural gas inlet stream (Figure Q1(a)). As the gas enters the drum, its velocity is reduced allowing the entrained liquid droplets to fall out and settle at the bottom of the vessel. Failure to fully remove the entrained liquids can cause damage to the compressor, leading to an extended plant shutdown. This may be caused by high inlet gas flowrates or high liquid level in the drum resulting in liquid entrainment in the gas stream. However, the flowrate of the high-pressure inlet gas (above design pressure of the vessel) is fixed by upstream operations. The liquid outlet is routed to a drain system with a design pressure significantly below the operating pressure of the drum.

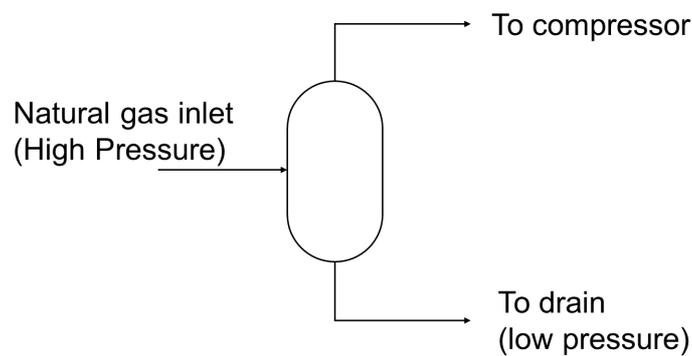


Figure Q1(a)

- (i) With the help of a figure, draw and justify suitable control loops required for this system. [6 marks]
- (ii) Suggest any additional instrumentation required to maintain safe operation of the system. [4 marks]

(b) You have also been asked to select and size the control valve for the system shown in Figure Q1(b). The system is to be used to control the flow of water (specific gravity = 1) between 20 and 60 L hr⁻¹ and the available pressure drop is 0.1 bar.

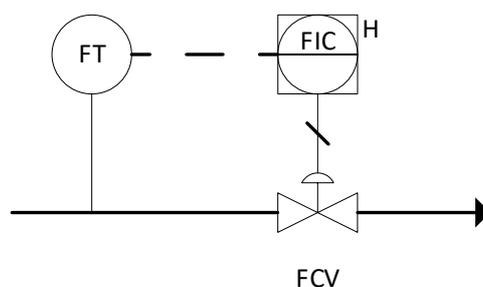


Figure Q1(b)

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Q1 Continued/...

- (i) Fully describe all features of the control system shown in Figure Q1(b). [4 marks]
- (ii) Using Figure Q1(c) and other data supplied at the end of the question, select and size a suitable valve for this application. Clearly state and justify any assumptions that you have made. [6 marks]

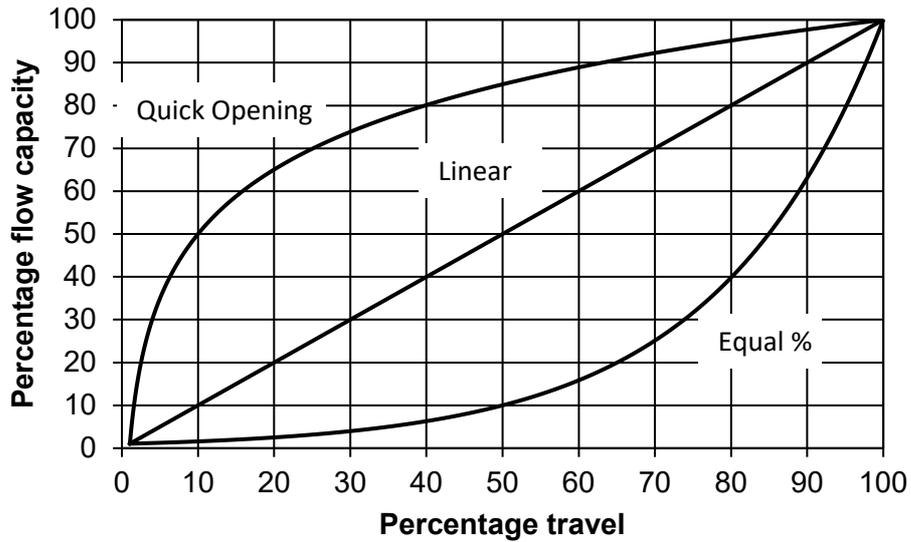


Figure Q1(c): Control valve selection chart

- (c) Describe, with the help of an example, the benefits of improved process control and how these should be balanced against control system complexity. [5 marks]

Data

Volume conversion: 1 gallon = 4.55 L

Pressure conversion: 1 bar = 14.5 psi

Useful equation

Valve sizing:

$$C_V = Q \sqrt{\frac{G}{\Delta P}}$$

Where: Q – valve capacity in gallons per minute

ΔP – pressure differential in psi

G – specific gravity of fluid

2. (a) Consider a pressure sensor/transmitter that has been calibrated to measure a process pressure between 20 psig and 50 psig. What is the range and span of this sensor/transmitter combination? If the sensor/transmitter output is an electronic signal (4-20 mA) what is the gain of the sensor/transmitter? [5 marks]

(b) A differential pressure sensor can be used to measure flow by measuring the differential pressure, h , across an orifice. The differential pressure is related to the square of the volumetric flow rate, q , i.e. $q^2 \propto h$. Eq. Q2 (below) describes the output signal from an electronic differential pressure transmitter with a range of 0 - q_{max} gpm (gallons min^{-1}). Using Eq. Q2, find the equation of the transmitter gain, K_T . If the nominal gain is defined as $K'_T = \frac{16}{q_{max}}$, complete Table Q2 (reproduce this table in your answer booklet), and hence comment on whether the gain is constant or a function of flow rate. Nowadays, most manufacturers offer differential transmitters with built-in square root extractors, explain the reason behind this based on your analysis of Eq. Q2.

Table Q2.

$\frac{q}{q_{max}}$	0	0.1	0.5	0.75	1.0
$\frac{K_T}{K'_T}$					

[10 marks]

Useful equation:

$$M_F = 4 + \frac{16}{(q_{max})^2} q^2 \quad (\text{Eq. Q2})$$

Where: M_F is the output signal in mA.

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Q2 Continued/...

- c) Draw the open loop responses expected of a P (proportional) controller, D (derivative) controller and an I (integral) controller separately for the situation shown in Figure Q2. Assume a reverse-acting controller. Consider the variation of process variable from t_5 to t_6 to be quadratic. A qualitative diagram will suffice, however, indicate the magnitude of response and slopes where possible. [10 marks]

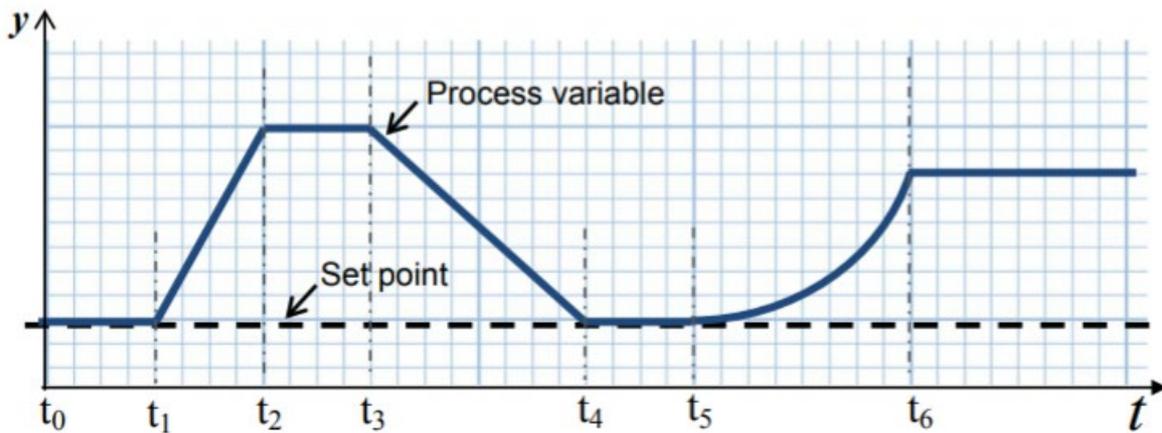


Figure Q2. Signal input to controller (open loop).

3. (a) Consider the level control loop shown in Figure Q3. The steady-state operating conditions are $q(t) = q = 150 \text{ litres min}^{-1}$ (inlet and outlet flow rates are the same) and $h = 6 \text{ m}$, which is the desired height. For this steady state, the AO (air-to-open) valve requires a 9 psig signal. The level transmitter has a range of 0-20 m. A proportional only controller, $K_c = 1$, is used in this process. Calculate the offset if the inlet flow increases to $170 \text{ litres min}^{-1}$ and the valve requires 10 psig to pass this flow. Report the offset in psig and meters. [10 marks]

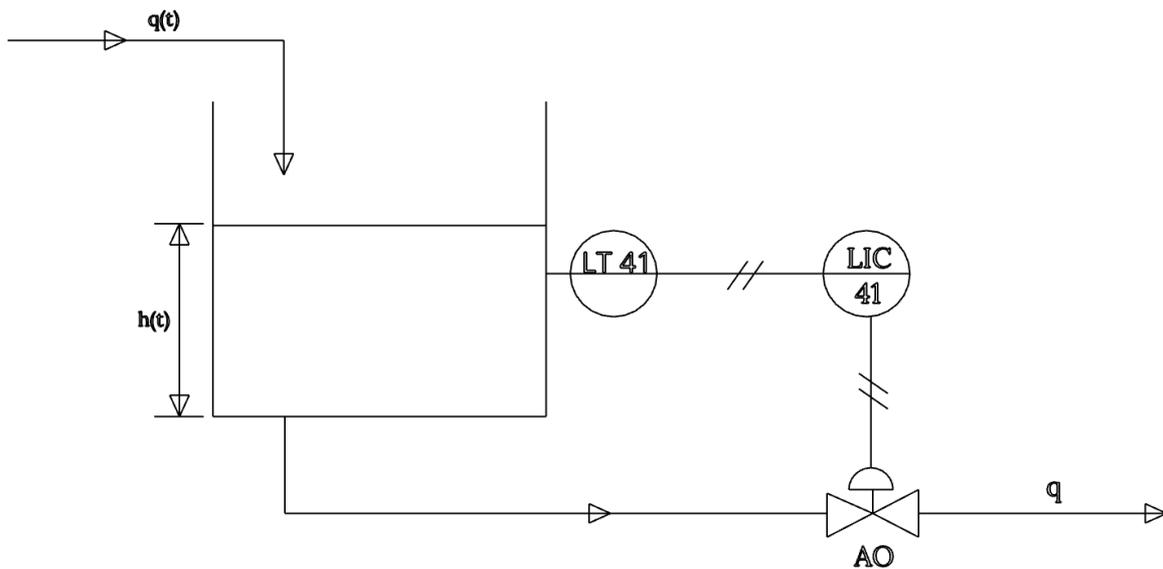


Figure Q3. Liquid level control loop.

- (b) In a different system, a control valve is sized so that at design conditions, the flow rate of water (specific gravity, $g_s = 1$) through the valve is 420 gpm, the pressure drop across the valve is 3 psig, and the valve is half open. The total dynamic pressure drop in the line, including across the valve is 20 psig and the valve has inherently linear characteristics. The pressure drop in the line (ignoring the valve) may be assumed to be proportional to the square of the flow rate, but the total dynamic pressure drop is constant. Calculate the valve C_v (fully open). Provide the equation for the installed valve characteristic (q as a function of valve stem position). [5 marks]

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Q3 Continued/...

- (c) Evaluate the suitability of the equal percentage control valve DN50 for a different system in which the maximum flow rate is 140 gpm, the operating flow rate is 70 gpm, the minimum flow rate is 40 gpm, and the pipe diameter is 3 inches. Use the six-step sizing procedure and the data given in Table Q3. Assume a pressure drop across the valve of 10 psi. [10 marks]

Table Q3.

Valve size		Valve opening, percent of total travel			
DIN	Inches	10	30	70	100
		C_v			
DN 25	1-1/4	0.78	2.20	7.83	17.2
DN 40	1-1/2	1.52	3.87	17.4	35.8
DN 50	2	1.66	4.66	23.4	57.7
DN 65	2-1/2	3.43	10.8	49.2	99.4
DN 80	3	4.32	10.9	66.0	136

END OF PAPER

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